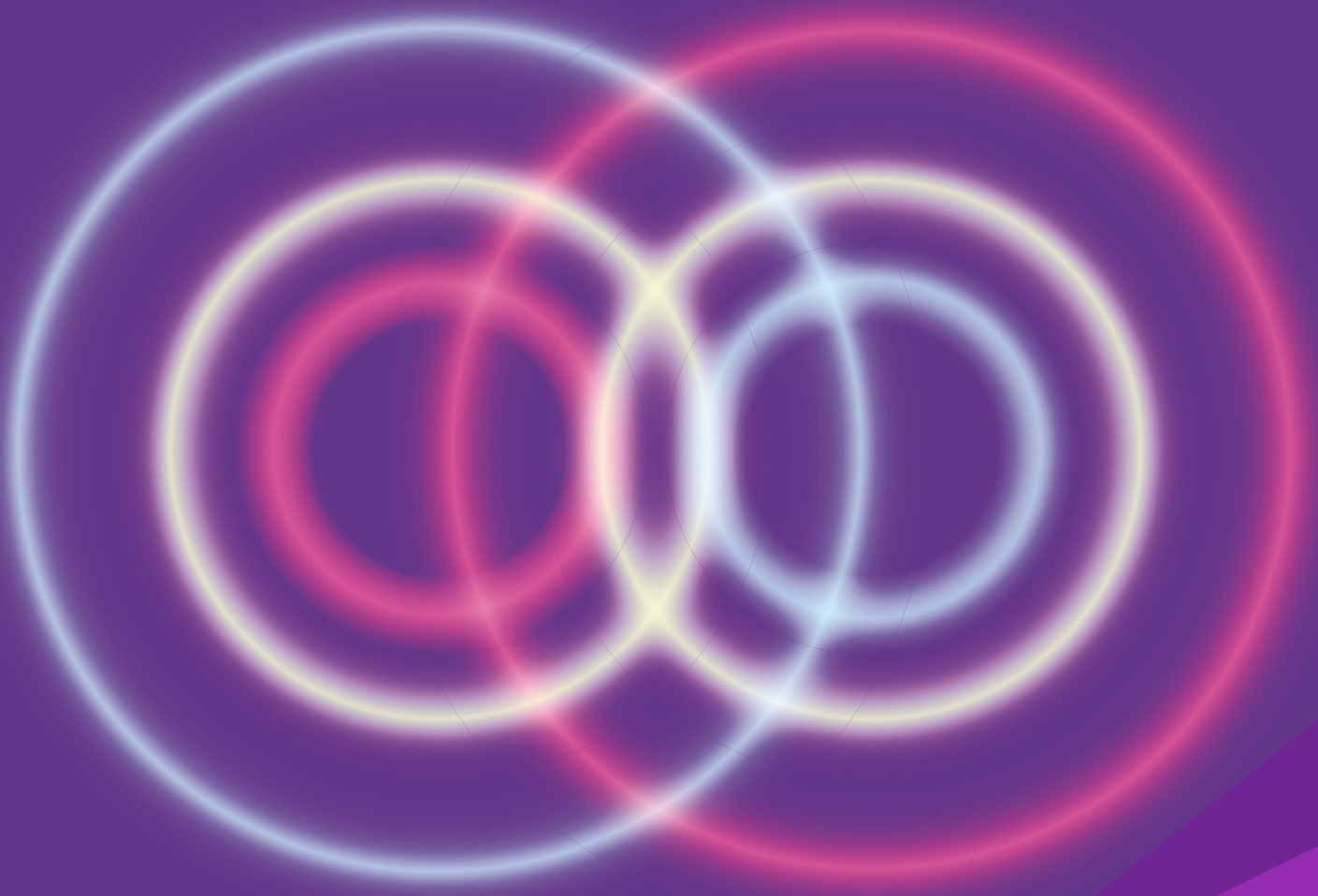
Delivered by Innovate UK

UK NATIONAL QUANTUM TECHNOLOGIES PROGRAMME

UK Quantum Technologies Challenge

The Directory



Autumn 2023

UK Research and Innovation

CATEGORY KEY

COMMUNICATIONS

COMPONENTS

COMPUTING

IMAGING

SENSING & TIMING

QUANTUM TECHNOLOGIES CHALLENGE LED COMPETITION QTC

Contents

UK Research and Innovation

CATEGORY KEY

COMMUNICATIONS

COMPONENTS

COMPUTING

IMAGING

SENSING & TIMING

QUANTUM TECHNOLOGIES CHALLENGE LED COMPETITION QTC

CR&D/TECHNOLOGY PROJECTS ROUND 2 | 2022 - 2025

FEASIBILITY STUDIES ROUND 2 | 2022 - 2024

UK Research and Innovation

CATEGORY KEY

COMMUNICATIONS

COMPONENTS

COMPUTING

IMAGING

SENSING & TIMING

QUANTUM TECHNOLOGIES CHALLENGE LED COMPETITION QTC

UK Research and Innovation

CATEGORY KEY

COMMUNICATIONS

COMPONENTS

COMPUTING

IMAGING

SENSING & TIMING

QUANTUM TECHNOLOGIES CHALLENGE LED COMPETITION QTC

QTC FEASIBILITY STUDIES IN QUANTUM COMPUTING APPLICATIONS | 2022 - 2025

UK Research and Innovation

CATEGORY KEY

COMMUNICATIONS

COMPONENTS

COMPUTING

IMAGING

SENSING & TIMING

QUANTUM TECHNOLOGIES CHALLENGE LED COMPETITION QTC

UK Research and Innovation

CATEGORY KEY

COMMUNICATIONS

COMPONENTS

COMPUTING

IMAGING

SENSING & TIMING

QUANTUM TECHNOLOGIES CHALLENGE LED COMPETITION QTC

Foreword

ROGER MCKINLAY
CHALLENGE DIRECTOR
COMMERCIALISING QUANTUM TECHNOLOGIES

Much has changed since our 2022 directory was published.

Firstly, the publication of the £2.5B 10-year National Quantum Strategy in March 2023 has maintained the UK's position as a leading country in the creation and exploitation of quantum technologies. As we invest more public money, we expect private investment to rise with it. The strategy includes an aim to raise an "additional £1 billion of private investment into the programme". Since the Challenge was launched in 2018, we have committed £204M in 189 business-led projects involving 182 companies. These companies we have raised over £500M of private investment. Our ambition is well founded.

Secondly, the public investment now extends beyond the Industrial Strategy Challenge Fund. During 2023 we have launched programmes under the banners of: Technology Missions (£85M total); a Quantum Catalyst (£15M); a collaborative R&D programme on Scalable Quantum Network Technologies (£10M); and a Small Business Research Initiative (SBRI) programme for Quantum Networks, Enabling Components & Systems (£10M). The SBRI programme not only marks a move from grant funding to procurement but also increased cooperation with the National Quantum Computing Centre. (The new building opens in 2024.) Activity in Quantum Networks will yield opportunities for international collaborations.

Thirdly, amongst this new activity is a programme dedicated to quantum Position, Navigation and Timing. This is a reminder that quantum clocks and sensors are an important part of our strategy which covers a broad range of quantum technologies, not just quantum information science.

Our colleagues in the Engineering and Physical Sciences Council are currently planning new Quantum Technology Research Hubs and Centres for Doctoral Training. We look forward to continuing to help UK companies fulfil their ambitions in quantum technologies with the scientific research, talent and financial support they need.

The numbers

THE UK QUANTUM TECHNOLOGY CHALLENGE

7 years strategy (2018-2025)

TO DATE

£204M UK government investment awarded to

189 business-led projects involving

182 UK companies in collaboration

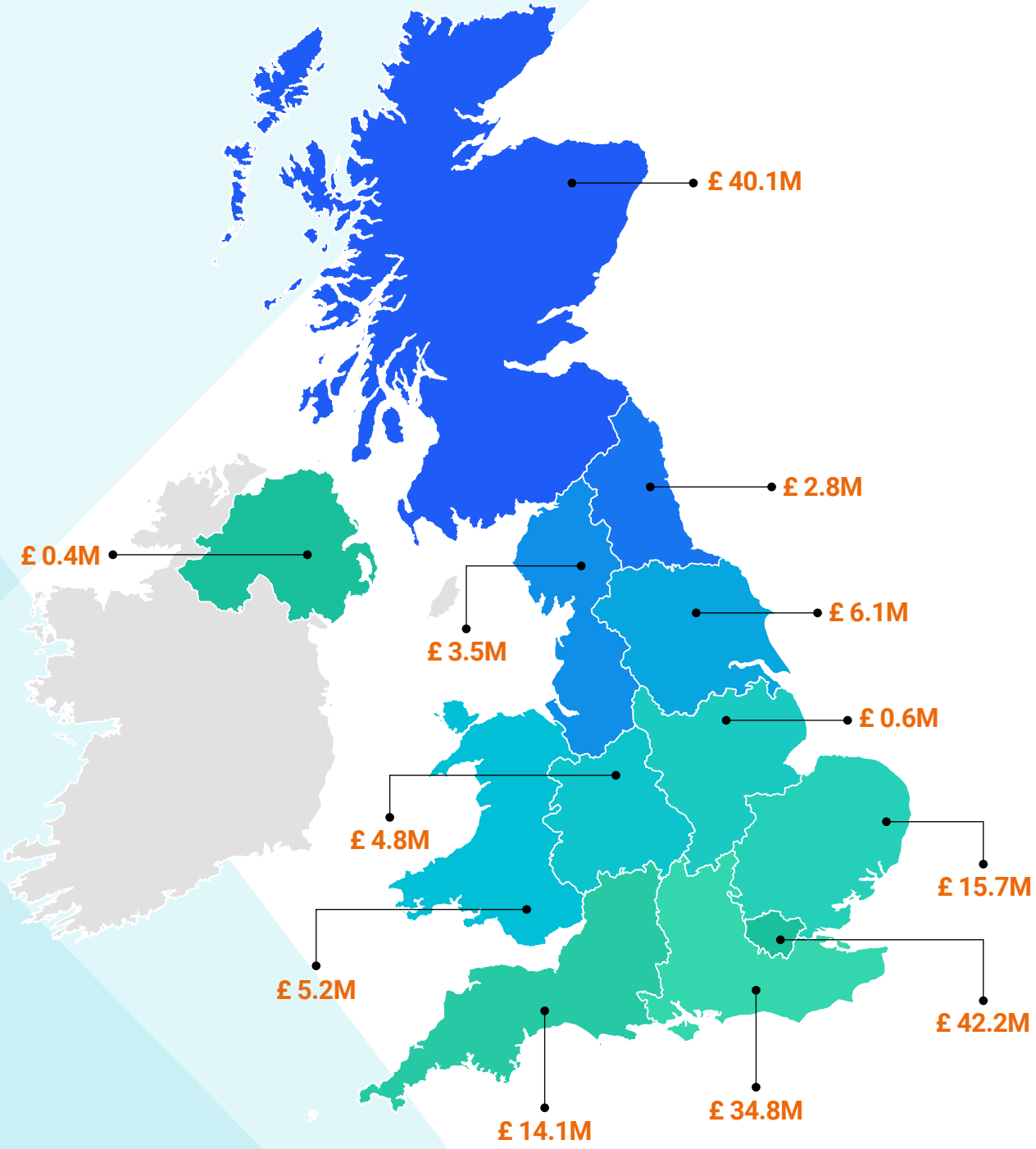
THE UK QUANTUM LANDSCAPE

Over **£513M** private investment since 2018

Global market forecast to be **$21Bn** by 2025

One of the UK's **6** fastest growing sectors in 2020

The challenge in place: breakdown of awards by region



The UK Quantum Technologies Challenge is delivered across a range of funding programmes to drive collaboration, catalyse private investment and build UK industrial leadership.

Collaborative Research & Development (CR&D) Projects.
Up to 3 years and £10M grant. These are organised around the commercial advancement of a quantum product or service. Consortia are typically comprised of full technology chains, from research organisations to component manufacturers, systems integrators and end-users. Innovation progresses to system demonstration in end-user trials at the final stages of the project.

Technology Projects.
Up to 3 years and £10M grant. These projects are primarily focused on the removal of technical barriers that are shared across the quantum industry to accelerate commercialisation. Consortia bring together a range of businesses with the support of research organisations to address these common challenges.

Feasibility studies.
Up to 1.5 years and £0.5M. These are earlier stage innovation projects that focus on advancing user defined quantum products, services and devices, components or supply chain elements for the current or future quantum technologies market.

Investor partnership.
Delivered in partnership with IP Group, this programme sees project grant funding aligned with direct equity investment to accelerate and de-risk private investment into quantum technology companies with high growth potential.

Small Business Research Initiative (SBRI).
SBRI offers organisations the opportunity to work directly with the public sector to develop new technologies and processes, helping to meet efficiency targets and improving public services. SBRI supports the research and development of solutions to solve public sector challenges. The initiative is not limited to small businesses but open to any organisation, regardless of size or previous experience of working in a specific sector. SBRI is responsible for some of the most exciting and innovative projects that have made the public sector more efficient and effective. SBRI challenges have supported collaborative projects across the UK to solve problems for various public sector organisations including the Department for Transport, NHS and local councils.

INTERNATIONAL

UK-Canada programme.
Projects up to 3 years and £0.5M. Building mutually beneficial international collaboration in commercial quantum technologies innovation, involving both industry and academia. These projects are laying the technical foundations for advancing commercial ties between UK and Canada, both nations with a deep and rich heritage in quantum science and technology. In partnership with the Natural Sciences and Engineering Research Council of Canada.

Quantum Pioneer

3QN: Towards A New UK Industry for Novel Quantum Receivers in Nascent Satellite QKD Global Markets

Quantum Key Distribution (QKD) is a well understood application of quantum technology and there are several metropolitan fibre networks already established for QKD demonstrations. However, key distribution is limited by absorption inside optical fibres which mean that transmissions can occur over only limited distances. Free space communications do not suffer the same degree of attenuation and single photon communication with satellites orbiting the Earth at several hundred kilometres has already been demonstrated. Satellites then, provide an ideal vehicle for distributing quantum key information across very large distances between end users spread across countries or continents.

The 3QN project brings together quantum and optical expertise from across the UK to develop a new generation of Optical Ground Receivers (OGRs) to work with these satellites. These new OGRs will play a crucial role in the deployment of a ubiquitous QKD network, enabling quantum safe communications from London to Sydney and anywhere else on the globe. Arqit has invented its own quantum encryption method which are trustless and provably secure. Its recently launched QuantumCloud™ delivers the most effective, efficient, and secure form of key exchange to devices – anywhere in the world. This new low-cost, lightweight OGR will revolutionise the field of advanced quantum communications and help to secure the global Internet from the threat posed by the imminent arrival of quantum computers.

FUNDING GRANTED: £3,251,717

- ARQIT LIMITED
- TELEDYNE E2V (UK) LIMITED
- UNIVERSITY OF CAMBRIDGE
- BT
- UNIVERSITY OF YORK
- HERIOT-WATT UNIVERSITY
- REDWAVE LABS LIMITED
- FRAUNHOFER UK RESEACH LIMITED
- NPL MANAGEMENT LIMITED
- WIDEBLUE LIMITED

AQuaSec

Much of the cryptography we rely on everyday is based on the difficulty of certain mathematical operations, such as finding the prime factors of a very large integer. However, recent advances in quantum computing means that these difficult math problems might soon be solved efficiently, with a potentially serious impact upon our security and digital economy. This project will develop technologies for 'quantum-safe' communications, which are not threatened by a quantum computer. It will combine efficient implementations of new quantum-resistant algorithms and techniques from quantum cryptography, which are immune to all advances in computing, including quantum computing. The project will build prototypes, test their security and demonstrate their benefits to end users.

FUNDING GRANTED: £5,798,748

TOSHIBA EUROPE LIMITED
HERIOT-WATT UNIVERSITY
BP PLC
IQE PLC
QUEEN'S UNIVERSITY BELFAST
BT
DASHBOARD LIMITED
UNIVERSITY OF SHEFFIELD
SENETAS EUROPE LIMITED
UNIVERSITY OF CAMBRIDGE
TETHERED DRONE SYSTEMS LIMITED
BAY PHOTONICS LIMITED
KETS QUANTUM SECURITY LIMITED
NLP MANAGEMENT LIMITED
UNIVERSITY OF GLASGOW
ROYAL HOLLOWAY UNIVERSITY OF LONDON

Pioneer Gravity

Despite our increasing ability to detect and monitor objects that exist on land, sea, around buildings or in space, our ability to detect objects beneath the ground has not improved significantly. When it comes to attempting to locate a buried and forgotten pipe, telling the extent of a sink hole or assessing the quality of infrastructure we still often resort to digging or drilling holes. This presents a huge economic and societal cost as road networks are dug up, oil wells are dry or brown-field land is left undeveloped. Existing techniques are all fundamentally limited in either their sensitivity (classical microgravity), their penetration (ground penetrating radar) or their cost (seismic).

For over 30 years, universities and academics have been exploiting the strange effects of quantum superposition to measure gravity with astonishing sensitivity. Using a process called cold-atom interferometry, the wave-partial duality of a rubidium atom is compared to the phase of a laser beam in a way which can detect very small changes in the way atoms fall freely in a vacuum. Changes in this free-fall can be used to determine the local strength of gravity and if this measurement is sensitive enough, the measurement can be used to tell whether there are voids, pipes, tunnels, oil and gas reserves in the ground beneath your feet.

Although the potential is there, there are huge scientific and engineering challenges to delivering this performance.

This project is proposed by the UK consortium of the best scientific and engineering companies the UK has to offer. Working with leading UK universities, these companies are looking to overcome these challenges, and develop a new industry of 'quantum' cold-atom sensors in the UK. If these advanced performances canbe demonstrated, the economic and societal benefit of this new 'quantum' industry in the UK is expected to be significant and long-lasting.

FUNDING GRANTED: £6,005,395

RSK ENVIRONMENT LIMITED
GEOMATRIX EARTH SCIENCE LIMITED
TELEDYNE (E2V) LIMITED
ALTER TECHNOLOGY TUV NORD UK LIMITED
FRAUNHOFER UK RESEARCH LIMITED
UNIVERSITY OF SOUTHAMPTON
UNIKLASERS LIMITED
SILICON MICROGRAVITY LIMITED
MAGNETIC SHIELDS LIMITED
UNIVERSITY OF BIRMINGHAM
ALTRAN UK LIMITED
QINETIQ LIMITED

Kairos

This project will develop a pre-production prototype of a miniature atomic clock for providing precise timing to a variety of critical infrastructure services, such as reliable energy supply, safe transport links, mobile communications, data networks and electronic financial transactions. The precise measurement of time is fundamental to the effective functioning of these services, which currently rely on Global Navigation Satellite Systems (GNSS) for a timing signal. However, GNSS signals are easily disrupted either accidentally or maliciously, and in prolonged GNSS unavailability, these critical services stop functioning. The reliance on GNSS for precision timing, and the consequent vulnerability of our essential services prompted Innovate UK to commission a report published by London Economics in June 2017.

It estimated the impact on the UK economy of a five day GNSS outage at £5.2billion. That message is becoming widely understood and is creating a demand for timing solutions that are not GNSS dependent. The next generation miniature atomic clock arising from this project fulfills this need and will find widespread application in precision timing for mobile base stations, network servers for financial services, data centres, national power distribution networks and air traffic control systems. Further applications arise in areas where an independent timing reference is needed on mobile platforms and especially in areas where no GNSS signal is available. A high performance compact clock would benefit a range of useful capabilities, addressing civil and military applications, bringing both technical and economic gains for the UK.

FUNDING GRANTED: £4,450,252

TELEDYNE E2V (UK) LIMITED
UNIVERSITY OF YORK
NPL MANAGEMENT LIMITED
INTEGRATED COMPOUND SEMICONDUCTORS LIMITED
CARDIFF UNIVERSITY
HCD RESEARCH LIMITED
LEONARDO MW LIMITED
COMPOUND SEMICONDUCTOR CENTRE LIMITED
ALTRAN UK LIMITED
ALTER TECHNOLOGY TUV NORD LIMITED

CR&D Round 1

AirQKD

AirQKD establishes a UK ecosystem, from single-photon components to networked quantum systems, to protect short to mid-range communication in free space. In particular we carry out pilot demonstrations of the enabling infrastructure for quantum-secure 5G and autonomous and connected vehicles.

FUNDING GRANTED: £5,791,335

- BT
- UNIVERSITY OF WARWICK
- UNIVERSITY OF STRATHCLYDE
- UNIVERSITY OF BRISTOL
- FRAUNHOFER UK RESEARCH LIMITED
- UNIVERSITY OF EDINBURGH
- HERIOT-WATT UNIVERSITY
- NPL MANAGEMENT LIMITED
- ARQIT LIMITED
- COMPOUND SEMICONDUCTOR APPLICATIONS CATAPULT LIMITED
- BAY PHOTONICS LIMITED
- ANGOKA LIMITED
- OPENLIGHTCOMM LIMITED
- NU QUANTUM LIMITED

High-BIAS 2

Navigation using space-based satellite signals underlies many critical technologies across the UK. Most advanced navigation technologies rely on the signals from networks known as the Global Navigation Satellite System (GNSS) to remain accurate over long distances. Loss of these signals result in an unstable navigation systems and increasingly less accurate location and direction estimation during operation.

GNSS signals may be lost accidentally from criminal activity or due to military action. For example, in 2018 several passenger flights off the Norwegian coast lost GNSS signals due to signal 'jamming' from military exercises. In addition, 'spoofing' or deliberately transmitting false guidance signals has been demonstrated as an insidious cyberweapon that can deliberately mislead and fool cargo or passenger vessels. As systems are increasingly automated, the consequences of the loss of GNSS signals dramatically increase and may include loss of property, or in the extreme case, loss of life. Local on-board instruments can provide measurements to stabilise current navigation system technology without GNSS signals.

Quantum technology-based sensors have the potential to provide stability to navigation systems over long periods of time due to the unique combination of high sensitivity to motion with superb isolation from changes in the surrounding environment. High-BIAS2 will demonstrate the ability of a quantum rotation sensor's ability to stabilise the orientation of aircraft guidance system in the absence of GNSS signals. Local stabilisation using quantum technology will decrease the reliance of navigation systems on GNSS and provides a measure of protection against signal loss, jamming, and spoofing to increase safety and security.

FUNDING GRANTED: £2,851,861

COLDQUANTA UK LIMITED
FRAUNHOFER UK RESEARCH LIMITED
ALTER TECHNOLOGY TUV NORD UK LIMITED
PA CONSULTING SERVICES LIMITED
CALEDONIAN PHOTONICS LIMITED
BAE SYSTEMS PLC
REDWAVE LABS LIMITED

Mag-V

Quantum magnetometers optically monitor the interaction between alkali-metal-atoms and an external magnetic field and detect the change in electron spin due to the magnetic field being applied. This allows the detection of micro-defects in materials and objects tha are not visible or hidden from view.

The MagV project will deliver the world's first commercial miniaturised Radio Frequency (RF) atomic magnetometer that can operate in unshielded environments allowing general use and wide deployment.

Primary applications have been identified in consultation with an extensive industry advisory board, who have defined industry challenges driving the need for miniaturised-RF-quantum-magnetometers as novel sensors within non-destructive testing.

The project brings together substantial research on quantum magnetometers with route to commercialisation through established Vertical Cavity Surface Emitting laser supply chain partners and an end-user to maintain UK leadership in quantum technologies.

FUNDING GRANTED: £1,869,569

MICROCHIP LIMITED
UNIVERSITY OF NOTTINGHAM
COMPOUND SEMICONDUCTOR CENTRE LIMITED
INEX MICROTECHNOLOGY LIMITED
NPL MANAGEMENT LIMITED
CARDIFF UNIVERSITY
COMPOUND SEMICONDUCTOR TECHNOLOGIES GLOBAL LIMITED

Next generation satellite QKD

Quantum Key Distribution (QKD) facilitates the secure sharing of encryption keys using quantum technology. These keys can encrypt data for transmission over conventional fibre links across any distance, but QKD itself is limited over fibre to around 151km. Beyond this, 'trusted nodes' are required, but at major risk of creating security vulnerabilities. A number of fibre QKD networks are being built, including in the UK, but all are subject to this constraint. QKD through free space is less sensitive to distance. Thus, satellites provide the means for distributing keys across very large distances between end users spread across countries or continents – they are a facilitator of global QKD networks.

Satellite components in QKD networks are being planned or researched in a number of countries. A consortium led by ArQit aims to establish the world's first commercial QKD satellite constellation. The first satellite is being built under contract with the European Space Agency, with a quantum payload being manufactured by European partners.

There is an opportunity for the UK quantum technology industry to leapfrog other countries by creating a capability to manufacture the next generation of space QKD payloads here in the UK. The 'Quantum Payload Factory' project will work with organisations across the UK to progress the state of the art of promising quantum communications technologies, understand their potential to enhance the performance of ArQit's global QKD system, validate their capabilities and technology readiness, engineer them to become 'space ready' and develop an enhanced performance payload design that brings these new UK technologies into the second generation of Arqit satellites.

FUNDING GRANTED: £4,505,983

ARQIT LIMITED
STFC – LABORATORIES
HERIOT-WATT UNIVERSITY
FRAUNHOFER UK RESEARCH LIMITED
BT
TOSHIBA EUROPE LIMITED
NU QUANTUM LIMITED
ORCA COMPUTING LIMITED
AEGIQ LIMITED

Quantum computing platform for NISQ era applications

Rigetti Computing, Oxford Instruments, Standard Chartered, Phasecraft, and the University of Edinburgh will collaborate to advance quantum computing in the UK. The team will address several key aspects of quantum computing including:

1. hardware, infrastructure, and supply chain;

2. accelerating industrial applications; and

3. developing the quantum ecosystem to help solve important but currently intractable problems.

This work positions the UK as a global leader in the emerging quantum industry, expected to be £4 billion by 2024, growing to £350 billion/year by 2050.

To demonstrate value beyond this project, the consortium will develop the UK's nascent quantum ecosystem to extend industry capabilities in finance, energy, pharmaceuticals, aerospace, and automotive. Through existing relationships and forums, the consortium will expand the community by delivering workshops, computing credits, and technical support, helping end users to validate their research and business concepts.

FUNDING GRANTED: £6,327,690

RIGETTI UK LIMITED
UNIVERSITY OF EDINBURGH
OXFORD INSTRUMENTS NANOTECHNOLOGY TOOLS LIMITED
PHASECRAFT LIMITED
STANDARD CHARTERED BANK LIMITED

Quantum sensors for end-of-line battery testing

It is anticipated that 50% of vehicle production will be wholly or partially electric by 2030. This project aims to commercialise known quantum technology to address identified challenges in the manufacture of batteries and lithium cells. Quantum technology enables highly sensitive measurements of magnetic fields. This project will use these magnetic measurements to diagnose current flows in lithium cells and the consortium will develop a complete environmentally controlled ageing test production system deployed at the largest commercial powder to power lithium-ion and sodium-ion manufacturing plant in the UK (project lead: AMTE Power). The system will be integrated into AMTE Power's pouch cell assembly and test processes trialled on the range of High, Ultra High power, High Energy and Sodium-ion cells currently being scaled-up and commercialised for UK niche automotive market in particular.

Having gained global acclaim for best-in-class ICE's, Cosworth are perfect examples of what's best about the UK's high-performance automotive developers. Now they are seeking to build equally successful electric drive trains and only power cells of the very highest quality will suffice. The project is fortunate to have Cosworth as an active partner taking advantage of the Quantum Sensor technology ability to select A-Grade cells for the best hybrid battery performance and good lifetime state-of-health. The technology adds strength to second life use of cells viability due to better state-of-health confidence through first life.

The UK Battery Industrialisation Centre opened for use on 15 July 2021. This will be closely followed by AMTE Power's parent company's AMTE GigaFactory which will be capable of manufacturing millions of cells in the UK every year. Like all cell manufacturers, AMTE Power will be burdened with the bottleneck of cell formation and ageing processes. This project aims to significantly reduce this impact and also improve quality yields providing the ability to grade cells effectively. This could prove massively beneficial to the fledgling industry providing a competitive edge enabling AMTE Power to take market share earlier.

FUNDING GRANTED: £3,771,863

AMTE POWER LIMITED
UNIVERSITY OF STRATHCLYDE
ALTER TECHNOLOGY TUV NORD UK LIMITED
UNIVERSITY OF SUSSEX
MAGNETIC SHIELDS LIMITED
CDO2 LIMITED
COMPOUND SEMICONDUCTOR CENTRE LIMITED
CENTRE FOR PROCESS INNOVATION LIMITED
COMPOUND SEMICONDUCTOR TECHNOLOGIES GLOBAL LIMITED
KELVIN NANOTECHNOLOGY LIMITED

SPIDAR

This project will develop novel range finding and 3D-imaging systems which will be used for driver assistance and the autonomous vehicles of the future. The cameras are based on detecting single photons (light particles) in the infra-red region of the electromagnetic spectrum. Depth information is gained by measuring the time of flight of the photons from the illuminating laser, to the object and back to the photon detector in the camera with sub-nanosecond precision. By detecting single photons, the faintest possible light signals, we will realise cameras that can 'see' further than the 3D-cameras available today.

FUNDING GRANTED: £3,652,519

TOSHIBA EUROPE LIMITED
THALES UK LIMITED
NETWORK RAIL INFRASTRUCTURE LIMITED
BAY PHOTONICS LIMITED
IQE LIMITED
HERIOT-WATT UNIVERSITY
COMPOUND SEMICONDUCTOR TECHNOLOGIES GLOBAL LIMITED
UNIVERSITY OF CAMBRIDGE
HORIBA MIRA LIMITED
UNIVERSITY OF EDINBURGH
UNIVERSITY OF GLASGOW

SPLICE

As natural gas becomes the leading fossil fuel, industrial gas leaks are becoming a major source of climate changing carbon emissions. The SPLICE project assembles a world-leading scientific and industrial consortium to develop and industrialise gas (methane) imagers based on time-correlated single photon counting, one of the early applications of quantum technology. This revolutionary UK technology will make accurate leak measurements at a fraction of existing costs, allowing the global gas industry to control fugitive gas emissions, help save many billions of pounds, and building a sustainable world leading business that reduces climate change.

Shortwave infrared (SWIR) wavelength single photon avalanche detectors (SPADs) are emerging from initial applications to quantum telecommunication networks into new sensing applications, including vehicle lidar. QLM, a start-up out of the University of Bristol and QuantIC, the Quantum Enhanced Imaging Hub, and ID Quantique, the world leader in near infra-red (IR) single photon detection, have used non-cryogenic SWIR SPADs to demonstrate innovative, low-cost, highly sensitive, long range, single-photon lidar gas imagers that see and measure invisible toxic gases. These quantum gas imager prototypes have demonstrated outstanding performance, but the technology remains at prototype level, using individually packaged commercial-off-the-shelf (COTS) photonic and optical components and only addressing a single gas, methane, so is not yet ready for industrial use.

The SPLICE project will be a major expansion of engineering talent and effort aiming to build the first scalable industrial product to come from the UK's billion pound investment in quantum technology.

The SPLICE team will innovate this technology into a flexible sensor platform that addresses key customer demands for robust, low cost and industrially qualified products that can simultaneously image multiple greenhouse gases. Commercial photonics experts QLM, IDQ, Compound Semiconductor Application Catapult and Bay Photonics will collaborate to expand the range of critical components, develop new multiple gas designs, start UK development of enabling SPAD detectors with the University of Sheffield, and expand work on new mid-IR quantum sensing architectures that can measure all possible gases with the University of Bristol. Together we will integrate the best of these new designs into compact state-of-the-art packages and develop and qualify complete networked IoT imager products to industry requirements. And then with gas emissions experts at the National Physical Laboratory and natural gas and industrial sensor leaders National Grid, Ametek, and BP we will validate our imagers' capabilities for commercial applications and start to address the multi £100million business opportunity.

FUNDING GRANTED: £2,442,956

QLM TECHNOLOGY LIMITED
NPL MANAGEMENT LIMITED
NATIONAL GRID GAS PLC
BAY PHOTONICS LIMITED
BP PLC
UNIVERSITY OF BRISTOL
LAND INSTRUMENTS INTERNATIONAL LIMITED
UNIVERSITY OF SHEFFIELD
COMPOUND SEMICONDUCTOR APPLICATIONS CATAPULT LMITED
ASTON UNIVERSITY
STL TECH LIMITED

Transforming tissue differentiation via quantum digital tomosynthesis

This application is about improving an existing medical imaging technique which is used during cancer surgery to distinguish between healthy and non-healthy tissue. The improvements will rely on the application of quantum technology.

Pathology is the study and diagnosis of disease through examination of surgically removed organs, tissues (biopsy samples) and fluids. When a cancerous tumour is taken out, the surgeon needs to be certain that all the diseased tissue has been removed, and therefore they also remove some surrounding tissue around the edge of the tumour (the 'margins'). The surgeon needs to be sure these margins are free of cancer and can be described as 'clear or negative'. Clear margins suggest all the cancer has been removed and is not able to spread, giving the best outcome for the patient.

So, a highly sensitive method of differentiating between healthy and unhealthy soft tissue is vital, and also between soft and hard tissues (bones). The establishment of these 'clear tissue margins' is best done whilst surgery is ongoing – so the technique also needs to give accurate 3D images quickly and not take up much room in a busy operating theatre.

Currently this is done via 'pathology cabinets' which give 2D or 3D images – but are often slow (several minutes) and bulky (similar to a filing cabinet). There is a need for more accurate differentiation of the boundaries between the tumour and healthy tissue, enabling surgeons to make confident real-time decisions during operations. The equipment also needs to be cost-effective, have a small footprint in the operating theatre and give accurate, easily understandable images.

This grant will be used to build a prototype of a new type of pathology cabinet – using quantum technology applied to key parts of the system (the x-ray source and detector), plus new software to produce high-resolution material discriminating images (which are also better suited for the training of machine learning and application of artificial intelligence).

The resulting images would give better differentiation between cancerous and healthy tissue, enabling surgeons to confidently remove the minimum amount of healthy tissue whilst being sure of clear margins. This will benefit healthcare providers in terms of better patient care, reduced workflow and costs, and most importantly, improve outcomes for patients in terms of reduced risk of more than one operation and a reduced chance of cancer spreading from positive margins left after initial surgery.

FUNDING GRANTED: £1,376,669

ADAPTIX LIMITED
KROMEK LIMITED
UNIVERSITY OF MANCHESTER

Technology Projects Round 1

Assurance for quantum random number generators

Data is one of the world's most valuable commodities – affecting every person, every company, every government, everywhere. Most of the world's cybersecurity infrastructure is based on the exchange and use of digital cryptographic keys. Random number generators (RNGs) are essential components of this existing infrastructure, and newer technologies such as quantum key distribution. Quantum random number generators (QRNGs) are devices that utilise the inherent randomness in natural physical processes to create random numbers, assured unique to each device if the process is truly quantum, and are one of the first practical implementations of quantum technologies. A key differentiator of quantum RNGs over other conventional pseudo RNGs, crucial for all security applications, is that identically manufactured and prepared pseudo RNGs are certain to produce the same random sequences, while QRNGs are not.

A method for providing authoritative assessment of the unique randomness produced by QRNGs does not currently exist. This project will address that need, thereby overcoming this important technological barrier to their commercial and industrial exploitation, and maximising UK return from quantum technology research in this field.

Current tests for RNGs, based on numerical analysis of their outputs, give information about the statistical properties of the output randomness but cannot assure that the output is unknown to others. Stronger assessment is possible for QRNGs, since in addition to numerical analysis to assure randomness, the physical process used to create the output can be modelled and physically tested. Assessing the 'quantumness' of the process also assesses the privacy of the output.

This project will take QRNGs that are either already on the market or near-market prototypes and implement this assessment approach. It will thereby provide the expertise and capability for creating a UK assessment process for QRNGs.

FUNDING GRANTED: £2,753,822

NPL MANAGEMENT LIMITED
UNIVERSITY OF YORK
CAMBRIDGE QUANTUM COMPUTING LIMITED
NU QUANTUM LIMITED
UNIVERSITY OF KENT
KETS QUANTUM SECURITY LIMITED
TOSHIBA EUROPE LIMITED
ID QUANTIQUE SA

Discovery

The UK has world leading capability in scalable, high fidelity qubit generation for quantum computing, with two particularly compelling approaches being neutral atoms and ion microtraps. These technologies, however, remain at low Technology Readiness Level (TRL) because a viable commercialisation approach requires the provision of test beds available to the UK community, and test beds are unavailable owing to two technology barriers – qubit scalability and fidelity. Providing these test beds requires inter-disciplinary expertise beyond any one company.

Our vision for this project is to bring together a such world-leading multidisciplinary consortium of UK industry and academic partners – the only group capable of overcoming the two barriers and creating a globally leading industry for commercial quantum computing and simulation hardware.

The programme will show a transition from fundamental, academic TRL activity to scalable, commercial deployments of cold matter quantum information systems; overcoming the fidelity and scalability barriers via advancement of system manufacturability including microfabrication and vacuum hardware; development of the photonics backbone including advanced lasers for state preparation, qubit control and readout, requiring high levels of optical power, stability and noise suppression; and the design and delivery of electronics and control systems, including modular electronics and advanced control and sequencing hardware.

The key objectives in overcoming the barriers as described above is to bring the technology to a level where pragmatic test bed facilities for the benefit of the quantum community can be realised. Commercially, by establishing the potential scalability of the technology the consortium will establish a supply chain cluster, evidencing the potential impact, and producing a roadmap to industrial production.

The partners have extensive experience in the sector and can already demonstrate commercial deployment of relevant technologies across the global market for quantum information systems. Furthermore, the planned work can be expected to dovetail with existing national quantum computing infrastructure, to realise coordinated growth of the UK quantum computing sector for the wider benefit of UK PLC, and trigger significant additional investment outside the project funding.

FUNDING GRANTED: £7,161,243

M SQUARED LASERS LIMITED
UNIVERSITY OF OXFORD
UNIVERSITY OF STRATHCLYDE
UNIVERSITY OF GLASGOW
TMD TECHNOLOGIES LIMITED
NPL MANAGEMENT LIMITED
KELVIN NANOTECHNOLOGY LIMITED
ORCA COMPUTING LIMITED
OXFORD IONICS LIMITED

NISQ.OS

Without an operating system, computers would be much less useful. Before the invention of operating systems, computers could only run one calculation at a time. All tasks had to be scheduled by hand. Operating systems automate the scheduling of tasks and make sure that resources such as memory and disk space are allocated properly. Because operating systems simplify computers, everyone can handle them and benefit from them.

Quantum computers are a new type of powerful computer. Big and high-quality quantum computers can outperform conventional computers at specific tasks, such as predicting the properties of a drug. Currently, it is difficult for users to interact with quantum computers because there is no good operating system. The systems that exist don't schedule tasks optimally and cannot perform calculations quickly. Building this operating system is difficult -- many have tried and no solutions have worked. We have invented an operating system to overcome this technical challenge: NISQ.OS.

While competitors present quantum computers as a 'black box', NISQ.OS exposes all its different elements. Many of them look far more familiar than you might think. Quantum computers consist of a quantum processing unit, which contains the qubits, a couple of layers of special-purpose chips that control the qubits, and a conventional computer for overall control. By providing access to all these layers of the 'quantum computing stack', we give the user the power to schedule tasks in an optimal way.

This will improve the performance of quantum computers by a 1,000-fold compared to other leading approaches. Once we integrate hardware and software tightly, we expect that the performance will improve by 1,000,000-fold.

We have assembled a group of experts from across the UK to build the operating system. This includes the UK's leading quantum hardware companies:

- Riverlane, a quantum software company
- Duality Quantum Photonics
- Arm, a UK-based chip manufacturer
- SeeQC UK
- The National Physical Laboratory
- Hitachi
- Oxford Quantum Circuits
- Oxford Ionics, and
- Universal Quantum.

The National Physical Laboratory plays an important role because their expertise lies in developing technical standards for breakthrough technology. To build our operating system, we need to define a new standard interface between software and hardware that everyone can use. Our project will attract many important customers, such as pharmaceutical or chemical companies, as well as the financial industry. Because our operating system is so much better, they will want to run their applications on UK-based quantum computers.

FUNDING GRANTED: £5,363,744

RIVERLANE
DUALITY QUANTUM PHOTONICS LIMITED
ARM LIMITED
SEEQC UK LIMITED
NPL MANAGEMENT LIMITED
HITACHI EUROPE LIMITED
OXFORD QUANTUM CIRCUITS LIMITED
OXFORD IONICS LIMITED
UNIVERSAL QUANTUM LIMITED

QT Assemble

QT Assemble brings together a consortium of UK companies to develop highly-innovative assembly and integration processes for new markets in quantum technologies. Waveguide writing, nanoscale alignment and monolithic integration will be used to deliver new levels of performance in robust and reliable platforms. High-performance components and systems will be demonstrated including highly-integrated lases, photon sources, photon detectors and ultra-cold matter systems.

New commercial opportunities have been identified that require reliable and robust operation in quantum sensing and quantum information processing markets.

FUNDING GRANTED: £7,363,560

FRAUNHOFER UK RESEARCH LIMITED
UNIVERSITY OF STRATHCLYDE
UNIVERSITY OF SOUTHAMPTON
INEX MICROTECHNOLOGY LIMITED
POWERPHOTONIC LIMITED
PHOTON FORCE LIMITED
GOOCH AND HOUSEGO (TORQUAY) LIMITED
COLDQUANTA UK LIMITED
COVESION LIMITED
UNIKLASERS LIMITED LTD
REDWAVE LABS LTD
CALEDONIAN PHOTONICS LIMITED
ALTER TECHNOLOGY TUV NORD UK LTD
AEGIQ LTD

QuEOD

The QuEOD project brings together academic and industrial partners to break through the technology barriers for novel types of time-resolved short-wave infrared detectors and pave the way forwards for UK sovereign supply and leadership. The project will develop a unique supply chain and engage in commercial exploitation for both cadmium mercury telluride and gallium antimonide detector technologies for next generation quantum technology applications.

Industrial partners include:
- Photon Force (project leader)
- Leonardo
- ArQIT
- IQE
- QLM

Academic partners are:
- Heriot Watt University
- Cardiff University
- Sheffield University
- RTO – Compound Semiconductor Applications Catapult

FUNDING GRANTED: £2,464,893

PHOTON FORCE LIMITED
UNIVERSITY OF SHEFFIELD
CARDIFF UNIVERSITY
HERIOT-WATT UNIVERSITY
LEONARDO MW LIMITED
ARQIT LIMITED
COMPOUND SEMICONDUCTOR APPLICATIONS CATAPULT LIMITED
IQE PLC
QLM TECHNOLOGY LIMITED

Reliable, high throughput production and characterisation of coherent superconducting devices (FABU)

Advanced production capabilities have allowed conventional electronics based on semiconductors to become more powerful and support almost all technologies we use today, from laptops to washing machines and cutting edge medical equipment. But semiconductors are now facing hard limits as the miniaturisation of components reaches closer to the atomic scale.

The limitations of these classical circuits can be overcome with quantum circuits, which utilise all the tricks of nature to open up areas in sensing, security and information processing technology that previously remained elusive. One of the most successful ways of building these quantum circuits is with superconductors, which can be built with many of the tools already used for conventional electronics and allow for a large degree of customisation to be applied to almost any area within quantum technology.

Building these superconducting circuits is currently a challenging feat, requiring close to atomic level accuracy of circuit writing and total isolation from any radiation, contamination and defects that would otherwise disturb the delicate quantum state of these circuits. Furthermore, accessing cryogenic equipment and state-of-the-art electronics for verification also presents a significant up-front investment. The capacity to produce these circuits is therefore confined to academic and national labs, and a very small number of secretive commercial ventures.

Whilst there are many potential business opportunities ready to be exploited in this space, the superconducting circuits' production challenges present a large barrier to entry to most companies in the UK. They simply do not have the resources available to catch-up and compete with commercially available solutions.

Fortunately, the UK is home to world-leading experts in the manufacture and validation of high quality superconducting circuits, and to world-class commercial partners across the whole supply chain from production to integration and measurement. Together we are bringing the capability to produce superconducting circuits at commercial scale and quality, for a nascent quantum economy that is about to rapidly expand.

To provide lower barriers to entry and empower UK-based ventures, we will develop R&D centres for businesses, as well as foundries for the purchase of superconducting devices and access to testing equipment. This unique extra capability will empower the UK as a hub for technology based on superconducting circuits, bringing in jobs and investment, and delivering a domestic supply of a technology with many strategic benefits.

FUNDING GRANTED: £4,555,185

OXFORD QUANTUM CIRCUITS LTD
UNIVERSITY OF GLASGOW
ROYAL HOLLOWAY UNIVERSITY OF LONDON
KELVIN NANOTECHNOLOGY LTD
SEEQC UK LIMITED
OXFORD INSTRUMENTS
NANOTECHNOLOGY TOOLS LTD

QFoundry

QFoundry brings together UK's most established supply chains for quantum semiconductor components to address critical challenges in manufacturing and deliver a national – and world – first open-access quantum device foundry.

Utilising existing infrastructure and capital, QFoundry will deliver the foundations for robust, scalable component manufacture in the UK to enable future volume Quantum Technology applications.

QFoundry will initially focus on developing manufacturing platforms and supply chains for single-mode Vertical Cavity Surface Emitting Lasers (VCSELs) and single-photon emitters/detectors to include Quantum Dot (QD) and Multiple Quantum Well (MQW) structures.

QFoundry will leverage knowledge gained to-date across the UK QT programme to:

- Upscale discrete component manufacture using standard semiconductor manufacturing techniques.
- Consolidate links in existing UK supply chains for robust, open-access supply of VCSELs and single photon devices, from design to packaged components.
- Develop the methodology to accelerate high-uniformity, reproducibly and reliability in the context of QT applications.

FUNDING GRANTED: £3,727,598

COMPOUND SEMICONDUCTOR CENTRE LIMITED
UNIVERSITY OF SHEFFIELD
UNIVERSITY OF CAMBRIDGE
INTEGRATED COMPOUND SEMICONDUCTORS LIMITED
CARDIFF UNIVERSITY
NPL MANAGEMENT LIMITED
MICROCHIP TECHNOLOGY CALDICOT LIMITED
BAY PHOTONICS LIMITED
IQE PLC
TOSHIBA EUROPE LIMITED
COMPOUND SEMICONDUCTOR APPLICATIONS CATAPULT LIMITED
AMETHYST RESEARCH LIMITED
CS CONNECTED LIMITED

Feasibility Studies Round 1

369GaN

The Yb+ atomic clock is a highly accurate and stable frequency standard which can be made to be much more compact and portable than other optical clocks, primarily as there is no need for an optical cavity or frequency comb. The Yb+ clock requires a key cooling laser operating at a wavelength of 369nm, achieved by a large, complex, and very expensive laser, limiting the technology to the laboratory.

The 369GaN project develops a 369nm GaN laser diode that meets the wavelength, power and linewidth requirements of Yb+ clocks. The 369GaN project is a highly innovative development beyond state-of-the-art, and represents a significant step forward in the rapid commercialisation of Yb+ clock technology (and other quantum Yb+ cold-atom sensors) by providing small form-factor, simple and cost-effective laser solutions that are easily transportable for field use.

FUNDING GRANTED: £388,757

TOPGAN QUANTUM TECHNOLOGIES LIMITED
FRAUNHOFER UK RESEARCH LIMITED
UNIVERSITY OF GLASGOW
HELIA PHOTONICS LIMITED

ABGRAV

Underground surveying is a rapidly growing sector ($5 billion, 11% compound annual growth rate), driven by the construction industry needing to identify existing utilities such as sewers, electric cables, telecoms cables, gas and water mains prior to invasive excavating, drilling and tunnelling. Without these workers can easily strike pipes and cables, that risks lives, cost money and cause havoc for residents and road-users. It is estimated to cost the UK's economy £1.2 billion per annum, and dissuades re-development of brown field sites. Concurrently, geophysical surveying is widely used in the mining industry, to locate oil reserves or mineral deposits, and for environmental monitoring of water tables and ice sheets.

Cold atom gravimetry offers a potential step change in sensitivity to underground surveying, and a dramatic increase in capability to these industries. M-Squared Lasers Limited's (MSL) quantum gravimeter has already reached significant milestones in its development path within a commercial setting, being demonstrated in 2018 at a national showcase, and recently taking measurements on a barge in London. A key issue with the system is its susceptibility to environmental noise, a limitation of all quantum sensors. With this project MSL aim to comprehensively address these issues with a range of noise compensation subsystems. The output of this project will enable quantum sensors to make leaps forward in sensitivity within field settings, enabling faster commercialisation, and faster return on investment for the benefit of the consortium and UK PLC.

FUNDING GRANTED: £336,412

M-SQUARED LASERS LIMITED

OXFORDSHIRE COUNTY COUNCIL

Compact optics for high- performance portable atomic timing and quantum sensors

Precision timing is key to all aspects of modern infrastructure, from the national grid, to telecommunications, to financial trading, through to global, national, and individual navigation systems. In most cases this timing is received wirelessly through global navigation satellite systems, commonly known as 'sat-nav' or GPS. However, these signals do not have guaranteed security, either through their ownership (the GPS system is run by the US Air Force) or due to the vulnerability of the wireless signal to hacking or jamming. There is an urgent need for a UK source of clocks to protect core infrastructure.

Additionally, the development of a step-change in the accuracy and stability of timing and frequency sources will drive new technologies, including faster telecoms and ever more secure communication protocols, precision navigation for autonomous transport networks and earth observation techniques to monitor climate change.

This project brings a team of leading UK universities with many decades expertise in atomic physics together with industry leaders specialising in nanofabrication and optical systems engineering to deliver a world leading miniature optical system for atom cooling. This innovative approach will generate a source of ultra-cold strontium atoms suitable to deliver highly accurate time referenced to atomic standards. Ultimately, this technology could be employed in a fully isolated clock that is capable of providing a GNSS-surpassing timing standard at the heart of future autonomous vehicles and critical infrastructure networks.

FUNDING GRANTED: £394,541

KELVIN NANOTECHNOLOGY LIMITED
UNIVERSITY OF STRATHCLYDE
WIDEBLUE LIMITED
UNIVERSITY OF BIRMINGHAM

Gravity Delve

The feasibility study Gravity Delve is a collaborative project between the UK Quantum Technology Hub for Sensors and Timing led by the University of Birmingham and Nemein Ltd. Gravity Delve will evaluate the benefits and challenges associated with using quantum gravity sensors down boreholes, and develop designs for new state of the art tools allowing future optimisation of applications including geothermal energy harvesting and carbon capture and storage, which will help the UK meet its legally-binding target of net-zero greenhouse gas emissions by 2050.

FUNDING GRANTED: £424,982

NEMEIN LIMITED

UNIVERSITY OF BIRMINGHAM

IN-QUEST

Superconducting quantum technology, currently regarded worldwide as the leading candidate architecture for the creation of a quantum computer, requires ultra-low temperatures close to 10 milliKelvin. Access to such low temperatures has until now relied on large research-scale cryogenic platforms that typically occupy several tens of square meters of floorspace, and require either helium liquefaction plant or high-power 3-phase electricity and water cooling. These cost and infrastructure requirements are significant barriers to the marketisation of quantum computing technologies.

Commercial cryocooler systems reaching temperatures below 4K are now available in a compact, mobile format that requires only single-phase domestic electrical supply. This creates the technical opportunity to access ultra-low temperatures using compact add-on modules to provide the next-step cooling from 4K down to milliKelvin temperatures. All necessary technological solutions are, in principle, already available for such 'desktop' quantum technology, but they have never before been integrated together into a low-power, low-cost cooling platform designed for quantum computing applications. Demonstrating the feasibility of such a product is the central aim of this project. By dramatically cutting both the capital and operational cost of quantum computing, this development would hugely accelerate its deployment, for example, in hospitals, banks, ports and airports, in both fixed and 'mobile' field-based applications.

The project leaders, Chase Research Cryogenics (CRC) are leading world experts in self-contained cryocooler modules operating from 1K to 0.1K and have an established track record of designing and manufacturing instruments for academics, research institutions and quantum technology companies around the world. CRC will work closely with project partners SeeQC UK, a company specialising in the development of a cryogenic qubit controller that forms the core of practical quantum computing resources. CRC and SeeQC UK will together explore and demonstrate the feasibility of operating the SeeQC UK quantum technology on CRC's novel cooling platform.

Meeting the major challenge of extending CRC's current cooling technology to millikelvin temperatures will require us to unlock the deep specialist knowledge currently residing in the world-leading low-temperature research groups in UK universities, and transfer their know-how into the commercial world. This project will therefore bring together, for the first time, academic and commercial partners in a unique team, encompassing a unique range of knowledge, skills and expertise that could revolutionise the potential for commercialisation of quantum computing.

FUNDING GRANTED: £352,651

CHASE RESEARCH CRYOGENICS LIMITED
SEEQC UK LIMITED
LANCASTER UNIVERSITY
CARDIFF UNIVERSITY
ROYAL HOLLOWAY UNIVERSITY OF LONDON

MANATEE

Single photons are the workhorse of the future quantum technology industry, being a fundamental component to high fidelity quantum computing, quantum communications, quantum imaging and some types of quantum sensors.

They are also a fundamental step in ORCA's plans to build a fully-scalable, optical fiber based photonic quantum computing platform, which will overcome the connectivity and scaling challenges that other platforms face in the medium-term. However, these fields have been held back because of the availability of high-performance single photon sources. For quantum computing single photons are not deterministic, meaning that it is not certain that they will be produced. Instead, current single photon sources fire 'blanks' for most of the time, with spaces where the single photons should be. For quantum communications the rate at which single photons can be created is also limited, which limits the viability of commercial Quantum Key Distribution systems.

For many other applications, single photon sources are low maturity, high-cost or require cryogenic cooling; all features which significantly limit the extent of their market uptake. This project will leverage ORCA's patented optical memory technology, know-how in parametric down conversion and optical memories to deliver a highly efficient, deterministic single photon source.

FUNDING GRANTED: £349,940

ORCA COMPUTING LIMITED

MIRUS

The ability to generate and detect single photons is a critical and enabling aspect of quantum technology, making it possible to encode and transmit quantum secure information, create lidar systems that can see around corners, and quantum imaging systems for enhanced situational awareness in the most obscured environments. Technologies for single photon detection are maturing through the development of Single-Photon-Avalanche Diodes (SPADs) in combination with complementary metal-oxide-semiconductor processes for efficient detection (>35%) of single photons with high timing resolution (<50 ps). Using this technology, high performance and low-cost sensor systems have been commercialised that operate in the sensitivity range of SPADs (400-900nm).

Extending the operating range of SPADs into the 2-5um mid-infrared region would enable longer-range lidar, new thermal imaging modalities, and gas-specific spectral fingerprinting at low concentrations. The MIRUS (Mid-Infrared Upconversion Single-photon detection) project addresses this challenge; our novel detection scheme will use Covesion's recently developed Periodically Poled Lithium Niobate (PPLN) crystal waveguides to enable efficient conversion of single photons in the 2-5um spectral range to the 400-900nm operating region, extending the benefits of low-cost, robustness (operation at room temperature) and high timing resolution SPADs to new wavelengths and applications.

FUNDING GRANTED: £386,943

COVESION LIMITED

BAE SYSTEMS PLC

FRAUNHOFER UK RESEARCH LIMITED

Multicore NISQ processors on silicon chips

Quantum computers represent harnessing nature at its deepest level to build the most capable computing machines we can imagine based on the laws of physics we know today. They have been predicted to transform areas ranging from logistics, to the discovery of materials and drugs, and security.

The most profound impacts of quantum computing will require the full correction of errors in the calculation, and this capability is expected to require up to millions of quantum bits, or 'qubits', all connected by quantum links. However, there is mounting evidence that even relatively small-scale quantum processors, without error correction, will be capable of solving useful problems and offering disruptive advances. For example, a quantum computer with just 53 elementary quantum bits (and no error correction) has recently beaten the world's most powerful supercomputer in a competition to solve a computation problem.

However, the computation problem chosen was a contrived one of no practical value, designed to favour the quantum computer, and it remains an open and important challenge to use such small-scale quantum processors to solve useful problems and achieve what some have termed 'quantum advantage'.

One way to enhance the power of small-scale quantum processors is to operate them in parallel – essentially taking many copies of the quantum processor and giving them related tasks to solve. In practice, this 'multi-core' approach can offer substantial speed-ups for quantum algorithms design for modelling materials and drugs.

However, implicit in this approach is a low 'cost per qubit', which allows the manufacture of many independent quantum processors, and the ability to interface the quantum processors to a conventional computer for control. Silicon offers a platform for quantum computing which is ideally suited to this approach, being able to leverage Complementary Metal-Oxide-Semiconductor (CMOS) technology to produce qubits, as well as the conventional electronics to connect the quantum processors to the required controller.

In this feasibility project, we will further develop the multi-core quantum processor concept in silicon, both experimentally and theoretically, to establish how it can be realised using CMOS technology and what its predicted capabilities will be and what new problems it will be able to solve.

FUNDING GRANTED: £509,835

QUANTUM MOTION TECHNOLOGIES LIMITED

PICAS2

ColdQuanta, Alter Technology and Fraunhofer CAP will develop a commercially-available complete high-flux cold atom source system with uniquely low size and cost. The high flux cold atom source is a complex and critical element of cold matter systems used in a variety of applications such as gravity surveying, atomic clocks, magnetic and electric sensors, navigation, and quantum information systems. The lack of a commercial complete source system at a moderate size and price point is a fundamental barrier to the expansion of atomic quantum technology into deployed applications.

The small size and low cost of our approach turns the entire source system into a module that can be easily added to, or removed from, a more complex system in a modular manner. This simplifies research and development, aids in system integration, and eases maintenance.

FUNDING GRANTED: £301,924

COLDQUANTA UK LIMITED
FRAUNHOFER UK RESEARCH LIMITED
ALTER TECHNOLOGY TUV NORD UK LIMITED

SAFIRE

Progress in commercializing cold-atom-based quantum instruments is limited by the availability of reliable size, weight, power and cost-reduced narrow linewidth lasers. Great progress has been made in the development of semiconductor laser platforms to allow for many of the laser-cooling functions to be achieved, but some of the more-challenging functional requirements are unlikely to be met by this approach. The SAFIRE project will accelerate the commercialisation of cold-atom quantum technologies including optical clocks, gravimeters, inertial-navigation units and ion-trap quantum computers.

In optical clocks, the magic wavelengths for the creation of an optical lattice at 813 nm (Sr) and 759 nm (Yb) require high power and narrow linewidth. This function is generally achieved with a tunable Ti:Sapphire laser. These laser systems generally cost ~£100,000 and are large and fragile devices, making them one of the primary impediments to system miniaturisation and cost-reduction.

Many quantum instruments based upon cold-atom interferometry, such as gravimeters and inertial navigation units for GNSS-free navigation, require a narrow-linewidth Raman-beam to operate. In rubidium interferometers the relatively high-power (multiple Watts in some systems) and narrow linewidths (~10s of kHz) required are often provided by a frequency-doubled telecoms-fibre laser. These lasers are expensive (\>£50,000) and their complexity often leads to unreliable operation. This represents a significant risk to the potential commercialisation of interferometer-based instruments that must be fielded in non-laboratory environments.

The SAFIRE project will develop a new capability in ultra-compact diode-pumped-solid-state lasers that addresses the requirements of the optical lattice function in clocks, the Raman-beam function in atom interferometers, and also for ion-trap quantum computers, in a form-factor appropriate for integration into robust quantum instruments usable outside of the laboratory environment. This development builds upon NPL's long history in optical clock development, Alter technology and RAL-Space's experience in micro-ECDLs for cold-rubidium instruments from the Innovate REMOTE project, and on Caledonian Photonics' capability in miniaturised, robust monolithic DPSS lasers.

FUNDING GRANTED: £327,009

CALEDONIAN PHOTONICS LIMITED
ALTER TECHNOLOGY TUV NORD UK LIMITED
STFC – LABORATORIES
NPL MANAGEMENT LIMITED

Sidewinder

The Sidewinder project develops a component targeted for quantum technology systems integrators looking for a component to replace multiple lasers and control equipment, which can be included in a system with a minimum of complication. It will result in a component that outputs dual frequencies with narrow linewidth, intrinsically stable in respect to each other, for control of atomic states, e.g. cooling and repump without additional sources. The component will be fundamentally simple to integrate and operate by a non-academic user.

FUNDING GRANTED: £376,410

REDWAVE LABS LIMITED

BAY PHOTONICS LIMITED

FRAUNHOFER UK RESEARCH LIMITED

SOLACE

Precision timing plays a vital role in the economy, from enabling satellite-free navigation to protecting the integrity of electronic financial trading. The current state-of-the-art commercial timing systems use microwave frequency atomic clocks, but commercial optical frequency atomic clocks are expected to be available within the next four years, promising a 100x improvement or better over current technology. This will enable submarine navigation to improve from 2km accuracy over a 24hr period to 100m accuracy over several months. It will also prevent millions of pounds in losses due to timing errors in the financial sector.

In this project, M Squared Lasers, together with the University of Birmingham, will design and build the core components of a commercial atomic clock based on the strontium atom. As forerunners in this field of new quantum technology development, we will develop compact and modular subsystems laser sources, optics assemblies and robust electronics packages that will accelerate commercialisation of this new state-of-the-art precision timing system.

FUNDING GRANTED: £398,888

M-SQUARED LASERS LIMITED

UNIVERSITY OF BIRMINGHAM

IPC

Quantum technology systems are currently held back by the lack of qualified, commercial off the shelf sub-systems and components to translate new ideas and system designs (for gravitometers, optical clocks etc) quickly into reality. In most cases the underlying enabling technology needs to be developed which adds risk to these projects.

In this project the consortium partners have identified a need by industry and large research organisations for a key enabling component for rubidium-based quantum technology systems (traps/clocks etc). We will develop a novel high power, high efficiency frequency doubler unit for converting 1,560nm to 780nm for use with rubidium atom traps. High power (>1W) systems are not commercially available, nor academically available with high efficiencies. However, these components are required for enabling novel quantum sensors. The consortium will focus on developing a novel high efficiency non-linear crystal capable of converting 1,560nm to 780nm in a commercially viable package for integration by end-users in space- and ground-based quantum technologies. This will enable the exploitation of innovative, but commercially viable, quantum technologies to benefit wider society.

FUNDING GRANTED: £384,556

COVESION LIMITED

COMPOUND SEMICONDUCTOR APPLICATIONS CATAPULT LIMITED

STFC - LABORATORIES

STREAMLINE

Quantum Technologies are set to transform the technology landscape and change the way we fundamentally navigate, compute, communicate and secure vast quantities of data that is the backbone of modern society. However, the technologies at the heart of this potential revolution are currently, largely shackled to sophisticated laboratories.

The STREAMLINE project will build on highly-successful work from this consortium and will develop a reliable commercial solution for the cooling of strontium ions by addressing the challenges associated with the handling and packaging of novel GaN semiconductor materials. This demonstration represents a key step in meeting the demands of important systems covering the whole GaN-enabled spectrum (365-550nm).

FUNDING GRANTED: £330,128

ALTER TECHNOLOGY TUV NORD UK LIMITED
TOPGAN QUANTUM TECHNOLOGIES LIMITED
FRAUNHOFER UK RESEARCH LIMITED

TuNaFISH

Quantum technologies are set to transform the way we measure the world around us, how we navigate and communicate, and how we process vast amounts of data. At the core of many quantum technology systems currently trapped in laboratories around the world are lasers with extremely stringent requirements on their wavelength, stability and linewidth. Current commercially available lasers are bulky, expensive and struggle to meet these requirements without significant development effort from the user.

To address these challenges, the TuNaFISH project will develop a versatile, compact, narrow-linewidth laser module capable of meeting the requirements for any laser that will be used in a commercial atom interferometer. In this project the consortium will combine advanced spectroscopy and laser locking schemes with mature packaging capability.

This innovative approach will allow us to produce a laser module that is small (approximately 60x40x20mm) and simple to use by system integrators intending to commercialise quantum technologies based on cold atom interferometry, while providing highly tuneable narrow-linewidth laser light without the need for any bulky third-party hardware.

FUNDING GRANTED: £314,063

ALTER TECHNOLOGY TUV NORD UK LIMITED

FRAUNHOFER UK RESEARCH LIMITED

PRISMS

Quantum technologies provide both a threat to, and a solution for, ensuring security in the the communication systems which underpin our daily lives. As quantum computing increases in capability, existing methods for securing data will become obsolete. In parallel new quantum cryptographic methods are being developed which will help to mitigate this threat (for example, Quantum Key Distribution). This will ensure that our most sensitive data can be protected from external agents, be they state actors or sophisticated hacker groups, both now and in the future. A proposed method to deliver a quantum key service is through satellite assets, however for adoption, the security of these assets must be assured.

This project aims to assess particular vulnerabilities of very small satellites (nanosatellites) to backdoor attacks on quantum payloads through the satellite platform. Nanosatellites are increasingly used in commercial services due to their low cost, and as such can be used to fulfil niches roles within a wider capability (e.g. can be produced quickly and cheaply to smooth spikes in demand). The approach to be developed is to ensure that quantum components can be segmented from the rest of the platform, ensuring even if the platform is breached, secure quantum information cannot be accessed. Monitoring of the quantum technologies within the space environment will be required to ensure that their proporties are uncompromised. This will have the added benefit of allowing quantum subsystems to be hosted as a secondary payload on larger satellites.

Bringing together extensive experience in the space, security and quantum domains, this project will assess the potential attack vectors and provide a bench top demonstration of a fully tested system which is aligned to relevant standards. The quantum elements of the programme will be the implementation of a Quantum Random Number Generator and quantum protocol processing algorithms on representative space hardware. Test points will then be defined for threat analysis and penetration testing. This will serve to increase trust levels in these platforms to facilitate the delivery of quantum cryptography, and other secure quantum services, from space-based assets.

FUNDING GRANTED: £385,434

CRAFT PROSPECT LIMITED
DOTQUANTUM LIMITED
UNIVERSITY OF GLASGOW
BARRIER NETWORKS LIMITED
NPL MANAGEMENT LIMITED

QT-MIBA

Quantum technology-mapping and map integration for buried assets (QT-MIBA) seeks to evaluate the feasibility of obtaining and publishing more complete and accurate information on the location of buried assets through enhanced processing of geophysical sensor data. The goal of QT-MIBA is to address the accidental strikes on underground utility pipes and cables that cost the country £1.2billion a year as well as reducing the traffic delays caused by utility streetworks estimated as 6.16 million days of work lost between 2014 and 2015. It will also prevent incidents of workers accidentally hitting gas and electric pipes and thereby endangering their lives and interrupting supply of services to customers.

QT-MIBA represents a major collaboration between Great Britain's national mapping agency and world-leading geospatial authority, an asset owner, a survey company, a data processing SME and an academic partner leading the application of quantum technology sensors for civil engineering applications.

The project aligns with quantum technology sensor development, by providing a roadmap and value assessment of the data to end users. It also supports the initiative promoted by the Geospatial Commission to bring together existing data on underground infrastructure currently held by individual organisations (both privatised and non-privatised) to create a National Underground Asset Register (NUAR). Ordnance Survey Limited and Northumbrian Water Limited currently collaborate on a pilot project in the North East to explore how accurate geospatial data can reduce the likelihood of utility strikes, improve underground infrastructure maintenance and inform new-build development projects. While bringing together existing buried infrastructure data is a significant step forward, there are many questions about the quality of this existing data, including omissions. There is, then, a role for data derived from geophysical surveys to update statutory record data.

QT-MIBA will deliver a feasibility study to assess how data from QT, combined with data from traditional geophysical sensors, can be enhanced using novel processing techniques including artificial intelligence, deep learning and quantum machine learning.

Moreover, it will develop protocols which will enable survey data collected at disparate locations across the network to be integrated into geospatial maps. This will enable an assessment of the value of enhancing the positional accuracy of buried asset records without the need to wait until they are dug up for maintenance.

FUNDING GRANTED: £371,972

NORTHUMBRIAN WATER LIMITED
ORDNANCE SURVEY LIMITED
UNIVERSITY OF BIRMINGHAM
RSK ENVIRONMENT LIMITED
RAHKO LIMITED

QuanTICo

A new generation of Terahertz (THz) imagers has been developed by Durham University using quantum technology. This high speed, sensitive, safe, non-ionising, imaging system is based on the concept of transforming low energy THz radiation to visible light, which can then be easily imaged using any well-established imaging technology.

This breakthrough technological advancement has substantial potential in providing radical new solutions to real and current challenges in industry, specifically where current techniques are limited by material discrimination and throughput.

FUNDING GRANTED: £387,143

UNITIVE DESIGN AND ANALYSIS LIMITED
ALTER TECHNOLOGY TUV NORD UK LIMITED
FRAUNHOFER UK RESEARCH LIMITED
DURHAM UNIVERSITY
PROCTER & GAMBLE TECHNICAL CENTRES LIMITED

QUANTIFI

QUANTIFI aims to develop a world-leading Quantum Computing Dynamical Mean Field Theory (DMFT) solution for strongly correlated catalytic materials. DMFT is needed to properly describe a large number of important transition metal oxides used as catalytic materials for emissions reductions as well as oxides for batteries and other applications. On conventional computers DMFT is restricted to very small systems due to the prohibitive computational cost. Quantum computers (QCs) are expected to lead to exponentially large speedups, making currently unfeasible calculations feasible. We will bring the resulting quantum software product to the market and integrate it in cloud services. This will enable the UK to maintain its world leading position in the quantum materials software market with the advent of QCs.

This will be achieved through the development of a framework based on quantum algorithms that interfaces with a QC to solve the electronic structure problem using DMFT. The vision directly relates to the overall need of the chemicals/materials sector for accurate, rapid modelling solutions, overcoming existing limitations that prevent accurate modelling of materials, reducing the need for lengthy, expensive lab trials. Application of the solution to the materials sector will enable faster discovery of new materials, new economies and new (patentable) discoveries.

The technology will be innovative in a number of clear ways, in particular this will demonstrate the feasibility of using quantum computing to accelerate materials modelling and discovery, including:

- Use of a Variational Quantum Eigensolver (VQE) for ground and excited states within an exact diagonalization (ED) DMFT approach.
- Quantum Machine Learning algorithms for noise reduction and error mitigation.
- Use of quantum DMFT solvers on currently available and near-term ('NISQ') QCs for real materials of industrial relevance. These are expected to be able to solve systems, where state-of-the-art classical methods fail due to the exponential growth of computational times.

QUANTIFI is innovative in that we use a Variational Quantum Eigensolver (VQE) for ground and excited states within an exact diagonalization (ED) DMFT approach to demonstrate the feasibility of quantum DMFT solvers on currently available and near-term (NISQ) QCs for industrially relevant materials.
The work is supported by NPL and KCL, world-leading experts in DMFT.

QUANTIFI, therefore, has potential high impact in catalysis and hence a large product relevance for many of the UKs chemistry manufacturers, materials designers, and pharmaceutical companies. By achieving this, it is estimated that the consortium and wider supply chain will achieve significant benefits.

FUNDING GRANTED: £341,574

RAHKO LIMITED
NPL MANAGEMENT LIMITED
JOHNSON MATTHEY PLC
KING'S COLLEGE LONDON

Quantum computing for battery materials

Quantum computers are expected to be able to solve hard computational challenges that are beyond the reach of our best standard supercomputers. After many years of research in both academia and industry, quantum computers are at the point of outperforming their standard ('classical') counterparts in certain specialised problems. One of the most exciting and plausible applications for near-term quantum computers is modelling quantum-mechanical systems. Understanding such systems is essential for many practical applications, ranging from the design of more efficient catalysts and solar panels to the development of novel drugs. However, exact modelling of a quantum system using a classical computer rapidly becomes infeasible as the system size increases. Quantum computers could overcome this limit and enable us to model currently inaccessible physical systems.

Although there have been many years of theoretical work on quantum algorithms for this modelling task, there remain significant challenges associated with applying these results to practically-relevant problems, and with calculating their complexity. Here our focus will be on modelling problems relating to battery materials. Batteries are essential in many areas of technology, especially for sustainable energy applications, yet modelling their behaviour on a quantum-mechanical level is a daunting challenge for classical methods. This area has been proposed as a likely and important target for quantum algorithms to address, yet little is currently known about whether quantum computing techniques will truly outperform the best classical approaches. We will develop quantum software that demonstrates how to solve battery materials modelling problems of direct relevance to practitioners, and will benchmark these results against leading practical methods. Our consortium includes experts in quantum software (PhaseCraft), computational materials design (UCL) and commercial battery materials (Johnson Matthey).

We will bring together these areas to determine the feasibility of quantum computing for battery material design, and will develop roadmaps that will determine the requirements on quantum computing for their potential to be achieved. A key deliverable of the project will be a demonstrator suitable for integration within an end-user workflow. This project aims to open the door to some of the first commercially relevant applications of quantum computing beyond the classically emulable regime.

FUNDING GRANTED: £421,286

PHASECRAFT LIMITED
UNIVERSITY COLLEGE LONDON
JOHNSON MATTHEY PLC

ViSatQT

Major organisations rely on strong encryption, including the process of encryption key agreement. Future quantum computers have the potential to compromise key agreement schemes based on asymmetric encryption and widely deployed public key infrastructure.

Over long distances and without quantum repeaters, Business Continuity (BC) can be maintained if commercially and technically viable Satellite Quantum Key Distribution (SatQKD) becomes available in time. Current free space optical approaches are not considered commercially viable because they can only operate at night time and in clear sky conditions; and by waiting for overhead satellites in low Earth orbit.

The future BC market, anticipated to be worth billions of pounds, will be addressed by this project through accelerated commercialisation of the SatQKD technologies necessary for operation during daylight hours, cloudy skies and other weather conditions. The project will combine and align technical developments from UK SME's within a system context from Airbus: a major provider of UK-developed secure satellite communication systems.

The objective of this project is to prepare new modular flexible system architectures, technology landscape surveys and technology development roadmaps for lower cost, longer range, free space optical quantum communications directed towards institutional and commercial customers.

The primary focus of innovation in this project is to extend the envelope of satellite-to-ground QKD operations beyond the current state of the art: to enable daytime operation, cloud tolerance and reach key distribution rates several orders of magnitude faster than existing demonstrators.

The project will influence and enhance the coherence of academic research, SME developments, and prime system integration readiness for operational quantum secured communications.

FUNDING GRANTED: £358,644

AIRBUS DEFENCE AND SPACE LIMITED
UNIVERSITY OF STRATHCLYDE
SATELLITE APPLICATIONS CATAPULT
CRAFT PROSPECT LIMITED
KETS QUANTUM SECURITY LIMITED
NU QUANTUM LIMITED
ARCHANGEL LIGHTWORKS LIMITED

Collaborative R&D/Technology Round 2

Aeon-Rb

The project will develop a novel UK designed and manufactured compact Rb-oscillators to serve as holdover clocks in Global Navigation Satellite Systems (GNSS)-independent applications requiring precision timing. The state-of-the-art compact atomic clocks arising from this project shall take advantage of recent advances in Quantum Technologies to find widespread application in new and revamped UK critical national infrastructure applications requiring precision timing.

At present, many of these applications rely on GNSS for a stable clock signal, but these signals are easily disrupted and prolonged GNSS unavailability can lead to vast disruption to critical UK services and economy. New options for a UK satellite navigation and timing capability programme are presently being explored to support the nation's critical infrastructure, and these are anticipated to require a vast number of holdover clocks for added resilience.

The clocks produced in this project will bring a new generation of atomic clocks using new enhanced atom-interrogation methods developed at HCD Research and the National Physical Laboratory to provide extended holdover capabilities. These clocks will also address timing challenges in many civil and military applications, providing more assurance in supply to the UK, better security through better use of technology, and safeguarding and exploiting UK-developed intellectual property to provide economic gains for the UK.

FUNDING GRANTED: £2,568,928

HCD RESEARCH LIMITED
ALTER TECHNOLOGY TUV NORD UK LTD
INEX MICROTECHNOLOGY LIMITED
MBDA UK LIMITED
NPL MANAGEMENT LIMITED

Altnaharra: Cryoelectronics for Quantum Circuits

Quantum computers are expected to have a revolutionary impact on many areas vital for humans to flourish in the 21st Century, ranging from the discovery of new chemicals, materials, and drugs, to the reduction of energy wastage by optimisation of resource usage. However, these high-impact applications are likely to need many thousands or millions of qubits to deliver advantage over a conventional computer based on the algorithms that we know today.

Developing such large-scale quantum processors brings a number of new challenges, not present in the current small qubit number demonstrations. One is how to control and readout each qubit in such a large array without needing to bring in an excessively large number of external wires.

The Altnaharra project brings together leading researchers in superconducting, ion trap and spin qubits along with a world-leading cryogenic equipment supplier and world-leading centre for measurement standards to develop a cryogenic chip for integrated qubit control and readout, manufactured in a standard CMOS foundry. The development of such a chip is a fundamental enabler for the whole quantum computing community and a requirement for creating a quantum processor not limited by IO wires and therefore able to scale sufficiently to solve meaningful problems.

FUNDING GRANTED: £4,371,978

QUANTUM MOTION TECHNOLOGIES LIMITED
NPL MANAGEMENT LIMITED
OXFORD INSTRUMENTS NANOTECHNOLOGY TOOLS LIMITED
OXFORD IONICS LIMITED
UNIVERSITY OF GLASGOW

Autonomous quantum technologies (AutoQT)

For quantum computing to become commercially useful, it is needed to be able to control hundreds or even thousands of qubits at the same time. This is the biggest bottleneck in QC. This project will solve this challenge by building a system that can control hundreds of qubits and that can be used across different types of quantum computers. It will also use a type of artificial intelligence called machine learning to automate the tuning of qubits and maximise the time they are 'spinning in the air'.

The project brings together the UK's leading quantum software company (Riverlane), quantum hardware companies (SeeQC UK, Oxford Ionics) and research organisations (NPL, University of Oxford). They develop different types of qubits that we can test our control system on. Mind Foundry, a University of Oxford spin-out, will develop the artificial intelligence framework that can automatically keep the qubits "spinning". The University of Edinburgh will detect the state of the quantum computer and guarantee optimum performance after intervention.

The partners work together to combine quantum software and artificial intelligence to build a control system for quantum computers that is powerful and intelligent. The project brings together UK-based academic and industrial organisations to strengthen the UK quantum industry and help produce quantum computers that will transform the way several industries, such as finance, drug discovery and materials development, work.

FUNDING GRANTED: £5,336,416

RIVERLANE
MIND FOUNDRY LIMITED
NPL MANAGEMENT LIMITED
OXFORD IONICS LIMITED
SEEQC UK LIMITED
UNIVERSITY OF EDINBURGH
UNIVERSITY OF OXFORD

CIFS – Calcium Ion Frequency Standard

Timing systems based on trapped ions can deliver significantly improved accuracy over currently available commercial systems. Clocks based on trapped ions will enable both backup and stand-alone systems to be built. Currently, these systems, which give accuracies of 10^-18, like an error of one second in the age of the universe, have only been demonstrated in research labs. Furthermore, due to their complexity, power consumption and environmental requirements, these systems are far from portable as well as being too expensive for widespread deployment.

The University of Sussex has developed a portable optical atomic reference based on trapped calcium ions probed by a "clock" laser pre-stabilised to a compact optical cavity and, in conjunction with an optical micro-comb, can turn the output of the system into a useable signal. Together these systems function as an atomic clock with the accuracy required to support future communications and infrastructure systems.

This project aims to improve and industrialise the current calcium ion clock design, reducing the size and weight of the system and ruggedise it by increasing subsystem integration. This will make it a much more useable product for many systems and should open a new market for advanced timing devices with a wide range of applications.

FUNDING GRANTED: £2,170,686

- TMD TECHNOLOGIES LIMITED
- BT
- CHRONOS TECHNOLOGY LIMITED
- COVESION LIMITED
- LEONARDO UK LTD
- QINETIQ LIMITED
- UNIVERSITY OF SUSSEX

Developing an error corrected quantum processor solution for commercial quantum computing

One of the biggest challenges for universal quantum computation is scaling up to fault-tolerant machines with millions of qubits. The quantum hardware developed in QCorrect will be capable of overcoming the limitations faced by competitors around the world, propelling the UK to become a leader in commercial QC. While competing platforms based on superconducting qubits are limited because of the requirement to cool microchips to -273C, our platform is based on trapped-ions and does not require such cooling.

Full silicon microchip integration will allow the creation of self-sufficient electronic QC modules to be deployed and made cloud-accessible for end-user investigation. Hardware/software development is led Universal Quantum and Riverlane, together with leading subsystem manufacturers for vacuum systems (Edwards) and microwave technologies (TMD Technologies, Diamond Microwave) incubating a QC supply chain in the UK.

To ensure a pathway to commercialisation, applied Computational Fluid Dynamics experts at Rolls-Royce and STFC will work to develop a quantum approach to solving partial differential equations that underpin commercially relevant simulations in the UK aerospace sector. Exploitation/dissemination partners Sia Partners will develop a roadmap to commercialisation of application-specific tools in CFD and Qureca will develop broader use-cases. The consortium will execute the first use-case demonstrations and streamline hardware/software development towards practical applications.

FUNDING GRANTED: £5,666,492

UNIVERSAL QUANTUM LTD
DIAMOND MICROWAVE LIMITED
EDWARDS LIMITED
IMPERIAL COLLEGE LONDON
QURECA LTD
RIVERLANE
ROLLS-ROYCE PLC
SIA PARTNERS UK PLC
STFC - LABORATORIES
TMD TECHNOLOGIES LIMITED
UNIVERSITY OF SUSSEX

Development of cryo-CMOS to enable the next generation of scalable quantum computers

The race is on to build the world's first practical quantum computers, which requires scaling from a few dozen qubits to millions. In most implementations, the qubits require cryogenic cooling, typically to a fraction of a degree above absolute zero. Yet conventional CMOS electronics is designed to operate at room temperature.

Most QC companies don't have the resources to develop silicon CMOS processes for cryogenic temperatures. Instead, they rely on semiconductor fabrication via foundries, looking to various silicon IP companies to provide technology to enable them to exploit the manufacturing capability. This model has worked well for development of chips for room temperature operation, however it requires significant updating to create new designs that can work at ultra-cold temperatures.

This project brings together world-leading expertise in CMOS design and QC. It will create updated process design kits for cryogenic temperatures and an ecosystem of silicon IP products to enable chip designers to exploit foundries using the established fabless model. Thus, the project will enable QC companies to scale their hardware systems to create a new generation of more powerful quantum computers.

FUNDING GRANTED: £4,855,090

SURECORE LIMITED
OXFORD INSTRUMENTS NANOTECHNOLOGY TOOLS LIMITED
SEEQC UK LIMITED
SEMIWISE LIMITED
SYNOPSYS (NORTHERN EUROPE) LIMITED
UNIVERSAL QUANTUM LTD
UNIVERSITY OF GLASGOW

HYDRI – HYDrogen sensoR for Industry

The HYDRI project aims to develop stand-off gas sensing devices critical to the safe roll-out of hydrogen as a widely used energy source in domestic, industrial, and transportation sectors. It harnesses the UK's world-leading expertise in single-photon detector arrays and quantum-sensor technology products.

The HYDRI consortium comprises internationally recognised UK organisations at the forefront of the innovative and high technology sectors they serve, who are extremely well placed to deliver the state-of-the-art modules required for these devices. The consortium is led by a globally recognised end-user of the technology who will steer the performance of the project and carry out extensive testing in a range of high-value application scenarios.

Finally, the project benefits from the expertise of the UK's leading academic and research technology organisation, who are performing critical system modelling, design, and integration activities throughout this exciting project.

FUNDING GRANTED: £2,559,928

BP P.L.C.
CALEDONIAN PHOTONICS LIMITED
FRAUNHOFER UK RESEARCH LIMITED
IS-INSTRUMENTS LIMITED
PHOTON FORCE LTD
REDWAVE LABS LTD
UNIVERSITY OF STRATHCLYDE

Quantum Enhanced Computing Platform for Pharmaceutical R&D – QuPharma

This project will develop a quantum computer and use it alongside a classical supercomputer to solve problems that are of real value to the pharmaceutical companies. SeeQC and Riverlane, two of the most successful UK-based companies developing quantum hardware and software respectively will join forces to develop a useful quantum machine. SeeQC will work with the Oxford Instruments to improve the quantum hardware, while Riverlane will develop the software to operate the quantum machine and the quantum algorithms to be used for the calculations.

With the help of Merck, a global pharmaceutical company, the University of Oxford, and the Medicines Discovery Catapult it will be identified some of the pain points of the drug discovery process where quantum computers can help. The project will solve them by interleaving a quantum machine with a very powerful supercomputer, that belongs to the Science and Technology funding Council. In this way, the most demanding part of the calculations will be solved on the quantum machine. This trick will deliver more accurate results ten times faster than standard computers.

The UK is a world leader in the pharmaceutical sector and a pioneer in developing the quantum technology industry. This project is of real national value as it will boost the development of quantum computers, while showing how useful they can be in solving major problems of a very important industry.

FUNDING GRANTED: £4,751,474

SEEQC UK LIMITED
MEDICINES DISCOVERY CATAPULT LIMITED
MERCK
OXFORD INSTRUMENTS
NANOTECHNOLOGY TOOLS LIMITED
RIVERLANE
STFC - LABORATORIES
UNIVERSITY OF OXFORD

The quantum data centre of the future

Quantum technologies has long been described as the solution to the world's most challenging data problems. Quantum computing has the ability to significantly enhance our ability to process optimisation, machine learning and sorting problems which are beyond the reach of today's computers, and quantum communications provides the answer to ever-increasing challenges of security.

However, to date, very little activity has taken place to understand from a systems perspective how quantum technologies can integrate with existing data centres. Quantum computers and communications systems are often described in isolation, at odds with the direction of the industry for the last 50 years. This misses the possibility for very significant near-term value to be created with quantum/classical hybrid systems.

For the first time ever, this project seeks look at quantum technologies through the lens of the existing industry. It brings together experts in classical data centres and networking, quantum computing and quantum communications and will develop a blueprint for a quantum/classical hybrid data centre and a quantum internet.

FUNDING GRANTED: £8,919,656

ORCA COMPUTING LTD.
BP P.L.C.
BT
DIGITAL CATAPULT
IMPERIAL COLLEGE LONDON
KETS QUANTUM SECURITY LTD
NCC GROUP SECURITY SERVICES LIMITED
NCC OPERATIONS LIMITED
PQSHIELD LTD
RIVERLANE
UNIVERSITY COLLEGE LONDON
UNIVERSITY OF BATH
UNIVERSITY OF BRISTOL
UNIVERSITY OF SOUTHAMPTON

Towards a Quantum enabled Cloud

Quantum Key Distribution (QKD) facilitates the secure sharing of encryption keys using quantum technology. These keys can encrypt data for transmission over conventional fibre links across any distance, but QKD itself is limited over fibre to around 151km with current technology. Trusted nodes are required, but at major risk of creating security vulnerabilities. QKD through free space is less sensitive to distance. Thus, satellites provide the means for distributing keys across very large distances between end users spread across countries or continents.

Satellite components in QKD networks are being planned or researched in several countries. A consortium led by Arqit aims to establish the world's first commercial QKD satellite constellation. The first satellite is being built under contract with the European Space Agency, with further satellite already being developed.

This project aims to overcome important barriers to the adoption of QKD based infrastructure and services by government customers that will need accreditation. It will establish sector specific demonstrators of the service prior to satellite launch to support live end to end demonstrations, enabling customer integration to accelerate adoption; develop QKD optimised detectors to enhance performance of optical ground receivers whilst reducing cost; address operational security by performing practical side channel attacks on key elements of the system; and develop satellite specific QKD standards, supported by generating portable test equipment to support interoperability testing with other satellite QKD systems.

FUNDING GRANTED: £2,930,501

ARQIT LTD
BABCOCK INTEGRATED TECHNOLOGY LIMITED
BT
FRAUNHOFER UK RESEARCH LIMITED
HERIOT-WATT UNIVERSITY
PHOTON FORCE LTD
WIDEBLUE LIMITED

Underwater Single Photon Imaging System

Quantum photonic detection technologies can offer a step change in the resolution, accuracy, coverage, and speed of generation of 3D maps compared to existing acoustic or traditional imaging solutions. The approach proposed in this project differs from other techniques, as it relies on state-of-the-art single-photon detection technologies, which allow for three-dimensional imaging with extremely low light level return, typically less than one photon per pixel (in the so-called "sparse-photon" regime) - that corresponds to high underwater attenuation.

This project exploits recent advances funded under the UK National Quantum Technology Programme in underwater single-photon LiDAR measurements and CMOS silicon single-photon avalanche diode (SPAD) detector array development. One major advantage for underwater imaging; it is in the ideal spectral region for CMOS based SPAD detectors, which have made significant recent advances. This project is led by the marine industry, addressing current industry requirements and will utilise bespoke CMOS SPAD arrays and laser sources for subsea terrain mapping.

This project brings together key industrial and academic institutions with world-class backgrounds to collaboratively develop a commercially viable subsea mapping system based on the time-correlated single-photon counting imaging technique. The key objective is to deliver a complete mapping system based on novel 2D spatial single-photon array detector technology, which can be deployed to a subsea vehicle and robustly generate 3D maps at high altitude above the sea floor.

FUNDING GRANTED: £2,346,772

SONARDYNE INTERNATIONAL LIMITED
FRAUNHOFER UK RESEARCH LIMITED
HERIOT-WATT UNIVERSITY
PHOTON FORCE LTD
REDWAVE LABS LTD
UNIVERSITY OF EDINBURGH

UpScale: Scalable quantum information enabled by integrated optics

Quantum information processing (QIP) will revolutionise many industries with applications ranging from drug discovery to supply chain management. However, QIP faces a technological challenge in scalability. UpScale brings together five commercial partners and two research organisations to address this challenge.

By using a scalable integrated photonic routing and addressing platform, different QIP architectures of trapped-ions, diamond NV centres and semiconductor photon sources will be supported. The integrated photonic platform leverages decades of development in telecommunications systems and semiconductor manufacturing and is compatible with cryogenic temperature operation and multiple independent qubit systems. UpScale will develop and deploy two major and innovative integrated photonic technologies: a silicon nitride photonic integrated chip platform and cryogenic-compatible photonic coupling and packaging.

The focus of UpScale is delivery of high-TRL scalable demonstrators rather than fundamental research. It will build on several recently published results and use photonic foundry services to provide a reliable supply chain and solve technical challenges associated with scalability at the pace required for commercialisation. The project is designed to maximise return on investment by developing technological solutions for scaling of QIP systems, for the benefit of multiple commercial partners. Additional routes to market include the commercialisation of photonic systems and cryogenic packaging services.

FUNDING GRANTED: 3,143,886

FRAUNHOFER UK RESEARCH LIMITED
AEGIQ LTD
ALTER TECHNOLOGY TUV NORD UK LTD
OXFORD INSTRUMENTS NANOTECHNOLOGY TOOLS LIMITED
OXFORD IONICS LIMITED
UNIVERSITY OF OXFORD

Feasibility Studies Round 2

ACCOLADE: ACcelerometry with COLd Atoms in Dynamic Environment

Navigation has been at the heart of the UK's prosperity and international standing for centuries and this is closely tied to the nation's historic innovations in the science and engineering of navigation technologies. The strategic roadmaps associated with the UK National Quantum Programme have identified navigation as an area with the potential to benefit greatly from emerging quantum technology developments. As a market sector, navigation technologies underpin large swathes of the economic output of the UK, whilst also taking a variety of forms across the different platforms that depend upon it. This project seeks to develop and test a cold-atom based accelerometer unit that can deliver useful performance in challenging dynamic environments, including a variety of moving platforms.

FUNDING GRANTED: £398,709

M SQUARED LASERS LIMITED

IMPERIAL COLLEGE LONDON

A quantum photonics PDK

Integrated quantum photonics offers a scalable platform for many emerging quantum technologies, such as quantum communications and quantum computing. Critical to its success is the development of tools used for the optimisation of fabrication tolerant components which can enhance the control of quantum states on chip and mitigate errors leading to high photon losses. Such tools would be a key enabling feature in the development of photonic quantum logic circuits, offering much greater scalability. The UK has considerable academic expertise in these areas and is well positioned to move forward, however, the complete supply chain to convert research into commercial success is lacking. Our vision for this project brings together a consortium from all areas in the UK supply chain of integrated quantum photonics in order to overcome a key issue and establish the UK as a leader in photonic quantum technologies. Our approach is based on the optimisation of fundamental photonic components, the building blocks of quantum logic circuits and quantum communications transceivers, with a key focus on mitigating fabrication imperfections. Our project plan will develop this capability and demonstrate its potential for the integrated quantum photonics industry in the UK.

FUNDING GRANTED: £391,502

LUMINIFEROUS

CARDIFF UNIVERSITY

COMPOUND SEMICONDUCTOR APPLICATIONS CATAPULT LIMITED

KETS QUANTUM SECURITY LTD

WAVE PHOTONICS LTD

Blue FLAME

Quantum Technologies are set to transform the technology landscape and change the way we fundamentally navigate, compute, communicate and secure vast quantities of data that is the backbone of modern society. However, due to their complexity and lack of robustness, the technologies at the heart of this potential revolution are currently, largely shackled to sophisticated laboratories.

The BlueFLAME project will build on previous highly successful work from this consortium and will develop a reliable commercial solution for the cooling of calcium ions, a key technological milestone in next generation, out-of-the-lab quantum systems. This will be achieved by addressing the challenges associated with the handling, packaging, and reliability of novel GaN semiconductor materials. This demonstration represents a key step in meeting the demands of important systems covering the whole GaN-enabled spectrum (365-550nm) which in turn will unlock further atomic transitions and utile atom and ion-based systems. Only through palm-sized and more compact laser systems, will the true potential of quantum technologies be commercially realised.

FUNDING GRANTED: £374,014

ALTER TECHNOLOGY TUV NORD UK LTD
FRAUNHOFER UK RESEARCH LIMITED
TOPGAN QUANTUM TECHNOLOGIES LIMITED

Dual-FISH

Cold atom based quantum technologies have great potential because of the versatility of this platform. Cold atoms can be used in optical clocks, inertial sensors, gravimeters, and magnetometers just to name a few. They rely on stable and agile lasers with stringent requirements on their optical frequency. Current commercially available lasers are bulky, expensive and struggle to meet these requirements without significant development effort from the user. This limits many quantum technologies to the laboratory.

To address these challenges, the Dual-FISH project will develop a versatile, compact and easy-to-use laser solution for cold atom systems, particularly commercial atom clocks. In this project the consortium will produce a single device that provides both optical frequencies (the so-called “cooling” and “repump”) required for the operation of cold atom traps in a single optical fibre. We will exploit mature, efficient 780 nm diode laser technology and combine advanced spectroscopy and offset locking schemes with mature packaging capability and compact, powerful bespoke electronics. This innovative approach will allow us to produce a complete laser system that is small (approximately 120x80x50 mm) and ready to use by system integrators intending to commercialise quantum technologies based on cold atom technology, while providing agile laser light without any need for third-party stabilisation hardware.

FUNDING GRANTED: £362,101

ALTER TECHNOLOGY TUV NORD UK LTD
FRAUNHOFER UK RESEARCH LIMITED
REDWAVE LABS LTD

Establishing the Need - Finding the future market for UK Quantum Random Number Generators

Danish physicist, Neils Bohr, said "it is difficult to make predictions, especially about the future." However, to efficiently commercialise Quantum Dice's Quantum Random Number Generator (QRNG) technology, the company must have reliable forecasts on countries, market sectors and form factors to inform its commercialization and product strategy.

Quantum Dice will undertake a market research study for QRNGs. Primary market research with industry input will be conducted over twelve months, to be then used to road map future markets and establish where and how the supply chains and scale up in quantum random number generation technology will occur. It is anticipated that this approach will guide Quantum Dice's routes to market and will map out how scale up and supply chains can be established. It is anticipated that this approach can be translated to other emerging quantum technologies from within the UK.

Quantum Dice will build a sophisticated market model based on a detailed understanding of the fundamental macro market drivers using a technique called Scenario Planning (Lindgren, 2017). The Scenario Planning process will allow an explicit macro view of the future and build a QRNG forecast model based on assumptions consistent with that view. The second part of the project is to build a market model based on volume forecasts for QRNGs across multiple countries, market sectors, and form factors.

FUNDING GRANTED: £34,163

QUANTUM DICE LIMITED

Fibre-based memory module for photonic quantum computing

We are developing photonic quantum computers that will use individual particles of light known as photons to carry out computational tasks in more powerful ways than conventional supercomputers. However, operations in photonic quantum computers are fundamentally unreliable, hence memory elements are required to store successful outcomes of quantum logic gates until all have functioned correctly.

One way of storing light in a material system is by mapping the quantum state of a photon into a collective excitation of a cloud of atoms using an energy level transition mediated by a bright laser beam. The photon can then be retrieved a few hundreds of nanoseconds later by switching the laser on again. Although the storage time seems short, it is sufficient to buffer enough gates to build large-scale photonic quantum processors. Unfortunately, the atoms with the best energy levels for this application are rubidium -- a highly reactive element that is difficult to handle -- and existing quantum memories are limited by the characteristics of the vapour cells in which the rubidium must be contained.

In this project, we will design, build, and test advanced vapour cells that contain clouds of rubidium atoms in the hollow cores of special optical fibres. This will ensure not only that the reactive rubidium remains protected from the environment but also that light can interact with atoms over the whole length of the hollow fibre. Combined with the ease with which our compact fibre memory modules will integrate with other optical components, the products that we develop will enable a much larger number of memories be operated simultaneously at much higher efficiencies than was previously possible. This will open up new markets both within the scientific and technological development of quantum computation and beyond in the applications of photonic quantum computers to societal challenges including drug discovery, industrial process optimisation, or modelling new materials for batteries and solar cells.

FUNDING GRANTED: £389,710

TMD TECHNOLOGIES LIMITED

ORCA COMPUTING LTD.

UNIVERSITY OF BATH

High Rate of Entangled Photons (HiREP)

The HiREP project aims to develop a high-rate polarisation-entangled photon-pair source based on a new nonlinear optical crystal platform recently developed by Covesion Ltd.

FUNDING GRANTED: £270,016

COVESION LTD

FRAUNHOFER UK RESEARCH LIMITED

High Quantum Efficiency Detectors

Quantum technologies are a core asset in the UK industrial strategy. They will secure the digital world, see where current cameras cannot, and underpin new drugs, thanks to quantum computers solving currently intractable calculations. In collaboration with the Universities and Research Centres, UK high-tech industries are working on translating them from scientific concepts to available technologies, products, and capabilities. To support this challenge, more than £1Billion has been committed in both Government and Industry funding. Photonics is one of the sectors leading the development and deployment of quantum technologies

Light can carry quantum-secured communications, measure faint signal such as gravitational waves, and solve quantum algorithms. Photonics-based quantum technologies are either required to measure single photons one at a time (single-photon detectors) or to record continuous quantum light signals (proportional detectors) with minimal losses to retain the signatures that make them different from classical light. Here we address this second approach to quantum optical technologies. Today, applications based on such measurement schemes are limited, and detectors are home-built by researchers, often at significant cost in time and monetary. With this project, we join the expertise and capabilities of Bay Photonics (optical packaging and optoelectronics), RedWave Labs (electronics), the experience and resources of the Centre for Process Innovation (photonic applications) and of research teams at the Universities of Strathclyde and Glasgow (quantum sources, low-noise electronics, quantum metrology) to design, build and test a prototype of a quantum sensor able to address this gap in the market and supply chain. We aim to provide the first commercial solution for measuring quantum states of light composed of thousands to several billion photons. The engagement of the Centre for Process Innovation and the University teams will, on the one hand, contribute to the design of the product, and on the other, serve as an end-user test for the developed technology. The outcome of this endeavour will be a versatile solution for the high sensitivity measurements empowering quantum metrology and some of the most advanced concepts of quantum computing.

FUNDING GRANTED: £424,188

BAY PHOTONICS LTD
UNIVERSITY OF GLASGOW
UNIVERSITY OF STRATHCLYDE
REDWAVE LABS LTD
CENTRE FOR PROCESS INNOVATION LIMITED

Kuano: A novel second generation quantum computing technique using transition state modelling for efficient drug discovery

Kuano is a company dedicated to bringing the latest innovation and technology for drug discovery to the pharmaceutical industry. Kuano's unique approach tackles common challenges in both AI-driven drug design and target driven drug discovery.

This Feasibility Study seeks to exploit second generation quantum techniques to solve currently intractable problems associated with molecular simulation within the drug discovery sector.

Kuano will evaluate the feasibility of a second-generation quantum technology to overcome current limitations associated with accurately modeling the behaviour of the catalysis process: specifically, extracting a description of the transition state and understanding the binding mechanisms for metalloproteins. This would enable large-scale, precise molecular simulations and support broad application in the field of 'AI in drug discovery' (as well as other industrial applications).

The project output is a discovery platform that aims to unlock intermediate-to-high levels of entanglement, creating a step-change for Kuano and the UK drug development industry.

FUNDING GRANTED: £207,136

KUANO LTD

Noise Analysis and Mitigation for Scalable Quantum Computation

The goal of the project is to develop combined noise characterisation and mitigation framework for improved quantum algorithms, scalable to beyond 1000 qubits. It will form an integral part of CQC's high performance quantum software development kit (SDK) Tket, and will make it ready for the 1000+ noisy qubit systems that will be available within the next years. Quantum computers (QCs) promise to perform computations and simulations that are orders of magnitude faster than those run on a classical computer for many applications varying from chemistry, material science and physics to optimisation, machine learning and finance. However, since current and near-term devices cannot yet incorporate full error correction, to practically use them it is essential to control and mitigate the large sensitivity these devices have to the undesired effects of the environment. The way that computations are affected by local and non-local perturbations, including cross-talk errors, is not well understood and characterised, especially as the number of qubits increases.

Our framework has two distinct innovations. We develop i) methods for device characterisation and ii) techniques for error mitigation that scale-up and remain viable in terms of resources in the 1000+ qubit regime. Our innovative software solution directly incorporates the specifics of the new hardware characterisation methods to maximise performance for practical applications. The tasks targeted will be the most used quantum algorithms for applications: variational quantum eigensolvers (VQE) and Quantum Approximate Optimisation Algorithms (QAOA). We will benchmark the techniques on superconducting qubit platforms, which currently have the largest number of qubits. The general methodology will be applicable also to other quantum hardware platforms.

The vision for this integrated hardware/software approach will be achieved by the synergy of the expertise of the partners (CQC, NPL, and UEDIN) in quantum compiler and software development on the one hand, and noise characterisation and mitigation on the other.

Key milestones:

Small scale noise model and characterisation of crosstalk errors developed (month 6)

Error mitigation methods for sub-circuit structures acting on few qubits designed and tested (month 12)

Scalable noise mitigation software tested and integrated in Tket SDK (Final output, month 18)

CQC's Tket SDK is already one of the world leading quantum compilers for tens of qubits, and within this project we will scale it to systems beyond 1000 qubits, giving it a critical advantage over competing products.

FUNDING GRANTED: £399,725

CAMBRIDGE QUANTUM COMPUTING LIMITED
NPL MANAGEMENT LIMITED
UNIVERSITY OF EDINBURGH

Performance Magnetic Shielding for Commercial Quantum Technologies

There is a global race to build the world's first practical quantum computers. One of the many challenges in building a quantum computer (as well as other quantum technologies including sensors) is shielding the superconducting circuits from ambient magnetic fields. Currently solutions create a large volume and weight of fixed magnetic shields that takes up valuable space and cooling power within a cryostat. These existing large volume shields are difficult to maintain in the limited cooling capacity of a quantum circuit compatible cryostat. This ultimately limits the potential of a quantum computer or quantum sensor to scale to commercial levels. The commonly employed solution to this problem is to use a combination of high permeability and superconducting shields around the device. As superconducting circuits become larger and more complex the limitations of this approach become more apparent.

This project will design, simulate, manufacture, and test a magnetic shielding solution that employs active magnetic shielding. This will confirm the feasibility of employing active magnetic shielding for quantum processors within a cryostat to reduce the weight and size overheads associated with current state-of-the-art shielding methods. The use of active magnetic shielding is an entirely novel approach within quantum computing, though it has been successfully utilised for alternative technologies, including quantum gravity sensors. This project is taking an established method and applying it to an entirely new technology area that has highly specific and challenging magnetic shield requirements. The novelty will be in demonstrating that these strict performance requirements can be delivered using cryogenic passive shielding and active magnetic shielding, thus demonstrating a clear path to scaling the technology to commercial levels. Success in this project would represent a significant disruption to the current state-of-the-art approaches to quantum computing platform development.

FUNDING GRANTED: £339,670

SEEQC UK LIMITED
MAGNETIC SHIELDS LIMITED
UNIVERSITY OF NOTTINGHAM

Practical improvements to the performance of quantum simulation for drug-protein binding

The process of discovering and testing new drugs is very expensive and takes a long time. The average cost of discovering a new drug and bringing it to market has tripled since 2010, reaching almost $3bn in 2018. Current methods for discovering new drugs are unreliable and involve a 'trial-and-error' approach. Pharmaceutical companies want to reduce the cost and shorten the time it takes to develop a new drug.

We want to solve this problem by using quantum computers to speed up the process of drug discovery. This is a fundamentally different approach to using normal or so-called 'classical' computers. In this project, we will use the properties of quantum systems to make big improvements in computational speed and accuracy. Pharmaceutical companies could then identify, screen and simulate new drugs on a computer rather than using expensive, trial-and-error approaches in the laboratory.

Some early work has been completed using quantum computers in drug discovery, but there are still many errors using this approach. Another problem is the quantum industry, which is currently very fragmented as it is in such an early stage of development. This project brings together the UK's leading quantum software and hardware companies -- Riverlane and Rigetti UK -- to help solve the technical challenge of reducing errors in quantum computing. We will work together to fine-tune the algorithms and methods used in quantum computing by developing an 'error mitigation layer'. We will also build a computer platform that can be used by the pharmaceutical industry to screen new drugs. To check that it works, we will integrate our new technology into the existing workflows of UK pharmaceutical company, Astex, a global leader in cancer drug discovery.

The UK is home to several large pharmaceutical companies. It is also a global leader in quantum technology. Our project therefore has real national value. By bringing Riverlane, Rigetti UK and Astex together, our ambition is to take a first step towards creating a game-changing quantum product for UK pharmaceutical companies to make their drug discovery easier, quicker and cheaper. This project will also allow Riverlane and Rigetti UK to accelerate the development of their software and hardware products to strengthen the UK quantum industry.

FUNDING GRANTED: £326,506

RIVERLANE
ASTEX THERAPEUTICS LIMITED
RIGETTI UK LIMITED

Q-Cell - Functionalised Plug and Play Vapour Cell Module

Success in commercialising thermal vapour-based atomic sensors and devices is hampered by the availability of reliable, low-cost, quality vapour cells. Progress has been made in the manufacturing of wafer cells to allow for proof-of-concept demonstrations, but some of the more-challenging performance and functional requirements necessitate added functionality, particularly control of the cell environment.

The Q-Cell project will develop a novel type of wafer cell with increased functionality (temperature and magnetic field control, reduction of heat dissipation, ambient magnetic field shielding). The cell will have a generic form appropriate for integration into a wide spectrum of robust quantum instruments. The project will accelerate the commercialisation of these atomic devices including: miniature atomic clocks; field sensors as magnetometers and inertial sensors.

This development builds upon INEX expertise in manufacturing silicon wafer devices, NPL's know-how in atomic magnetometry, inertial sensors and clock development and the University of Birmingham's modelling, design, characterisation, and qualification expertise.

The innovative Q-Cell design will exploit INEX' new concepts in integration of environmental controls into the wafer cell, and the University of Birmingham's solutions for magnetic field control and screening. NPL will validate the Q-Cell performance against the requirements defined by potential end-users and system integrators.

FUNDING GRANTED: £392,317

INEX MICROTECHNOLOGY LIMITED
NPL MANAGEMENT LIMITED
UNIVERSITY OF BIRMINGHAM

Quantum enhanced control systems

Many industries stand to benefit from the commercialisation of quantum computing, particularly those industries that need high levels of processing power, such as the autonomous vehicle market. Quantum computers can provide a huge increase in processing speed for a number of applications in chemistry, materials science, and general linear algebra operations, and their potential for use within finance and pharmaceuticals is being explored. In this project, we will explore and develop quantum computing solutions for autonomous vehicles, and more specifically driverless cars.

The aim of this project is to develop an end-to-end control system deployed in cars, where quantum computers are used to enhance the decision-making process in the control system. Autonomous systems need to repeatedly take decisions as to whether they should take a specific action or not. This is a difficult challenge, particularly when the input from different sensor data is considered. For example, deciding whether a lane change is safe is relatively straight forward for humans, but is difficult for automated control systems. QCs process data in an inherently parallel way, with a possibilistic outcome of the measurements. These can provide complementary information to the control system and hence enhance its decision-making capabilities.

In a recent joint research collaboration, Massive Analytic Limited (MAL) and the National Physical Laboratory (NPL) have demonstrated that neural networks implemented on quantum computers, the so-called Quantum Neural Networks, can predict the safety of specific autonomous car manoeuvres. This result was shown on a simplified system as proof of concept. In this project, we will extend this to a real-life scenario, where the decision depends on the positions and velocities of multiple surrounding cars, and integrate the quantum neural networks in MAL's end-to-end commercial APACC control framework of a driverless car. To this aim, we will combine the expertise in control systems of MAL and the quantum software expertise at NPL, and use the autonomous systems dynamics and test facilities at the Centre for Autonomous and Cyber-Physical Systems in Cranfield University.

Quantum Neural Networks have been shown to train faster than classical models for certain cases, and hence have the potential to outperform classical machine learning algorithms used in the autonomous vehicle industry. We will systematically assess this in the project. If successful, it will be a disruptive enhancement to MAL's commercial APACC control system, giving it a significant advantage over competitors.

FUNDING GRANTED: £369,342

MASSIVE ANALYSTIC LIMITED

NPL MANAGEMENT LIMITED

QUANTUM SPECS - Single Photon detection for Excellence in Communication and Sensing

The ability of single-photon detectors to time the arrival of individual photons to within less than a billionth of a second enables remarkable advances in imaging, chemical detection, and communication in challenging environments. Quantum SPECS (Single-Photon detection for Excellence in Comms and Sensing!) will bring together Nu Quantum's innovative high-performance single-photon detector technology and Fraunhofer Centre for Applied Photonics' experience in cutting-edge applications enabled by single-photon detection and timing.

By testing the novel detectors against existing commercial offerings in multiple applications, covering underwater imaging, time-resolved Raman spectroscopy, and free-space optical communications, QUANTUM SPECS will identify the optimal markets and uses-cases for this technology, open up new advances in these techniques, and establish Nu Quantum as the go-to supplier for single-photon detector chips - thus establishing a UK supply chain from chip level for these critical components which underpin much of the quantum technology revolution.

FUNDING GRANTED: £412,618

NU QUANTUM LTD

FRAUNHOFER UK RESEARCH LIMITED

QuPix

Quantum computing is poised to be a driver of innovation in the next decade. Its information processing capabilities will radically accelerate drug discovery, improve online security, and will boost artificial intelligence algorithms. Building a quantum computer promises to have a major positive impact on society. However, current qubit numbers are insufficient to realise quantum computation of significant practical use. For instance, simulations of simple materials require hundreds or thousands of qubits, while for the most economically and socially significant algorithms many millions or billions will be required. An industry manufacturable technology that can achieve that level of integration is required to move from the $1.1 B market of small-scale quantum processors to the projected $130 B for large-scale quantum computers.

Quantum Motion is tackling the challenge by building qubits using silicon transistors, the technology capable of integrating more elements in a single chip than people on the surface of Earth. Silicon spin qubits embedded in silicon transistors have great scalability prospects since they can leverage the technology underpinning today's semiconductor industry. However, qubits are not exactly transistors and small modifications are needed to exploit the quantum nature of these devices. For example, the readout circuitry currently used to read the quantum state of a silicon spin qubit is orders of magnitude larger than the transistors themselves posing a bottleneck for scaling.

Project QuPix enters at the core of this idea and focuses on developing an integrated and industry manufacturable qubit cell, including the circuitry surrounding the qubit dedicated to the readout, with an unparalleled small footprint, a million times smaller than the most scalable alternative quantum hardware. Our scalable approach is designed to have a qubit cell density of 108 cm^-2, offering a platform to cram on a chip the size of a fingerprint the qubit numbers needed to tackle society's most demanding computational problems placing the UK at the forefront of an industrial race to realise an integrated silicon-based quantum computer.

In the path to scaling, the QuPix cells can offer technological applications today. In the same way that the first transistors were used for amplification purposes until digital computing got traction, we will use a single QuPix to demonstrate a new kind of quantum-limited amplifier: a silicon-based an amplifier adding the minimal noise allowed by the laws of quantum mechanics capable of entering the market due to its cost-effective industrial manufacturability, compactness, and resilience against magnetic fields.

FUNDING GRANTED: £393,683

QUANTUM MOTION TECHNOLOGIES LIMITED

Rapid and Scalable Single Colour-Centre Implantation for Single Photon Sources

Beams of ionised atoms find widespread use in many fields from production applications in semiconductors, to medical instrumentation and cancer diagnosis.

A new application of ion beams is the manufacture of Quantum Technology (QT) devices, allowing the future creation of immensely powerful Quantum Computers with applications including medical research and drug discovery. A QT that is already on the market is the Quantum Cryptography system for sending unbreakable codes, which relies on single photon transmission. At present the "qubits" that make up existing quantum computers, and the light emitters producing the single photons, are made only in research labs.

If the wider potential of QT is ever to be realised and reach the tipping point of widespread rather than niche commercialisation, the industry needs a manufacturing solution that is reliable and fast with high accurate ion placement. This is vital to be able to generate arrays of qubits for quantum computing.

Ion beam implantation could be that solution. However, there is a major challenge to ensure ions are placed with great accuracy and to ensure that there is precisely one atom in each quantum "qubit" or each single photon source emitter. For example, a cryptography system containing a light emitter with two emitter atoms inside would be useless, because then two photons will be generated in each pulse, giving the chance to capture one and eavesdrop the conversation.

Ionoptika's new Q-One single ion implantation system is aimed squarely at the emerging area of single atom QT device production. The remaining limiting factors are ensuring accurate ion placement (for array generation) and the availability of desirable ion sources from across the periodic table of the elements. Currently, a few sources are readily available, such as gallium and bismuth, but all are poor light emitters. Creating new sources is extremely difficult, requiring advanced expertise in metallurgy and ion beam physics, limiting commercial availability. Having this expertise is, currently, a pre-requisite to owning an ion implantation device, significantly limiting Q-One's market penetration.

Ionoptika and the University of Surrey will test the feasibility of a new quality control process for confirming accurate ion placement and investigate two new sources more relevant to the quantum industry. Ionoptika will then be able to develop an improved Q-One machine suitable for research and manufacture of quantum technologies, the first such device in the market.

FUNDING GRANTED: £425,000

IONOPTIKA LIMITED
UNIVERSITY OF SURREY

Towards a Quantum Internet

The goal of this project is to develop a source of time/frequency-entangled photon pairs suitable for multipurpose quantum communications in daylight conditions the context of next generation wireless communications. The large background noise due to solar radiation limits satellite-to-ground and, in general, free-space entanglement distribution to night operation, strongly reducing the time of operation of quantum communications links. In this project, we propose to investigate integrated narrow-linewidth sources of entangled photons.

The project will also explore the opportunities from flying the source on future Arqit satellites to validate it for future Quantum Communications networks and for entanglement distribution experiments with international partners for a variety of applications in the context of the future Quantum Internet.

FUNDING GRANTED: £421,244

ARQIT LTD

FRAUNHOFER UK RESEARCH LIMITED

HERIOT-WATT UNIVERSITY

ORCA COMPUTING LTD.

Germinator R1

Brain Imaging Using OPM-MEG: Newborn to Toddler Learning for Fraud Detection

Treating disorders of the human brain is a fundamental challenge for 21st century medicine. Much of the architecture of the human brain is laid down in the first few months of life, and there is a great deal to be gained from studying this early neurodevelopmental trajectory. More importantly, neurological disorders can strike the very young, underscoring a critical need for methods that can probe neural function in infants. However, technology to safely and effectively probe the brain in infant populations is lacking. Our vision is to bring to market the world's most advanced technique for brain imaging, in babies and children.

Techniques like X-ray CT and MRI generate images of brain structure. These are useful for identification of growths or tumours. However, in many disorders we must move beyond structure, and use methods to assess neural function, as our brains respond to cognitive demand. A number of such techniques exist including functional (f)MRI, functional near-infrared spectroscopy (fNIRS) and electro/magnetoencephalography (E/MEG). All provide a non-invasive window on brain activity. However, they are unsuitable for infants due to their intimidating environment (fMRI and MEG), lack of temporal precision (fMRI/fNIRS), lack of spatial accuracy (fNIRS and EEG) or poor sensitivity (MEG).

Thanks to advances in quantum technologies, optically-pumped magnetometers (OPMs) have emerged as stand-out second-generation quantum sensors, with the potential to revolutionise the functional imaging landscape. These small and lightweight sensors can be configured into a wearable imaging device that can measure electrophysiological brain function with unparalleled sensitivity and spatial accuracy. Further, they enable a completely naturalistic scanning setting. Cerca Magnetics currently offer the world's first fully-integrated OPM-based imaging system. This device is wearable (like a helmet) and dramatically outperforms the current state-of-the-art. Currently, the Cerca system is built for adults but the fundamental idea is uniquely adaptable to scanning babies and young children. In this project, we will solve the fundamental physics challenges required to bring a baby functional neuroimaging system to market. We will work with key stakeholders to design an ergonomic and naturalistic scanner platform, where babies can be scanned in the arms of their parents. We will also deploy our method in a demonstration that high fidelity imaging data can be acquired in babies. In doing this, we will not only develop a new product; we will further cement the position of Cerca, and the UK, as the world leader in this emerging second-generation quantum technology.

FUNDING GRANTED: £49,999

CERCA MAGNETICS LIMITED
UNIVERSITY OF NOTTINGHAM

Design and layout of a dark noise QRNG

Random Number Generators RNGs are one of the key components needed in encryption systems. In fact, the more random the key, the more secure the encryption. While existing RNGs are compact and cheap, they are exposed to the rise of Quantum technology that may be a threat to existing encryption protocols. To solve this problem, a new class of RNGs is emerging which is also based on a Quantum source the Quantum RNGs (QRNGs). Unfortunately, existing QRNGs are mainly using photons to generate random numbers and for this reason, they are bulky and expensive. In this project, we propose to use a Quantum Noise source that is available in the absence of light. For this reason we exploit traditional technology without the need to employ a light source with a significant reduction of cost, power consumption, volume occupation and production yield. The project consists in the design and layout of a CMOS based dark noise QRNG.

FUNDING GRANTED: £49,979

ABSENSING LTD

Developing the first Space-suitable Quantum Random Number Generator

Quantum technology can enable highly-secure communications through satellite-based Quantum Key Distribution (QKD) which exploits UK expertise in miniature satellites. The space approach mitigates current limitations of terrestrial QKD networks: the relatively high price-tag of infrastructure as compared to miniature satellites, and restrictions on range resulting from terrestrial QKD's fibre-based networks. Our vision for this project is to develop a crucial component required for (satellite-)QKD, a space-suitable and high-rate Quantum Random Number Generator (QRNG). The focus of such R&D will be novel globally.

This project's key objective is to develop and test a compact, lightweight and low-power consuming QRNG package that can provide reliably secure random numbers at a high enough bitrate for by satellite-QKD developers of at least 400Mbps. The main area of focus is on the environmental testing of such a QRNG device, to ensure that the QRNG is robust enough to withstand the extreme harshness of the space environment. This will be accomplished by leveraging modern integrated photonics and integrated electronics methods to produce a deployable QRNG subsystem that can begin addressing the growing market need for space-suitable sources of entropy.

The innovation behind this project is in two parts. First, Quantum Dice is developing an innovative way of generating secure and high rates of random numbers from a quantum process, which was developed at the University of Oxford. This innovation is based on a newly developed and patent-protected protocol called source-device independent self-certification (DISC) which allows for the distillation of quantum entropy into verified random numbers while also accounting for the sources of internal classical noise in the hardware source. The latter classical noise can compromise the security of the output and has in-fact been reported to be the root cause of many security failures in currently-used random number generators. Second, the results of the series of space-environmental testing done by Craft Prospect will be innovative research that is crucial to quality a QRNG for deployment in a space-QKD demonstration mission, after which the QRNG will gain space heritage and hence space-qualification, which is normally both a costly and time-consuming process.

FUNDING GRANTED: £49,819

QUANTUM DICE LIMITED

CRAFT PROSPECT LTD

Diamond Quantum Sensing Platform

Quantum technologies takes advantage of the strange world of quantum mechanics where, for example, objects can exist in two places at once. This world typically occurs on the atomic level at low temperatures which has meant that technologies that exploit these properties have been challenging to implement and manufacture. Diamond is quickly becoming a leading quantum material due to the unique way quantum properties of impurities imbedded in diamonds crystal lattice can be controlled simply by the application of light. What is even more amazing is that, unlike other materials that require specialist cryogenic cooling, these quantum properties persist at room temperature making it possible to be widely deployable. These 'quantum defects' have the potential to be used for a range of applications such as measuring the magnetic fields emitted from molecules, enabling key understanding of the molecules composition for development of new medication. It also has the potential to detect different types of proteins which can provide information about the processes occurring in your body and allow the diagnosis of early diseases. Lastly it has applications in quantum computing which has the potential to solve problems no current computer can. Critical to the development of these technologies is to have the 'quantum defects' close to the surface of the diamond but retaining their unique quantum properties. This projects objective is develop a process to create near-surface quantum defects and therefore allow the further development of these revolutionary technologies.

FUNDING GRANTED: £49,881

DIAMOND QUANTUM SENSING PLATFORM

ELEMENT SIX (UK) LIMITED.

KELVIN NANOTECHNOLOGY LIMITED

Photonic chips as a platform for DIY QKD

Quantum key distribution (QKD) provides a means to exchange information with total privacy, where the security the key generation is guaranteed by the laws of quantum mechanics. This quantum-safe cryptography is future-proof, even to a quantum computer. Within this framework, however, there are subtleties in the operation of the devices and components used in the QKD systems and protocols which can lead to compromised security. The most obvious route for a malicious adversary is to target these vulnerabilities in the devices and software controlling the protocol. Furthermore, the adversaries may look to target the internals of the QKD system manufacturer, compromising security from within. In this project, we look to explore a radical alternative. Based on the concepts of 'open-source' and the notion of 'do it yourself', we will consider an alternative chip-based passive scheme to QKD coupled with open-source software. This DIY-QKD would allow customers greater flexibility to build their owns systems using tried and trusted components, with the trust of completely passive chips and open-source software closing many of the channels open to a malicious adversary.

FUNDING GRANTED: £49,989

WAVE PHOTONICS

QUANTUM 4 IOT

The vision behind QUANTUM4IOT is to investigate how Quantum Random Number Generator's (QRNG) can be used to secure low cost Internet of Things (IoT) devices. The key objectives are to investigate how this technology can be used to address two pressing cryptography issues. The first is entropy depletion where attacks can affect the generation of secure keys and therefor the effectiveness of cryptographic algorithms. The second is how techniques such as Quantum Key Distribution and Post Quantum Cryptography can be combined with QRNGs to secure and authenticate resource constrained IoT devices.

The main area of focus is the use of Quantum Technology to solve cryptography problems for low cost devices. Estimates suggest that over the next two years there will be over 30 billion connected devices and they will be generating 2.5 quintillion (10^18) bytes of data every day. Many of these devices have long operational lives and therefore can be subject to Quantum attack once such techniques become available.

The project will combine the industrial and academic expertise of Ioetec Ltd and Quantum Dice Ltd to investigate hybrid solutions utilising quantum and conventional cryptographic technology.

FUNDING GRANTED: £49,866

IOETEC LIMITED

QUANTUM DICE LIMITED

Quantum Gas Jet-based Helium Atom Microscope (qHAM)

Conventional microscopy tools have a number of limitations: Light microscopy is intrinsically limited to around micron length-scales; electron microscopy often leads to sample damage or charging; and scanning probe methods (such as atomic force microscopy) are limited to small areas on predominantly flat surfaces.

These limitations cause significant problems for surface morphological studies: delicate samples such as 2-dimensional organic thin films risk being damaged by energetic electron beams; more complex insulating structures cannot be imaged with high resolution by electron beams as they are accumulating charges; and bio-materials with complex topographies cannot be imaged by conventional scanning probe techniques such as Atomic Force Microscopy (AFM).

This project will overcome these limitations by exploiting two quantum phenomena: Wave-Matter duality and matter wave Interference. The de Broglie wavelength λ of a particle is related to its momentum p by $\lambda=h/p$, where h is Planck's constant. For a helium atom moving with thermal velocity at room temperature, the average de Broglie wavelength is 0.9 Angstroem. An atom sieve designed on the principle of Fresnel Zone Plates (FZP) achieves a focus at the point where the path difference between molecules travelling via adjacent zones is equal to one wavelength. From this condition, the radius at the focal point can be derived - this extremely small and in the micrometer range, giving access to high resolution imaging.

A quantum gas jet-based Helium Atom Microscope (qHAM) will be developed as a compact, low cost and table-top microscope with superior imaging capabilities.

FUNDING GRANTED: £42,932

UNIVERSITY OF LIVERPOOL

D-BEAM LTD

Quantum diamond magnetometry for magnetocardiography

Diamonds are best known as jewellery but by adding particular impurities called nitrogen vacancy centres (NVCs) they become pink instead of colourless. Each NVC behaves like an atom with useful quantum behaviour including the fact that they are sensitive to magnetic fields. We have used a diamond with many NVCs to build a very sensitive magnetometer. It doesn't require cooling or heating which makes it more suitable for applications including the medical applications we are focusing on.

In this project we aim to improve the sensitivity enough to see the tiny magnetic fields created by our heartbeats. This is called magnetocardiography (MCG). The magnetic field from a heartbeat is one million times weaker than the Earth's magnetic field. We will make our diamond magnetometer up to ten times more sensitive in this project, but then we would still need to make it at least 10 times more sensitive again to be medically useful. We will combine quantum and classical engineering to achieve this.

Detecting MCG should help us (in further work after the timescale of this 6-month project) to predict sudden cardiac death (SCD), which is responsible for half of all heart disease deaths. SCD occurs when the electrical function of the heart malfunctions and unregulated patterns of conduction predominate. This can cause the heart to fail to output blood and rapidly lead to a life threatening situation. MCG is known to be medically useful but has not been successfully commercialised so far because it has required expensive magnetometers that must be cryogenically cooled. An advantage of MCG is that it is completely non-invasive as it simply involves detecting the magnetic fields that are naturally emitted by our hearts.

FUNDING GRANTED: £49,797

UNIVERSITY OF WARWICK

ELEMENT SIX (UK) LIMITED.

Quantum Machine Learning for Fraud Detection

Financial fraud and unauthorised payments represent a threat to the digital economy. With the annual increase of 5% in transaction rates, and 60.3 million payment card transactions performed in the UK every day, accurate fraud detection requires the analysis of large datasets. For the card transaction total of £829 billion in 2019, £620.6 million were lost due to fraudulent and unauthorized operation [UK Finance, Fraud the Fact 2020 report]. The current fraud prevention rate is estimated to beat 62% percent. To minimise the incidence and impact of cyber threats, this must be improved.

HSBC uses artificial intelligence (AI) in various branches of business to improve operations, offer data-driven predictions, increase customer satisfaction, and detect financial fraud. The latter requires analysing financial data to identify and flag the unusual and potentially fraudulent activity. As the strategies employed by fraudsters change over time, the detection needs to be performed without prior knowledge about normal (nominal) and abnormal (fraudulent) transactions. In this ISCF Germinator project, HSBC will partner with the University of Exeter to develop quantum computing protocols for anomaly detection to address this challenge: advancing the state-of-the-art unsupervised Machine earning (ML) methods with quantum computing approaches. Testing these methods as a proof-of-concept, we will assess the power of unsupervised ML with quantum resources and estimate the timeline for their future implementation.

Our goal is to develop a quantum-enabled solution which will significantly reduce and prevent fraud, whilst building on current state-of-the-art ML solutions.

FUNDING GRANTED: £48,979

HSBC BANK PLC

UNIVERSITY OF EXETER

Sakurai: A Quantum Error Mitigation Platform-as-a-Service for Privacy-Preserving Genomics Data Analysis

Quantum computing harnesses the power of quantum mechanical properties such as superposition and entanglement, to solve problems that are beyond the reach of classical computing. There is a limit to how much more powerful our classical computers can become as suggested by that the famous Moore's Law, which posits that computing power doubles roughly every two years, and due to physical constraints involved in the further miniaturisation of transistor chips this is nearing its limit. Moreover, the speedup in computing offered by parallelization is limited by the famous Amdahl's law.

This project aims to build a privacy-preserving platform for genomics datasets that harnesses the exotic properties of quantum computing such as superposition and entanglement to enable data analysis of encrypted datasets faster than what is currently possible with classical computing. Our vision for the platform is to become a ubiquitous quantum orchestration environment for developing and deploying privacy-preserving quantum algorithms for sensitive data e.g. genomics datasets. This project will also focus on establishing an early commercial pilot with; individual organisations, regional healthcare data sharing ecosystems and global healthcare economies.

As per the NHS England "Five Year Forward View" and the National Information Board's "Personalised Health and Care 2020", the priorities of; data capture, mining, analysis and sharing are rightly seen as essential keys to transforming health outcomes for patients and citizens. Plus, with the potential value of health data being huge according to a recent Unilever Research report that estimates that a person's health information is 50x more valuable than their financial data. As such, cyber criminals prize health data very highly as it allows them to create very convincing false identities based on personal histories. Likewise, the public is also acutely sensitive to their personal health information being misused by businesses, which they believe could expose them to discriminatory practices.

As a result of all these insights, this project represents attempts to address this global challenge which will create fantastic export opportunities for the UK. A recent report, commissioned by IBM Security, looked at the annual cost of data breaches at 419 sample organisations in 13 nations or regions. The report found that the average total cost per organisation was a staggering £2.7 million, based on an average £106 per lost or stolen record. An organisation that rigorously protects its records with our Homomorphic Encryption solution could remove these costs and associated legal, regulatory and reputational risks.

FUNDING GRANTED: £49,966

ZAIKU GROUP LTD

UK Supply cHAin for stRontium clocK Vertical External Cavity Surface Emitting Lasers (UK-SHARK-VECSELs)

Lasers are the light engines required for all quantum technologies based on ultra-cold atoms. They are also very often the major contributor to the size, weight, power consumption, and cost of a quantum system. For this reason, significant effort is being undertaken worldwide to develop novel compact laser sources capable of the same high performance as the existing laboratory-bound lasers required for atom cooling. A leading candidate for strontium-atom-based optical clocks, as required for next-generation quantum timing applications, is vertical-external cavity surface-emitting laser technology (VECSELs). With VECSEL technology we are able to design the lasers to operate at almost any wavelength from the ultraviolet to the midinfrared with high brightness, while simultaneously achieving the very low frequency and intensity noise demanded for quantum applications. Pre-prototypes of such lasers have been successfully delivered by the Strathclyde group under the National Quantum Technology Hub for Sensing and Timing, achieving world-record VECSEL performance and initial demonstrations of strontium atom cooling at the Midlands Ultracold Atom Research Centre. With this new partnership with III-V Epi Ltd, they will transfer their expertise in visible VECSELs and initiate a UK industry supply of highly specialised semiconductor wafers. Supported by this Germinator Project, III-V Epi Ltd will fabricate VECSEL gain structures for the first time and the Strathclyde group will provide fast feedback into an aggressive fabrication and testing campaign for iterative optimisation. This will enable III-V Epi Ltd to demonstrate this unique capability to their target customers in commercial quantum technology.

FUNDING GRANTED: £49,264

III-V EPI LIMITED

UNIVERSITY OF STRATHCLYDE

Feasibility Studies Round 3

ADRENALIN (lAser Diodes in the veRy nEar iNfrared for quantum AppLIcatioNs)

Quantum computing is a rapidly emerging technology offering transformative changes to society as a whole by providing vast improvements in computational capability that will solve complex many-body problems that are currently intractable. It will potentially deliver advancements in diverse fields such as finance, climate change, infrastructure planning, drug discovery, secure communications and material science.

Trapped-ion Quantum Computing (TIQC) systems are one of the most advanced and promising quantum computing platforms in which an oscillating electric field is used to confine ions which serve as the qubits used to encode quantum information. This approach offers a route towards scaling up the number of qubits and thereby delivering the increase in computing power that is ultimately desired, allowing the technology to emerge from small scale lab-based experimental environments to integrated user-friendly systems for everyday use. Laser sources are a key requirement in TIQC, performing essential system functions including ionisation, cooling, repumping and spectroscopy. Typically these different requirements are served by a wide range of laser sources, each with different wavelengths and performance requirements.

The ADRENALIN project will develop a novel type of laser, a Photonic Crystal Surface Emitting Lasers (PCSEL) for use in QT applications. PCSELs employ photonic crystals to produce 2nd order out-of-plane diffraction and enable vertical, single-frequency emission. This novel device architecture provides excellent beam quality compared to other laser diodes and significantly reduces manufacturing costs. PCSELs can also be configured in 2D arrays with steerable individually addressable output, enabling different lattice sites to be addressed simultaneously. In addition these devices can be manufactured in most III-V semiconductors, allowing most of the wavelength range used in QT applications to be addressed.

The many advantages of the PCSEL device will help facilitate scaling in next generation TIQC systems to accommodate larger numbers of qubits thereby enabling exponential increases in computational power and more widespread utilisation of the technology. The PCSEL will also help drive miniaturisation in QT applications -- this is important in TIQC but is also a key driver in the development of miniature atomic clocks for portable high-precision time-keeping, enabling a more widespread adoption of the technology and providing the potential to significantly advance improvements in transportation, defence and communication sectors. In both applications, PCSELs will ultimately displace incumbent light sources which typically rely on relatively bulky, expensive and complicated external cavity lasers and will become essential components in future QT systems.

FUNDING GRANTED: £409,303

VECTOR PHOTONICS LIMITED
NPL MANAGEMENT LIMITED
UNIVERSITY OF GLASGOW

Advancing the practical implementation of quantum error correction with fault-tolerant syndrome extraction

Quantum computers are a new type of powerful computer, based on building blocks called quantum bits, or qubits, that carry information in a more effective way than bits on a conventional computer. However, both bits and qubits can be affected by errors that change the information they contain.

For quantum computers to perform complex calculations accurately and become commercially useful, we need to be able to 'correct' these errors. This is the biggest bottleneck in quantum computing. When solved, it will be the turning point in the quantum industry, turning quantum computers into extremely powerful machines. But it is not that simple. According to quantum mechanics, every time we try and 'read' a qubit, the information gets destroyed. We therefore need to use a second group of qubits that will tell us if and where an error occurred without disturbing the qubits carrying the original information. However, collecting this indirect information -- a process called syndrome extraction - can introduce errors too.

We will solve this challenge by developing codes to perform syndrome extraction in the most accurate way possible. We'll then test these codes on a real quantum computer. In this project, the UK's leading quantum software company, Riverlane, will work closely with Rigetti, a company developing quantum computers based on superconducting circuits. Rigetti owns the most powerful quantum machine in the UK, which will feature 80 qubits in early 2023. We will work together to combine quantum software and hardware to take a first big step in implementing error correction in quantum computers. This is the only way for quantum computers to become powerful and stable enough to solve real-world problems that require complicated computations. Our project brings together the best UK companies in quantum software and hardware able to deliver on this task. Our work will strengthen the UK quantum industry and accelerate the production of quantum computers that will transform several industries, such as drug discovery and materials development.

FUNDING GRANTED: £331,945

RIVERLANE

RIGETTI UK LIMITED

AIR SPAD - AlGaAsSb Infrared Single Photon Avalanche Diodes

To address climate change, attention on greenhouse gases has recently expanded from an overwhelming focus on carbon dioxide to include methane. Methane is the second most important greenhouse gas, because for 20 years after release, it is 84 times more potent than carbon dioxide. Methane is a major constituent of natural gas, which has experienced increased demand, owing to a global switch from coal and oil to natural gas. In addition to its detrimental effects on climate change, methane loss caused by leaks is estimated to cost more than 23 billion GBP per year.

Ideally, continuous monitoring for methane with good spatial resolution is needed to identify and minimise methane loss. However, current technologies to detect methane leaks are expensive and time-consuming, resulting in only occasional inspections. Handheld "sniffers" detect leaks at short range, requiring them to be passed over every square foot of a facility. Satellite imaging, (ESA's Copernicus Sentinel 5P satellite) provides wider coverage but suffers from poor spatial resolution (19.5 km2) and intermittent data.

The AIR SPAD project addresses this important shortcoming of current methane detection technology, by developing high-performance single photon detectors, with 4X higher detection efficiency for quantum gas sensing cameras. The project team consists of Phlux, QLM, and The University of Sheffield (TUoS).

QLM has recently demonstrated quantum gas sensing cameras (based on single photon infrared LIDAR) that can image and quantify greenhouse gases at long range. These cameras have great potential to drastically reduce the complexity and cost of gas monitoring of large industrial sites, but their camera performance is currently limited to low frame rates, and static operation caused by inadequate performance of the single photon detectors available.

Phlux Technology Ltd and TUoS have recently demonstrated a new infrared single photon detector technology that has the potential to deliver 4X higher single photon detection efficiency (SPDE) than commercial Single Photon Avalanche Diodes (SPADs). Deployed in QLM's quantum gas sensing, Phlux's AIR SPAD detector could increase the framerate by 4X, while increasing measurement range and methane sensitivity.

We believe this project will not only be a game changer for quantum gas sensing camera capability, but also lead to a UK supplier for SWIR SPADs. AIR SPAD could also be an equally disruptive technology for fibre-based quantum key distribution systems and infrared quantum imaging.

FUNDING GRANTED: £396,844

PHLUX TECHNOLOGY LTD
QLM TECHNOLOGY LTD
UNIVERSITY OF SHEFFIELD

A PAckageD source of Multiplexed Entangled photons (PADME)

Quantum technologies (QT) are transforming our economy and education. Slowly but steadily delivering novel capabilities to secure communications, measure undetectable signals, and in a not-so-far future, revolutionise computing.

Light plays a pivotal role as a carrier for quantum signals and as the interface between the new quantum hardware and the available technology. For example, entangled photons -- light particles strongly connected even when far apart -- can be routed over the available fibre network and are required in several quantum cryptographic schemes and all-optical quantum computers. For light to fulfil its mission as quantum herald, we need to embed it in a compact, scalable, and mass-producible platform.

With PADME, we propose investigating Photonic Integrated Circuits (PICs) as a source of quantum states of light, following the steps that brought electronics to today's consumer market a few decades ago.

We will study how to generate and extract entangled photons from a PIC component of our own design and fabricated by a commercial foundry. We will combine our in-house photonics and optoelectronics packaging know-how (Bay Photonics), years of academic research excellence (Universities of Strathclyde and Glasgow), and the most recent advances of commercial PIC foundries to deliver a high-performance, compact, and reliable source of entangled photon pairs that will service a global market and bolster the UK's position as a world-leader in quantum and photonic innovation.

We expect this feasibility study to stimulate further R&D and market awareness into adopting the PIC approach for quantum technologies and developing a national quantum PIC supply chain.

FUNDING GRANTED: £384,072

BAY PHOTONICS LTD
UNIVERSITY OF GLASGOW
UNIVERSITY OF STRATHCLYDE

CALYX : Cold-Atom Light via efficient Cavity Extraction

This project addresses a fundamental, rate-limiting, aspect of matter-to-light conversion; proving a principleof cavity-coupling that can unlock greater performance from quantum computing, sensing and networking systems.

This project takes Nu Quantum's existing microcavity know-how into ColdQuanta's proven cold-atom system-platform; maintaining a large separation between the atoms and the cavity surfaces, whilst providing strong atom-cavity coupling to enable efficient photon extraction.

The project approach is to demonstrate - in a realistic environment - techniques that can offer significant competitive advantage to high-value quantum systems offering compute, security and sensing functionality; allowing customers and partners a highly differentiated offering.

FUNDING GRANTED: £323,637

NU QUANTUM LTD

COLDQUANTA UK LIMITED

CompaQT

Detecting the world around us has long been a cornerstone of scientific research, with many sensing technologies developed for commercial use rather than purely scientific merit. For a long time, the ability to view the subterranean environment was limited to destructive exploratory techniques, but in recent years commercial remote sensors have become more widespread. However, all these non-destructive methods can be severely hindered, ground features can be obscured and vibration or electromagnetic interference can completely prevent the generation of any useful data. These issues fundamentally limit the existing technologies for construction and infrastructure monitoring due to costly excavation and site closures, which in some cases may not be possible at all.

Quantum sensing techniques offer the opportunity to overcome these barriers with precision measurements of gravity. Through cold-atom interferometry the quantum nature of a rubidium atom is compared to the phase of a laser beam in a way which can detect very small changes in how the atoms fall freely in a vacuum. Changes in this free-fall can be used to determine the local gravitational acceleration and the measurement can be used to tell whether there are voids, pipes, tunnels or oil and gas reserves beneath your feet.

Significant strides have been made in the world of quantum sensing; recent scientific achievements have proven atom interferometry is an invaluable tool for subsurface detection of features like buried tunnels or pipelines (doi.org/10.1038/s41596-021-04315-3). The technology to make the step to quantum sensors already exists, and has been proven in the field, however it needs commercial engineering techniques to bring it into everyday use by those without highly specialised training.

This project is led by Delta-g Limited; a new quantum start-up in a unique position to take advantage of this second-generation quantum technology, with a team experienced in construction and use of quantum gravity gradiometers for field measurements and direct links to the University of Birmingham, also partnered in the project to provide scientific support from their experienced Quantum Hub. They will partner with STL, who have a successful history of guiding quantum start-ups to commercial success and taking functional prototypes from the laboratory to field instruments and will provide the expertise to take the sensor closer to market readiness. End-user expertise within the project will be achieved through an advisory board formed by representatives from companies with a direct interest in the success of a commercially available quantum gravity gradiometer.

FUNDING GRANTED: £360,068

DELTA G LIMITED
STL TECH LIMITED
UNIVERSITY OF BIRMINGHAM

Exploiting Quantum Computing for Large-Scale Transport Models

THE PROBLEM:

Moore's Law imposes a fundamental ceiling on what can be achieved by classical computing. This has an extensive impact on numerous applications, described as NP-hard/intractable problems, which simply cannot be feasibly solved on classical hardware. The transportation and energy sectors are home to numerous NP-hard problems.

Computation speed is a critical customer issue with demonstrable demand for faster, larger models across both the transportation and energy sector.

OUR PROJECT:

Our project explores game-changing opportunities for faster computation by developing and testing the formulation of transport and energy optimisation problems as Quadratic Unconstrained Binary Optimization (QUBO) problems and Quantum Approximate Optimization Algorithms (QAOA) relevant to different types of quantum hardware.

Our innovation builds on techniques such as minor embedding and uses cutting-edge systems being developed in the UK and elsewhere.

FUNDING GRANTED: £399,953

CITY SCIENCE CORPORATION LIMITED

UNIVERSITY OF EXETER

Feasibility study of using Quantum Sensors when developing new batteries and when recycling batteries

Battery recycling and second life application is a key challenge facing the current drive to electrified powertrains. Batteries use scarce natural resources and due to current battery designs and manufacturing processes, they are difficult to recycle. Without action now, there will be a significant problem as electric vehicles reach the end of their useful life.

The battery cells from vehicles at the end of their useful life can vary in the level of aging, so knowledge of the level of aging is essential to understand how they can be reused in 'second life' applications. For example, a cell that has reduced power may be suited to an energy storage system for solar energy, whilst a cell that is only slightly aged may be reused in an automotive application.

Quantum magnetometers are one of the most advanced quantum technology devices to date. The University of Sussex and CDO2 have demonstrated that self-discharge currents from lithium cells produce a magnetic field that can be observed using an array of quantum sensors (optically pumped magnetometers). This imaging system can be used to identify cells with different levels of aging.

Ricardo are a world leading automotive engineering company with a history in developing electrified vehicles and associated battery systems. Ricardo are currently researching new manufacturing processes that take advantage of battery cell recycling.

The project will apply the quantum imaging techniques to a wide range of battery cells which will be aged during this project, including cylindrical and pouch cells. These cells will be configured to assess how magnetic fields interact with the cells when formed into modules to address the question of whether the quantum sensors can detect differently aged cells within a module.

The study will then consider the implications of this imaging technique on the designs of new battery modules and the design process for a new battery production facility, with a focus on second life usage, that was studied by Ricardo as part of an ATF funded study.

FUNDING GRANTED: £337,756

RICARDO UK LIMITED

CDO2 LIMITED

UNIVERSITY OF SUSSEX

GRADUATE

Quantum enabled Gravity Gradiometry, the measurement of the rate of spatial change of the earth's gravity field, offers significant performance improvements over conventional gravimetry including much better signal to noise ratios (by cancelling out vibrations) and a method better suited to producing geodesy -- gravity maps.

The GRADUATE project (gravity gradiometry for end user trials) aims to shrink and ruggedize the apparatus, realising appropriate SWAP (size, weight and power) to produce field deployable technology. Bandwidth improvements will allow for application as a survey tool in moving vehicles, the spatial resolution of measurements being dependant on the bandwidth. This is a particular consideration in airborne survey tools.

The team assembled for the GRADUATE project to deliver a commercially feasible quantum gravity gradiometry tool Project lead CPI-TMD will bring their vacuum and sub-system integration capabilities as well as a strong commercial drive from their network of potential end users. M Squared are photonics and quantum technology solutions providers, who in 2017 made the UK's first commercial cold-atom gravity measurement and have continued to invest in maturing the technology. The University of Strathclyde quantum group are rated world class, and with an established record of collaborating closely with both industrial partners underpin this project with exceptional capability in the physics of innovative quantum devices.

FUNDING GRANTED: £360,661

CPI TMD TECHNOLOGIES LIMITED
M-SQUARED LASERS LIMITED
UNIVERSITY OF STRATHCLYDE

Grating-based lattice optical clock (G-BLOC)

Precision timing is key to all aspects of modern infrastructure, from the national grid, to telecommunications, to financial trading, through to global, national, and individual navigation systems.

When we switch on our smartphones or satellite navigation systems, we are unconsciously using networked oscillators utilising the performance of current commercial atomic clocks. The exact sychronization of these oscillators is necessary to make much of today's technology work and it also underpins many precision experiments in research laboratories. As outlined in the UK Blackett Report on Global Navigation Satellite System dependencies, we are very dependent upon precision frequency and time transfer.

However, these signals do not have guaranteed security, either through their ownership (the GPS system is run by the US Air Force) or due to the vulnerability of the wireless signal to hacking or jamming. There is an urgent need for a UK source of clocks to protect core infrastructure. Additionally, the development of a step-change in the accuracy and stability of timing and frequency sources will drive new technologies, including faster telecoms and ever more secure communication protocols, precision navigation for autonomous transport networks and earth observation techniques to monitor climate change.

This project brings a team of leading UK universities with many decades expertise in atomic physics together with industry leaders specialising in optical systems engineering to deliver a world leading miniature optical system for atom cooling, trapping and probing. This innovative approach will generate a source of optically trapped strontium atoms suitable to deliver highly accurate time referenced to atomic standards. Ultimately, this technology could be employed in a fully isolated clock that is capable of providing a GNSS-surpassing timing standard at the heart of future autonomous vehicles and critical infrastructure networks.

FUNDING GRANTED: £380,756

WIDEBLUE LIMITED
M-SQUARED LASERS LIMITED
UNIVERSITY OF BIRMINGHAM
UNIVERSITY OF STRATHCLYDE

Gravity Array

The ability to distinguish gravitational signatures is of great value to anyone looking to either explore for new material resources or monitor existing ones, as this can be done without need to physically dig it up or bring measurement instruments directly to the source. The greater the ability to distinguish gravity and the more measurements that can be taken, the better the available data will become and the ultimate value that is derived from it.

The size of opportunity that quantum based gravity measurements present is significant, but so too are the challenges in doing it. For the last decades, researchers across the world have strived towards enabling better control of the physics that govern these systems and, while it has enabled unprecedented sensitivity, the fragility and cost of such systems has resulted in limited commercial use. Through this project, the intention is to correct this by combining the world leading expertise in quantum gravity measurements from the University of Birmingham with the low cost, small size and simplified cold atom trap design of Aquark Technologies. This approach has never been explored before due to the only recent discovery of magnetic free cold atom traps by Aquark Technologies.

The combination of Aquark Technologies and the University of Birmingham offers exciting new ways of putting together quantum gravity measurement systems, and specifically, this project looks to explore the concept of using a single high performance interrogator and multiple sensor heads. To date, no attempt to achieve this goal has been undertaken as often sensors and systems have to be co-designed due to the bespoke nature of their operation. If successful in demonstrating the feasibility of combining the systems and knowhow, the potential to unlock more high quality gravity data, at a much lower cost, is within reach. The result of this will lead to less environmental disruption for all as a better monitoring of what is underground can be determined, without the need for excavation. Examples of where quantum gravity sensors could make a significant difference include; monitoring of volcanoes leading to improved warning times, potentially saving hundreds of lives each year; better monitoring of groundwater could lead to better understanding and use of this resource preventing droughts and floods and improved monitoring at carbon storage sites could lead to improved efficiency and help us combat climate change.

FUNDING GRANTED: £381,359

AQUARK TECHNOLOGIES LIMITED
UNIVERSITY OF BIRMINGHAM

High-speed self-certifying Quantum Random Number Generator for simulations

Random number generators (RNGs) are used for a myriad of different applications, ranging from encryption to non-cryptographic use cases such as stochastic simulations. However, the quality of RNGs is often overlooked but can significantly improve the accuracy and time to solution of stochastic modelling methodologies in addition to the effectiveness of encryption schemes. Quantum Random Number Generators (QRNGs) improve on the commonplace pseudo- and quasi-random generators due to the intrinsically unpredictable nature of quantum physical processes. We will combine a QRNG from Quantum Dice with the Hartree Centre's Monte Carlo capabilities and demonstrate their usage on test cases relevant to the Financial Services sector under the guidance of HSBC.

FUNDING GRANTED: £320,544

QUANTUM DICE LIMITED

HSBC GROUP MANAGEMENT SERVICES LIMITED

STFC - LABORATORIES

High Performance Quantum Light Source

A wide range of emerging quantum technologies including communication, photonic computing, microscopy and sensing all require a high-quality source of quantum light in order to succeed. Aegiq's goal for this project is to develop a complete field-ready, turn-key solution that can easily be incorporated into a commercial setting. We will achieve this by leveraging our leading-edge indistinguishable single-photon sources, by driving them at GHz rates with a novel ultrafast laser, developed by Fraunhofer CAP. Our deterministic source technology means this high-purity single-photon output rate will by far surpass rates that are currently limited by the performance of commercially available lasers. This will make our system ideal for high-speed quantum key distribution and quantum information processing, as well as being a brighter source for imaging or sensing applications. We aim to break down several barriers to adopting quantum technology, namely the performance and cost so that Aegiq products will be used to shape the future technology market.

FUNDING GRANTED: £386,717

AEGIQ LTD

FRAUNHOFER UK RESEARCH LIMITED

Hue- Manatee: temporal and spectral multiplexing for super high-efficiency photon sources

Single photons are the workhorse of the future quantum technology industry, being a fundamental component to high fidelity quantum computing, quantum communications, quantum imaging and some types of quantum sensing. However, to date, no truly single photon sources of high quality, high efficiency, indistinguishable exists on the market. Current single photon sources on the market are not ideal for many reasons. All, including ORCA's current source, are very far from being 'on demand' with efficiencies between 1-15% (firing 'blanks' for most of the time, with spaces where the single photons should be). The most efficient sources that have been demonstrated are complex free space experiments, which achieve efficiencies of 30%+, however, these are far from being suitable for a reliable product. Quantum dot sources can achieve efficiencies of 15%, but are unstable, due to the properties of the photons drifting from one photon to another, or from one source to another.

All of these properties diminish the quality, also known as the fidelity of interactions between photons, and make them fundamentally poorer in performance when used for quantum computing and communications (for example, limiting how far photonic quantum computers can be scaled up).

In this project, temporal multiplexing techniques from ORCA's previous Innovate UK project 'Manatee' will be implemented alongside a completely new spectrally multiplexing technique. Together, the two techniques will be combined in a prototype product with unparalleled performance and efficiency.

FUNDING GRANTED: £349,941

ORCA COMPUTING LTD

INTERCOM: A high-performance ion-photon interface to enable multi-core trapped ion quantum computing

Quantum computation is heralded as a paradigm shifting technology, to revolutionise drug discovery, chemistry, communications, and even our understanding of the natural world. However, the vast promises of any scientific discovery must be measured against the engineering challenges which hold back its delivery. In this project, partners from industry, academia, and the public sector will produce a core component that is critical to the realisation of scalable quantum computing. This will help enable the efficient interfacing of light and matter at the single quantum level, which will allow quantum processing nodes to combine resources and operate in synchronicity over vast distances. The construction of networked processors from large numbers of smaller modules will lift one of the principal technical restrictions on the route to full-scale quantum computation.

At its heart, our challenge is to create a device enabling the transfer of quantum information between trapped atomic ions and single optical photons. However, while atoms may be readily trapped with electric and magnetic fields, 'trapping' light remains a considerable endeavour. The natural solution is to confine the light between two micro-mirrors in the form of a resonant optical cavity, engineering a strong interaction between the atom and optical field via their mutual overlap. However, the realisation of optical cavities as a quantum interface has been historically limited to an academic environment, relying upon fabrication methods that are unsuited to the construction of the quantum computers of the future. To fulfil the objectives of this project, we will harness and develop innovative technologies in the creation of a robust, turn-key cavity interface suitable for scalable integration in ion and atom-based quantum networks.

FUNDING GRANTED: £338,063

NU QUANTUM LTD

STFC - LABORATORIES

UNIVERSITY OF OXFORD

MANGROVE

MANGROVE will develop novel integrated-photonic circuits that could be incorporated into ORCA's products and unlock significant new opportunities in the quantum research, computing, communications and imaging markets.

FUNDING GRANTED: £421,409

ORCA COMPUTING LTD

FRAUNHOFER UK RESEARCH LIMITED

Medusa: the networking heart of a trapped ion multi-core quantum computer

Nu Quantum, University of Cambridge, University of Oxford, and Cisco Systems come together to develop and commercialise inte grated quantum photonic technology aimed at enabling entanglement-based networking of multi-core quantum computing clusters.

Project Medusa employs Integrated Photonic technology to develop a Quantum Networking solution aimed at interconnecting small clusters of Trapped Ion Quantum Computers (TIQC).

The motivation for this project is the scaling of TIQCs. TIQCs are the best-performing qubit technology today, however it is widely accepted that it will be extremely difficult to create TIQC cores of over 50-100 qubits. Interconnecting small, efficient clusters using photonic networking is the most promising solution to achieve large, powerful computers.

The technological challenge is that there currently exist no commercially-available quantum networking photonic products - integrated switches, entanglement optics, and single-photon detectors - which meet the requirements of speed and efficiency, at the required wavelengths.

The main output of this project is a world-first prototype of an integrated 4-node switched entangler which targets the necessary requirements of rate, loss, and wavelength to enable multi-core TIQC.

FUNDING GRANTED: £420,187

NU QUANTUM LTD
CISCO INTERNATIONAL LIMITED
UNIVERSITY OF CAMBRIDGE
UNIVERSITY OF OXFORD

Miniature Packaged Ion Traps

The next 20 years are poised for growth of the "second quantum revolution", with the widespread emergence of technologies and devices leveraging the properties of superposition and entanglement which govern the dynamics of light and matter at the smallest scales. Atomic ions trapped in electromagnetic potentials have long been used for fundamental studies in experimental quantum physics. Over the past two decades, trapped ions have also emerged as a promising platform for a wide range of quantum-based technologies such as quantum computing and simulation, atomic clocks, and quantum sensors. Advanced trapped-ion-based technologies have the potential to impact the entire emerging quantum technology sector, however, it remains a challenge to obtain even the simplest experimental ion trapping system. This is perhaps not surprising given the extensive control and extremely high quality of vacuum required to prepare and maintain delicate quantum states. If practical large scale quantum technologies are to be realized over the next decades, then individual ion trap nodes must become standardized off-the-shelf components.

ColdQuanta, the University of Oxford, and the NQCC will develop and produce a high-performance, miniature, and self-contained ion trap system. By integrating Oxford's microfabricated 3D radio-frequency trap into ColdQuanta's miniature vacuum packaging, a new route for delivering ion traps can be exploited commercially. The NQCC will further investigate use-cases for miniature packaged systems and provide input into the design and development process ensuring alignmentwith their roadmap for building quantum computing infrastructure in the UK, covering both hardware and associated supply chains.

FUNDING GRANTED: £343,843

COLDQUANTA UK LIMITED
STFC - LABORATORIES
UNIVERSITY OF OXFORD

Near-term quantum computing for solving hard industrial optimisation problems

Optimisation and constraint satisfaction problems are ubiquitous in industry, ranging from straightforward tasks such as arranging a timetable to exceptionally challenging ones such as laying out a telecommunications network or a high-performance integrated circuit. Problems like this are associated with the need to search over exponentially many potential solutions to find the best possible solution. Finding better solutions to optimisation problems could enable outcomes as diverse as reducing shipping costs for package deliveries and increasing the capacity of cellular networks. Yet these problems remain exceptionally challenging for standard computers, despite many years of effort from theorists and practitioners.

It has been known since the 1990s that quantum computers could solve optimisation problems significantly more quickly than standard computers. For example, Grover's famous quantum search algorithm can solve optimisation problems with a runtime that scales like the square root of the runtime of classical unstructured search. However, this approach and others for solving optimisation problems are suitable only for long-term, fault-tolerant quantum computing, raising the question of whether quantum computers can be applied to optimisation problems in the near future, enabling them to unlock the associated value.

In this project we will determine the potential for near-term gate-model quantum computing to solve optimisation problems. Project partner BT will identify problems, in particular in the domain of telecoms network optimisation, that are particularly suited to being solved by quantum computers. Project partner Phasecraft will design and implement quantum algorithms for these and related problems, which will be executed and evaluated on cutting-edge quantum hardware developed by project partner Rigetti. Commercial feasibility of the results of the project will be evaluated by comparing against leading classical approaches for solving optimisation problems.

Our work will build on the results of a previous InnovateUK funded feasibility study, which explored the potential for fault-tolerant quantum computers to solve optimisation problems relevant to telecom networks in the long term, but did not implement near-term algorithms on real hardware.

We will hold an innovation workshop targeted at leading organisations for whom optimisation problems are relevant to their businesses, to determine which problems are the most promising to be addressed by quantum computing and to present the results of the project. We expect that the project will deliver a quantum solution for solving optimisation problems, demonstrated on real quantum hardware, as well as a clear roadmap for applicability to real-world problems.

FUNDING GRANTED: £288,454

PHASECRAFT LIMITED

BT

RIGETTI UK LIMITED

Next-Generation Satellite Telecommunications Entangled Photon Source (NextSTEPS)

Quantum Computers have the potential to offer a huge range of benefits. By increasing processing power exponentially, they will unlock new, exciting capabilities and improve our current capacity considerably. This does however put at risk technologies which have long relied on computational expense for their function. An example of this is encryption, which keeps data secure via the use of asymmetrical mathematical problems which are beyond the capability of most classical computers. These problems will, however, be easily solvable by quantum computers, creating a problem referred to as the "Quantum Apocalypse".

There are currently two front-runner technologies to keep data secure in a post-quantum world. Post-Quantum Cryptography (PQC) aims to provide mathematical challenges which a quantum computer will not be able to solve, as a new iteration of current methodologies. Quantum Key Distribution (QKD) offers a novel method for distributing keys which enables robust symmetrical encryption techniques, with the key transfer mechanism being protected by fundamental laws of physics, as opposed to mathematical complexity. Both are receiving significant focus and investment, with the most likely outcome being hybrid solutions incorporating the benefit of each.

To support the roll out of these new technologies, space has emerged as a critical component in networks for quantum security. Satellites offer the ability to distribute information globally, and also allow for free-space optical transfer, which isn't limited by distance in the same way as terrestrial fibre networks. The Chinese Micius satellite demonstrated a number of fundamental technologies in 2016, which has led to a race to match this achievement in other countries. As such a number of satellite missions orientated towards quantum security are in development, predominantly focusing on cost effective small- or nanosatellites.

Within this landscape a consortium featuring Craft Prospect, Alter Technologies and Fraunhofer Centre for Applied Photonics has formed to develop the next generation of products for space-based quantum security. NextSTEPS will look to build a benchtop demonstrator of an entangled photon source. The benefits of this type of unit are increased security and future relevance, due to the need for the creation of networks of quantum computers. The work will also consider the requirements of the unit for use in space, and in particular for low Size, Weight and Power (SWaP) satellite platforms such as nanosatellites. Through the project the team will create enabling technologies for future quantum computing networks while also defining near-term entangled-source QKD products.

FUNDING GRANTED: £369,694

CRAFT PROSPECT LTD

ALTER TECHNOLOGY TUV NORD UK LIMITED

FRAUNHOFER UK RESEARCH LIMITED

Non-invasive quantum sensing for continuous glucose monitoring

The objective of the project is to conduct in-vitro feasibility studies for a second- generation quantum sensor, codenamed LUX1, that optically monitors glucose in a revolutionary new way. Unlike currently available sensors, LUX1 will allow people living with diabetes (PLWD) to conveniently measure real-time glucose levels without drawing blood or breaking the skin surface, simply by bringing their finger or wrist into contact with the device. The vision for LUX1 is initially a point- of-care device and we aim to miniaturise it into a smartwatch-like wearable, e.g., Apple watch, aligning with current trends of measuring multiple vitals all in one device.

Our innovative approach will be instrumental in tackling a significant worldwide problem. Currently, there are around 463M diabetes sufferers worldwide and this is predicted to rise to 700M over the next 25 years, with millions of additional undiagnosed cases. Diabetes significantly reduces life expectancy -- Type I on average by more than 20 years, and up to 10 years for Type II. In the UK, there are around 500 premature deaths every week and the NHS spend 10% of the annual budget contributing to the treatment of diabetes and the complications, equating to an expenditure of £10B per year (or £192M per week). Despite the growing severity of the situation, many people are still using invasive, non- reusable and non-cost-effective methods to monitor glucose. This demonstrates a compelling need for next-generation glucose monitors, like LUX1, to help PLWD/healthcare professionals to be more proactive in diabetes management to reduce the number of amputations/premature deaths, and associated costs.

To develop our LUX1 prototype, we have split the project into four work packages:

- Business development
- Sensor design/manufacture
- Sensor packaging/testing
- In-vitro feasibility studies

FUNDING GRANTED: £421,350

NIQS TECH (LEEDS) LIMITED
COMPOUND SEMICONDUCTOR APPLICATIONS CATAPULT LIMITED
UNIVERSITY OF LEEDS

PAssively STabilised Laser (PASTEL)

Cold atom-based quantum technologies have great potential because of the versatility of this platform. Cold atoms can be used in a variety of high-performance sensors, including optical clocks, inertial sensors, gravimeters, and magnetometers just to name a few. They rely on stable lasers with stringent requirements on their optical frequency. Recently, these quantum sensors began to be used in the harsh and dynamic environment of space, where inherent stability, reliability, size, weight and low power consumption are critical in determining the success of a mission, even more so than in terrestrial applications. In the PASTEL project we propose to develop and test a completely novel laser architecture that will improve on all the critical performance parameters indicated above over any competing laser technology. This new laser will be passively stabilised to an atomic reference within the laser itself. Our innovative approach eliminates the need for external frequency references and active feedback electronics. This development reduces the size and weight of both the laser module and associated electronics and lowers power consumption, while also improving stability and reliability since the laser cannot lose lock to a reference. We will exploit mature, power-efficient 780 nm diode laser technology, industry-leading miniaturisation and packaging capability, and compact, stable bespoke electronics. We will deliver a fully tested demonstrator laser unit.

FUNDING GRANTED: £351,501

ALTER TECHNOLOGY TUV NORD UK LIMITED
FRAUNHOFER UK RESEARCH LIMITED
REDWAVE LABS LTD

Persistent Homology on near-term Quantum Computers

Fairness, trust, and transparency are the primary concerns hindering the wider adoption of AI in critical application domains. AI systems have been found to produce unfair, biased, and unethical decisions in many instances. Explainability is one way to understand the reasons behind a model's predictions can help ensure models are treating all users fairly. The field of Explainable AI (XAI) is focused on developing tools, frameworks, and methods that help understand how machine learning models make decisions.

Topological Data Analysis (TDA) is an nascent field of data science that aims at characterizing data using its shape. It is one of the enabling technologies for Explainable AI. TDA extracts topological features to capture multi-scale, global, and intrinsic properties of complex data sets. It has applications across all the industry verticals ranging from finance, biology, neuroscience, computer vision and text analytics.

Persistent Homology (PH), the workhorse of TDA, is a useful way to summarise the topological characteristics of noisy and high dimensional datasets as an intuitive, interpretable and lower dimensional representation. However, the use of TDA/Persistent Homology in commercial applications is often hindered by the computational complexity required to compute topological descriptors exactly.

Our project will study the implementation of persistent homology techniques suitable for near-term quantum hardware in order to establish commercial deployment roadmap aligned with hardware developments. We take advantage of recent advancements in quantum computing algorithms and hardware availability to extract topological features from high dimensional big datasets.

FUNDING GRANTED: £384,857

VORSUS LTD

UNIVERSITY OF EXETER

Photon Absorption Spectroscopy CAmera for Leaks (PASCAL)

For the UK to reach a net-zero carbon economy, the regulation and limitation of greenhouse gas (GHG) emissions needs to rapidly expand. Natural gas is fast becoming our most dominant fossil fuel and industrial leaks are now a leading source of GHG emissions. Industry majors have committed to expanding emissions monitoring, but the technologies currently available are expensive, labour intensive, and inaccurate. Quantum Gas Imaging (QGI), invented by QLM, is an emerging technology that uses non-cryogenic Shortwave Infrared (SWIR) Single-Photon Avalanche Detectors (SPADs) to demonstrate innovative and highly sensitive long-range, single-photon lidar gas imagers that locate and measure invisible gases including methane, CO2 and more.

The current generation of the QGI camera uses mechanical scanning to analyse an area with a single sensor. This limits the data acquisition rate, thus prohibiting fast mobile deployment, in the interest of maintaining the sensitivity and spatial resolution necessary. Commerical-off-the-shelf (COTS) SPAD arrays can allow for non-mechanical scanning, but current readout electronics are limited in throughput to allow for such developments. SWIR SPAD array readouts, such as these, require high-speed data acquisition. When combined with the flexibility of Field-Programmable Gate-Array (FPGA) technology, this is going to be a key enabling technology for all other photonic 2nd generation quantum technologies based on single-photon quantum optics research, including free-space quantum telecommunications, photonic quantum processors, and lidar.

In this project, QLM Technology will develop a non-mechanical scanning QGI camera that exploits SPAD arrays and their high throughput capabilities to achieve state-of-the-art acquisition rates, sensitivity, and large detector dynamic range. Aston University will develop the advanced signal processing algorithm required to achieve high speed real-time Time to Digital Converter (TDC) and Time-Correlated Single Photon Counting (TCSPC) on FPGAs and utilises multi-photon information for the formation of the correlations. RedWave will build the electronics platform to incorporate the advanced high speed time tagging capability into new standalone products, which can be applied in other fields for the 2nd generation quantum technology used in life science and free-space communications, thanks to the flexibility of the FPGA based system.

FUNDING GRANTED: £377,648

QLM TECHNOLOGY LTD
ASTON UNIVERSITY
REDWAVE LABS LTD

Platipas - Passive Platform Development for Visible Wavelengths

This is a feasibility project concerned with developing the next generation GaN laser sources for quantum applications. The GaN laser devices will be co-packaged with passive waveguide structures to provide single frequency operation or other functionality such as wavelength referencing ands locking. The consortium consists of Kelvin Nanotechnology, TGQT, Alter, University of Glasgow and Fraunhofer-CAP.

FUNDING GRANTED: £362,653

KELVIN NANOTECHNOLOGY LIMITED
ALTER TECHNOLOGY TUV NORD UK LIMITED
FRAUNHOFER UK RESEARCH LIMITED
TOPGAN QUANTUM TECHNOLOGIES LIMITED
UNIVERSITY OF GLASGOW

Project U-Quant: Ultra-low SWaP quantum communication payload for tactical and space applications

QKD provides a secure method for the sharing of encryption keys. Via free-space satellite links, long-distance key sharing can be achieved and global access to the benefits of quantum technologies is enhanced. Current state-of-the-art technology has limitations, such as the need for complex, large control systems, susceptibility to loss, or a low-key generation rate. U-Quant aims to bring together collaborators with expertise in single photon source and QKD control system development to provide the market with a low-loss, low-SWaP integrated QKD system that utilises the superior performance of true quantum light sources. This development will allow ultracompact product manufacturing to take place, providing the market with a low-cost, true-quantum technology that is suitable for integration into current satellite systems.

FUNDING GRANTED: £409,798

AEGIQ LTD

UNIVERSITY OF EXETER

Q3MD: single photon sensitive detector for methane gas detection operating at 3μm

For the UK to reach a zero-carbon economy, the measurement, regulation, and enforcement of greenhouse gases (GHG) emissions needs to rapidly expand. Natural gas (primarily CH4 methane) remains the dominant fossil fuel and industrial leaks are a leading source of GHGs. Currently there are a lack of surveying methods and equipment for the European Union's (EU) ~200,000km of high-pressure pipeline, the UK's ~7,660km of high-pressure pipeline and the ~500,000km of high-pressure pipe-line in the United States in addition to the 100s of above-ground facilities.

The project seeks to develop a single photon sensitive detector for methane gas detection operating at 3μm. Methane can be detected at much lower concentrations at this wavelength than at the 1.65μm used in commercial detectors. By applying Differential Absorption Lidar and Time Correlated Single Photon Counting, we can extend the remote spectroscopy capabilities to increase the distance range or decrease the response time; by accessing the 3μm spectral region, low concentration sensitivity is to be increased up to 50-fold. In addition, we can expand the gas species and target other applications are that currently not addressable with a SWIR wavelength.

The technical approach is to combine unique III-V alloy material developments with innovative science and engineering at Bay Photonics (optics packaging), Redwave Labs (control electronics) and QLM (signal processing and spectral analysis). The aim will be to optimize solid state cooling to bring the detector to very low temperatures without having recourse to Stirling engines. The project specifications, modelling and detector validation for methane applications will be led by the channel partner QLM. The overall goal is a detector resolvable to single photon/few photon level at 3 μm and evaluated in bench top prototype form.

FUNDING GRANTED: £347,478

REDWAVE LABS LTD
BAY PHOTONICS LTD
QLM TECHNOLOGY LTD

QGyro

Accurate inertial measurement units (IMUs) are critical for autonomous navigation in where access to Global Navigation Satellite System (GNSS) is denied/ unavailable/unreliable. This is particularly relevant to defence/security applications (e.g. cruise missiles) or civilian applications such as remote search and rescue situations.

The QGyro project will develop a navigation-grade based on an atomic spin gyroscope and evaluate the miniaturisation potential of the technology.

The 18-month project builds on outputs of several quantum projects to create a pathway to developing the commercial atomic spin gyroscope based on co-magnetometry.

FUNDING GRANTED: £399,702

MICROCHIP TECHNOLOGY CALDICOT LIMITED
INEX MICROTECHNOLOGY LIMITED
NPL MANAGEMENT LIMITED

QUantum communication Development with Increased Throughput for information Systems (QUDITS)

Project QUDITS is a feasibility study which aims to develop a demonstrator platform to showcase the feasibility of developing quantum communication systems using qudits based on orbital angular momentum (OAM). By using using commercially available novel photonics technologies from the UK supply chain, photonic crystal surface-emitting lasers (PCSELs) and low-noise Avalanche Photo-Diodes (ALDs), able to operate at optical communications wavelengths.

Quantum information is shaped around the use of qubits, the quantum analogy to the standard bit. This is a two-level, binary system, which is well known and has been used for many years. All quantum technologies currently being commercialised are based on qubits as the building block of quantum information. However, a two-level system inherently limits the density of information that can be carried in a quantum system. Higher dimensional Hilbert states of quantum information exist, known as qudits, and have more than two discrete states and can carry more information.

The QUDITS project is developing a new area of quantum technologies for a potentially disruptive future communication system that will greatly enhance the state-of-the-art. It will demonstrate the feasibility of generating and detecting qudits from commercially available components from the UK supply chain. Qudits are a natural scale up technology for communication systems, enabling more data to reside on one quantum state, instead of having to send more qubits.

FUNDING GRANTED: £403,213

VECTOR PHOTONICS LIMITED
COMPOUND SEMICONDUCTOR APPLICATIONS CATAPULT LIMITED
PHLUX TECHNOLOGY LTD

Quantum computing for materials modelling applications in photovoltaics

Accurate simulation of complex materials yields useful insights, guiding experimental efforts and technological advancements. In photovoltaic applications, these can help to increase solar cell efficiency, their durability and manufacturability, key challenges in the industry. Designing novel materials for clean energy use, or even gaining a full understanding of existing materials, is currently a major challenge due to the necessity of taking quantum effects into account. Standard modelling techniques are unable to solve the required problems with sufficient speed and/or accuracy, implying that costly experiments in the lab are often needed in order to characterise the properties of materials.

Quantum computers can natively represent quantum-mechanical systems and could efficiently solve materials modelling problems that are beyond the reach of today's best supercomputers. This could enable "in quanto" materials design and selection, where many materials are screened for their properties without needing to perform experiments. After many years of development of quantum computing technology, quantum computers have outperformed the world's fastest supercomputers for certain targeted problems. Nevertheless, the capabilities of current quantum computers are insufficient to enable standard quantum simulation algorithms to be run, and therefore the development of targeted quantum software is critical to harness the potential of existing quantum technologies.

In this project we will develop efficient quantum algorithms and software to solve modelling problems in photovoltaics. Our algorithms will be targeted at specific use-cases developed in collaboration with end-users, while being sufficiently general to address other materials modelling challenges. Based on our encouraging previous results, we expect to find significant improvements on previously known algorithmic complexities, reducing the resources required to simulate quantum systems, and bringing the solution of previously unfeasible problems into reach.We will implement our quantum software on a leading quantum hardware platform, and will evaluate it against the requirements of our expert end-users Oxford PV, and also against the results of classical simulation performed by UCL. Our results will enable the development of a roadmap for future exploitation and will open the door to quantum computing solving hard materials modelling challenges beyond the capability of standard methods.

FUNDING GRANTED: £369,295

PHASECRAFT LIMITED
OXFORD PHOTOVOLTAICS LIMITED
UNIVERSITY COLLEGE LONDON

Quantum Hive gravity system

The Quantum Hive project is a joint initiative between the University of Birmingham (UoB) and Silicon Microgravity (SMG). It aims to deliver an innovative, viable way forward for commercialising the cold atom Quantum sensor developed at the UoB by adopting a hybrid approach with MEMS gravity sensors developed by SMG. Gravity sensors have historically struggled to gain commercial traction but by adopting a hybrid approach using the technical strengths of each sensor system will deliver a gravity sensing system which meets the end-users needs.

The Quantum gravity sensor has the ability to a) provide levels of sensitivity unachievable today with MEMS sensors, b) measure with very low levels of drift and c) provide absolute gravity and gravity gradiometer measurements. However, its form factor, lack of mobility and cost provide a challenge where surveying of larger areas is required. MEMS gravity sensors lack the absolute accuracy of Quantum sensors and have larger drift levels but have a form factor, power consumption and cost which enable them to be deployed either as a single sensor or swarm on drones or autonomous vehicles, stopping to make measurements and then moving again. As a result of these different attributes, a hybrid approach can take advantage of the relative strengths to provide a truly innovative system for use in real world environments.

The Quantum system will be used as a Base station providing an absolute gravity reference for the MEMS sensors. The Quantum Base station (the hive) will have limited mobility being either stationary or mobile of a rail. The MEMS sensors (the bees) will leave Base station on autonomous vehicles or drones, stop to take stationary measurements at pre-defined locations and then return to the Quantum Base for drift elimination.

By adopting this hybrid approach, the project will meet the needs of the end customers who require gravity surveys over a large area in an acceptable time period and at a viable cost. End customers are multiple but include civil engineering companies, utilities, environmental organisations, carbon capture facilities and defence/security entities.

FUNDING GRANTED: £424,779

SILICON MICROGRAVITY LIMITED
UNIVERSITY OF BIRMINGHAM

Quantum Photonic Integrated Circuit Packaging (QPICPAC)

Quantum Photonic Integrated Circuits (QPICs), similarly to their classical counterparts Photonic Integrated Circuits (PICs), are a technology that takes advantage of the decades of development in semiconductor processing for the integrated electronics to create chip-based circuits for light that can be cost-effectively mass produced. QPICs are at the centre of most of the photonic approaches to quantum computing such as those being taken by PsiQuantum, Xanadu and QuiX, but are also vital for the scalability of light-dependent quantum technologies trapped ion/diamond-impurity-based quantum computing, quantum sensing, quantum key distribution (QKD) and quantum random number generation.

Unlike their classical counterparts, QPICs often need extremely low loss and to perform in extreme environments such as at low temperature or in space, which results in difficulties in packaging these devices. At present, QPIC packaging is done on a bespoke, case-by-case basis, meaning that is slow and costly, creating a barrier to the development of QPIC-based products.

Led by Wave Photonics, the consortium comprised of Alter Technology, SENKO Advanced Components, Southampton University and Bristol University will develop a template, design guide and packaging process to allow for rapid and cost-effective packaging of QPICs. Quantum Dice will act as a representative end user.

FUNDING GRANTED: £400,573

WAVE PHOTONICS LTD
ALTER TECHNOLOGY TUV NORD UK LIMITED
SENKO ADVANCED COMPONENTS (EURO) LIMITED
UNIVERSITY OF BRISTOL
UNIVERSITY OF SOUTHAMPTON

QuILT - Quantum element Interposition by Laser Transfer

Telecommunications has become one of the most vital part of human life globally and continues to expand and increase its impact on our lives and as a result on commercialisation and industrial progress. Information security is continuously at risk as the communication channels and data volumes continue to increase. Data encryption methods and algorithms are advancing but lag behind the evolution of intercepting systems and codes. Moreover, with the advancement of quantum computing we are at anticipation of the quantum apocalypse, where encryption by conventional computing means will be inadequate. Quantum encryption of transmitted data, at low cost and integrated in simple, low power consumption and small size devices that match personal electronics specifications will become of paramount importance before the point where quantum computing becomes available to everyone. The QuILT project aims at addressing this need by introducing a manufacturing step to simplify the implementation of quantum emitters in Quantum Key Distributor (QKDs) and other quantum entangled photon emission devices.

The current state of the art in devices that utilise quantum entanglement requires superconductors and cryogenic systems while in the case of photonic based entanglement, complex device creation with multiple active and passive layers suffers from low probability of entangled photon emission. QuILT will allow for photonic entanglement capability to be applied directly on photonic or opto-electronic devices without risking or changing the current processes being followed by the manufacturer. The approach, using the well-established LIFT (Laser Induced Forward Transfer) process to deposit quantum dots on simple or complex photonic integrated or semiconductor devices and enable devices for quantum entanglement based operation. The process can also be applied on chalcogenide quantum dots which have been proven to increase efficiency in entangled photon generation. The process feasibility will be tested on low cost wet etched silica on silicon wafer device and entangled photon emission will be captured by advanced sensors and analysed with probabilistic algorithms.

The QuILT technology solution aims at the heart of the technical issues that complicate the construction of quantum devices and make them very expensive for mass use and introduction to the wider industrial or even consumer market. Devices can thus be constructed in the miniature chip size that we are used to from the semiconductor and micro-electronics industry, and also observe the cost models of microelectronics, hence allowing their integration into commercial appliances.

FUNDING GRANTED: £253,606

POWERLASE LIMITED
MICRON SEMICONDUCTOR LIMITED
UNIVERSITY OF ESSEX

Q-Pods - Holistically Packaged Integrated Optoelectronic Devices for Quantum Systems

QPods is a dedicated mechanically and thermally stable optoelectronics module to drive magneto-optical traps (MOT) used in several UK Quantum projects. The QPods project will considerably reduce the SWAPC by holistically integrating all the essential components into a single ruggedised package.

Existing systems are based on laboratory-grade components (often Thorlabs). Manual alignment of optical components on optical tables leads to instability of the overall system and reduction in performance due to continual alignment drift. This leads to difficulties in system-level production of atom trap-based quantum products.

In this project, Bay Photonics will develop QPods, in collaboration with NPL and with close engagement with a user advisory board (UAB) comprising several end-users and system integrators. Several UAB members are developing/have systems that include various configurations of MOT chambers; each have expressed the critical need for QPods to compliment/complete their product offerings.

Compared with existing systems, QPods offers (i) \>3000x improvement in optical alignment drift (vs. manual tuning X-Y stages/mounts), (ii) reduction in the number of components (no alignment optics required), (iii) considerable improvement in mechanical and thermal stability (e.g. MIL-spec), (iv) reduction in overall form-factor from ~60,000 cm3 to <100 cm3, (v) highly scalable production thereby reducing future costs, (vi) eliminates the need for labour intensive manual tuning -- essential for applications outside the laboratory.

QPods will enable Bay Photonics to establish themselves as key suppliers to the UAB and wider cold-atom community. Augmented designs will seek exploit opportunities in ion-trapping applications (for e.g. Quantum Computers), high-speed telecoms and LIDAR will also be explored in the project.

FUNDING GRANTED: £408,094

BAY PHOTONICS LTD

NPL MANAGEMENT LIMITED

QTEAM: Quantum Technologies Enabled by Additive Manufacturing

Quantum technologies (QT) have the potential to transform many aspects of our technology and society. To date, they provide the world's most accurate clocks for precision timing and navigation, as well as high-performance sensors for e.g. magnetic and gravitational fields, which are already finding applications in subterranean mapping and medical imaging. However, the complexity of these devices makes them bulky and unreliable; so far, this has heavily restricted their use in real-world applications.

Additive Manufacturing (AM), more commonly known as "3D printing", is a key emerging technology that can provide a step-change in the quest to make quantum devices smaller, more power-efficient, and more reliable. AM allows the rapid, cost-effective manufacture of geometrically complex parts, featuring performance-enhancing structures that would be near impossible or extremely expensive and laborious to produce via conventional methods. So far, the application of AM within quantum technologies has been extremely limited. However, just as in many other technological areas, AM has the potential to offer substantial benefits for QT. Developing design methods and exploiting AM techniques for the QT sector will be key to the future of the industry.

The current state-of-the-art in AM for QT, developed by Nottingham University and Added Scientific Ltd, represents a convincing proof-of-principle of the applicability of AM within the QT sector and the potential benefits it offers. QTEAM aims to take that further and fully exploit the benefits of AM to produce a best-in-class compact atomic gravimeter for space-based applications using industrial processes. This builds upon a design that is currently being developed by RAL space (STFC -- Laboratories). Proving the efficacy of AM components for QT will open a new market within the sector, as these techniques will be useful across a wide range of QT devices. UK-based project partners Metamorphic Additive Manufacturing Ltd and Torr Scientific Ltd, supported by the know-how and intellectual property resulting from this project, will be ideally placed to lead industry activity in this new and important area.

FUNDING GRANTED: £374,817

METAMORPHIC ADDITIVE MANUFACTURING LTD
STFC - LABORATORIES
TORR SCIENTIFIC LIMITED
UNIVERSITY OF NOTTINGHAM

Quantum Powered Sensemaking of People and Places

The Opportunity: Demonstrate a prototype quantum computing solution to an intractable problem important to both commerce and national security

This opportunity leverages the potential of quantum computing to discover correlations between people and places that empower confident decision-making for national security and commercial applications. The underlying general problem, maximum clique (MaxClique), is one of the most studied and important computationally complex problems for government and industry. Yet solutions remain elusive; the problem remains intractable on classical computers. Our solution demonstrates four prototype use cases that combine 1) the power of high quality geolocation and mobile ad tech data, with 2) the advantages of quantum computing, and 3) sensemaking visualisation tools.

The Approach: Big data sensemaking, powered by quantum computing

Rigetti UK and Atreides are teaming to deliver a quantum-enabled solution to the MaxClique data intelligence problem. Rigetti UK is a full-stack quantum computing company solving humanity's most important and pressing problems. Atreides is a UK data-intelligence provider accelerating the world's transition to applied data intelligence by making it easy, honest and intuitive. Our team will apply the power of Rigetti's hardware and experience in quantum approximation optimisation algorithms (QAOA) to Atreides' geolocation and mobile ad tech data-intelligence platform, Caseri, to uncover the most highly correlated relationships between people and places to understand and visually predict human behaviour.

Our approach leverages quantum computing to solve for MaxClique---the most highly correlated cliques or groups of people and places---in geolocation and mobile ad tech data to provide high-confidence sensemaking visuals that answer these questions:

How are these data points related?

Where are they connected over multiple sites?

What are the largest number of points with the largest number of people correlated across sites?

Innovation and Benefits:
Quantum computers process information in a fundamentally different way---solving problems simultaneously instead of sequentially---allowing them, when scaled, to tackle computationally complex problems at unprecedented speed. Quantum algorithms offer analysis capabilities to mitigate decision-making risks. Applying these tools to geolocation and mobile ad tech data will enhance Cesari's capabilities while pursuing Quantum Advantage (QA)---the point at which quantum computing outpaces classical computing for practical problems.

Like GPS, this quantum-analysed data visualisation product is dual-use for defence and industry, offering powerful, far-reaching impact across business sectors. Users gain meaningful insights for actuarial risk exposure, network topology optimization, contact tracing, and disaster relief logistics, expanding the market for Atreides's services and creating demand for Rigetti's UK-based quantum computers.

FUNDING GRANTED: £323,258

RIGETTI UK LIMITED

ATREIDES CASERI UK LTD

RALFS – Rydberg Atom Low Frequency Sensing

Microwave and radio-frequency electromagnetic field sensors are key commercial application areas for quantum atomic technology. These unique sensors use atoms excited into “Rydberg states” to unlock capabilities not available through other approaches. Rydberg states are highly excited electronic states of an atom where one outer electron is kicked into a very large orbit around its parent nucleus. Due to the size of these orbits, atoms in a Rydberg state can be extremely sensitive to electric fields and RF radiation. Over recent decades, successive advances in laser science and atomic physics have made it possible to explore these states in a laboratory setting.

In the coming decade, we anticipate devices built upon these techniques to become widespread as sensitive probes for electro-magnetic radiation across a range of key applications. In this project, we will demonstrate the feasibility of using ultracold atoms in Rydberg states to detect RF radiation in the increasingly used “very-high-frequency” (VHF) and “ultra-high frequency” (UHF) bands. This will pave the way to field-deployed devices that significantly reduce the space, spectral, and polarisation constraints of standard detection systems.

FUNDING GRANTED: £319,861

COLDQUANTA UK LIMITED
DURHAM UNIVERSITY
LEONARDO UK LTD

Realistic machine learning based ultra fast simulator for semiconductor spin qubit devices

Spin qubits are one of the potential hardware platforms for quantum computing. For semiconducting spin qubits to be operated most devices must be kept at 20 mK. This low temperature operation requires very expensive cryogenic lab equipment to maintain the semiconducting spin qubit devices at operational temperatures.

As quantum computing companies ramp up their production during this exciting period of growth, experimental time is a limited resource as the suppliers of cryogenic lab equipment try to keep up with demand.

The development of a qubit control software for quantum computing requires access to quantum devicehardware to test and improve the performance. Aspin qubit machine learning based ultra fast simulator (MLUS) will enable the development of this qubit control with limited access to quantum computing hardware removing a major obstacle for QuantrolOx and other companies. The difficulty is that available quantum device simulators are significantly slower than the measurements that can be performed in this hardware. In order to develop software able to control quantum devices in real time, we require MLUSs. With this goal, our MLUS will be based on novel machine learning approaches.

This represents an enormous market opportunity to accelerate the QuantrolOx qubit control software that will enable UK quantum computing hardware companies to scale and also for other companies to develop their qubit control algorithms using the MLUS.

The proposed project will be a key step in realising automated qubit tuning, optimisation and stabilisation. The implemented automated qubit control software that will enable quantum computers to scale substantially beyond current capabilities.

This is a joint project between the leading UK company producing automated control software for quantum technologies, the leading UK laboratory developing AI for quantum technologies, and the UK National Centre for Quantum Computing.

FUNDING GRANTED: £385,619

QUANTROLOX LIMITED
STFC - LABORATORIES
UNIVERSITY OF OXFORD

Singly-doped Colloidal Quantum Dots For Quantum Technology

Quantum dots (QDs) are excellent platforms for quantum technologies applications. While other types of QDs are already in use for building quantum devices, colloidal quantum dots (CQDs) are exciting alternatives. CQDs demonstrate many of the same desirable quantum mechanical properties as other QD types, but also allow qubit positioning with nanoscale precision, provide a defect-free environment for the qubit, and enable fabrication and incorporation into devices via facile and benign solvent-based techniques. Singly-doped CQDs are particularly good platforms for optically-addressable spin-qubits that will be used in 'quantum repeaters', which are devices for extending the range of quantum communications and for enabling distributed quantum computing. These are both important future applications that will, respectively, ensure secure encryption for financial transactions and for data privacy, and allow new drug molecules to be modelled, fast-tracking their development.

The key challenges in exploiting CQDs for quantum technologies are ensuring that CQDs are singly-doped only, and that dopants remain in the core. Nanoco Technologies Limited (Nanoco) has developed and patented a molecular seeding process that can precisely and stably dope QD cores, with the dopant number controlled by the cluster stoichiometry. However, molecular clusters suitable for singly-doping CQDs have yet to be synthesised. The innovative aim of this project is to develop such clusters, then use the clusters to synthesise singly-doped CQDs, building on Nanoco's existing expertise and IP. Confirming that the CQD cores are singly doped and characterising their properties relevant to quantum technology is demanding and requires the specialised facilities and expertise found in the photon physics group at the University of Manchester (UoM), with which Nanoco has a long-established relationship, and the National EPR facility. A successful project will support the UK's aim to be recognised as a leading nation for developing quantum technologies.

FUNDING GRANTED: £360,181

NANOCO TECHNOLOGIES LIMITED

THE UNIVERSITY OF MANCHESTER

Single photon detection for ultra-low dose Molecular Breast Imaging

Breast screening was introduced in the UK almost 30 years ago and relies principally on x-ray mammography. This technique is effective where there is a significant difference in the density of a cancer tumor and the surrounding breast tissue. Around a third of women have denser breast tissue, such that mammography is unable to clearly image tumors, resulting in undiagnosed cancers. The age for breast screening is gradually extending from 50-70 to 47-73. As there is a higher prevalence of dense breasts in younger women, the current provision of mammography even less satisfactory.

Kromek has identified that earlier diagnosis of breast cancers is possible with an addition of a nuclear imaging technology, Molecular Breast Imaging (MBI), as a primary screening tool for women with dense breast tissue. MBI is a technique whereby a radioactive tracer is used to identify a tumor that is then imaged by a specialist camera. The tracer is concentrated to a much greater extent in malignant breast tissue compared to normal tissue, therefore the malignant tissue shows up as a bright area on the image. MBI currently has the disadvantage of requiring a higher radiation dose than received with a mammogram and longer measurement time.

Since 2018, Kromek has been engaged with UCL and NUTH in developing a quantum technology for a faster and safer MBI system addressing these shortcomings and facilitating a change in the screening pathways. Kromek has developed a proprietary MBI camera design based on a new generation of single photon CZT detectors and a conceptually new type of collimator. Combined with novel 3D image reconstruction methods, the new camera will allow uncovering spatial information about tumours and their structure. That information will help to significantly increase chances for early cancer detection and improve cancer staging process required for precise diagnostics and successful treatment prescription.

The project will contribute towards the commercialisation of the low-dose quantum technology by proving the feasibility of he single-photon detection methodology for MBI.

FUNDING GRANTED: £298,816

KROMEK LIMITED

TALENT – Tapered AmpLifiErs for quaNtum Technologies

TALENT will overcome a clear technology barrier to the commercialisation of quantum technologies by increasing the robustness, reliability and reducing size, weight and power consumption (SWaP) of the underpinning critical lasers and laser systems. TALENT will open new markets for the UK in quantum sensors and clocks for next-generation quantum-enhanced Position, Navigation and Timing (PNT) though the development of a UK supply chain of reliable and low-SWaP laser components.

Quantum sensors and clocks for next-generation PNT require high power lasers to precisely control and manipulate the atoms. Typically, quantum system use semiconductor laser diodes that have limited output powers - tapered amplifiers allow laser light to be amplified from mW levels to Watts without affecting the spectral properties. At the core of TALENT lies the development of robust, reliable and alignment-free tapered amplifiers with a focus on ease of integration, making them ideal for next-generation field-deployed quantum systems.

TALENT will produce tapered amplifiers with performance, reliability, SWaP (Size, Weight and Power) and ease of integration not commercially available. High reliability packaging and manufacturing techniques will be implemented to ensure stable operation over a range of environmental conditions - perfectly suited for real-world deployable quantum systems. ColdQuanta will test the developed tapered amplifier with their cold-atom hardware, providing valuable end-user benchmarking ensuring the tapered amplifiers are application relevant and ready for commercial uptake after the project.

The combination of performance, low-SWaP and reliability will address the commercialisation barrier in quantum technologies and secure the commercial opportunity identified within the QT supply-chain. TALENT will lead to new products, job opportunities and company growth and critically open up new markets in the ever-expanding field of quantum technologies. Although TALENT will focus on the development of tapered amplifiers for quantum sensors and clocks, the technology is applicable in LiDAR and automotive sensing sectors.

TALENT brings together a high-quality consortium with a track record in commercialisation of quantum technologies, all of whom are committed to utilise the development of state-of-the-art reliable and low-SWaP tapered amplifiers to unlock new commercial opportunities.

FUNDING GRANTED: £335,400

ALTER TECHNOLOGY TUV NORD UK LIMITED
COLDQUANTA UK LIMITED
FRAUNHOFER UK RESEARCH LIMITED

TransmissION

TransmissION takes an innovative approach to meeting the critical need for integrated photonics required to scale up trapped-ion quantum computing. It is led by Oxford Ionics, experts in high performance quantum computing, in collaboration with the Fraunhofer Centre for Applied Photonics who have expertise in the development of photonic systems.

Quantum computing, an area of heated and ongoing global competition, will revolutionise industries ranging from drug discovery to finance with market values in the hundreds of billions. As one of the favourable universal quantum computing platforms, trapped-ion quantum computing also needs to overcome the barriers to scaling before fully tapping into these huge markets. Current state-of-the-art systems are built with bulk-optics, which are not scalable, not to mention difficult to align and unstable. Therefore, a truly scalable integrated photonic chip is needed to replace the current bulky optics used in trapped ion quantum computing.

TransnissION will study the feasibility of this new type of photonic chip aimed at addressing all of the requirements for integration and scalability in trapped-ion systems.

As a project that has the potential to drastically advance the current state-of-the-art in trapped-ion quantum computing and beyond, TramsmissION is in the scope of the call and also well aligns with the heart of UK's national effort in quantum computing.

FUNDING GRANTED: £402,850

OXFORD IONICS LIMITED

FRAUNHOFER UK RESEARCH LIMITED

Ultracold quantum memories

Quantum technologies have demonstrated the potential for vast technological improvements in communication, metrology, and computation. Although there are a variety of ways to leverage quantum technologies, photonic technologies -- those which are based upon encoding information in light -- are an exciting paradigm. Photons can be transmitted over complex free-space or fibre networks with minimal decoherence. This is due to their weak interaction with other fields or particles. Although this is a desirable feature, it also becomes a technical challenge as this leads to the requirement of probabilistic protocols for quantum information processing.

Over recent decades, successive advances in laser science and atomic physics have made it possible to store and then retrieve, on demand, photonic information in an atomic vapour, therefore transitioning from probabilistic to deterministic protocols. This is named a photonic quantum memory. A substantial limiting factor in this technology is due to the motion of the atoms in which the photonic information is stored, leading to a reduction in memory lifetime. While long-lifetime quantum memories in ultracold-atom systems have previously been demonstrated, to date, these have only been laboratory demonstrations, and not commercially viable. The goal of this feasibility study is to leverage ColdQuanta's ultracold-atom technology to build a photonic quantum memory using laser-cooled atoms, showcasing state-of-the-art memory lifetime in a commercially scalable platform. In the coming decade, we anticipate devices built upon these techniques to become widespread as key components of vast quantum computing networks.

FUNDING GRANTED: £308,976

COLDQUANTA UK LIMITED
CISCO INTERNATIONAL LIMITED
ORCA COMPUTING LTD.

UP-conversion of Single-photons for ENvironnmental SEnsing (UP-SENSE)

Reducing human contributions to global warming and the journey to net-zero is a major problem for society to tackle. Technology developments will be a large part of the process to reduce greenhouse gas emissions. The simplest way to reduce is emissions is to reduce gas leaks, requiring very sensitive leak detection equipment.

Natural gas (largely consisting of methane) is becoming the dominant fossil fuel due to the reduced carbon dioxide emissions. However, industrial leaks are a major source of Greenhouse gases (GHGs). After COP26, industry and legislation attention is shifting towards reducing methane emissions. Traditional sensitive equipment can be bulky and labour intensive to operate. There is a need for wide-spread continuous monitoring equipment for detection of methane and other GHGs.

QLM has pioneered deployment of quantum technology, in the form of an infrared LiDAR camera to image, locate and quantify GHGs. However, this is just the first step along the way and improvements in sensitivity of detection can be used to extend the range of operation, or speed of detection.

This project collaboration between QLM, Fraunhofer, Covesion and the University of Bristol provides an innovative approach to solve this problem, by generating scattering at longer wavelengths, then using quantum up-conversion of photons to shorter wavelength for detection on low-noise, efficient visible wavelength detectors with single-photon sensitivity. This requires development of upconversion technology by Covesion, to work at longer wavelengths than currently demonstrated, but that are theoretically viable. Initial work will prove the concept at wavelengths that are known to be feasible and will offer increased detection efficiency.

This technology will open up the possibility of detecting more varied gas species with high sensitivity in a wavelength region where there are limited solutions.

FUNDING GRANTED: £424,897

QLM TECHNOLOGY LTD
COVESION LIMITED
FRAUNHOFER UK RESEARCH LIMITED
UNIVERSITY OF BRISTOL

Feasibility Studies in Quantum Computing Applications

A next-generation quantum computing based approach to enzyme targeted drug discovery

Kuano is a techbio startup dedicated to bringing the latest innovation and technology for drug discovery to the pharmaceutical industry. As part of their long term strategy to unlock currently undruggable enzymes they are developing advanced simulation approaches to target complex quantum systems.

This Feasibility Study seeks to exploit novel algorithms to study key details of drug design targets inaccessible to alternative technologies using near term quantum computing.

Kuano intends to use simulation to tackle quantum complex drug targets such as metal containing enzymes (metalloenzymes). These systems exhibit complicated long range interactions (called “correlations”) that are largely inaccessible to conventional computational approaches. The company has previously developed a platform capable of selecting the most important regions of such targets to enable proof of concept simulations. This project will build on this to link the existing platform to quantum computing resources and to enable the use of new calculations that capture dynamic features particularly relevant in metalloenzymes (as well as other industrial applications).

Kuano has partnered with Professor Andrew Green of University College London (UCL) and the National Quantum Computing Centre (NQCC). Professor Green is an expert in quantum computing algorithms for modelling chemical systems and will help develop and benchmark simulation approaches. NQCC will provide support in accessing and using quantum computing resources.

The project output will be a new simulation engine for the Kuano drug design platform designed to unlock targets with intermediate-to-high levels of entanglement, providing a step-change for Kuano and the UK drug development industry.

FUNDING GRANTED: £330,295

KUANO LTD
UNIVERSITY COLLEGE LONDON
STFC - LABORATORIES

A novel, quantum model for NLP: a step towards AGI.

Large language models such as ChatGPT have recently undergone a step-change in their user-perceived efficacy, and as such they have caught the attention of journalists and then the imagination of the general public. These A.I. systems appear to deliver responses to user-posed questions that are both informative and delivered with substantial expertise. The application of this nascent, yet extraordinarily useful, technical breakthrough across whole ranges of industries is only starting to become apparent.

Large language models are effective since they capture and codify, in their models, significant portions of all human knowledge, through the process of ingesting the entirety of the World-Wide-Web. The resultant models are staggeringly large (for example, ChatGPT3 contains some 175 billion parameters) and thus, these models take months to train and use a great deal of power to run.

It is our intention to build a Chat-GPT like large l anguage model A.I. system that utilises a quantum calculation engine. The system shall employ a fundamentally different processing, model and systems architecture to current systems, leading to a step change in the efficiency and power of the resultant system. We shall build software to run such a system and demonstrate its increased efficiency in both training models, which shall be much more energy efficient during the training process, and in speed of execution and energy use when in operation. These benchmarks shall be performed against the requirements of the NLP and voice processing industry as understood by the consortium.

FUNDING GRANTED: £313,058

SECQAI LTD

INTELLIGENT VOICE LIMITED

BOSTON LIMITED

OXFORD QUANTUM CIRCUITS LIMITED

Developing valuable operational healthcare applications using quantum computing techniques

The project will research the feasibility of applying and commercially exploiting quantum computing techniques to address operational healthcare use cases (e.g. theatre list patient allocation, urgent care patient triage, community nurse visit schedules) through the development of one or more software applications. If successful, the product will be capable of serving both the UK and international healthcare markets.

The project seeks to exploit emerging quantum computing technology in a new and important area of application. In the project we will:

* Identify several valuable use cases which will deliver improved care for patients and help healthcare providers, e.g. hospitals, organise their patient activity more efficiently to make the greatest possible use of scarce resources such as operating theatres, diagnostic equipment and outpatient consulting rooms.

* Investigate in depth the potential for quantum computing methods to address the use cases for problem sizes are that beyond the sizes that can be dealt with by classical computing software by undertaking a technical evaluation.

* Make an overall business assessment of the feasibility of developing classical-quantum applications for the targeted use cases and specifically when this may be possible based on the rate of advance of quantum hardware/methods.

We will explore a range of quantum methods on different quantum hardware seeking to find the optimum performance possible on today's technology. We will also be considering how best to combine quantum and classical methods to maximise the overall performance of the potential applications.

This is a highly innovative project combining experts in quantum computing (Applied Quantum Computing and National Quantum Computing Centre), healthcare specialists (The PSC) and an important end user participant (Hampshire Hospitals NHS Foundation Trust).

FUNDING GRANTED: £161,422

APPLIED QUANTUM COMPUTING LIMITED
STFC - LABORATORIES
THE PUBLIC SERVICE CONSULTANTS LIMITED
HAMPSHIRE HOSPITALS NHS FOUNDATION TRUST

Feasibility of catalyst simulation on near-term quantum hardware

Quantum computers are expected to be able to solve hard computational challenges that are beyond the reach of our best standard supercomputers. After many years of research in both academia and industry, quantum computers are at the point of outperforming their standard ("classical") counterparts in certain specialised problems. One of the most exciting and plausible applications for near-term quantum computers is modelling quantum-mechanical systems.

Understanding such systems is essential for many practical applications, ranging from the design of more efficient catalysts and solar panels to the development of novel drugs. However, exact modelling of a quantum system using a classical computer rapidly becomes infeasible as the system size increases. Quantum computers could overcome this limit and enable us to model currently inaccessible physical systems. Although there have been many years of theoretical work on quantum algorithms for this modelling task, standard algorithms for these applications require quantum hardware that is still decades away.

Quantum software startup Phasecraft's goal is to maximise the potential of near-term quantum technologies for real world application. To achieve this, it has adopted a new approach to quantum algorithm development that has led to results so significant as to bring applications of quantum computing to materials modelling into the near-term quantum computing realm. These breakthroughs are already integrated into a quantum software demonstrator.

The focus of this feasibility study is to make the next advance in quantum simulation algorithms, beyond even these ground-breaking recent results. This next step requires tight integration between quantum algorithm design, quantum hardware design and the specific applications in catalyst modelling. As well as their significant industrial importance, catalysts also represent the next challenge for quantum computation beyond crystalline materials, as it requires simulation of both structured crystalline materials and less structure molecules. The goal of the project is show how quantum simulation of this type of system can be made feasible on near-term quantum hardware, run proof-of-principle demonstrations on Oxford Ionics' ion trap quantum hardware and QuERA's cold atom hardware (accessed through AWS), and integrate the new algorithms into Phasecraft's quantum software.

Our consortium includes world-renowned experts in quantum software and algorithms (Phasecraft), catalyst research (UCL), ion trap quantum hardware (Oxford Ionics), and commercial materials development (Johnson Matthey). Only this combination of expertise will be able to deliver on this ambitious goal.

FUNDING GRANTED: £393,067

PHASECRAFT LIMITED
UNIVERSITY COLLEGE LONDON
OXFORD IONICS LIMITED
JOHNSON MATTHEY PLC

Feasibility Study on Quantum Optimization of Aircraft Container Loading

Air cargo load planning today is often a manual task that has to be performed by experienced load planners. The air cargo business practice still involves a lot of pen-and-paper or spreadsheet-based planning and trial and error during the actual packaging and loading.

This leads to high labour costs but often also to suboptimal results, as there is a constant pressure of time, and the problem complexity can be pretty high.

Accordingly, in today's highly competitive air cargo market, optimizing the loading process can provide a significant advantage for airlines, first by increasing the productivity of its load planning staff and second, producing high-quality solutions tailored for each flight.

The first objective of an air-cargo loading solution is to maximize the mass of goods loaded to make air freight more profitable. However, the arrangement of the containers affects the position of the aircraft's centre of gravity, which in turn impacts aircraft drag. The challenge is to balance the load so that the aircraft will fly more safely, fly faster, and use less fuel. In this feasibility study, we are concerned with the problem of optimizing the layout of containers within the cargo holds to take into account these conflicting objectives.

Finding the optimal loading for a plane is challenging for classical algorithms, mainly because the solution must respect several flight constraints simultaneously. This problem can be viewed as an extension of the knapsack problem. This combinatorial optimization problem aims to select the optimal set of items subject to a budget constraint.

The knapsack problem belongs to a class of "NP" problems, meaning "nondeterministic polynomial time." The name references how these problems force a computer to go through many steps to arrive at a solution. The number increases dramatically based on the size of the inputs, for example, the inventory of items to choose from when stuffing a particular knapsack. A computer must run through every possible combination to generate the single one with the most lucrative haul. Given an indefinite amount of time, a computer could use brute force to optimize large cases like this, but not on timescales that would be practical.

Complicated scenarios meant to solve multiple variables are not achievable by a classical computing algorithm in a short time. This feasibility study explores how algorithms leveraging quantum computing may achieve this objective.

FUNDING GRANTED: £271,462

UNISYS LIMITED
NEWCASTLE UNIVERSITY
STFC - LABORATORIES

Feasibility study to quantify the potential of using quantum algorithms to simulate MHD effects in liquid metals

This work addresses the computational challenge of simulating the magnetohydrodynamic equations of liquid metals such as Li or LiPb, which are used as coolants and sources of neutron multipliers and tritium breeding in nuclear fusion reactors. This project is a feasibility study into the use of quantum algorithms for simulating the magnetohydrodynamics of liquid metals, which are used as coolants and sources of tritium in nuclear fusion reactors. The fusion industry requires accurate predictions of liquid metal dynamics under high intensity magnetic fields.

Simulating liquid metal flows within fusion reactors presents some specific challenges, due to the presence of phenomena such as turbulences induced by the magnetic fields present. In the case of tritium breeding in fusion reactors, this will directly influence the diffusion of tritium into the fuel cycle. It is also essential that liquid metals operate at high flow rates under these conditions. Accurate simulation of the magnetohydrodynamics of liquid metals could pave the way for more realistic simulation of liquid metals and computer-aided design of future fusion reactors.

Modelling turbulences accurately with traditional finite difference methods requires very fine grids to achieve a high enough resolution, with accurate solutions quickly becoming computationally intractable using classical computers. Quantum computers present a new computational paradigm which has the potential speed up computational tasks such as solving certain partial differential equations (PDEs). Quantum computing algorithms for solving PDEs have shown promise in modelling scenarios which require extremely high resolutions, such as turbulence.

This project aims to assess the feasibility of applying quantum algorithms for simulating liquid metal flows. Currently proposed quantum algorithms for solving nonlinear PDEs are formulated in an abstract way, which cannot readily be implemented. Those algorithms typically address simpler PDEs than the MHD equations. A specific novelty of the proposed idea is the inclusion of the Lorentz force term present in the PDE, which has not been considered in quantum algorithms before and is essential to accurately modelling liquid metals in fusion reactors. This project will also investigate the resources required for running such algorithms on future fault-tolerant quantum devices and attempt to provide a framework for estimating the resources of these nonlinear PDEs. Successful deployment of these algorithms in the future could address the challenges of high-resolution simulation of liquid metals, accelerate engineering cycles for new reactors and potentially reduce the massive costs associated with experimental testing.

FUNDING GRANTED: £199,787

CAMBRIDGE QUANTUM COMPUTING LIMITED

UNITED KINGDOM ATOMIC ENERGY AUTHORITY

Investigating the use of quantum computing and quantum machine learning to reduce carbon emissions in aviation

Quantum Base Alpha in collaboration with the University of Edinburgh and specialised advice form the NQCC will investigate the potential of Quantum Computing (QC) together with Quantum Machine Learning (QML) to help solve a vital but currently intractable problem. The project's main focus is to minimise the carbon emissions caused by aviation by optimising flight paths.

The Climate Change Committee, an independent body advising the UK Government ,has reported that Aviation currently produces 8% of UK Greenhouse Gas Emissions . By 2050,the legally binding target for Net Zero Carbon , it is predicted to be the key sector with significant remaining emissions . Given their view that major technological breakthroughs in aviation are unlikely to make significant differences given long development and certification lead times and the slow turnover of fleets , they conclude that aviation will be the largest emitting sector then.

Hence , the need to improve the use of Airspace including the deployment of cutting edge tools in Air Traffic Control.This includes the need to research and develop the use of evolving Quantum Computing techniques alongside AI and Machine Learning.

FUNDING GRANTED: £391,106

QUANTUM BASE ALPHA LTD

STFC - LABORATORIES

UNIVERSITY OF EDINBURGH

ProAtom: Programmable Atom Arrays for Analogue Optimisation Solutions

M Squared and the University of Strathclyde have embarked upon a highly productive strategic alliance in the area of neutral atom quantum computing. The collaboration targets the commercialisation of industrially-relevant quantum computing and simulation based on a jointly developed hardware and software platform. The neutral atom approach to quantum computing has emerged as a highly relevant and versatile candidate for quantum information processing through both analogue and digital computation and simulation. The compelling combination of high qubit gate fidelities, large-scale entanglement and scalability will enable this approach to address commercially-useful problems in accessible timeframes.

M Squared have established themselves as a key supplier in cold matter approaches to quantum computing. The coordination and alignment of M Squared's technology roadmap for promising quantum computing architectures, with the ground-breaking research being undertaken at Strathclyde, provides a unique opportunity for the UK to take a leading role of the commercialisation of quantum computing. The feasibility study will complement large-scale investments into both the academic group and the industrial computing team and focus on enabling neutral atom-based analogue simulations in the commercial realm.

FUNDING GRANTED: £342,705

M-SQUARED LASERS LIMITED

UNIVERSITY OF STRATHCLYDE

QECCO: Quantum End-to-end Compilation for Combinatorial Optimisation

Quantum computation has the potential to revolutionise a vast number of industries that rely on high-performance computation, such as in pharmaceutical and chemical research, automotive, finance, and logistics. A well-known example in logistics is that of the travelling salesman problem: Given a list of destinations and the distances between them, what is the shortest possible route to visit each destination once and return to the starting position? In complexity theory, this is categorised as an NP-hard problem in combinatorial optimisation, meaning that the difficulty of solving the problem can scale exponentially with the number of destinations.

The goal of this project is to identify the most pressing problems in combinatorial optimisation affecting industries today and apply Infleqtion's unique approach to solving them with quantum computation. This involves an end-to-end view of compilation which enables layer-to-layer optimisation, enabling the compilation of end-user applications directly to true quantum hardware. Compiling directly to hardware in this manner gives key advantages such as the ability to exploit characteristics of the problem for better mapping to suitable quantum algorithms, pulse-level compilation to the target hardware, and algorithmic enhancements based on the physics of the target hardware.

FUNDING GRANTED: £252,988

COLDQUANTA UK LIMITED

QINETIQ LIMITED

Q-REALM Wind

Q-REALM Wind is a feasibility study being undertaken by EY and ORCA Computing, together with critical input from a multi-national energy producer to explore the potential of using generative modelling techniques on ORCA's PT-Series photonic quantum processor for onshore and offshore wind farm location optimisation. The objective of the project is to assess the impact of novel algorithms that use data science and quantum computing (vs traditional techniques) to optimise the placement of wind turbines for maximum energy output and cost efficiency, while considering various environmental and regulatory considerations.

The project is particularly timely because of the imperative to improve the UK's energy security while simultaneously helping more organisations achieve net-zero. The project aims to show that more efficient use can be made of the nation's resources, thus delivering a better return on the investment in renewables, as well as improving the stability and reliability of wind power to minimise power transmission loss and reduce dependencies on fossil-fuel backup. The project also encourages further innovation within the renewables industry by showcasing the potential for quantum computing to be used in other parts of the supply chain -- from more efficient turbine design to reliable operation over the long lives of these assets. In addition, this project will help to demonstrate the feasibility of near-term quantum computing applications and encourage more organisations to start their journey to quantum readiness.

The project also builds on EY's broad base of research and thought leadership in quantum computing and AI, allowing the project team to explore quantum readiness in a hands-on fashion, while bringing to bear EY's & ORCA's breadth and depth in AI, data science, and the energy domain.

FUNDING GRANTED: £299,276

ERNST & YOUNG LLP

ORCA COMPUTING LTD.

Quantum Annealing for Transport Optimization – QATO

Quantum Annealing for Transport Optimisation (QATO) is a research project exploring the practical use of quantum for smart mobility solutions for smart cities. It uses a logistics planning tool developed by CGA Simulation for Transport for Greater Manchester, and the Hartree Centre will provide advanced computing facilities for developing software that can run on a D-Wave quantum annealer. The project aims to develop a formulation for quantum annealing, evaluate hybrid classical-quantum solutions, and analyse the hardware and software requirements for solving these industrial problems with quantum computers. The project also aims to demonstrate the commercial benefits of using quantum computing for predictive analytics. By accurately predicting outcomes, decision-makers can save time on deliveries, resulting in significant value.

The project aims to use quantum annealing to solve complex optimization problems related to last mile delivery logistics and Mobility as a Service, which classical optimization methods find computationally expensive and time-consuming. This is addressing a need identified by Transport for Greater Manchester in the transport industrial sector that consultation with the Hartree Centre suggests would be a suitable use-case for Quantum Computing. Hartree can apply Quantum Computing approaches to an existing set of software solutions developed by CGA Simulation to increase the accuracy of predication provided by classical optimisation methods such as Agent Based Modelling.

During past Research and Development cycles on the project, consultation with Stakeholders such as Liverpool City Region Combined Authority, the Transport Research Laboratory and industry indicates a commercial need for better tools to simulate the impact of new approaches to logistics and travel on future transport patterns.

Demonstrating the advantage of quantum in predictive accuracy has a clear industrial application. If decision makers installing infrastructure can accurately predict outcomes they can save time on deliveries,. Small savings on individual journeys add up to vast profits.

For problems observed in industry we want to develop a formulation for quantum annealing and evaluate hybrid classical quantum solutions and analyse the hardware and software requirements for solving these industrial problems with quantum computers.

Hartree intends to test the Atos Quantum Learning Machine (QLM), with simulated quantum annealing, to develop a software approach that can run on a D-Wave quantum annealer. The problem formulation will be valid for both gate-based quantum computers and quantum annealing. The team intends to evaluate quantum annealing to support the development of different technologies complementary to existing efforts in gate-based quantum computing.

FUNDING GRANTED: £353,238

CGA SIMULATION LIMITED
FUTURE CODERS LIMITED
THE SCIENCE AND TECHNOLOGY FACILITIES COUNCIL

Quantum Computing based density functionals for fast and accurate materials and chemistry simulations

Quantum computers have the potential to lead to a transformative increase in the available computational power. The size and quality of the quantum computers available today are increasing rapidly, and advancements in ability to implement quantum error correction are getting us closer to have quantum computers which will be able to outperform even the best existing classical computers. One of the most promising improvements offered by quantum computers is the ability to accurately simulate atomic scale physical systems, which is a challenging task for classical computers. Various algorithms are being developed today that aim to make use of this advantage that is offered by quantum computers.

Density functional theory (DFT) is a core classical computing method for product development across industries such as pharmaceuticals, chemicals, and materials. For instance, DFT can be used to model and evaluate the properties of new materials, drugs, catalysts, etc. to complement expensive developments in the lab. Compared to alternative methods, DFT is the only approach fast enough for large systems comprising metals and molecules as required in many applications. However, approximations made in the DFT algorithms used today make them unsuitable for a lot of important problems. Improvements in DFT can lead to the development of better batteries, more efficient catalysts, faster and more reliable drug and vaccine candidate assessments, and greener chemical production.

Recently, machine learning (ML) methods have been demonstrated to lead to improvements in DFT. However, even the ML + DFT methods rely on a large number of accurate simulations of the physical systems, which are challenging to do with classical computers. In this project, we aim to harness the superior ability of quantum computers to perform accurate simulations in order to improve DFT. Our approach will combine the advantages provided by quantum computers and ML in order to significantly improve the DFT method that is widely used in various industries.

This project combines the expertise in machine learning, quantum computing, DFT, and modelling in industrial settings of InstaDeep, NPL, Atos UK, and Johnson Matthey.

FUNDING GRANTED: £289,818

INSTADEEP LTD

NPL MANAGEMENT LIMITED

JOHNSON MATTHEY PLC

Quantum Machine Learning for Financial Data Streams

Financial institutions need to continuously interpret complex data streams to extract information necessary for providing accurate credit risk evaluation, managing market-making services, and predicting emissions in the context of green finance. Current classical machine learning (ML) techniques used to assist and provide insights to these services have limitations as these data streams evolve in complexity. There are three key challenges that financial institutions are seeking to address in an effort to improve their offerings: (1) Providing clients accurate credit-risk evaluation services, (2) Offering competitive rates for market-making services, and (3) Predicting emissions for informed sustainable finance decisions in line with ESG targets. Improving upon the current classical ML approaches could result in reduced risk, better market rates and targeted sustainable investments for financial institutions and their customers.

Recent quantum computing advances have the potential to offer significant improvements to the computations financial institutions rely on to improve upon efficiency, to reduce risk, to provide better service to customers and to develop personalised products. The team's offering using cutting-edge quantum machine learning techniques, running on an optimised full-stack Rigetti platform, will offer financial institutions a vertically integrated solution, allowing them to use the full capability of NISQ-era quantum computing. We will develop quantum signature kernels and leverage the results to enhance Rigetti's recent breakthroughs in quantum kernels. We will benchmark the results against classical ML methods for streamed data. Additionally, we will build and study quantum algorithms for computing efficient signatures and their inner products for long and high-dimensional data streams.

A successful project outcome will have significant benefits for the UK financial sector and the quantum computing industry, including the participating organisations. Accelerating the development of quantum machine learning for financial data streams will enable Standard Chartered to be an industry leader in a future quantum-ready economy and continue to provide the best possible services to its clients. Developing quantum-enabled solutions will also bolster the UK finance sector. Rigetti will be able to accelerate its work to achieve narrow quantum advantage, the point at which a quantum computer outperforms the best classical resources. The project will also benefit Imperial College London by providing a framework for and use cases to test new quantum machine learning tools. Making these tools open access will further allow UK academics to test state-of-the-art quantum algorithms for their own applications (possibly beyond those in this proposal).

FUNDING GRANTED: £191,198

STANDARD CHARTERED BANK
IMPERIAL COLLEGE LONDON
RIGETTI UK LIMITED

Quantum Optical Neural Networks for Quench Prevention

The need for secure, clean, reliable, and sustainable sources of energy has grown in both importance and urgency. Part of the solution to meet these needs is nuclear fusion. While experimental progress in fusion has evidenced its viability, a range of engineering challenges must be met and coordinated before fusion reactors can operate reliably for long periods, and to deliver a net energy gain.

Among these challenges is the processing of large real-time data sets from cryogenically cooled superconducting magnetic coils that maintain the plasma from which energy is released. Superconductivity can break down if a hotspot forms in part of a coil; the subsequent rapid warming and loss of plasma confinement results in damage and downtime. To prevent this, hotspots must be rapidly located so individual coils can be protected.

Hotspots can be detected using a process called optical frequency domain reflectometry (OFDR). Laser light is sent down an optical fibre that is co-wound with a coil; a hotspot affects some of the light reflected back along the fibre; its detection allows the hotspots to be located. However, precisely locating hotspots in multiple coils within fractions of a second, requires the rapid processing of vast amounts of data. This information processing challenge is a barrier to clean energy from fusion.

As information processing has matured beyond the central processing unit (CPU), a variety of tailored control and computational hardware has emerged including graphics processing units (GPUs), application-specific integrated circuits (ASICs), field-programmable gate arrays (FPGAs), Neural Networks (NNs) and quantum computing. Each of these sacrifices a general purpose (classical) computing capability to enable much greater power for particular information processing tasks.

The people at Duality Quantum Photonics have pioneered integrated photonics as a platform for both Optical Neural Nets (ONNs) and quantum information processing. Quantum Optical Neural Nets (QONNs), the combination of these two paradigms, in integrated photonics, provide an appealing platform for a range of information processing tasks, including the processing of real-time data required to sustain fusion energy generation.

In this project, Duality will partner with the private fusion energy company Tokamak Energy, and with the UK Atomic Energy Authority, to design and fabricate QONNs in photonic chips to process OFDR data for the rapid location of hotspots. The project will demonstrate how quantum computing can help tackle some of the information processing challenges that stand in the way of net gain fusion energy.

FUNDING GRANTED: £356,515

DUALITY QUANTUM PHOTONICS LTD
TOKAMAK ENERGY LTD
UNITED KINGDOM ATOMIC ENERGY AUTHORITY

Quantum Unsupervised Learning for Anti-Money Laundering Detection

Financial crime is one of the fastest-growing areas of risk management. Money laundering in particular poses a significant threat to national and international security. Inadequate methods for detecting financial crimes have serious consequences for financial organisations and society. Developing improved methods of detecting and reducing money laundering is seen as imperative by financial services institutions and their regulators.

Quantum algorithms for anomaly detection on classical data are rather understudied. This project will enhance current quantum machine learning models beyond supervised learning to detect anomalous behaviour indicating money laundering activity. In this work, we will use a quantum computer's output as a component to a classical machine learning algorithm by leveraging techniques that generalise projected quantum kernel methods. The project will utilise Rigetti's quantum computer, with its scalable superconducting chip architecture, supporting rapid, high fidelity entangling gates. Rigetti has recently unlocked the possibility of executing projected quantum kernels and their generalisations at speed.

Machine learning technology holds great promise to detect and prevent financial crime by flagging potential suspicious transactions and adapting to ever-changing criminal behaviour. Quantum computing can serve as an accelerator to classical computing. By extending capabilities from existing classical machine learning techniques to quantum computing enhanced capabilities, financial institutions will be better equipped to tackle financial crime. Developing improved machine learning capabilities to combat financial crime will provide financial institutions a competitive advantage, accelerate the commercialisation of quantum computing, and provide more effective ways of identifying and reducing criminal activity. By joining HSBC's deep domain expertise, the University of Edinburgh's algorithm expertise, Rigetti's state-of-the-art quantum computing hardware and software, and the National Quantum Computing Centre's pivotal role in the UK's quantum computing ecosystem, this project will not only harness industry-leading resources and world-class researchers, but will pave the way for future quantum algorithm and application development to benefit the financial services industry and numerous other verticals.

FUNDING GRANTED: £369,067

RIGETTI UK LIMITED
HSBC BANK PLC
STFC - LABORATORIES
UNIVERSITY OF EDINBURGH

Security-first Federated Quantum Machine Learning for Genomics

Over the past decade, there's been an enormous explosion of Machine Learning (ML) use cases across multiple industries, healthcare included.

However, for many key organisations with sensitive private datasets, such as NHS Trusts, the mainstream/generic centralised ML training doesn't provide the necessary assurances in terms of the privacy and security. This is where an emerging ML paradigm, known as Federated Learning (FL), comes into play. Usefully, FL allows multiple parties, that don't necessarily trust each other, to collaborate on training a common machine learning model, all without having to share their data with each other. Thus this technology fundamentally addresses the problem of data privacy and security.

Nevertheless, a crucial detail to note is that, while FL is a robust solution when it comes to; data access, governance, and ownership, it does not guarantee security and privacy unless combined with other security add-ons. Thus, FL is subject to some cyber security attacks, an example of which is if the local training datasets are not encrypted, attackers can steal personally identifiable data directly from the training nodes, or interfere with the communication process via the classical technique of a poisoning attack. Moreover, in a normal FL setup, the models are also not encrypted, leaving them open to adversarial attacks, including extraction of sensitive training data from attacks on the models.

Now, a natural question one may ask is, what can be combined with FL to make it a viable solution in the healthcare space? The answer is, yes, and our proposal for this project is to supplement FL with two emerging technologies:

1. Fully-Homomorphic-Encryption (FHE): In a nutshell, FHE is a novel computational paradigm that allows computation to be applied to encrypted datasets i.e. directly to cipher-text, without any decryption before/during/after the computation. The results of the computation, once decrypted, should in practice be identical to a situation in which it was applied to unencrypted data.

2. Quantum-Machine-Learning (QML): In effect, QML sits at the intersection between Quantum Computing and ML. In our case, this is aimed at exploiting quantum mechanical properties, including; superposition and entanglement to build better and faster algorithms.

In the healthcare sector, this solution would provide even greater security assurances, significantly lowering information governance barriers when sharing sensitive data with third-parties. This would thereby naturally enhance; collaboration, service innovation, and patient outcomes, without compromising data integrity & security. In-brief, we're aiming to address the unmet need for privacy-enhancing ML.

FUNDING GRANTED: £227,590

ZAIKU GROUP LTD
UNIVERSITY OF MALTA
HOMOMORPHIC LABS LTD
STFC - LABORATORIES

Silicon Nitride for Quantum Computing (SiNQ)

Project SiNQ will investigate the hardware requirements for quantum computing technologies to meet challenging applications in drug design and material development. Quantum Computing will revolutionise these applications and Oxford Ionics is looking to develop novel quantum computers based on high-performance trapped-ion technology. The challenge is to develop new technologies which will enable these high-performance systems to be developed and commercialised. Photonic Integrated Circuits represent an exciting new technology able to underpin the quantum computing hardware needs for these applications.

This project will look to develop an R&D supply chain for innovative PICs for Quantum Computing. The project will develop new designs, fabricate novel PICs and develop testbeds to industrial test standards. The project partners will work to develop a roadmap for the future development of this exciting technology which can underpin the accelerated commercialisation of Quantum Computing products. A benchmarking exercise will be performed as to the hardware developments and steps required to enable trapped ion technology to be exploited using this novel technology.

FUNDING GRANTED: £422,419

WAVE PHOTONICS LTD
UNIVERSITY OF SOUTHAMPTON
OXFORD IONICS LIMITED
COMPOUND SEMICONDUCTOR APPLICATIONS CATAPULT LIMITED

The Quantum Accelerator for Materials Design (QuAMaD)

Today's pharmaceutical, chemical and materials companies rely on simulation to develop new materials and medicines. But the computers we currently use are not powerful enough to simulate large molecules or 'solid state' materials, which are used to build electronic components and devices.

This is where quantum computers can help. Quantum computers are a new type of powerful computer. They are based on building blocks called qubits. Quantum computers need to get much bigger to become powerful enough to help simulate new materials and molecules. However, it's not enough to simply build quantum computers with more qubits. We also need to develop better 'algorithms', a set of instructions for the computer, to help reduce the number of qubits needed for the simulation of new materials. By meeting halfway, developers of quantum hardware (the qubits) and software (the algorithms) will allow materials design experts to benefit sooner from quantum computers.

Building on existing algorithms research at Riverlane, this project will drastically reduce the number of qubits required for the quantum simulation of new materials. Riverlane will partner with Rolls-Royce and Samsung R&D Institute UK to build computational tools that will help them simulate large and more complex materials on a quantum computer. Riverlane will also work with the National Quantum Computing Centre to engage with other big companies who are considering using quantum computers. The results of the project can be used to help these companies understand the potential of quantum computing for their sectors and business models.

The tools and knowledge developed in this project will also be integrated into Riverlane's operating system for quantum computers. This work will benefit the companies who are building quantum hardware (the qubits). By using Riverlane's operating system and algorithms, they can strengthen their relationship with 'end-users' of their technology.

In summary, this project has the potential to benefit multiple industries. It will help researchers speed up the discovery of better materials while taking businesses one step closer to useful quantum computing.

FUNDING GRANTED: £313,904

RIVERLANE LTD

STFC - LABORATORIES

ROLLS-ROYCE PLC

SAMSUNG ELECTRONICS (UK) LIMITED

2022-2025

SBRI: Quantum-enabled positioning, navigation and timing systems

ORACL (Optical Rubidium Atomic CLock)

Modern infrastructure is increasingly dependent on highly accurate timing. This ranges across navigation systems on multiple platforms, the delivery of power throughout the national grid, and timestamping of financial transactions though MiFID II regulations to name but a few. The demand for highly accurate timekeeping across ever larger systems is growing with the uptake of new technologies, and access to less expensive and more resilient timing sources will drive further innovation.

Accurate timing is typically disseminated over large distances via the global navigation satellite systems (GNSS), which has made GNSS the backbone of modern-day systems, being described as the “invisible utility”. While GNSS continues to deliver precise timing to millions, our over-reliance on a single system is of great concern (Blackett Review, Satellite-derived time and position, 2018). In the absence of GNSS-derived timing, local timing references are required. While efforts are underway to improve both the performance and SWAP-C of conventional microwave-based frequency references, the improvements are marginal. Quantum Optical atomic clock technology has been demonstrated to provide a step-change in capability in numerous basic and applied research settings and is well suited for the long-term stability demands of next-generation PNT systems. Until now, quantum optical atomic clocks have not been possible to commercialise due to their technical complexity and the immaturity of the required laser systems within the optical supply chain.

Infleqtion has developed an optical atomic clock demonstrator with a 6U 19” rack form factor which has demonstrated frequency stability performance surpassing the state-of-the-art microwave-based frequency references. Within this project, we will use knowledge gained from initial testing of this demonstrator to create a robust, field deployable optical rubidium atomic clock - ORACL. In addition, CQUK will develop the capability to produce critical subsystems, such as optical frequency combs, to ensure sovereign capability in this sector.

FUNDING GRANTED: £4,990,242

COLDQUANTA UK LIMITED

HARLEQUIN - High-Accuracy Robust deployable QUantum Inertial Navigation

Global navigation satellite systems (GNSS) provide an easily-accessed source of timing and location data. However, GNSS is vulnerable to jamming and spoofing and is not available in sub-terrain and sub-marine environments. A dead reckoning-based inertial navigation system (INS) utilises accelerometers and gyroscopes to deduce movement without reliance on any external systems. However, no sensor based on classical physics has reached the necessary stability and accuracy desired for GNSS holdover.

A quantum-hybrid INS, measuring spatial movement using the input from both quantum-enabled and classical sensors, can offer significant performance improvements over existing classical INSs. This project will deliver a quantum-classical hybrid INS demonstrator, built around CPI TMD's existing gMOT product -- a compact, portable magneto optical trap (MOT) powered by a USB battery. The system will integrate a MOT-derived accelerometer with a classical ring laser gyroscope and an atomic clock to allow precise measurement of changes in position, and will be suitable for use on a maritime platform.

Project lead CPI TMD Technologies Ltd. will output a commercially viable sovereign system that can be manufactured at scale for use by civilian and defence end-users. CPI TMD will bring their vacuum and sub-system integration capabilities as well as a strong commercial drive from their network of potential end users, and leverage a UK supply chain built over 8 years developing quantum technologies.

FUNDING GRANTED: £5,179,285

CPI TMD TECHNOLOGIES LIMITED

Silurum

Accurate inertial measurement units (IMUs) are critical for autonomous navigation where access to Global Navigation Satellite System (GNSS) is denied/ unavailable/unreliable. This is particularly relevant to aerospace/security applications (e.g. autonomous vehicles and systems) but also civilian applications such as remote search and rescue situations.

The 18 months Silurum project will develop a miniature atomic spin gyroscope (ASG, quantum-enabled sensor) based on co-magnetometers to improve the accuracy of Inertial Measurement Units (IMUs).

The proposed activities, led by Microchip, will demonstrate a prototype miniature device fully integrated ASG, including optics sensor and electronics, developed and manufactured in a commercial UK sovereign capability supply chain capable of volume scale up to post project.

FUNDING GRANTED: £3,595,487

MICROCHIP TECHNOLOGY CALDICOT LIMITED

NX Micro COTS laser system for quantum gravity Gradiometry

The NX Micro COTS laser system for quantum gravity gradiometry project brings together a team of academic and industry experts to enhance existing technical capabilities within quantum technologies and accelerate the commercialisation process of Positioning, Navigation, and Timing (PNT) sensors. The key deliverable of this project is a state-of-the-art laser system to control the quantum state of a sample of atoms within a quantum gravity sensor. The laser system is based on solid-state laser technology, which shows critical advantages compared to other laser sources. Current solid-state quantum lasers are large and expensive, and whilst they provide a good solution for research purposes, they promise limited scalability and hence are hard to justify in integration and product development projects. Other technologies, such as distributed feedback (DFB) lasers provide a more economical option but they lack the superior performance of a solid-state platform. Our proposal brings diode-pumped solid-state technology much closer to the price point of a DFB laser, while also providing all the advantages existing solid-state lasers offer.

Furthermore, we work with Heriot Watt University and Glasgow University to integrate these lasers into a packaged, system-level solution, providing a turn-key product to existing quantum sensor manufacturers, saving costs, space and complexity in their development process. The proposed solution is unique in terms of its functionality and the overall system costs a fraction of existing products. We will validate and test our system in existing gravity gradient map matching capabilities, in collaboration with Delta g.

FUNDING GRANTED: £2,341,472

SKYLARK LASERS LIMITED

QWRTY

White Rabbit (WR) is an emerging technology developed at CERN for GNSS-independent, Ethernet-based time distribution over optical fibre. WR provides affordable sub-nanosecond accuracy and few-picosecond precision, and thus is an ideal method to synchronise large and complex distributed systems.

The WR switch is the key component of the WR technology. The latest official version in production of the WR switch is v3.4\. CERN is currently completing the specification and prototyping of a new version of the switch (v4). A key feature of the new switch is the incorporation of an expansion board to provide further functionalities. The expansion board allows the development of attractive proprietary products white maintaining the open-hardware philosophy.

One application of the expansion board is to host a high-end clock that bypasses the inexpensive default oscillator on the WR main board. The purpose of an alternative high-end clock is the provision of extended holdover, which is the capacity of a clock to maintain accurate time when its source of sync is disrupted or temporarily unavailable. If for any reason the link to the master is broken the inexpensive internal clock of the slave switch accumulates time error rapidly. For some applications it is essential to maintain a bounded time error in holdover until the link is repaired. A widely adopted requirement (e.g., telecom) is not to exceed 1.5 microseconds after 24 hours. This is roughly three orders of magnitude better than the standard WR switch performance.

New miniaturized atomic clocks provide unprecedented stability levels at a reasonable cost, with low size and power consumption. Our proposed Rubidium chip scale atomic clock (CSAC) uses the Coherent Population Trap (CPT) method to obtain a very stable frequency. While common Rb oscillators detect the atomic transition with the help of a Rb discharge lamp (Rb lamp), our clock uses a laser to induce quantum transitions. A major advantage of the laser is a much lower power consumption. Additionally, the life cycle of a Rb lamp is very limited (typically around ten years) whereby the laser has a much longer life expectancy.

Our project offers a fully functional PNT product with advanced quantum-enabled features. For the first time a WR switch (v4) will be manufactured in the UK using national quantum clock technology and improving the holdover performance of the standard switch by several orders of magnitude.

GMV leads the project consortium with the participation of IQD and ZYXT Technology.

FUNDING GRANTED: £2,033,869

GMV NSL LIMITED

QS-EXACT: Quantum SiC for EXtreme Application Clock Technology

QS-EXACT, Quantum SiC for EXtreme Application Clock Technology, will integrate a series of building block technologies developed by UK industry into a robust timing system built by Nascent Semiconductor. This technology takes a new approach to the realisation of a precision clock that is highly accurate and will result in stable timing systems which are crucial to the operation of a wide range of infrastructure.

There are a number of different types of atomic clock currently in operation, ranging in size, accuracy, and stability. Typical atomic clocks use microwave emissions from rubidium or caesium as a frequency standard. An example of a more accurate clock is based on the hydrogen MASER (the microwave equivalent to the LASER). However, these MASER systems are very large and unsuited to many applications. This project will exploit the quantum mechanical properties of atomic scale defects in silicon carbide, a wide bandgap semiconductor, to create a clock with a unique combination of stability, accuracy, portability and durability. The electronic structure of the silicon vacancy defect in silicon carbide results in the emission of a spectrally pure microwave signal when the defects are optically excited; allowing for the construction of a solid state silicon carbide MASER.

Such an approach to crafting a clock is advantageous in a number of ways. Silicon carbide has exemplary physical properties and so such a system will be intrinsically resilient and radiation hard. The system does not suffer from stability issues that restrict the deployment of other clocks, as the frequency of the MASER is constrained by the quantum properties of the defects.

The technology will offer a more compact and durable timing system that those currently available, but with a comparable performance. As a result it will be ideally suited for operations in challenging environments, from subsea to space, navigating submarines and delivering precision on-orbit operations.

FUNDING GRANTED: £3,052,918

NASCENT SEMICONDUCTOR LIMITED

AQlock

Aquark Technologies is a cutting-edge start-up in quantum technologies that will radically enhance our ability to sense, measure and compute on a mass-market scale. We have created a game-changing system to capture, manipulate, and exploit the quantum characteristics of atoms by way of a low-cost, low-power module based on ultra-cold atoms. Using cold atoms as a basis for position, navigation and timing enables both a step change in performance and autonomy when compared with existing state of the art. However, the required components of cold-atom traps to-date have rendered them too complex, large and power-intensive for meaningful real-world use, and therefore limited in their application.

Aquark has successfully overcome this major limitation by miniaturising our cold-atom engine. This miniaturisation offers us the opportunity to be first-to-market with portable, scalable quantum devices for use across sectors. Ultimately, we aim to enable mass-scale implementation of highly precise sensors and clocks, GPS-independent inertial navigation, and quantum computing, delivering against UK government priorities and urgent international need for non-GNSS alternatives as well as augmenting existing systems for increase in performance and reliability.

Our first product and vital demonstrator for our cold-atom engine is a quantum clock, the AQlock, which will enable us to commercialise and expand rapidly into new verticals. During a previous Innovate UK-funded project, we successfully proved feasibility of this technology, including technical demonstration of an open-loop clock signal.

This project now aims to transition the AQlock to commercial readiness, including extensive lab and live-environment testing. As part of the project, we will confirm and stress-test two supply chains (bespoke UK-based and commercial off-the-shelf, including international suppliers) to finalise a single, robust supply chain that can successfully scale manufacture of the AQlock ready for wide deployment. At all stages we will prioritise UK manufacturers and suppliers, falling back on international alternatives only when we are unable to secure necessary resources or expertise within the UK due complexity of the cold-atom engine and the AQlock.

The AQlock is designed to integrate into existing systems as an accompaniment or augmentation to GNSS-enabled technology. Initial target sectors include telecoms, defence, finance and aviation, with committed end-users informing the scope of technical development. Delivery of the AQlock will open up quantum-enabled systems for global PNT, and simultaneously establish an underpinning UK-prioritised supply chain for quantum sensing vectors, providing the opportunity for wholesale transition away from GNSS dependency and replacing vulnerable systems with UK-grown quantum technology.

FUNDING GRANTED: £3,445,347

AQUARK TECHNOLOGIES LIMITED

UK-Canada projects

Advanced Manufacturing Toolkit for Quantum Sensing and Quantum Computing

Quantum technologies are at an inflection point in technology readiness that will change the way we live, do business, and even how scientific research is conducted. Globally $2.2B are being invested every year to progress this technology. The United Kingdom has been at the forefront of developing the science and is home to world-leading experts in the manufacturing and validation of quantum technology and to world-class commercial partners across the whole supply chain from production to integration and measurement.

However, the ecosystem for robust fab-ready processing of these novel devices and circuits needs further development. This project addresses this gap by leveraging links between recognized academic institutions in quantum science and engineering, industry leaders, and emerging commercial efforts in quantum computing and sensing with an aim to drive this technology towards higher readiness levels.

The quantum technology platform that will be addressed in this consortium on the UK side are atomic layer deposited films for superconducting and hybrid quantum systems. These films are integrated in quantum circuits and thereby form the basis for high-coherent devices exploration academically and commercially. A second platform, albeit smaller on the UK side, are diamond NV centres to be harnessed for quantum sensing applications by the Canadian partners. Fabrication processes for manufacturing of these devices will be developed and optimized with characterization feedback using quantum technology figures of merit to ensure these materials are strongly tailored to function efficiently in quantum computers, simulators, networks, and sensors.

Altogether, this project will provide an advanced manufacturing toolkit readily available for commercial exploitation by the industry partners (SMEs and startups) and new discovery means for the academic institutions.

FUNDING GRANTED: £225,000

OXFORD INSTRUMENTS NANOTECHNOLOGY TOOLS LIMITED

ELEMENT SIX (UK) LIMITED

UNIVERSITY OF GLASGOW

KELVIN NANOTECHNOLOGY LIMITED

Building a standardised quantum-safe networking architecture

Quantum computing has moved from academic labs to commercialization and start-ups are making rapid, demonstrable progress as evidenced by new and emerging product and service offerings. While this is good news for advances in things like quantum chemistry and simulation, it also means that the `quantum threat' to our current cryptographic methods is getting closer by the day. Quantum Key Distribution (QKD) and Post Quantum Cryptography (PQC) are quantum-safe cyber security tools that are resilient against the computational threats of quantum computing. These tools are typically not used on their own, but instead, are sub-components of larger secure networks and broader cybersecurity product offerings.

Building on the already rich heritage of UK and Canadian efforts into quantum communications technologies, our vision in this project is to bring these together to develop and define a QKD network software library and hardware integration standard for all types of physical systems (fibre, free-space, satellite, etc), develop a new integrated QKD-HSM (hardware security module) appliance as a key component of a quantum-safe network fabric, and develop a first proof-of-principle quantum-safe network implementation in order to prepare for Canadian and UK QKD networks to be connected.

The end goal of this project is to provide commercial businesses and governments a common quantum-safe network standard and abstraction layer which they can then use to build their required higher level applications on top of, such as websites and e-commerce platforms, while ensuring their security is quantum-safe and the communication is interoperable with other organisations.

FUNDING GRANTED: £298,178

KETS QUANTUM SECURITY LTD
UNIVERSITY OF BRISTOL

Connectorizing Integrated Quantum Photonics Devices

Quantum information science is the discipline that studies the information present in quantum systems. Numerous new technological applications in communication and computing can be unlocked thanks to purely quantum phenomena. As opposed to classical information bits, which can be either 0s and 1s, the quantum bits (or qubits), are associated to the state of quantum objects. Because of the quantum superposition principle, the qubits can be 0s, 1s, or coherent superposition of both, thus giving access to an extraordinarily richer alphabet. Quantum information science also exploits quantum entanglement, i.e. strong correlation between quantum objects, as a resource for fast and secure quantum communication in the development of the so-called quantum networks. Thanks to the no-cloning theorem, quantum networks can detect whether shared cryptographic keys have been intercepted and/or compromised by the presence of an eavesdropper. At the same time, they prove prone to photonic loss because the no-cloning theorem forbids amplification of quantum states. Single- and two-photon sources and quantum memories are key components of quantum networks, as they allow the generation of quantum states encoded on photons and their long-term storage. The implementation of such devices on small chips has the potential to replicate the revolution of modern electronic miniaturization. The integration of quantum devices can in fact enhance the light-matter interaction and provide high-level scalability and intrinsic mechanical stability. However, current realizations are limited either by the low extraction/insertion efficiencies of the generated/stored photons in free-space or by the complexity of the setups which hinders the scalability potential.

This proposal tackles the challenge of implementing efficient and robust interconnects between integrated quantum photonics devices and optical fibres with the aims of 1) minimizing the optical losses throughout the networks and 2) making them scalable beyond simple proof-of-principle demonstrations. The effort involves two quantum technology companies, Duality Quantum Photonics (DQP, UK) and OptoElectronic Component (OEC, Canada) and two research groups at the Institut National de la Recherche Scientifique (INRS, Canada) and Heriot-Watt University (HWU, UK). Such consortium gathers world-leading partners in integrated quantum photonics, with widely recognized expertise in all steps of the development: design and fabrication of integrated circuits and mode conversion structures (DQP), implementation of integrated quantum devices, as single photon sources (HWU), sources of photonic entanglement (INRS), and quantum memories (HWU), and efficient detection of quantum states of light (OEC). The project outcomes will provide a significant contribution towards the development of quantum secure communication networks.

FUNDING GRANTED: £299,934

DUALITY QUANTUM PHOTONICS
HERIOT-WATT UNIVERSITY

Development of highly efficient, portable, and fibre-integrated photonic platforms based on micro-resonators

Compact optical reference development allows novel ultra-precise, compact optical atomic clocks to become feasible. Crucial system components are ultra-compact coherent optical frequency combs to convert the optical reference frequency into an electronic signal, enabling applications such as hold-over references for GNSS denial/interruption in facilities and telecom networks, data centres and novel defence applications.

Simultaneously, quantum cryptography has gained tremendous momentum in the last decade. Key to enabling quantum cryptography are the development of quantum key distribution (QKD) and quantum random number generation (QRNG) techniques ensuring safe, reliable, and robust communication networks. Current protocols utilize highly attenuated laser beams or single photon sources for encryption. Lasers offer advantages in terms of high bit rates, simplistic experimental setups, and low hardware costs. Truly secure communication can only be achieved by embedding quantum light sources with lasers.

Applications need high-quality, low-cost optical solutions. Compact, fibre-integrated micro-resonators exhibit large nonlinear optical behaviour which facilitates their application in a wide range of systems, from efficient entangled single photon sources to optical frequency comb generation. With industrial fabrication established and their easy integration into an all-fibre system, micro-resonators are ideal devices for portable systems with demanding robustness and stability requirements.

We will develop effective optical sources tailored for quantum technology applications based on architectures embedding fibre-laser and chip-integrated micro-resonators. Using the exceptional optical nonlinearity of these chips and the expertise developed by the collaboration between INRS-EMT and Sussex, efficient, compact optical sources will be developed for (i) quantum cryptography, developing a probabilistic source of single photons for QKD and QRNG and (ii) portable atomic clocks, realizing a ruggedized optical frequency comb and locking it to an atomic reference.

The same underlying physics and technology allows the targeting of key applications of optical sources in quantum technology. The Canadian team will employ these systems as entangled single photon sources for quantum cryptography, the UK team will focus on their integration into a portable optical reference to build a compact atomic clock.

With unique in-house, world-leading expertise in vacuum electronics (TMD), non-classical light sources (OEC), non-linear micro-resonators (INRS-EMT), photonics (Pasquazi-Sussex) and atomic science (Keller-Sussex); the goal will be achieved by using the joint expertise in non-linear optics with integrated micro-resonators to develop a high-efficiency photon source and a highly-precise optical frequency comb. The shared expertise, technology and techniques of the Canadian and UK teams, as well as of their industrial partners will facilitate rapid progress and commercialization.

FUNDING GRANTED: £299,802

CPI TMD TECHNOLOGIES

UNIVERSITY OF SUSSEX

Diamond NV Sensors for Quantum-Limited Magnetic Field Measurements

In this proposal we propose to design, build and demonstrate a quantum magnetometer, with the ability to measure extremely weak magnetic fields such as those within the human body or local fluctuations in the earth's magnetic field.

This industrial research project brings together a complementary consortium of industrial and research partners in the UK and Canada, each experts in their respective fields, including M Squared Lasers (specialists in laser systems for quantum applications), Dias Geophysical (specialists in environmental and exploration imaging), University of Saskatchewan (specialist in diamond NC centre chips), and University of Nottingham (specialists in simulation and design of field-stabilised environments for quantum sensing).

FUNDING GRANTED: £110,668

M-SQUARED LASERS LIMITED

UNIVERSITY OF NOTTINGHAM

Making noisy quantum processors practical

Quantum computers harness the strange features of quantum mechanical systems in order to solve computational problems that cannot be solved using current (classical) computing technology. The most well-known task where quantum computers outperform classical computers is factoring large numbers, which can be used for breaking encryption. Quantum computers also naturally excel at simulating quantum systems, a notoriously difficult computational problem that has applications in materials science and drug design. The potential of quantum computers has attracted investments from technology giants including Google, IBM and Amazon, as well as from national governments and venture capitalists.

FUNDING GRANTED: £299,609

PHASECRAFT

UNIVERSITY COLLEGE LONDON

ReFQ: Modular WCP Sources & RFI Protocols for Space-based QKD Demonstration

Quantum Key Distribution (QKD) is expected to form a critical part of future secure communications infrastructure. Keys are a highly valuable cryptographic tool for securing valuable and sensitive data. Current key methods protect transactions including mobile telephony, corporate intellectual property, diplomatic cables and financial transactions. The distribution of keys to global communication nodes within a network presents a challenge commonly addressed using computationally hard mathematics, such as calculating the prime factors of large numbers. Security for these keys is therefore based on the premise that the computational cost remain impractically high and expensive relative to the value of the data. This premise is now under threat from mathematical advancement and quantum computing where the ability to factor large numbers becomes significantly less challenging. Should these keys be compromised, all data and nodes on the network using these methods becomes vulnerable to interception and cyberattack.

QKD provides a'quantum-safe' solution for sharing keys assured by fundamental physics. Space provides an ideal and highly scalable medium for key distribution, given that a satellite can deliver keys globally over long distances as it flies about an orbit. Space-based QKD is therefore expected to complement ground based local QKD networks which are already beginning to emerge. Satellites will provide these keys to ground nodes globally for use in existing telecommunication networks, particularly to remote locations or across international boundaries.

This work leverages ongoing mission developments in the UK and Canada bringing together the two teams responsible for upcoming QKD missions: QEYSSAT in Canada including Honeywell and University of Waterloo, and ROKS in UK including Craft Prospect, and the Universities of Bristol and Strathclyde. The work will allow a UK based QKD technology to fly on the QEYSSAT mission, providing valuable performance data for the system and extending the capabilities of the satellite to perform another class of QKD link. It will additionally allow the development of new protocols for secure key distribution from space overcoming challenges resulting from the motion of the satellite understanding of interoperability, ready for adoption as the security of existing approaches becomes more open to challenge and cyberattack.

FUNDING GRANTED: £300,386

CRAFT PROSPECT LTD
UNIVERSITY OF STRATHCLYDE
UNIVERSITY OF BRISTOL

Scanning probe fabrication and readout of atomically precise silicon quantum technologies

Quantum computing promises tremendous advances in a number of applications, including finance, medicine, cryptography, and materials simulation. The fundamental computation element of a quantum computer is the quantum bit, or qubit, and to perform calculations that are truly transformative, huge numbers of qubits (potentially millions) are required. We propose to develop a process for fabricating many more qubits than have previously been made. Furthermore, we will do so using the material system silicon, which is directly compatible with the only ready-made industry currently available for largescale market production of a many qubit quantum computer.

Our qubits will be made from impurity atoms in silicon, known as dopants. This is done using a scanning tunnelling microscope (STM), which ""feels"" the atoms on a surface with an extremely sharp probe tip, much like an audio record player feels the grooves of a vinyl record. Previously, only a pair of dopant qubits have been made, and with no route to scaling-up to a useful number. In order to move and see the millions of individual dopant atoms that will make up a quantum computer, we require advanced machine controls and data processing tools. Nanolayers Research Computing will use the proprietary machine learning software they have pioneered to train the STM to perform control and processing tasks on its own, without human user intervention. The use of this type of data processing, also known as artificial intelligence (AI), is particularly well-suited to image processing and pattern recognition, and can be used to find the proverbial ""needle in a haystack"". This is exactly what needs to be done when we use a scanning tunnelling microscope to move and then see a large collection of atoms in a silicon quantum computer component. In short, this project uses artificial intelligence to control an atomic resolution microscope and precisely position a large number of individual impurity atoms in silicon. This technology will enable the eventual fabrication of a silicon-based quantum computer.

FUNDING GRANTED: £183,231

NANOLAYERS RESEARCH COMPUTING
UNIVERSITY COLLEGE LONDON

Canada UK Commercialising Quantum Technology Programme: CR&D

Broadband Quantum Synthesizer (BQS)

Quantum technologies are a vital component of the industrial strategy in the UK and Canada, with the potential to revolutionize the digital world, expand the capabilities of current imaging devices, and facilitate the development of new drugs using quantum computing to solve complex calculations. Collaborations between UK and Canadian high-tech industries, universities, and research centres are ongoing to translate these scientific concepts into accessible technologies. To achieve this goal, funding of over £1 billion has been pledged by governments and industries. Photonics is among the sectors spearheading the advancement and application of quantum technologies. Light is an ideal carrier of quantum states, essential for quantum communication, and it is also a powerful measuring tool, allowing us to observe the structure and the evolution of matter in processes underpinning the most advanced technologies and life itself.

In the realm of photonics-based quantum technologies, there are two fundamental approaches: either radiation with a limited number of photons is prepared and then measured with the aid of single-photon detectors, extracting the non-classical properties by analyzing the correlations between measured events, or macroscopic quantum states called squeezed light are generated, carrying entanglement among many (billions and more) photons at one time. This latter approach takes the name of continuous-variable quantum optics, it empowers the most advanced metrological endeavours of our time, such as advanced LIGO for the detection of gravitational waves and requires high sensitivity measurements and low losses to retain the quantum properties entailing an enhancement over the classical light. Pulsed squeezed light, with picosecond or shorted duration, is now being applied to enhance sensing of biologically relevant effects, for instance, in microscopes. However, the current technology has limits in how short squeezed light pulses can be effectively generated.

With this feasibility study, we aim to develop a tool for the generation and manipulation of ultrashort squeezed light pulses with durations below 100fs (potentially sub 40fs) and \>3dB squeezing, overcoming the current state-of-the-art and empowering future research in crucial fields such as bio-photonics.

FUNDING GRANTED: £450,000

FEW-CYCLE INC.
NATIONAL RESEARCH COUNCIL OF CANADA
UNIVERSITY OF GLASGOW
COVESION LIMITED

Hybrid compilation framework to accelerate quantum application development (CATALYST)

Quantum computers are new types of powerful computers that are based on building blocks called qubits, that carry information in a more effective way than the bits on a conventional computer. Quantum computers have the potential to achieve computational times that are orders of magnitude faster than conventional computers.

While qubits work differently from conventional bits, the computation workflow is somewhat similar: when we wish to run an algorithm, we write some lines of code that get translated into the so-called quantum circuit which then enacts a series of operations on the qubits before delivering a result. However, at the moment, this process is far from optimal, and the times needed for the pre-quantum steps required to run a calculation are prohibitively high. For quantum computers to become commercially useful, we need to not only optimise the algorithms we want to run and minimise the resources they need, but also reduce the time needed to translate them into a series of operations that can be then run on the qubits.

While this constitutes an important problem for quantum computers, so far very little work has been done to address it. Another problem is that the quantum industry is currently very fragmented and still in its early stage of development.

This project brings together leading quantum software and hardware companies from the UK and Canada - Riverlane and Xanadu - to help solve the technical challenge of improving the quality of the quantum algorithms and making them run easier, faster and better on the qubits. Riverlane will work on implementing techniques that allow algorithms to run using less resources, while Xanadu will develop a new hybrid classical-quantum compiler that will significantly decrease the calculation times and will allow users to use the appropriate resources in an optimal way. Rolls-Royce, a leader in power and propulsion systems will lead this project, providing real-world testcases that cannot be solved by today's quantum computers. Rolls-Royce will also develop new application software to best exploit the Riverlane and Xanadu developments.

The partners will work together to combine improvements in quantum software, hardware and algorithms to significantly improve the runtime and results when running quantum algorithms. Our project brings together companies from UK and Canada to help develop quantum computers that will transform the way several sectors, such as finance, pharmaceuticals, aerospace etc. design and develop their products.

FUNDING GRANTED: £299,802

ROLLS-ROYCE PLC
RIVERLANE LTD
XANADU

H3Lo-QP: High-voltage High-IO High-transmission Low-temperature Quantum Photonics

Integrated optical circuits are a cutting edge method of trapping and guiding light in millimetre sized chips that will be used to power the next generation of information and communication technologies. Optical chips are already ubiquitous in data centres that power the internet and enable an ever more interconnected digital society.

Quantum technologies using single particles of light - photons - facilitate secure communications, enhanced environmental sensors, and ultra-fast computers. Since information is carried on individual photons, losing them represents an irretrievable loss of information. Switches that retain as much of the light as possible are a fundamental building block for all of these applications.

Photons interact weakly and are mostly undisturbed by the environment at room temperature. The detectors used to measure photons, however, must be operated cryogenically. The next generation of scalable quantum photonics must solve the challenge of operating the optical chips, and switching light in the same environment as the detectors.

The largest scale quantum information experiments to date have used switches that operate by creating a large temperature change in the material. These switches, however, cannot be operated en masse at cryogenic temperatures due to limited cooling power in cryostats. This roadblock can be overcome by using a different switch where an electric field is applied across the switch and facilitating active control with minimal heat dissipation.

The H3Lo-QP (High-IO High-transmission High-voltage Low-temperature Quantum Photonics) project will address important challenges of designing, fabricating, post-processing, and developing the system-level architecture for cryogenically operating a large number of low heat-dissipation integrated photonics switches necessary for the next generation of optical quantum technologies.

We will investigate the feasibility of two types of switches by post-processing silicon chips made using mass-manufacturing techniques, and by developing fabrication techniques to deliver optical switches in a cutting edge integrated photonics platform: thin-film lithium niobate.

The architecture for the control electronics will be developed, enabling a large number of device switches to be rapidly reconfigured. We will package fabricated optical chips using special techniques where a polymer optical wire directly connects the silicon/lithium niobate chips to optical fibres used to transmit light in and out of the cryogenic environment. Finally, we will demonstrate a large-scale device operating at cryogenic temperatures using the electro-optic switches developed in this project.

This work will ensure that photonic quantum technologies will flourish and with far reaching impacts across science, academia, industry, and society.

FUNDING GRANTED: £450,000

DUALITY QUANTUM PHOTONICS LTD

QONTROL LTD.

DREAM PHOTONICS INC.

QUAMINEX - A drone deployed integrated gravity/ magnetics measurement system for mineral exploration

The need for new mineral resources is key to the energy transition away from hydrocarbons. Unfortunately many of the easy to find mineral deposits have been already exploited leaving the world with the challenge of finding new deposits for batteries and electrification. Magnetic and gravity sensing have long been identified as tools for detecting mineral deposits, but current sensors have operational limitations and when used, are deployed independently.

Exploiting quantum properties in nitrogen vacancy diamonds, SB Quantum have developed a cutting-edge quantum magnetometer which provides vector analysis removing the need for careful orientation. The compact and rugged sensors can be fitted into autonomous vehicles. However magnetometry provides a non-unique solution so complimenting the magnetometry measurement with additional sensors is important.

Gravity surveys have been used in the mining industry for many years but with traditional technology are time consuming and expensive to deploy. They cannot be deployed via drone / ATV or combined with other measurements. SMG have developed a next generation gravity sensor based on proprietary resonant MEMS sensors. The MEMS sensors are small, lightweight, more robust and low power consumption with very high sensitivity. Field trials of the hand portable gravimeter will start in the second half of 2023 with strong interest already demonstrated from a range of industries.

This project will combine the two technologies in a drone deployed solution in order to expedite the adoption of both new technologies. The drone will be required to land to take stationary gravity measurements but will have the ability to survey large areas with significant granularity in commercially viable timescales. The co-location of gravity and magnetic sensors will bring benefits not only in time to survey but also for data interpretation. Combining Quantum and MEMS technology in an integrated package will expedite the adoption of the quantum technology.

Combining the two technologies into a drone mounted acquisition system will need to address issues such as the impact of the drone and gravimeter on magnetic measurements with a need to mitigate impact. For the gravimeter self-levelling and elevation measurement to high degrees of accuracy will be critical. Form factor and power requirements for the combined device will need to be minimized.

The consortium has validated the project objectives with major mining companies such as BHP and organisations such as the Geological Society of Canada and will set-up a steering group of customers.

FUNDING GRANTED: £414,106

SILICON MICROGRAVITY LIMITED

SBQUANTUM

Quantum technology enabled blood diagnostics for safer and more patient centric cancer care & treatment management

A vital part of cancer therapy is to ensure the exact type and progression of the cancer is known for every patient. Unfortunately, this is very challenging, as cancer is a highly complex disease that changes over time. The way the tumours grow is incredibly complex. Doctors are frequently unsure if a patient will get better when given a particular drug.

Doctors need easy to use tools that enable them to know the exact "fingerprint" of the patient's type of cancer so that they can more precisely select which drug will be best for a particular patient.

Furthermore, drug companies are developing advanced new drugs that can treat specific types of cancer more effectively, but they must be specifically matched to the exact type of cancer for the specific patient. Consequently, there is a need to have more quick and convenient ways of understanding a patient's exact cancer type.

Thankfully, scientists have discovered that tumours release small quantities of "circulating cancer cells" floating into the patients' blood. If these small numbers of cells can be identified and counted, we would have the ability to conduct "liquid biopsies" on patients with a simple blood test.

This application is presented by a company in the UK developing an innovative diagnostic machine that is capable of analysing blood by automatically counting the different types of cells in a patient's blood. They have an opportunity to work with a Canadian company with very special "fluorescent materials" that will make it possible to make the floating cancer cells of interest light up and be more visible and easier to profile cancer cells in the blood.

The two companies wish to work together on research to modify the diagnostic machine in the UK and make the quantum dots attach to the cancer cells of interest. The team also wants to include a Canadian university with a highly sensitive camera that will improve the team's ability to count and identify rare floating cancer cells.

The enclosed team is seeking Canada UK Commercialising Quantum Technology Programme investment to conduct a programme of engineering, biochemical, optical and software-based research needed to enable the team to prove the system can detect the target floating cancer cells in patient's blood samples.

FUNDING GRANTED: £435,165

BEYOND BLOOD DIAGNOSTICS LTD
UNIVERSITY OF CALGARY
APPLIED QUANTUM MATERIALS INC.

QUARREFOUR - Benchmarking Multi-core Quantum Computing Systems

Quantum Computing (QC) will offer societal benefits through solving intractable problems across multiple scientific domains. The motivation for this project is to tackle the industry's biggest challenge: scaling.

It is increasingly recognised that _useful_ QC can only be delivered by networking together multiple QC nodes into a larger (data-centre-scale), more performant and better Error-Corrected computing service. There is an urgent business need to architect and deliver a solution for effective networking of QCs - photonic networking being the most promising route, relevant to all qubit types.

In this project, we will respond to the challenge of charting a path towards Distributed QC (DistQC) by modelling the performance of a Distributed QC, developing benchmarking protocols, and reviewing and refining the logical process that affect performance.

FUNDING GRANTED: £314,420

NU QUANTUM LTD

SOFTWAREQ INC

3LX - Developing low-cost, low-energy, low-detection limit X-Ray image sensors for critical industries using quantum dot technology

Demand for high-performance X-ray sensors is increasing as sensor technologies evolve to improve output and performance. From medical imaging and industrial inspection to defence applications and security screening, the ability and requirement to perform detailed, non-destructive quality inspection, control and imaging is creating exciting possibilities for image applications across key industries and the growing $8.87bn X-ray detector market.

Current photon-counting X-ray direct detectors that offer the highest-levels of accuracy are built using Si/Se/CdTe/CdZnTe materials, which are complex to manufacture (involving semiconductor growth and hybridization) and costly (up to $150k). This is significantly hampering their impact potential, adoption and commercialisation.

These limitations are felt most acutely in medical applications, where the high-cost of high-performance x-ray systems is restricting adoption, leading to global health inequalities, missed diagnosis and increased radiation exposure as a result of continued use of inadequate systems.

These challenges demand the development of novel, low-cost, next-generation semiconductors for direct X-ray detectors.

In an exciting UK-Canada collaboration between 2 progressive quantum technology SMEs Quantum Solutions (QS) and AY Sensors (AY) aim to co-develop a small-scale prototype of a low-cost, low-energy intensive, low-detection limit quantum X-ray image sensor.

The challenge is to deliver industry-leading high-performance (image quality, radiation levels, speed) at low-cost, integrating AY's X-ray absorbing CsPbI3 and CsPbBr3 quantum crystals with QS's innovative, custom-designed silicon readout integrated circuit (ROIC) using newly-developed , low-cost fabrication and bonding methods.

This involves 5 key-stages:

1. Optimize the growth of X-ray absorbing crystals
2. Develop binding/deposition strategies of absorbing materials on ROIC substrate
3. Fabricate X-ray imaging sensor
4. Test the fabricated X-ray image sensors for performance
5. Independent X-ray detector evaluation with the University of Southampton Centre for Cancer Immunology

FUNDING GRANTED: £107,446

QUANTUM ADVANCED SOLUTIONS LTD

AY SENSORS

Investor partnership projects

Compact Source-Device Independent QRNG

The need for truly random numbers for encryption purposes is ever-growing. A technology that can provide such numbers and can certify them at high operating speed is sought for in many applications. Due to their wide range of use cases, random number generators need to be built with a small form-factor and low power consumption while at the same time providing reliably secure random numbers at sufficiently high generation speeds to satisfy various applications ranging from securing data servers to providing on-chip security for consumer connected devices. Quantum random number generators (QRNGs) leverage the inherent randomness of quantum processes to provide true random numbers. Quantum Dice is commercialising an innovative and patent-protected method of generating secure random numbers from a quantum process, which was developed at the University of Oxford. The innovation addresses the problem of internal classical noise which plagues all implementation of random number generators, including even currently available QRNGs. This classical noise can compromise the security of the output and has, in-fact, been the root cause of many security failures in currently-used random number generators. The main objective of this project is to use our technology to create the world's first compact, fast, cost-effective and verifiably secure quantum random number generator. This will transform our underlying innovation into a commercially-ready QRNG product that can begin addressing the growing market need for true randomness.

FUNDING GRANTED: £499,601

QUANTUM DICE LIMITED

Global Spin Qubit Control

Developing qubits in silicon, compatible with the mature CMOS fabrication industry, is a promising pathway to realising a scalable quantum computer. Quantum Motion has achieved world-leading results in the development of such qubits, including record measurement fidelities and spin lifetimes of several seconds. A leading approach to manipulate spin qubits, and achieve single- and two-qubit operations, is to drive them resonantly using applied microwave fields, which are typically delivered to individual qubits via on-chip transmission lines. As the qubit arrays scale up, this approach brings problems of signal crowding and cross-talk errors, as well as layout challenges. Overall, such challenges remain tolerable for devices of intermediate scale (<100 qubits), but become intractable for a fully scaled system, which should be targeting thousands to millions of individual qubits to deliver a quantum processor of genuine value. This is the problem that will be addressed in this project by realising a system in which global control of a qubit array is achieved. Solving this "global spin qubit control" challenge in a truly scalable spin qubit architecture is a key enabler to providing wide access to quantum computers of real value.

FUNDING GRANTED: £918,333

QUANTUM MOTION TECHNOLOGIES LIMITED

High Performance Control and Error Correction Hardware for Quantum Computing

Realisation of the transformational benefits quantum computing can bring depends critically on the performance of classical computing needed to support it. Support is needed both for the control systems that maintain the systems in their quantum states as well as for the error correction systems that decode the desired results from noisy data.

One of the main challenges in providing this classical computational support is the unwanted transfer of heat to the cryogenic chamber. This flows through the cabling needed for sensor and control data into and out of the chamber and is generated by power dissipation within control electronics in the chamber itself. The heat load in the chamber can be minimised by doing as much of the computation as possible in the cryogenic environment, but this is limited by the power consumption of the control and error correction electronics.

A further constraint on the classical processing is that in many systems it must be done extremely quickly, i.e. within the decoherence time of the quantum system -- typically tens of microseconds.

Intrinsic, a spin-out of UCL whose team includes world-class academic founders and a deeply experienced semiconductor executive, is developing a novel, fast and lower power memory technology for embedded computation applications. This project aims to advance Intrinsic's technology in a new way such that it can deliver order-of-magnitude improvements in the power and performance of computers supporting quantum systems. For digital computing systems, performance gains will be achieved by developing Intrinsic's embedded non-volatile memory to reduce the memory bottleneck by bringing the required program or coefficient memory on chip in ways not possible with existing Flash technology. This dramatically improves both cost and power consumption by reducing the energy and latency of memory transfers. Further, this project will also explore more radical and innovative improvements that come from exploiting analogue computing. Intrinsic's memristors have analogue memory properties that are fundamental to analogue compute architectures. Prior tests suggest that our technology is compatible with cryogenic operation, producing minimal heat dissipation.

This project will first further develop and characterise our technology for digital applications, including at cryogenic temperatures. We will then explore the analogue properties of the devices and their suitability, also at cryogenic temperatures, as key components of analogue systems suitable for quantum control algorithms. Analogue computing could provide significant boost to what is possible 'in chamber' bringing huge benefits to the performance of cryogenic quantum systems.

FUNDING GRANTED: £998,196

INTRINSIC SEMICONDUCTOR TECHNOLOGIES LIMITED

Quantum PDK

In this project, we will produce that tool: An electronic company aided design (ECAD) software module for the microscopic modelling and simulation of qubit devices. The tool will have the predictive power to determine the impact of device design parameters on qubit performance. Furthermore, the development of the module will be made completely compatible with industry-standard circuit simulation tools such as it can be easily integrated with existing simulation environments reducing the cost of adoption.

This development will echo the development of CAD tools used conventional semiconductor industry, which have resulted in reductions in development time of up to 75% for new devices and are the building block of the CMOS industry.

FUNDING GRANTED: £786,441

QUANTUM MOTION TECHNOLOGIES LIMITED

UK Research and Innovation

Company Directory

UK Research and Innovation

UK Research and Innovation

ABSENSING LTD

absensing.com/

ABSENSING is a company with extensive industrial experience in the full development of customised CMOS Image Sensors.

Our ramp up process is designed to empower your team and outfit them with the knowledge they need to succeed.

Our service includes a comprehensive consult to help identify gaps and opportunities, a comprehensive report that includes a project plan with timelines and milestones, a cost analysis, and a schedule. We also offer customised services to reach the performance you need.

PROJECTS	
Design and layout of a dark noise QRNG	82

ADAPTIX IMAGING

adaptix.com

Adaptix are developing novel X-ray imaging technologies with a primary focus on the medical, dental, and veterinary markets although Adaptix have recently started to expand into the Non Destructive Testing sector.

The core of our business is the development of our 'Flat Panel Source' tomosynthesis technology, which uses a wafer-based emitter array to generate X-rays from multiple individually controlled emitters which allows the images to be reconstructed to produce 3D slices. This novel X-ray generation technology enables us to bring low cost, low dose, portable 3D X-ray imaging to the patient. In combining our x-ray imaging technology with a quantum detector, Adaptix see a way to add colour to 3D X-ray images.

Adaptix have two primary sites in the UK – at Oxford University's Begbroke Science Park and at Rutherford Appleton Laboratory – and our primary manufacturing site will be in Scotland. Adaptix work closely with a variety of academic institutions, veterinary clinics, and hospitals both in the UK and around the world to develop the core technology and validate its clinical applications.

PROJECTS	
Transforming Tissue Differentiation via Quantum Digital Tomosynthesis	24

AEGIQ

www.aegiq.com

AegiQ is on a mission to radically change data communications both in space and on the ground and make our world more secure using quantum technologies. AegiQ are supported by leading venture capital firms and are part of several large collaborative industrial R&D consortia.

PROJECTS	
UpScale: Scalable quantum information enabled by integrated optics	64

ALTER TECHNOLOGY TUV NORD UK LIMITED

www.altertechnology-group.com/en/home

Alter Technology (formerly Optocap), provides contact package design and precision assembly services for a wide range of optoelectronic, microelectronic and MEMS devices. Alter Technology offer end to end backend semiconductor manufacturing from wafer singulation to assembled product. Alter Technology will be responsible for the design and manufacture of the optical transmitter and received modules within the optical magnetometer which are used to extract magnetic field measurements.

PROJECTS	
KAIROS	15
Pioneer Gravity: Gravity sensors for infrastructure productivity, situational awareness and seeing the invisible	14
Next-Generation Satellite Telecommunications Entangled Photon Source (NextSTEPS)	111
PAssively STabilised Laser (PASTEL)	115
Platipas - Passive Platform Development for Visible Wavelengths	118
Project U-Quant: Ultra-low SWaP quantum communication payload for tactical and space applications	119
Quantum Photonic Integrated Circuit Packaging (QPICPAC)	125
TALENT - Tapered AmpLifiErs for quaNtum Technologies	134

AMETHYST RESEARCH LIMITED

http://amethyst-research.co.uk

Amethyst is an electro-optical solutions house based within the United Kingdom. We specialise in designing and developing custom III-V infrared detectors for research and customer needs, whether that be for defence and security, environmental monitoring or medical applications.

Our unique Amethyst Barrier Diode Technology (ABaTTM) offers low-noise broadband performance over the SWIR, MWIR or LWIR bands of the infrared spectra and is ideally suited for applications which require a complex thermal imaging solution.

Our enhanced resonant cavity photodetectors (RCE-PD) provides high sensitivity "laser-line" narrowband infrared detection over SWIR, MWIR and LWIR bands and can be customised to focus on particular spectral fingerprint lines of

compounds and is optimally suited for gas sensing, chemical analysis or biomarker detection.

PROJECTS	
UK National Foundry for Quantum Components (QFoundry)	31

AMTE POWER

amtepower.com

AMTE Power plc (formerly AGM Batteries Limited), is based in the far north coastal town of Thurso, Scotland and Oxford, England. Our business has been trading since 1997 and is a recognised brand in the production of high-quality lithium-ion and sodium-ion battery cells across a range of markets including automotive, aerospace, defence, oil & gas and energy storage.

PROJECTS	
Quantum sensors for end-of-line battery testing	21

ANGOKA LIMITED

angoka.io

Angoka is a start-up spun out of a successful feasibility study funded by the Centre for Connected and Autonomous Vehicles (CCAV) in order to develop a solution for securing in-vehicle communications. It has developed a solution for securing both communications in-vehicle and external (V2X) and is currently also developing secure drone communications. Headquartered in Belfast, with offices in London.

PROJECTS	
Quantum sensors for end-of-line battery testing	21

APPLIED QUANTUM COMPUTING LIMITED

https://appliedquantumcomputing.co.uk

Applied Quantum Computing has been formed to assist companies to take advantage of the potential offered by quantum computing. We offer consulting and technical advisory services to organisations looking to learn about and apply quantum computing approaches to business problems.

We concentrate on the use of quantum optimisation techniques to help provide better solutions, with a particular focus on the finance and healthcare sectors.

We are members of the IBM Quantum Partner and AWS Activate programmes.

PROJECTS	
Developing valuable operational healthcare applications using quantum computing techniques	140

AQUARK TECHNOLOGIES LIMITED

www.aquarktechnologies.com

Aquark Technologies is a spin-out of the University Southampton that provides portability and miniaturisation solutions for quantum technology applications. We benefit from more than a decade of research dedicated to building the worlds smallest cold atom system, and following recent pre-seed investment, we have established our state of the art facility in Southampton, UK, dedicated to delivering our mission.

PROJECTS	
Gravity Array	102
AQlock	156

ARCHANGEL LIGHTWORKS LTD

www.archangel.works

Archangel Lightworks have developed a new generation of space-air laser communication terminals and technologies to help solve the world's persistent challenges. They are working to close the gap between space operations and air operations and allow hybrid systems to operate at greater efficiency and efficacy. Being able to elevate the terminals above the cloud is a key enabler for industry uptake of laser communication. The best place to use laser communications is where the cloud isn't.

PROJECTS	
Quantum technology enabled blood diagnostics for safer and more patient centric cancer care & treatment management	175

ARM LIMITED

www.arm.com

Arm's foundational technology is defining the future of computing. A future built by the greatest technology ecosystem in the world. A future built on Arm.

Arm is everywhere technology matters. Technology matters everywhere. Arm is at the epicenter of the world's largest compute ecosystem. Our vast community of software, tools, and service partners support and enable the use of our technology across markets and applications.

Together, we'll power every technology revolution moving forward, including cloud computing, automotive and

autonomous systems, IoT, the metaverse, and beyond.

Changing the world. Again. On Arm.

PROJECTS	
NISQ.OS	27

ARQIT LTD

arqit.uk

Arqit has invented a unique quantum encryption technology which makes the communications links of any networked device secure against current and future forms of hacking – even an attack from a quantum computer. Arqit's product, called QuantumCloud™, creates unbreakable software encryption keys, using satellite to deliver quantum information to data centres. The keys which are easy and efficient to use remotely with no hardware or disruption to software required. The software has universal application to every edge device and cloud machine in the world. Headquartered in the United Kingdom with subsidiaries in the United States, Arqit was founded in 2017 by UK satellite industry veteran David Williams.

Arqit recently announced a proposed listing on NASDAQ in connection with a business combination transaction with Centricus Acquisition Corp. (NASDAQ:CENH, NASDAQ:CENHU and NASDAQ:CENHW).

PROJECTS	
Quantum Electro-Optic Detector Technology (QuEOD)	29
3QN: Towards A New UK Industry for Novel Quantum Receivers in Nascent Satellite QKD Global Markets	12
AIRQKD	16
Next Generation Satellite QKD - Creating a UK Sovereign Capability for Manufacturing Satellite QKD Payloads	19
Towards a Quantum enabled Cloud	62

ASTEX THERAPEUTICS LIMITED

www.astx.com

Astex Pharmaceuticals is a world leader in innovative drug discovery and development with a focus on Oncology and diseases of the Central Nervous System. The company has successfully applied its proprietary Fragment-Based Drug Discovery (FBDD) platform to generate multiple new drug candidates that are progressing in clinical development. Astex continues to grow and has opportunities at our Research Headquarters in Cambridge, UK, for experienced and innovative scientists and non-scientists, wishing to develop their careers in a thriving multidisciplinary, industrial environment.

PROJECTS	
Practical improvements to the performance of quantum simulation for drug-protein binding	76

ATREIDES CASERI UK LTD

atreides.io

Atreides is the Intelligence-as-a-Service company that brings its unique massive-scale data to a simple, intuitive CCIRM™ platform that everyone in your organization can put to work.

Customers demand their experience with data to be **1)** Brief, **2)** Painless and **3)** Accessible to everyone in the organization.

We make the nitty gritty tech be invisible so that organizations can rely on all their employees, not just data scientists, to fully exploit and refine their proprietary tradecraft to stay firmly ahead of the curve.

PROJECTS	
Quantum Powered Sensemaking of People and Places	129

BABCOCK INTEGRATED TECHNOLOGY LIMITED

www.babcockinternational.com

Babcock is an international aerospace, defence and security company, with a leading naval business, and provides value-add services across our main markets of the UK, France, Canada, Australasia and South Africa. We also operate in, and export to, additional markets.

Our strategy is to focus on our core activities in the UK, using our capabilities to work on exports from the UK and to develop our international presence in our target countries. We operate in attractive markets and are positioning ourselves for future growth.

These projects take all different kinds of professionals, from chartered engineers and project managers, to naval architects, data analysts and everything in between. To bring through the next generation of engineering and business experts, we offer apprenticeships and roles for students, graduates and fully-qualified professionals.

There's never been a better time to join us. Whether you're looking for a new business management project or engineering role, join Babcock and grow with us.

PROJECTS	
Towards a Quantum enabled Cloud	62

BAE SYSTEMS

www.baesystems.com/en/home

At BAE Systems, we help our customers to stay a step ahead when protecting people and national security, critical infrastructure and vital information. This is a long-term commitment involving significant investments in skills. We also work closely with local partners to support economic development through the transfer of knowledge, skills and technology.

PROJECTS	
High-BIAS2: High-Bandwidth Inertial Atom Source & Sensor	17
Mid-IR Upconversion Single-photon detection (MIRUS)	38

BARRIER NETWORKS

www.barriernetworks.com

Spending valuable budget on cyber security is a challenge for any organisation. There is no return on your investment, so getting the budget holders to approve a request for something that may never happen is difficult. Barrier Networks (BN) have spent over ten years delivering cyber security solutions to help organisations build cyber resilience. BN have built a reputation on trust with our customers. By engaging with BN, you benefit from our experience to ensure that when you do need to spend valuable budget it is for the right reasons and you can trust that the solution will deliver against the criteria.

PROJECTS	
PRISMS - Protocol, Randomness & Information Security Measures for Space	47

BAY PHOTONICS

www.bayphotonics.com

Bay Photonics provide semiconductor chip level packaging solutions, both protecting the delicate chip and enabling the interface between photonic integrated circuits (PICs) and the real world. In the AirQKD project Bay Photonics will be housing the quantum emitters and detectors in thermally controlled, hermetic packages providing the electrical connection to the control electronics. Additionally, Bay Photonics is the core photonic sensor developer for SPLICE and is working on compact integrated and manufacturable designs.

Bay Photonics design and develop robust, commercially viable optical modules utilizing proprietary optical packaging techniques. Bay Photonics highly experienced development engineering team have combined knowledge on thermal, mechanical and optical disciplines in order to design systems achieving the long-term stability requirements for narrow linewidth lasers which drive many quantum processes that are going to revolutionise navigation, sensing metrology in the near future.

PROJECTS	
Agile Quantum Safe Communications (AQuaSec)	13
AIRQKD	16
Single Photon Infrared Imaging, Detection and Ranging (SPIDAR)	22
Single Photon Lidar Imaging of Carbon Emissions (SPLICE)	23
Sidewinder	42
UK National Foundry for Quantum Components (QFoundry)	31
A PAckageD source of Multiplexed Entangled photons (PADME)	95
Q3MD: single photon sensitive detector for methane gas detection operating at 3µm	120
Q-Pods - Holistically Packaged Integrated Optoelectronic Devices for Quantum Systems	127
High Quantum Efficiency Detectors	72

BEYOND BLOOD DIAGNOSTICS LTD

www.beyondblood.co

Beyond Blood Diagnostics is working on the latest technologies to advance monitoring the health of chronic patients.

Our patented innovation allows for rapid and cost-effective isolation of blood cells with unparalleled accuracy. Whether you need to monitor your overall health or detect specific diseases, our user-friendly device brings the gold standard immunity test (Full Blood Count) right to your fingertips. Say goodbye to long wait times and expensive lab visits – experience the future of healthcare with BBD, where convenience, precision, and comprehensive health assessment meet.

PROJECTS	
Quantum technology enabled blood diagnostics for safer and more patient centric cancer care & treatment management	175

BOSTON LIMITED

www.boston.co.uk

With 30 years of trading within the distribution and OEM marketplace, Boston Limited continue to lead the way in providing the latest high performance power optimised technologies into the HPC, ISP, Military, VFX, Enterprise and Broadcast markets with our multi-award winning server, storage, workstation and clustered solutions.

We are uniquely placed with our experience in the assembly, testing and validation of high-performance bespoke solutions that have been designed to meet a client's/projects exact requirements. Combined with our ability to turn around a fully bespoke platform including client

specific branding, documentation, packaging and global on-site maintenance packages, we strive to provide a genuine range of value added services to our partners.

Following on from the successful launch of Boston IT Solutions (India) Private Limited in 2009, we announced the launch of Boston Server & Storage Solutions GmbH in 2010. Expansion into both regions has been driven purely by market demand for alternate vendors providing high-performance and high value-add systems. As our global reach continues to expand we plan on opening further global facilities to improve growth for the company in addition to catering for growing client and project needs.

PROJECTS	
A novel, quantum model for NLP: a step towards AGI.	139

BP

www.bp.com

BP is leading evaluating SPLICE gas cameras across their global operations.

PROJECTS	
Agile Quantum Safe Communications (AQuaSec)	13
Single Photon Lidar Imaging of Carbon Emissions (SPLICE)	23
HYDRI - HYDrogen sensoR for Industry	59
The quantum data centre of the future	61

BRITISH TELECOMMUNICATIONS PUBLIC LIMITED COMPANY

www.bt.com

Our core activity has been engaging in trials of QKD involving real world customer sites, of which the primary installation has been between the National Composites Centre and the Centre for Modelling and Simulation in Bristol. BT has also been engaged in a market study for quantum technologies in communications.

BT is the UK's leading telecommunications service provider, with particular expertise in optical and wireless (5G) communications as well as performing internationally-leading research into network security and quantum-secure communications. In AirQKD, BT is providing overall leadership to the project, offering key inputs into the design and specifications of the free-space optical AirQKD architecture, its quantum key distribution (QKD) requirements, and the techno-economic and commercial contexts for successful deployment of AirQKD technology. BT is also providing the test site for the field demonstrator studies involving 5G-interfaced secure connected vehicle communications.

PROJECTS	
Agile Quantum Safe Communications (AQuaSec)	13
AIRQKD	16
Next Generation Satellite QKD - Creating a UK Sovereign Capability for Manufacturing Satellite QKD Payloads	19
CIFS - Calcium Ion Frequency Standard	56
The quantum data centre of the future	61
Towards a Quantum enabled Cloud	62
Near-term quantum computing for solving hard industrial optimisation problems	110

CALEDONIAN PHOTONICS

www.caledonianphotonics.com

Caledonian Photonics Limited is a consultancy in the field of robust, miniaturised solid-state lasers and associated optical systems. Caledonian Photonics have expertise in design for manufacture, reliability and environmental insensitivity, with experience of the academic, scientific and defence markets. Based in central Scotland, Caledonian Photonics was founded in May 2018. Since that time Caledonian Photonics has been engaged in consultancy to the Photonics industry and in technology development for exploitation in future laser products.

PROJECTS	
High-BIAS2: High-Bandwidth Inertial Atom Source & Sensor	17
Safire	41
HYDRI - HYDrogen sensoR for Industry	59
QT Assemble: Integrated Quantum Technology Programme	28

CAMBRIDGE QUANTUM COMPUTING LIMITED

www.cambridgequantum.com

Cambridge Quantum (CQ), part of Quantinuum, is a quantum computing software and algorithms company, and in essence we solve one critical problem – to allow our customers to get the most out of quantum computers and make them useful both now and in the future. Our focus is in the areas of quantum chemistry, quantum machine learning, quantum natural language processing and quantum cybersecurity.

PROJECTS	
Noise Analysis and Mitigation for Scalable Quantum Computation	74
Assurance for quantum random number generators	25
Feasibility study to quantify the potential of using quantum algorithms to simulate MHD effects in liquid metals	143

CDO2

www.cdo2.com

CDO2 has developed a new technique for imaging the current flow in battery systems. This technology is being deployed in battery test systems so that researchers and manufacturers can improve the yield, performance and safety of battery cells. CDO2 also build sensors and control electronics into battery modules to produce lighter, safer and more efficient battery packs.

PROJECTS	
Quantum sensors for end-of-line battery testing	21
Feasibility study of using Quantum Sensors when developing new batteries and when recycling batteries	99

CENTRE FOR PROCESS INNOVATION

www.uk-cpi.com

We are over 450 scientists, engineers, and business specialists helping companies to develop, prove and commercialise new products and processes.

PROJECTS	
Quantum sensors for end-of-line battery testing	21
High Quantum Efficiency Detectors	72

CERCA MAGNETICS LIMITED

www.cercamagnetics.com

Cerca Magnetics Limited offer the world's most advanced functional brain scanner – an integrated lightweight, ergonomic and wearable device that will offer an unparalleled window on human brain function, in health and disease.
We have developed and brought to market the world's first commercial, fully integrated brain imaging device based on optically-pumped magnetometers (OPMs), the Cerca OPM-MEG System.

Conventional magnetoencephalography (MEG) systems employ cryogenic sensors – cooled to -269 °C using liquid Helium – to measure the extremely small fields generated by the brain. However, the need for cryogenic infrastructure severely limits usability and system performance.
New breakthroughs in physics have enabled fabrication of devices that exploit the quantum properties of atoms to measure very small magnetic fields. These sensors, known as optically-pumped magnetometers (OPMs) do not need liquid helium cooling, and they are around the size of a Lego brick.

This means they can be mounted on the head in a helmet, which is worn by the participant. Through this change in scanner architecture we are able to turn a half tonne, one-size-fits-all cryogenic machine with fixed sensors, into a lightweight, flexible and wearable system.

Helmets can be made to fit anyone, meaning it is possible to scan adults, or babies, using the same system and because the system is wearable, sensors move with the head meaning participants can move during a scan.

PROJECTS	
Brain Imaging Using OPM-MEG: Newborn to Toddler	81

CGA SIMULATION LIMITED

www.cgasimulation.com

CGA creates bespoke digital twin simulations that can help validate the safety of autonomous vehicle technology. We also develop smart city resilience models that predict how technologies will operate/interact together in the future, to prepare cities for upcoming crises like pandemics, terrorism, congestion, mobility and poor air quality.
CGA Simulation brings futurology to life. We create robust, dynamic and complex simulations that use our own source and destination data to model the world. This allows us to be more experimental, predicting transport and smart city models with data that doesn't yet exist - we've even modelled Covid 19 spread around a UK city. Our digital twin cities/road networks use pattern of life simulations to bring day-to-day interactions to life. The complexity of our models means we can validate the safety of autonomous vehicle technology against a diverse panoply of hazards. We work with academics in the field (University of Liverpool amongst others) to identify niche areas for exploration; our research has led us to intricately model the impact of rain on sensors, an area that had not been previously explored in this way.

PROJECTS	
Quantum Annealing for Transport Optimization – QATO	148

CHASE RESEARCH CRYOGENICS LTD

www.chasecryogenics.com

Chase Research Cryogenics designs and manufactures sub-Kelvin sorption cooler systems for a wide and growing range of scientific and engineering fields. Current applications include astrophysics, quantum technologies, nanotechnology, materials science and life sciences.

Our main activity is the design and manufacture of sub-Kelvin sorption coolers, with a strong emphasis on custom design to individual specifications. When pre-cooled to 4K using a liquid helium bath or mechanical cryocooler, our compact sorption coolers can achieve temperatures

between 100mK and 1K. Historically, most of our customers have come from the astronomical research community and our sorption coolers have been used in the detector arrays of many ground-breaking experiments. Increasingly, our gas-light systems, which offer great affordability and usability, are cooling
many of the new cutting-edge industrial applications of quantum technology.

We continue to innovate and extend our product range to offer new possibilities to work at ultra-low temperatures. Our continuous sorption cryocoolers can provide stable sub-kelvin temperatures for extended periods, even months at a time.
If you are already working with mechanical coolers at 4K, our systems are a surprisingly affordable way to reach the next level of cool!

PROJECTS

CHRONOS TECHNOLOGY LIMITED

http://chronos.uk

Chronos Technology is a leading international authority in resilient synchronisation and timing systems, smart technologies, GNSS and cyber security solutions for critical national infrastructure with unrivalled industry experience gathered over 35 years in specialist technologies such as GNSS, PTP, NTP and SyncE. Working closely with our customers and their evolving requirements, our team of technical experts provide complete solutions from network design, solution specification, installation & commissioning and 24/365 support, delivering best performance for timing & navigation applications. In addition, we offer novel GPS coverage solutions in hangars, manufacturing areas and underground and GNSS jamming detection and location solutions for law enforcement. We are trusted as experts by our customers across the telecom, finance, energy, data centre, broadcast, aerospace, defence & security, enterprise/IT, emergency services, transport and manufacturing sectors.

A world leader in GNSS vulnerability detection and geolocation technology, Chronos also specialises in equipment for industrial Positioning, Navigation and Timing (PNT) solutions via the GPS-World.biz website, including GPS coverage underground solutions.

ISO9001 accredited, Chronos is a member of the ITU Standards Committee (ITU-T SG15/Q13), and Prof. Charles Curry is founder of the International Timing Sync Forum (ITSF) which is the largest annual conference focusing on synchronisation and timing technology in networks.

PROJECTS

CISCO INTERNATIONAL LIMITED

www.cisco.com

Cisco (NASDAQ: CSCO) enables people to make powerful connections--whether in business, education, philanthropy, or creativity. Cisco hardware, software, and service offerings are used to create the Internet solutions that make networks possible--providing easy access to information anywhere, at any time.

Cisco was founded in 1984 by a small group of computer scientists from Stanford University. Since the company's inception, Cisco engineers have been leaders in the development of Internet Protocol (IP)-based networking technologies. Today, with more than 71,000 employees worldwide, this tradition of innovation continues with industry-leading products and solutions in the company's core development areas of routing and switching, as well as in advanced technologies such as home networking, IP telephony, optical networking, security, storage area networking, and wireless technology. In addition to its products, Cisco provides a broad range of service offerings, including technical support and advanced services.

Cisco sells its products and services, both directly through its own sales force as well as through its channel partners, to large enterprises, commercial businesses, service providers, and consumers.

PROJECTS

CITY SCIENCE CORPORATION LIMITED

www.cityscience.com

City Science is an independent firm of software developers, data scientists and experts in transportation and energy. We build products to help engineers, planners and leaders deliver the future. We were founded out of the need to respond to climate change, and, as a result, are committed to advancing our customers understanding of the systems they operate, helping them reduce waste, improve efficiency and hopefully make the world better.

PROJECTS

COLDQUANTA

coldquanta.com

ColdQuanta is the leader in Cold Atom Quantum Technology, the most scalable, versatile, and commercially viable area of quantum. ColdQuanta is dedicated to making quantum a reality through the development of a cloud-based Quantum Computer and Precision Sensing and Networking solutions. ColdQuanta collaborates with global customers, including major commercial and defence companies to advance products and services developed with Cold Atom Quantum Technology.

PROJECTS	
High-BIAS2: High-Bandwidth Inertial Atom Source & Sensor	17
PICAS2: Photonically Integrated Cold-Atom Source and System	40
QT Assemble: Integrated Quantum Technology Programme	28
CALYX : Cold-Atom Light via efficient Cavity Extraction	96
Miniature Packaged Ion Traps	109
RALFS - Rydberg Atom Low Frequency Sensing	130
TALENT - Tapered AmpLifiErs for quaNtum Technologies	134
Ultracold quantum memories	136
QECCO: Quantum End-to-end Compilation for Combinatorial Optimisation	146

COMPOUND SEMICONDUCTOR APPLICATIONS CATAPULT

www.csa.catapult.org.uk

Compound Semiconductor Applications (CSA) Catapult is focused on bringing compound semiconductor applications to life in three key areas: the road to Net Zero, future telecoms and intelligent sensing.

CSA Catapult is a Not for Profit organisation headquartered in South Wales. It is focused on three technology areas: Power Electronics, RF & Microwave and Photonics. As well as the three technology areas, CSA Catapult is also working in Advanced Packaging for these high-power innovations.

The next wave of emerging applications will have an enormous impact on our lives. Compound semiconductors will enable a host of new and exciting applications in the electrification of transport, clean energy, defence and security and digital communications markets.
CSA Catapult exists to help the UK compound semiconductor industry grow and collaborates across the UK and internationally.

PROJECTS	
AIRQKD	16
Single Photon Lidar Imaging of Carbon Emissions (SPLICE)	23
Space-certified Nonlinear Optics for Rugged Quantum Lasers (SNORQL)	44
A quantum photonics PDK	66
Quantum Electro-Optic Detector Technology (QuEOD)	29
UK National Foundry for Quantum Components (QFoundry)	31
Non-invasive quantum sensing for continuous glucose monitoring	112
QUantum communication Development with Increased Throughput for information Systems (QUDITS)	122
Silicon Nitride for Quantum Computing (SiNQ)	154

COMPOUND SEMICONDUCTOR CENTRE

www.compoundsemiconductorcentre.com

The Compound Semiconductor Centre (CSC) is Europe's new home for product, services and skills development in compound semiconductor technologies. Providing cutting-edge facilities that help researchers and industry work together CSC, based in Wales, will position Cardiff as the UK and European leader in compound semiconductors. CSC is a joint venture between compound semiconductor specialists IQE and Cardiff University.

PROJECTS	
KAIROS	15
MAG-V : Enabling Volume Quantum Magnetometer Applications through Component Optimisation & System Miniaturisation	16
Quantum sensors for end-of-line battery testing	21
UK National Foundry for Quantum Components (QFoundry)	31

COVESION LIMITED

www.covesion.com

Covesion is a world leading designer, innovator & manufacturer of magnesium doped, periodically polled lithium niobite (MgO:PPLN for highly efficient non-linear frequency conversion). With over 20 years of experience in the manufacture of PPLN, the team of experts at Covesion are well equipped to provide insight and guidance on the design of systems for generating visible and IR light.

MgO:PPLN is ideal for innovative laser applications due to its high effective nonlinear coefficient; allowing for high efficiency frequency conversion across multiple different mechanisms. MgO:PPLN supports a wide range of applications such as: quantum computing; frequency doubling of femtosecond lasers; mid-infrared generation; atom cooling; terahertz generation and biomedical imaging.

Off-the-shelf crystals & waveguides are available for SHG, DFG, OPO and SFG interactions. Covesion also manufactures a range of ovens and a temperature controller for precision thermal management.

The addition of MgO:PPLN waveguides to the Covesion product range allows end users to exploit greater conversion efficiencies and save on unnecessary pump sources within their applications.

A custom design and fabrication service provides application-specific technical consultation with specialist grating design and contract manufacture. A range of custom design packages are available, including: one-off crystals, OEM prototyping and large-volume manufacture.

PROJECTS	
Mid-IR Upconversion Single-photon detection (MIRUS)	38
Space-certified Nonlinear Optics for Rugged Quantum Lasers (SNORQL)	44
CIFS - Calcium Ion Frequency Standard	56
High Rate of Entangled Photons (HiREP)	71
QT Assemble: Integrated Quantum Technology Programme	28
UP-conversion of Single-photons for ENvironnmental SEnsing [UP-SENSE]	135
Broadband Quantum Synthesizer (BQS)	171

CPI TMD TECHNOLOGIES LIMITED

www.cpii.com/division.cfm/16

CPI TMD is one of the world's leading manufacturers of microwave power sources, high-voltage power supplies and transmitters for radar, electronic warfare, communications, industrial testing and scientific applications. CPI TMD's specialty is innovative, custom solutions for some of the industry's most challenging applications.

CPI TMD offers a unique range of microwave power modules, traveling wave tubes, high-voltage power supplies, as well as rugged amplifiers and instrumentation amplifiers for radar, electronic warfare, communications and electromagnetic compatibility (EMC) testing, scientific and medical applications. CPI TMD's products are optimized for use on airborne, ground based and shipboard platforms.

PROJECTS	
CIFS - Calcium Ion Frequency Standard	56
Developing an error corrected quantum processor solution for commercial quantum computing	57
Fibre-based memory module for photonic quantum computing	70
DISCOVERY: Developing UK Industrial Supply for Commercial Quantum Computing	26
GRADUATE	100
Development of highly efficient, portable, and fibre-integrated photonic platforms based on micro-resonators	166
HARLEQUIN - High-Accuracy Robust deployable QUantum Inertial Navigation	157

CRAFT PROSPECT LTD

www.craftprospect.com/

Craft Prospect is a space engineering practice based in Glasgow, UK. Our work includes NewSpace mission and systems engineering; collaborative R&D on enabling technology and novel downstream space applications. We aim to unlock the potential of Earth-observing nano-satellites for onboard data autonomy and deliver a higher mission return.

PROJECTS	
PRISMS - Protocol, Randomness & Information Security Measures for Space	47
Viable Satellite Free Space Optical Quantum Key Distribution Technologies (ViSatQT)	52
Developing the first Space-suitable Quantum Random Number Generator	83
Next-Generation Satellite Telecommunications Entangled Photon Source (NextSTEPS)	111

CRYPTA LABS LIMITED

www.cryptalabs.com

Crypta Labs is an Award Winning Quantum Security company that has developed quantum based encryption solutions to secure Aerospace Defence and Critical Infrastructure. We are FCC approved UK Network/5G Vendor, Quantum HSM. Our patented portolfio of solutions uses the quantum properties of light to detect the photons to generate a QRN.

PROJECTS	
Assurance for quantum random number generators	25

CS CONNECTED

csconnected.com

CS Connected is the Research and Technology Organisation that represents the activities of organisations involved in compound semiconductor related activities.

PROJECTS	
UK National Foundry for Quantum Components (QFoundry)	31

DASHBOARD

dashboard.net

Dashboard exists to make industry intelligent, safer, cleaner, and more efficient with its Industrial Internet of Things predictive platform. Dashboard harnesses new technologies

for customers to deliver profitability, safety, security and environmentally sustainable outcomes by the ethical use of knowledge and discovery from data.

PROJECTS	
Agile Quantum Safe Communications (AQuaSec)	13

D-BEAM LTD

http://d-beam.co.uk

Beam provides reliable, robust, and cost efficient diagnostic solutions for use at accelerator and clinical facilities, light sources, and reactors, with applications in research, healthcare, security, environment and manufacture. Our diagnostics are developed with the user in mind, to maximise value and minimise difficulties. Customer satisfaction is our main priority, therefore we take a consultation approach, ensuring each diagnostic solution is tailored to our customers' needs and values. We offer a range of instrumentation, from more tested and traditional systems to cutting-edge novel designs, from single components to full systems with software integration.

Our mission is to listen to our client's specific needs and deliver high performance products through continuous product innovation and operational excellence. Because of the pivotal role we play in your business, D-Beam is committed to creating and maintaining strong relationships with our customers, built on a foundation of excellence and trust. From the products we manufacture to our dedicated customer service and support, we know what's important to you.

D-Beam has been partner in a number of UK and EU projects, and has been awarded funding with academic partners through ARIES Proof of Concept, STFC Impact Acceleration Account and STFC Innovation Partnership Scheme Follow on Fund. Our optical-fibre beam loss monitor (oBLM) was selected as an ASTeC technology highlight of the year in 2018/2019. We were also selected an STFC Impact Acceleration Account success story in 2020. Cutting edge R&D is always at the forefront of priorities and we always welcome the chance to collaborate on novel and exciting instrumentation projects.

PROJECTS	
Quantum Gas Jet-based Helium Atom Microscope (qHAM)	87

DELTA G LIMITED

www.delta-g.co.uk

Delta g is a quantum technology and gravity gradiometry company on a mission to make gravity sensing technology as ubiquitous as GPS, radar and telecoms. Spinning out from the University of Birmingham in 2023, our technology is the world's first quantum technology based gravity gradient capability to successfully detect buried features from their gravity profile alone.

Gravity sensors have the potential to impact much of todays world for the better; reducing traffic jams by eliminating unnecessary roadworks, a reliable navigation alternative to GPS and improving the environment through better monitoring and models.

Limitations in current technology have prevented gravity sensing from reaching its disruptive potential. Our solution harnesses the quantum nature of atoms to produce a gravity gradient capability that is inherently immune to many of the noise sources hindering current technology. Enabling measurements in previously impossible environments at a fraction of the cost.

A world-class team of experts from science, engineering, and business, supported by end-users from civil engineering, infrastructure, defence, and rail, Delta g will realise our vision of creating the "Google Maps of the underground".

PROJECTS	
CompaQT	97

DIAMOND MICROWAVE LIMITED

www.diamondmic.com

Diamond Microwave Ltd (DML) is a technology startup, offering leading edge microwave GaN solid-state power amplifiers (SSPA). Our engineering resources have broad ranging research, design, development and manufacturing experience in the microwave field and we continue to work on improvements to bandwidth, power, efficiency and size.

Diamond Microwave's strength is in compact, High-Power, Microwave Solid-State Power Amplifiers (SSPA), designed for use in a range of demanding high-performance applications such as radar, communications, medical and routine laboratory use. Our microwave SSPA offer state-of-the-art peak power output performance with a power-to-volume ratio which we believe to be among the highest in the microwave industry for such products. Diamond Microwave SSPA portfolio ranges from 10W to 1kW, operating in specific bands between 2GHz and 18GHz. These compact and robust high power amplifiers are suited for use across a range of civil and military applications, such as:

- Weather radar
- Medical and materials science
- Marine radar and maritime vessel traffic control
- Air traffic control and Port security radars
- Military tracking radars
- Airborne or space-borne SAR for ground mapping
- EW and jamming

PROJECTS	
Developing an error corrected quantum processor solution for commercial quantum computing	57

DIGITAL CATAPULT

www.digicatapult.org.uk/

Digital Catapult is the UK authority on advanced digital technology. Through collaboration and innovation, we accelerate industry adoption to drive growth and opportunity across the economy.

Through our specialist programmes and experimental facilities, we make sure that innovation thrives and the right solutions make it to the real world.

PROJECTS	
The quantum data centre of the future	61

DOTQUANTUM LTD

www.dotquantum.co.uk

dotQuantum's technology provides up to a 10x increase in secure-key rate for quantum key distribution - offering what it takes to safe-guard the Quantum Internet.

PROJECTS	
PRISMS - Protocol, Randomness & Information Security Measures for Space	47

DUALITY QUANTUM PHOTONICS

www.dualityqp.com

Duality Quantum Photonics are an early-stage quantum computing start-up developing integrated photonics-based hardware architectures. They were founded in February 2020 and are based in Bristol.

PROJECTS	
NISQ.OS	27
Connectorizing Integrated Quantum Photonics Devices	165
Quantum Optical Neural Networks for Quench Prevention	151

EDWARDS LIMITED

www.edwardsvacuum.com

Edwards is a leading developer and manufacturer of sophisticated vacuum products, abatement solutions and related value-added services. Our products are integral to manufacturing processes for semiconductors, flat panel displays, LEDs and solar cells; are used within an increasingly diverse range of industrial processes including power, glass and other coating applications, steel and other metallurgy, pharmaceutical and chemical; and for both scientific instruments and a wide range of R&D applications. Edwards is part of the Atlas Copco Group

PROJECTS	
Developing an error corrected quantum processor solution for commercial quantum computing	57

ERNST & YOUNG LLP

www.ey.com/en_uk

EY exists to build a better working world, helping create long-term value for clients, people and society and build trust in the capital markets.

Enabled by data and technology, diverse EY teams in over 150 countries provide trust through assurance and help clients grow, transform and operate.

Working across assurance, consulting, law, strategy, tax and transactions, EY teams ask better questions to find new answers for the complex issues facing our world today.

PROJECTS	
Q-REALM Wind	147

ELEMENT SIX

www.e6.com

Element Six (E6) designs, develops and produces synthetic diamond and tungsten carbide solutions.

Since 1959, E6's focus has been on engineering and optimising the diamond synthesis process to unlock innovative, diamond-enabled applications, including ultra-precision machining, drilling, thermal management, optics, wastewater management and quantum-enabled sensing.

Element Six pioneered the development of single crystal diamond using the Chemical Vapour Deposition (CVD) method in the early 2000s.

With production facilities in the UK and California, the company has been at the forefront of a range of new developments in CVD diamond synthesis and associated industrial applications. Working in collaboration with a global network of partners, E6's patented technologies have unlocked many of the most exciting recent breakthroughs in quantum technology.

PROJECTS	
Diamond Quantum Sensing Platform	84
Quantum diamond magnetometry for magnetocardiography	88
Advanced Manufacturing Toolkit for Quantum Sensing and Quantum Computing	163

FUTURE CODERS LIMITED

www.future-coders.com

Future Coders is a Liverpool-based tech firm that connects universities, SMEs, Health, Social Care and Public Sector organisations to develop use cases for emerging technology. Driven by an inclusive approach to tech, we still want to hear from those we can help to make dreams a reality. We take TRL1 to TRL7.
Future Coders has a sister company, Digital Creativity in Disability, that focuses on technology for disabled persons and medical/social care-oriented technologies.

PROJECTS	
Quantum Annealing for Transport Optimization – QATO	148

FRAUNHOFER UK RESEARCH LIMITED

www.cap.fraunhofer.co.uk

Fraunhofer Centre for Applied Photonics, part of Fraunhofer UK, is a UK not-for-profit research and technology organisation (RTO) offering industry professional development services in the field of photonics. Fraunhofer CAP has been a delivery partner in a significant number of industry led projects within the UK Quantum Technologies Programme. It has catalysed collaborations with end users and as well as playing a project leadership role. Fraunhofer CAP has extensive experience in developing practical and robust laser sources, optical subsystems and full systems for quantum technology applications which meet stringent requirements while maintaining suitable size, weight, and power characteristics. These systems play a key enabling role in many applications such as timekeeping, sensing, navigation, computing, and secure communication.

PROJECTS	
3QN: Towards A New UK Industry for Novel Quantum Receivers in Nascent Satellite QKD Global Markets	12
Pioneer Gravity: Gravity sensors for infrastructure productivity, situational awareness and seeing the invisible	14
AIRQKD	16
High-BIAS2: High-Bandwidth Inertial Atom Source & Sensor	17
Next Generation Satellite QKD - Creating a UK Sovereign Capability for Manufacturing Satellite QKD Payloads	19
369GaN	32
Mid-IR Upconversion Single-photon detection (MIRUS)	38
PICAS2: Photonically Integrated Cold-Atom Source and System	40
Quantum Terahertz Imager using Coherent control (QuanTICo)	49
Sidewinder	42
STREAMLINE	45
TuNaFISH	46
HYDRI - HYDrogen sensoR for Industry	59
Towards a Quantum enabled Cloud	62
Underwater Single Photon Imaging System	63
UpScale: Scalable quantum information enabled by integrated optics	64
Blue FLAME	67
Dual-FISH	68
High Rate of Entangled Photons (HiREP)	71
Towards a Quantum Internet	80
QT Assemble: Integrated Quantum Technology Programme	28
High Performance Quantum Light Source	104
MANGROVE	107
Next-Generation Satellite Telecommunications Entangled Photon Source (NextSTEPS)	111
PAssively STabilised Laser (PASTEL)	115
Platipas - Passive Platform Development for Visible Wavelengths	118
TALENT - Tapered AmpLifiErs for quaNtum Technologies	134
TransmissION	135
UP-conversion of Single-photons for ENvironnmental SEnsing [UP-SENSE]	135
QUANTUM SPECS - Single Photon detection for Excellence in Communication and Sensing	79

GEOMATRIX EARTH SCIENCE LIMITED

www.geomatrix.co.uk

Geomatrix Earth Science (GES) Ltd offers one of the largest short term hire pool of near surface Geophysical Instrumentation in Europe.

GES are retained as exclusive sales representatives by many of the leading geophysical instrument and software manufacturers for products such as GPR, magnetometers, seismographs, gamma ray spectrometers, EM sounding and profiling instruments Gravity meters and resistivity meters. These manufacturers are world renowned for their emphasis on providing high data quality and instrument reliability in the most arduous of field conditions.

PROJECTS	
Pioneer Gravity: Gravity sensors for infrastructure productivity, situational awareness and seeing the invisible	14

GMV NSL LIMITED

www.gmv.com

GMV is a privately owned technological business group with an international presence. Founded in 1984, GMV offers its solutions, services and products in very diverse sectors: Aeronautics, Automotive, Banking and Finances, Cybersecurity, Space, Defense and Security, Healthcare,

Intelligent Transportation Systems, Telecommunications, and ICT for Public Administration and large corporations. Our goal is to support our client's processes by dint of technologically advanced solutions, providing integrated systems, specialized products and services covering the whole life cycle. These range from consultancy and engineering services up to the development of software a nd hardware, the integration of turnkey systems and operational backup.

PROJECTS	
QWRTY	162

GOOCH & HOUSEGO

gandh.com

G&H's advanced optical engineering and manufacturing enables effective OEM system supply and development. G&H's expertise in optical systems, subsystems and components extends from research through the development of prototypes to volume manufacturing and is a catalyst for innovation and effective manufacturing in the aerospace and defence, industrial and telecom, and life sciences and biophotonics sectors.

From eleven sites across the UK, USA and Asia, our capabilities span a uniquely broad range of photonic technologies: crystal growth, optical materials processing, acousto-optics and electro-optics, active and passive fibre optic components, precision optics, opto-mechanical and medical systems.

G&H's QA, compliance and supply chain management systems assure our customers of reliability extending beyond the technical.

PROJECTS	
QT Assemble: Integrated Quantum Technology Programme	28

HAMPSHIRE HOSPITALS NHS FOUNDATION TRUST

www.hampshirehospitals.nhs.uk

Hampshire Hospitals NHS Foundation Trust serves a population of approximately 600,000 people across Hampshire and parts of west Berkshire.

This includes people living in Andover, Basingstoke, Eastleigh and Winchester as well as the surrounding towns and villages across Hampshire and parts of west Berkshire including Tadley to the north; Alton and Bordon to the east; Romsey and Chandlers Ford to the south, Stockbridge, Bishops Waltham and Alresford.

Hampshire Hospitals NHS Foundation Trust came into being in January 2012 as a result of the integration of Basingstoke and North Hampshire NHS Foundation Trust, which achieved Foundation Trust status in 2006, and Winchester and Eastleigh Healthcare Trust. It is an NHS provider and care is free at the point of delivery.

Hampshire Hospitals NHS Foundation Trust employs around 8,600 staff and has a turnover of over £500 million a year. There are around 15,000 public and staff members. As a Foundation Trust it has directly accountable to its members through the governors. Council of Governors represent the interests of their constituencies and influence the future plans of the Foundation Trust.

PROJECTS	
Developing valuable operational healthcare applications using quantum computing techniques	140

HCD RESEARCH

www.hcdresearch.co.uk

HCD Research is a UK based company that has specialised in the design and manufacture of oven controlled crystal oscillators (OCXO) for over five decades. Our OCXOs are recognised throughout the world for quality and performance and are manufactured in the UK to the highest standards. Each individual OCXO is tested and setup independently to ensure the most accurate, consistent output possible. Our standard products meet a broad range of specifications and we also have the skill and capability to tailor bespoke solutions if required.

PROJECTS	
KAIROS	15
Aeon-Rb	53

HELIA PHOTONICS LIMITED

www.helia-photonics.com

Helia Photonics specialises in demanding optical coatings for micro-optics and light emitting semiconductor devices. With over 15 years of trading and over a hundred well established customers, Helia Photonics aims to become the premier player in its field.

Helia employs a range of vacuum optical coating technologies and with a keen interest in reinvestment and research, plans to ensure a strong foothold at the forefront of high power diode lasers and high performance antireflection coatings.

Helia are constantly looking at global developments in photonics devices & ensuring that processes are in place to address these ever-demanding requirements.

Active areas of internal research & development include:

- Lifetime enhancing antireflection (AR) coatings for GaN lasers
- Lifetime enhancing OC coatings for AlGaAs lasers
- Ultra-broadband antireflection (AR) coatings for long wave infrared quantum cascade lasers (LWIR QCLs)
- Tight-edge dichroics for Silicon detectors
- Ion Beam Sputtering (IBS) & Atomic Layer Deposition (ALD) for photonics devices
- Low energy deposition for organic devices

Helia Photonics are active in development & research with organisations such as the Technology Strategy Board (TSB),
The Scottish University Physics Alliance (SUPA) & the Small Companies Innovation Scheme.

- High damage threshold coatings for high power semiconductor pump lasers & arrays
- Novel high catastrophic optical mirror damage (COMD) threshold processes for AlGaAs lasers
- Ultra-low anti-reflection coatings for semiconductor laser facets & free space optics (FSO)
- Infrared anti reflection (AR)/ high reflectivity (HR) coatings for Quatum Cascade Lasers (QCL)
- Ultra-low reflectivity coatings (less than 0.01%) on a variety of substrates
- Range of bandpass & dichroic filters in the ultra-violet (UV), visible & infrared (IR)
- Coatings on optical fibre ends & plastics
- Optical metallic coatings

PROJECTS	
369GaN	32

HITACHI EUROPE LIMITED

www.hitachi.eu

Since its founding in 1910, Hitachi has responded to the expectations of society and its customers through technology and innovation. Our mission is to "Contribute to society through the development of superior, original technology and products." Over the past 100+ years this commitment has led us to work towards creating a more sustainable society through our "Social Innovation Business". We work to apply our expertise in information technology (IT), operational technology (OT), and a wide variety of products to advance social infrastructure systems and improve quality of life across the world.

Hitachi's Social Innovation Business is centered around 5 growth sectors: Mobility, Smart Life, Industry, Energy, and IT. Globally, we have nearly 300,000 employees who are working to improve people's quality of life and our customers' social, environmental, and economic values to create a sustainable future. The challenges we face as a society are unprecedented, but so are the opportunities. Together, let's start powering good.

PROJECTS	
NISQ.OS	27

HORIBA MIRA LIMITED

www.horiba-mira.com

HORIBA MIRA is a global provider of pioneering engineering, research and test services to the automotive, defence, aerospace and rail sectors. With over 70 years' experience in developing some of the world's most iconic vehicles, our engineers utilise the latest test facilities and simulation tools to make vehicles and journeys safer, cleaner, more efficient and rewarding.

PROJECTS	
Single Photon Infrared Imaging, Detection and Ranging (SPIDAR)	22

HSBC BANK PLC

www.hsbc.co.uk

HSBC Bank plc is a British multinational banking and financial services organisation. HSBC's international network comprises around 7,500 offices in over 80 countries and territories in Europe, the Asia-Pacific region, the Americas, the Middle East and Africa. We are opening up a world of opportunity for our customers, investors, ourselves and the planet.

PROJECTS	
Quantum Machine Learning for Fraud Detection	89
Quantum Unsupervised Learning for Anti-Money Laundering Detection	152

HSBC GROUP MANAGEMENT SERVICES LIMITED

www.hsbc.com

Opening up a world of opportunity for our customers, investors, ourselves and the planet.

We're a financial services organisation that serves more than 40 million customers, ranging from individual savers and investors to some of the world's biggest companies and governments. Our network covers 63 countries and territories, and we're here to use our unique expertise, capabilities, breadth and perspectives to open up a world of opportunity for our customers.

PROJECTS

High-speed self-certifying Quantum Random Number Generator for simulationsn	103

ID QUANTIQUE SA

www.idquantique.com

ID Quantique has established itself as a leader in the fields of quantum-safe crypto, scientific instrumentation and random number generators. Its products are used by government, enterprise and academic customers in more than 60 countries and on every continent.

QUANTUM-SAFE CRYPTO

IDQ provides high-performance quantum-safe network encryption solutions for the protection of data in transit; supporting up to 100Gbps on local and storage area networks for data center interconnect & DRC, as well as on fully meshed global WAN networks for international operations.

By using state-of-the-art algorithms and highly secure quantum key generation and quantum key distribution (quantum cryptography) IDQ ensures that solutions are "quantum-safe" for the long-term protection of sensitive data into and beyond the quantum era, when quantum computers will render most of today's conventional encryption algorithms vulnerable.

PHOTON COUNTING

IDQ also has a growing scientific instrumentation business, where the company's core quantum photonics technologies provide innovative solutions for industrial, commercial and research applications. Its product offering includes photon-counters for the visible and infrared regions of the optical spectrum, short-pulse laser sources, as well QKD platforms for R&D applications.

RANDOM NUMBER GENERATORS

IDQ also develops and commercializes random number generators based on quantum physics, which are used in several industries, including security and gaming and lotteries, where they have become a reference. The QRNG devices have been independently certified by a Swiss national laboratory and have been validated according to AIS 31 criteria.

IDQ has a global footprint through its R&D partnerships with leading companies and R&D institutions. It maintains close ties with academic institutions by participating in several Swiss and European R&D programs and plays a leading role in cutting-edge projects to drive innovation to the market.

PROJECTS

Assurance for quantum random number generators	25

III-V EPI LIMITED

www.iii-vepi.com

Wafer Design : Manufacturing : Test and Characterisation

III-V Epi provides a range of compound semiconductor wafer foundry services. We specialise in the manufacture of low to medium volume, MBE and MOCVD, III-V, epitaxial structures for compound semiconductor device applications. We offer wafer design, product development and process optimisation along with a complete range of test, metrology and characterisation services.

III-V Epi helps its customers to bring new compound semiconductor products to market, as quickly as possible.

PROJECTS

UK Supply cHAin for stRontium clocK Vertical External Cavity Surface Emitting Lasers (UK-SHARK-VECSELs)	91

INEX MICROTECHNOLOGY

www.inexmicro.com

INEX is an innovative company offering leading-edge production of micro/nano technology and semiconductor based systems. Established in 2002 as a commercial unit of Newcastle University in North East England, it rapidly grew a strong reputation for specialist manufacturing services and close collaborative relationships with partners and customers.

INEX is now a valued commercial partner for delivering next generation sensors, advanced RF/power devices and miniaturized systems.

The significant investment INEX has enjoyed over more than 10 years puts the company at an unqualified technological advantage. With full-featured processing on a 151mm line, we are seen as unique in the UK for comprehensive processing of microsystems and compound semiconductor based electronics.

Wherever you are in the world, INEX is your production partner.

PROJECTS

MAG-V : Enabling Volume Quantum Magnetometer Applications through Component Optimisation & System Miniaturisation	16
Aeon-Rb	53
Q-Cell - Functionalised Plug and Play Vapour Cell Module	77
QT Assemble: Integrated Quantum Technology Programme	28
QGyro	121

INTEGRATED COMPOUND SEMICONDUCTORS LIMITED

www.icsld.com

The ICS core expertise encompasses epitaxial structure design, optical and radio frequency chip design and fabrication and supply of prototype RF and optical components in chip and packaged formats.

This expertise is rooted in a long term proven ultra-high sensitive component design and fabrication which have been proven in the most demanding applications and under some of the harshest operational conditions.

PROJECTS	
KAIROS	15
Quantum sensors for end-of-line battery testing	21
UK National Foundry for Quantum Components (QFoundry)	31
High Performance Control and Error Correction Hardware for Quantum Computing	178

INSTADEEP LTD

www.instadeep.com

nstaDeep is a leading global technology company offering a range of AI solutions, ranging from optimized pattern-recognition, GPU-accelerated insights, to self-learning decision making systems.
-Decision-making systems: Life and business are all about decisions. InstaDeep harnesses the power of reinforcement learning to create systems that can make decisions on their own, based on their own autonomous training. Many fields can benefit greatly from this technology, be it robotics, mobility, logistics, finance or healthcare.
-GPU-accelerated insights: When you try to deploy AI in your business, compute power is key.
A Multi-GPU setup can be messy and complicated. With Nvidia's DGX-1 (one of the most
powerful AI machines on the market), InstaDeep can help you achieve insane computing power to solve even the most intensive AI problems.
-Optimized Deep Learning: Deep Learning delivers high-performance AI for pattern recognition yet is notoriously time-consuming to fine-tune. InstaDeep boosts this process to save you time and money on your computer vision, natural language processing or predictive analytics project.

PROJECTS	
Quantum Computing based density functionals for fast and accurate materials and chemistry simulations	149

INTELLIGENT VOICE

https://intelligentvoice.com/

Intelligent Voice provide secure speech and NLP solutions to regulated and privacy-sensitive industries. Pioneers in GPU-processing of speech, Intelligent Voice ("IV") takes audio, video and text in up to 25 languages and dialects and rapidly transforms it using transcription, NLP and biometric techniques into a structured, normalised format capable of further processing and indexing.
IV's LexiQal module adds in state-of-the-art AI and NLP techniques to define deeper insights, surfacing sentiment, deception and other key markers to help with sales enablement, fraud and other behavioural use cases.
The IV "SmartTranscript" is generated to give instant visual access to all of this information, allowing a user to quickly understand everything that is being said and surfaced in one interface.
IV can be deployed fully on-prem, in a private cloud (AWS/Azure), or via private SaaS. IV has multiple pre-built connectors and a REST-based API.

PROJECTS	
A novel, quantum model for NLP: a step towards AGI.	139

IOETEC LIMITED

www.ioetec.com

Ioetec connect IoT devices to authorised users securely, so the data is secure and the device is safe to use.
Ioetec supports virtually any type of device including low power, encompassing most common communication methods with no expertise required to embed.
We do this via a unique cloud based, fully automated multi layer encryption & authentication cyber security subscription solution that handles data safely and securely, for a device agnostic, 'true end to end', secure Internet of Things.
With Ioetec on-board, you don't need to be an IoT security expert to be secure.

PROJECTS	
QUANTUM 4 IOT	86

IONOPTIKA LTD

https://ionoptika.com/

As specialists in Ion Beam Technology, we constantly strive to deliver new and innovative technologies to power the discoveries of tomorrow.

Established in 1994, Ionoptika are one of the leading providers of high-performance ion beam technologies for surface analysis and nanofabrication applications, and are the experts in cluster ion beams for secondary ion mass spectrometry (SIMS). Our unique water cluster beam is at the cutting edge of Mass Spec Imaging, enabling discovery

in drug discovery, lipidomics, multi-omics and materials research.

We are also known as the developers of the Q-One, a state-of-the-art tool for deterministic single ion implantation with nanoscale precision. Featuring a host of powerful features, the Q-One is the most advanced system for fabrication of quantum devices and advanced materials engineering.
Our product range extends from instrumentation, to individual ion beam systems, components, and accessories.

We actively encourage collaboration, and are proud to have worked with some of the brightest minds in the scientific community. If you have a project in mind that we might be able to help with, we'd be delighted to hear from you.

PROJECTS	
QUANTUM 4 IOT	86

IP GROUP PLC

www.ipgroupplc.com

IP Group accelerates the impact of science for a better future. As the most active UK based, early-stage science investor, we develop and support some of the world's most exciting businesses in deeptech, life sciences and cleantech (led by Kiko Ventures). Through Parkwalk, the UK's largest growth EIS fund manager, we also back world-changing innovation emerging in leading universities and research institutions. Our specialist investment team combines sector expertise with an international approach. Together we have a strong track record of success, having backed high-profile companies including Oxford Nanopore Technologies plc, First Light Fusion, Hysata, and Oxbotica. IP Group is listed on the Main Market of the London Stock Exchange under the code IPO.

IQE PLC

www.iqep.com

IQE manufactures Compound Semiconductor epitaxial wafers by MOVPE using Gp III-V materials such as GaAs and InP – for ultimate end-use in many photonic and micro-electronic applications including telecoms, sensing, PV, automotive, aerospace, healthcare and industrial etc. It supplies these Strategic Materials to custom design using its unique "foundry style" Business Model forming key links with its supply-chain partners who provide subsequent steps in device fabrication, packaging and modules and systems integration.

In QFoundry IQE provides epitaxial material for single photon detectors and quantum light emitters – to project partners for fabrication and packaging into components for secure quantum communications and LIDAR sensing, amongst others. In QFoundry, it will establish a scalable and reproducible technology platform for such components for future commercial Quantum Technologies.

In QuEOD IQE provides epitaxial material for single photon detectors to project partners for fabrication and packaging into components for quantum LIDAR applications in e.g. free-space QKD and chemical/environmental monitoring.

In SPIDAR IQE provides epitaxial material for single photon detectors and telecom band emitters – to project partners for fabrication and packaging into components for quantum LIDAR sensing applications.

In AQUASEC IQE provides epitaxial material for single photon detectors and quantum light emitters – to project partners for fabrication and packaging into components for secure quantum communications.

PROJECTS	
Agile Quantum Safe Communications (AQuaSec)	13
Single Photon Infrared Imaging, Detection and Ranging (SPIDAR)	22
Quantum Electro-Optic Detector Technology (QuEOD)	29
UK National Foundry for Quantum Components (QFoundry)	31

IS-INSTRUMENTS LIMITED

http://is-instruments.com

ISI is a UK R&D company that designs and develops remote sensing instrumentation for use in hostile and high-temperature environments. Clients include National Grid, Xstrata, European Space Agency and ABSL Space Products. ISI was co-founded in 2010 by Directors Dr Michael Foster and Dr Jonathan Storey, with Nicholas Bantin. The Directors are renown worldwide as experts in Optical filtering systems, Laser-enhanced remote sensing instrumentation, Photon Counting Techniques and High-precision interferometry. Together, the Directors have developed a number of instruments in the field including the Solar Swedish Telescope CRISP (www.solarphysics.kva.se/crisp.html) instrument. The Directors have 10 years' experience working with LIDAR and 3D vision systems for space-borne applications and are internationally respected in the community. ISI's core business is providing innovative solutions typically requiring laser-based remote sensing instrumentation in difficult environments targeted at the specific problem. ISI provides an end to end solution designing instruments, from an initial simulated concept through to bench top instrument development and then to the manufacture of a complete, working instrument.

On-site, ISI has a range of optical, mechanical and electrical design tools including CAD and ray tracing facilities. In addition, the company has a fully equipped optical lab and dark room for testing new instrumentation.

PROJECTS	
HYDRI - HYDrogen sensoR for Industry	59

JAGUAR LAND ROVER LIMITED

www.jaguarlandrover.com

Jaguar Land Rover is a business built around two great British car brands that are designed, engineered and manufactured in the United Kingdom. Jaguar Land Rover is one of the world's premier manufacturers of luxury sedans, sports cars and SUVs.

Headquartered in Mahwah, New Jersey in the United States, Jaguar Land Rover North America, LLC has offices across the USA and Canada and is represented by more than 330 retail outlets.

PROJECTS	
Single Photon Infrared Imaging, Detection and Ranging (SPIDAR)	22

JOHNSON MATTHEY PLC

matthey.com

Johnson Matthey is a global leader in science that enables a cleaner and healthier world. With over 200 years of sustained commitment to innovation and technological breakthroughs, and improve the performance, function and safety of our customers' products. Our science has a global impact in areas such as low emission transport, pharmaceuticals, chemical processing and making the most efficient use of the planet's natural resources. Today around 15,000 Johnson Matthey professionals collaborate with our network of customers and partners to make a real difference to the world around us. For more information, visit www.matthey.com. Inspiring science, enhancing life.

PROJECTS	
QUANTIFI - QUANTum computIng For heterogeneous catalytIc materials solutions.	50
Quantum computing for battery materials	51
Quantum Computing based density functionals for fast and accurate materials and chemistry simulations	149
Feasibility of catalyst simulation on near-term quantum hardware	141

KELVIN NANOTECHNOLOGY LIMITED

www.kntnano.com

Kelvin Nano Technology (KNT) are a globally recognised supplier of quantum devices and components. The fabrication of these complex devices is underpinned by our breadth and expertise in processing different materials across a range of dimensions from tens of nanometres upwards. As one of the first suppliers of miniaturised quantum components in the market, KTN produce 3D ion traps, grating MOTs and MEMS gravimeters for international partners and customers. KTN are driving forward innovation in fabrication of quantum components to support quantum systems for information processing and computing, chip scale cold atom systems, sensors and high precision timing and navigation.

PROJECTS	
Quantum sensors for end-of-line battery testing	21
Compact optics for high performance portable atomic timing and quantum sensors	34
Diamond Quantum Sensing Platform	
DISCOVERY: Developing UK Industrial Supply for Commercial Quantum Computing	26
Reliable, high throughput production and characterisation of coherent superconducting devices	30
Platipas - Passive Platform Development for Visible Wavelengths	118
Advanced Manufacturing Toolkit for Quantum Sensing and Quantum Computing	163

KETS QUANTUM SECURITY LTD

kets-quantum.com

KETS Quantum is developing and delivering low Size Weight and Power (SWaP) Quantum Secured Communications products based on scalable Integrated Photonics technology.

PROJECTS	
Agile Quantum Safe Communications (AQuaSec)	13
Viable Satellite Free Space Optical Quantum Key Distribution Technologies (ViSatQT)	52
The quantum data centre of the future	61
A quantum photonics PDK	66
Assurance for quantum random number generators	25
Building a standardised quantum-safe networking architecture	164

KROMEK LIMITED

www.kromek.com

Kromek provides radiation and biothreat detection solutions

globally in four markets: medical imaging, nuclear detection, security screening and biological threat detection, designing and manufacturing OEM subsystems and components, and Kromek branded end user products.

With operations in four sites in the UK and US, Kromek sells internationally with partnerships and distribution channels in Asia, Europe, and North America, to a global customer base ranging from national security agencies, military, nuclear powerplants, international airport groups, and companies manufacturing airport security and medical imaging diagnostic equipment.

PROJECTS	
Transforming Tissue Differentiation via Quantum Digital Tomosynthesis	24
Single photon detection for ultra-low dose Molecular Breast Imaging	133

KUANO LTD

www.kuano.ai

Our discovery platform uniquely combines target quantum mapping and AI led chemistry to enable faster development of better drug candidates. Our unique approach tackles common challenges in both AI driven drug design and target driven drug discovery.

Quantum Mapping of targets introduces selectivity from the start, producing superior candidates in fewer design rounds. Identifying better starting points for AI-led chemistry eliminates bottlenecks in the hit to candidate optimization phase. Generating better Enzyme Inhibitors by targeting Quantum Transition States. We work with enzyme inhibitors in a unique way, continually developing tools to address the challenges of working with machine learning and quantum simulations in drug discovery. This strategy significantly improves the quality of new drugs being produced, as well as reduces discovery time.

Our advisors and partners include leading academics and providers in the fields of quantum computing, AI and machine learning and drug discovery. In addition to our in-house discovery programs, we are interested in drug discovery collaborations with pharmaceutical and biotech companies seeking new approaches to novel, first in class, best in class or next generation inhibitors for validated or intractable enzyme targets.

PROJECTS	
Kuano: A novel second generation quantum computing technique using transition state modelling for efficient drug discovery	73
A next-generation quantum computing based approach to enzyme targeted drug discovery	136

LAND INSTRUMENTS INTERNATIONAL LIMITED

www.ametek-land.com

AMETEK Land is the world's leading manufacturer of monitors and analysers for industrial infrared non-contact temperature measurement, combustion efficiency and environmental pollutant emissions.

Through our trusted range of leading-edge technologies, we are chosen the world over to deliver the highly accurate measurement solutions that precisely meet every customer's process needs. With unrivalled applications knowledge, choosing AMETEK Land ensures the highest standards of process safety, process control and product quality are reached.

Founded in the UK in 1947, Land Instruments International Limited developed a reputation for producing innovative, resilient measurement technologies designed to operate in the most challenging conditions. Acquired by the Process & Analytical Instruments Division of AMETEK, Inc., a global supplier of high-end analytical instrumentation, in 2006, today AMETEK Land is the premium supplier of product application solutions to world industries including steelmaking, glass making, minerals processing, hydrocarbon processing and thermal power generation.

Our success rests on award-winning technologies that push the limits demanded by the ever-increasing technical demands of global industry. Aligned with our expert knowledge, we meet the challenges of a wide range of applications, delivering process safety, process control and product quality our customers depend on.

PROJECTS	
Single Photon Lidar Imaging of Carbon Emissions (SPLICE)	23

LEONARDO UK LTD

www.leonardocompany.com

Leonardo is a world leading manufacturer of electro-optic sensors for advanced targeting systems and has unrivalled expertise in the development of high performance thermal imaging and 3D imaging lidar for target identification. Leonardo are a pioneer in the development of long range 3D single photon counting lidar and have a strategic interest in the development of quantum technologies for several defence and aerospace applications. Leonardo are at the forefront of developing the next generation of infrared detectors to meet the defence challenges of the next decade.

PROJECTS	
KAIROS	15
CIFS - Calcium Ion Frequency Standard	56

Quantum Electro-Optic Detector Technology (QuEOD)	29
RALFS - Rydberg Atom Low Frequency Sensing	130

LUMINIFEROUS

www.luminiferous.io

Luminiferous is using computational design techniques wto create better silicon photonic components. Better, smaller, cheaper.

PROJECTS

A quantum photonics PDK	66

M-SQUARED LASERS LIMITED

www.m2lasers.com

M Squared lead or contribute to a number of projects, including:

SOLACE: M Squared have an extensive track record in providing commercial subsystems for the leading lattice clocks systems operating worldwide and the team aim to expand their capabilities into wider system integration and delivery of time standards. The SOLACE project supports M Squared's strategic goal of developing a commercial-grade strontium lattice clock and the project focuses key developments in the creation of a strontium lattice have been targeted.

ABGRAV: M Squared have embarked upon the development of a series of atom interferometer devices for sensing. The measurement of absolute gravity using rubidium atom interferometry is now a well established technique with many synergies across cold matter-based quantum technologies. The challenge for ABGRAV is to iterate the gravimeter hardware into a more portable, sensitive and robust platform with key subsystem integration and increased overall engineering capable of higher TRL deployment. Relevant field trials planned in coordination with Oxfordshire County Council will highlight useful near-term application scenarios.

DISCOVERY: M Squared play a globally leading role in the provision of light sources for cold matter-based quantum computing systems. The combination of high optical powers and stable, spectrally pure output characteristics are ideally suited for the scalability and high fidelities that will be required for practical quantum computing systems. M Squared will focus on the setup of commercial neutral atom-based quantum computing hardware, with a view to deploy emerging hardware using other qubit preparation methods such as the ion trap platforms within the project.

PROJECTS

ACCOLADE: ACcelerometry with COLd Atoms in Dynamic Environments	65
Field Ready Absolute Quantum Gravimetry (ABGRAV)	33
Strontium Optical LAttice Clock (SOLACE)	43
DISCOVERY: Developing UK Industrial Supply for Commercial Quantum Computing	26
GRADUATE	100
Grating-based lattice optical clock (G-BLOC)	101
Diamond NV Sensors for Quantum-Limited Magnetic Field Measurements	167
ProAtom: Programmable Atom Arrays for Analogue Optimisation Solutions	145

MAGNETIC SHIELDS

magneticshields.co.uk

Magnetic Shields are leading specialists in the manufacture of bespoke Meatal® magnetic shielding and the supply of Mumetal® sheet, foil and bar.

Based in Kent, England, our manufacturing facility is fully equipped with the latest technology to provide our customers with the highest level of service and quality.

All of our manufacturing processes, including heat treatment, are integrated in our production plant, meaning that we can guarantee the final magnetic properties of your magnetic shield. Our magnetic shielding products are the preferred solution for the mitigation of unwanted interference used by many Industries, Universities and Institutes.

PROJECTS

Pioneer Gravity: Gravity sensors for infrastructure productivity, situational awareness and seeing the invisible	14
Quantum sensors for end-of-line battery testing	21
Performance Magnetic Shielding For Commercial Quantum Technologies	75

MASSIVE ANALYTIC LIMITED

www.massiveanalytic.com

Massive Analytic is a growing genuine AI company, whose three products straddle data science, video analysis and autonomous systems. With patented AI and deep learning IP Massive Analytic has developed algorithms and software for predicting the future with incredible accuracy accuracy across multiple industries, including defence, medicine, smart cities, 5G and transportation.

Massive Analytic's flagship product, Oscar Enterprise AI is an end-to-end workbench integrating an AI engine with data management, curation, and analysis. The unique capability to integrate Oscar with video analytics (Nethra)

and robotics (Aftos) enables Massive Analytic to tackle complex use cases in a wide variety of sectors. While the patented technology, Artificial Precognition, provides a specialist and unique form of data analysis called Precognitive AI that delivers incredible results across industries and use cases.
With offices in London, New York and New Dehli, Massive Analytic has an expanding and global presence.

PROJECTS

Quantum enhanced control systems	78

MBDA UK LIMITED

www.mbda-systems.com

A world leader in missiles and missile systems.
Our multi-national organisation is made up of around 13,000 employees working across the UK, France, Italy, Germany, Spain and the US, and is the first truly integrated European defence company.

As the European champion in our sector, our vision is to continue to grow our presence as a global player. Our mission is to achieve this by establishing ourselves as an industry leader; promoting co-operation and delivering technical and operational excellence to our customer.

Our values are:

- **Innovation:** Ensuring operational and strategic advantage;
- **Commitment:** Always delivering on our promises;
- **Integrity:** A reliable and trusted partner with the highest professional and ethical standards;
- **Passion:** Applying all our energy and focus to every task, recognising our role in providing mission critical capabilities;
- **Team Spirit:** Harnessing our diversity and collective purpose to deliver competitive advantage to all of our stakeholders.

We have a rich heritage of designing and producing missiles and missile systems to meet the whole range of current and future operational requirements for the three armed forces (army, navy, air force). We are proud to be a trusted partner to our armed forces and work with them to deliver a cutting-edge portfolio of products.

PROJECTS

Aeon-Rb	53

MEDICINES DISCOVERY CATAPULT LIMITED

md.catapult.org.uk

We collaborate with UK medicines discovery and diagnostics organisations, giving them access to industry-leading expertise, cutting-edge technology, and high-quality data. We accelerate their progress, precision drugs get to clinical trials more rapidly, and patients get life-improving medicines earlier than they otherwise would have.

PROJECTS

Quantum Enhanced Computing Platform for Pharmaceutical R&D - QuPharma	60

MERCK

www.merckgroup.com

Merck is a vibrant science and technology company. Science is at the heart of everything we do. It drives the discoveries we make and the technologies we create. The passion of our curious minds makes a positive difference to millions of people's lives every day.

In Healthcare, we discover unique ways to treat the most challenging diseases, such as multiple sclerosis and cancer. Our Life Science experts empower scientists by developing tools and solutions that help deliver breakthroughs more quickly. And in Electronics, we develop science that sits inside technologies and changes the way we access, store, process, and display information.

Everything we do is fueled by a belief in science and technology as a force for good. A belief that has driven our work since 1678 and will continue to inspire us to find more joyful and sustainable ways to live.
We are curious minds dedicated to human progress.

PROJECTS

Quantum Enhanced Computing Platform for Pharmaceutical R&D - QuPharma	60

METAMORPHIC ADDITIVE MANUFACTURING LTD

http://metamorphic.am

Metamorphic provides tailored consultancy services to organisations that want to evolve and accelerate their R&D through the use of Additive Manufacturing.

We combine expertise in Design for Additive Manufacturing (3D printing), computational design and simulation. Our team specialises in early-stage technology and innovation projects across a variety of sectors.

PROJECTS

QTEAM: Quantum Technologies Enabled by Additive Manufacturing	128

MICROCHIP TECHNOLOGY CALDICOT LIMITED

www.microchip.com

Microchip Technology Incorporated is a leading provider of smart, connected and secure embedded control solutions. Its easy-to-use development tools and comprehensive product portfolio enable customers to create optimal designs, which reduce risk while lowering total system cost and time to market. The company's solutions serve more than 120,000 customers across the industrial, automotive, consumer, aerospace and defence, communications and computing markets. Headquartered in Chandler, Arizona, Microchip offers outstanding technical support along with dependable delivery and quality.

PROJECTS	
MAG-V : Enabling Volume Quantum Magnetometer Applications through Component Optimisation & System Miniaturisation	16
UK National Foundry for Quantum Components (QFoundry)	31
QGyro	121
Silurum	162

MICRON SEMICONDUCTOR LIMITED

www.micronsemiconductor.co.uk

Micron Semiconductor Ltd is a specialist manufacturer and global supplier of silicon- and diamond-based radiation sensors.

Our products are custom-designed to meet a wide range of requirements and are used in various applications such as space exploration and communication, medical imaging, high energy physics research, and the energy, defence and civil nuclear industries.

Our consultancy and design services are key to turning our clients' ideas and constraints into reality, while our modular production line allows us to adapt quickly and fulfill small quantity orders. We design the sensor itself, as well as its PCB and connectivity for integration into the user's wider framework.

PROJECTS	
QuILT - Quantum element Interposition by Laser Transfer	126

MIND FOUNDRY LIMITED

http://mindfoundry.ai

Mind Foundry is an Oxford University company, founded by Professors Stephen Roberts and Michael Osborne, pioneers in the field of AI and Machine Learning.
With a deep understanding of how important these technologies are to our future, the mission of Mind Foundry is to enable Humans and AI to work together to solve the world's most important problems.

Mind Foundry has developed technology and products that help people bring machine learning closer to their work. Our platform is a new type of Machine Learning that is powerful enough to be trusted by experts and easy enough to be used by people throughout your organisation.
Built upon a foundation of scientific principle, organisations use Mind Foundry to empower their teams in entirely new ways.

PROJECTS	
Autonomous quantum technologies (AutoQT)	55

NANOCO TECHNOLOGIES LIMITED

www.nanocotechnologies.com

Nanoco is a world leader in the development and production of cadmium-free quantum dots and other nanomaterials for use in multiple applications including LCD displays, lighting, solar cells and bio-imaging.

Nanoco's unique and patented volume production technology, referred to as the "molecular seeding process", allows for the production of uniform, high quality quantum dots on a large scale. Moreover, Nanoco's quantum dots, called CFQD® quantum dots, are free from cadmium and any other heavy-metals so they are ideally suited for use in all consumer electronic devices.

One of the key application areas for CFQD® quantum dots is in LCD displays and LED lighting. In LCD displays, the technology can not only dramatically enhance the colour performance of the screen but also allows manufacturers to use their existing infrastructure. Similarly, CFQD® quantum dots can be used to control the colour temperature and improve the colour quality of LED lighting.

In the display market, Nanoco has non-exclusive manufacturing and marketing licensing agreements with The Dow Chemical Company, Merck KGaA and Taiwan's Wah Hong Industrial Corporation. Nanoco also has a strategy of direct sales in display and in its other target markets, including lighting.

Nanoco was founded in 2001 and is headquartered in Manchester, UK. It has production facilities in Runcorn, UK, and a US subsidiary, Nanoco Inc, based in Concord, MA. Nanoco also has business development executives in Japan, Korea and Taiwan. Its technology is protected worldwide by a large and growing patent estate.

PROJECTS	
Singly-doped Colloidal Quantum Dots for Quantum Technology	132

NANOLAYERS RESEARCH COMPUTING

nanolayers.com

Nanolayers Research Computing LTD: a London based digital research company that develops multi-scale modelling techniques and machine learning algorithms to design and control the properties of new molecular films and microelectronics devices. Nanolayers operates as consultants and builds bespoke research platforms with integrated simulators, data processing, and automation tools.

The founders have extensive experience working in both academia and industry, and their focus is on helping customers bridge the gap between fundamental physical insight and real world products.

PROJECTS	
Scanning probe fabrication and readout of atomically precise silicon quantum technologies	169

NASCENT SEMICONDUCTOR LIMITED

www.nascentsemi.com

We provide high-rel electronic capabilities for extreme environments by fabricating devices from the Wide Band-Gap Semiconductor Silicon Carbide (SiC). This results in superlative stability at temperatures beyond those possible with conventional silicon or silicon on insulator components. SiC devices also demonstrate superlative radiation tolerance, as well as high efficiency, low losses and fast switching in power electronic applications.

These capabilities open up new markets in the extreme environments that are common in the automotive, oil & gas, geothermal, aerospace, space and military sectors. The SiC devices are confined to value added, high performance applications where the added functionality is critical.

The technology offers the possibility of remote monitoring in extreme environments, something that is not possible using conventional electronics and hence enabling the Internet of Everything Everywhere (IoEE).

PROJECTS	
QS-EXACT: Quantum SiC for EXtreme Application Clock Technology	161

NATIONAL GRID GAS PLC / NATIONAL GAS TRANSMISSION PLC

www.nationalgrid.com

National Grid is an energy company operating in the UK and US. It delivers electricity and gas safely, reliably and efficiently to the customers and communities we serve – all while working towards a clean energy future.

PROJECTS	
Single Photon Lidar Imaging of Carbon Emissions (SPLICE)	23

NATIONAL PHYSICAL LABORATORY

www.npl.co.uk

The National Physical Laboratory (NPL) is the UK's National Metrology Institute and is involved in quantum projects in timing, sensors, computing, communication, imaging and components. NPL delivers a wide-ranging quantum programme in support of the NQTP, focussing on test and evaluation of quantum technologies as well as supporting industry in technology development.

PROJECTS	
3QN: Towards A New UK Industry for Novel Quantum Receivers in Nascent Satellite QKD Global Markets	12
Agile Quantum Safe Communications (AQuaSec)	13
KAIROS	15
AIRQKD	16
MAG-V : Enabling Volume Quantum Magnetometer Applications through Component Optimisation & System Miniaturisation	16
Single Photon Lidar Imaging of Carbon Emissions (SPLICE)	23
PRISMS - Protocol, Randomness & Information Security Measures for Space	47
QUANTIFI - QUANTum computIng For heterogeneous catalytIc materials solutions.	50
Safire	41
Aeon-Rb	53
Altnaharra: Cryoelectronics for Quantum Circuits	54
Autonomous quantum technologies (AutoQT)	55
Noise Analysis and Mitigation for Scalable Quantum Computation	74
Q-Cell - Functionalised Plug and Play Vapour Cell Module	77
Quantum enhanced control systems	78
Assurance for quantum random number generators	25
DISCOVERY: Developing UK Industrial Supply for Commercial Quantum Computing	26
NISQ.OS	27
UK National Foundry for Quantum Components (QFoundry)	31
ADRENALIN (lAser Diodes in the veRy nEar iNfrared for quantum AppLIcatioNs)	92
QGyro	121
Q-Pods - Holistically Packaged Integrated Optoelectronic Devices for Quantum Systems	127

NCC GROUP SECURITY SERVICES LIMITED

www.nccgroupplc.com/

NCC Group exists to make the world safer and more secure. We are a global cyber security business operating across multiple sectors, geographies and technologies.

We are experts in finding and exploiting vulnerabilities and use this to help businesses to identify, assess, mitigate and respond to the risks we all face so they become resilient and able to operate.

PROJECTS	
The quantum data centre of the futureo	61

NCC OPERATIONS LIMITED

www.nccuk.com/

As part of the High Value Manufacturing Catapult The NCC is the UK's world-class composite innovation centre that specialises in the design and digitally optimised manufacture of sustainable composites and facilitates their widespread industrial exploitation.

The state-of-the-art building at the Bristol and Bath Science Park provides manufacturing facilities at an industrial scale and rapid manufacturing processes capable of building prototypes to validate design concepts. We are the hub of the UK's effort to develop and implement rapid composite manufacturing technologies and systems.

We lead the co-ordination of a strengthened network of regional centres of composites excellence, providing direction and focus for fundamental research and collaborative links with UK universities, and helping to develop and co-ordinate training to support the skills base necessary for applying advanced and specialist composite technologies.

PROJECTS	
The quantum data centre of the future	61

NEMEIN LTD

www.nemein.co.uk

Nemein have developed innovative sustainable energy technologies to work in hostile down-hole environments. Resilient, world-first, long term answers to energy provision for MWD and LWD activities. Removing the need for battery replacement and the interruption of measurement and data logging.

This sustainable technology readily transfers to the renewable energy sector for innovative thermal storage.

PROJECTS	
Gravity Delve	35

NETWORK RAIL INFRASTRUCTURE LIMITED

www.networkrail.co.uk

Network Rail owns, operates and develops Britain's railway infrastructure.

That's 20,000 miles of track, 30,000 bridges, tunnels and viaducts and the thousands of signals, level crossings and stations. Network Rail manage 20 of the UK's largest stations while all the others, over 2,500, are managed by the country's train operating companies.

PROJECTS	
Single Photon Infrared Imaging, Detection and Ranging (SPIDAR)	22

NIQS TECH (LEEDS) LIMITED

www.niqstech.com/

NIQS - or Non-Invasive Quantum Sensing - Technology is a UK-based quantum technology company that was founded by expert physicists and engineers from the University of Leeds, and was officially incorporated in September 2020.

Our patented sensing technology was developed in the leading research groups of Prof. Gin Jose and Dr Almut Beige, and has been validated in a laboratory environment and early-stage clinical trials.

Our work represents the next generation of optical sensors that enables real-time, accurate biomarker monitoring, without breaking the skin surface or drawing blood samples.

PROJECTS	
Non-invasive quantum sensing for continuous glucose monitoring	112

NORTHUMBRIAN WATER LIMITED

www.nwl.co.uk

Northumbrian Water Group (NWG) operates in the northeast of England, where it trades as Northumbrian Water, and in the southeast of England, where it trades as Essex & Suffolk Water. NWG supplies water and sewerage services to just under 4.4 million people. Water is supplied to 794,000 properties in Essex & Suffolk, with water and sewerage services provided to 1.3 million properties in the North. Every day NWG supplies 1,104 megalitres (1.1 billion litres) of water. This water is drawn from reservoirs, where it is

collected and stored, rivers and groundwater sources. It is treated at water treatment works before being delivered by a network of pipes to homes and businesses. In the northeast of England, where NWG also provides sewerage services, wastewater is then collected from these properties via the sewerage network and treated before it is returned to the environment as either clean water or sludge which can be recycled as fertiliser or used to generate energy.

PROJECTS	
Quantum technology - mapping and map integration for buried assets (QT-MIBA)	48

NU QUANTUM

nu-quantum.com

Nu Quantum is the only company world-wide developing room temperature single-photon sources and detectors to enable the next generation of commercially-viable photonic quantum technologies, with potentially transformative implications for communications, sensing and computing industries.

The company was spun out of the Cavendish Laboratory, and has raised over £5million in private and public funds to-date.

PROJECTS	
AIRQKD	16
Next Generation Satellite QKD - Creating a UK Sovereign Capability for Manufacturing Satellite QKD Payloads	19
Viable Satellite Free Space Optical Quantum Key Distribution Technologies (ViSatQT)	52
Assurance for quantum random number generators	25
CALYX : Cold-Atom Light via efficient Cavity Extraction	96
INTERCOM: A high-performance ion-photon interface to enable multi-core trapped ion quantum computing	106
Medusa: the networking heart of a trapped ion multi-core quantum computer	108
QUARREFOUR - Benchmarking Multi-core Quantum Computing Systems	176
QUANTUM SPECS - Single Photon detection for Excellence in Communication and Sensing	79

OPENLIGHTCOMM

http://openlightcomm.com

OpenLightComm (OLC) is an SME, founded in 2016. OLC is a research-oriented spin-off that operates in the converged landscape of Telecommunications and IT. OLC is now part of the Innovation Martlesham cluster at Adastral Park, Ipswich. OLC has an extensive experience in directing and/or conducting R&D on Quantum networks (QKD), 5G/6G multi-layer architectures and performance, SDN-enabled networks, physical layer effects in optical transmission and network performance.

This experience was acquired from the participation of OLC's members in a larger number of EU-funded and national projects. More recently, OLC was involved to the H2020 METRO-HAUL project led by BT. In the framework of AirQKD, OLC contribute to the dimensioning of AirQKD's network in the context of an autonomous vehicle testbed. Moreover, OLC will be a lead partner to the implementation of an SDN-enabled management system for this testbed as it will provide an overarching platform for the management of the, heterogeneous, classical (wireless and fixed-line) and QKD deployments.

PROJECTS	
AIRQKD	16

ORCA COMPUTING LTD

www.orcacomputing.com

ORCA Computing is developing a unique and truly scalable quantum computing platform. ORCA's solutions leverage the significant advantages of photonic quantum computing and combines them with our breakthrough quantum memory technology.

Our approach allows us to utilize a room temperature and pressure core infrastructure based on industry-standard optical fibre that is scalable and will integrate into existing data centres and with classical high-performance computing systems. This will allow us to deliver solutions that are significantly less expensive, easier and cheaper to maintain and that also offer a commercially viable path to fully error-corrected quantum computing.

PROJECTS	
Next Generation Satellite QKD - Creating a UK Sovereign Capability for Manufacturing Satellite QKD Payloads	19
MANATEE: Deterministic single photon sources for quantum computing and communications	37
The quantum data centre of the future	61
Fibre-based memory module for photonic quantum computing	70
Towards a Quantum Internet	80
DISCOVERY: Developing UK Industrial Supply for Commercial Quantum Computing	26
Hue- Manatee: temporal and spectral multiplexing for super high-efficiency photon sources	105
MANGROVE	107
Ultracold quantum memories	136
Q-REALM Wind	147

ORDNANCE SURVEY LIMITED

www.os.uk

Ordnance Survey helps governments make smarter decisions that ensure our safety and security, we show businesses how to gain a location data edge and we help everyone experience the benefits of the world outside

PROJECTS	
Quantum technology - mapping and map integration for buried assets (QT-MIBA)	48

OXFORD INSTRUMENTS NANO TECHNOLOGIES

nanoscience.oxinst.com

Oxford Instruments NanoScience (OINS) designs, supplies and supports market-leading cryogenic and high flux superconducting magnetic research tools that enable quantum technologies, nano technology research, advanced materials and nano device development in the physical sciences. On the Innovate UK Project, as well as hosting the hardware installation, Oxford Instruments is responsible for delivering and installing the latest version of its Proteox family of dilution refrigerators, the ProteoxLX, which has been designed to provide the capacity and cooling power needed to operate large-scale quantum computers.

PROJECTS	
Quantum Computing Platform for NISQ Era Commercial Applications	20
Altnaharra: Cryoelectronics for Quantum Circuits	54
Development of cryo-CMOS to enable the next generation of scalable quantum computers	58
Quantum Enhanced Computing Platform for Pharmaceutical R&D - QuPharma	60
UpScale: Scalable quantum information enabled by integrated optics	64
Reliable, high throughput production and characterisation of coherent superconducting devices	30
Advanced Manufacturing Toolkit for Quantum Sensing and Quantum Computing	163

OXFORD IONICS

www.oxionics.com

At Oxford Ionics our mission is to revolutionise industries ranging from drug discovery to material design by building Quantum Computers; a radically new type of computer that harnesses the power of quantum physics to be exponentially more powerful than a conventional supercomputer. Oxford Ionics is setting a new standard for high-performance computing thanks to our unique trapped-ion technology.

PROJECTS	
Altnaharra: Cryoelectronics for Quantum Circuits	54
Autonomous quantum technologies (AutoQT)	55
UpScale: Scalable quantum information enabled by integrated optics	64
DISCOVERY: Developing UK Industrial Supply for Commercial Quantum Computing	26
NISQ.OS	27
TransmissION	135
Silicon Nitride for Quantum Computing (SiNQ)	154
Feasibility of catalyst simulation on near-term quantum hardware	141

OXFORD PHOTOVOLTAICS LIMITED

www.oxfordpv.com

Oxford PV is the pioneer and technology leader in the field of perovskite solar cells.

The company was established in 2010, as a spin-out from the University of Oxford. Today, we have the largest team globally, exclusively focused on developing and commercialising a perovskite based solar technology. We have a research and development site in Oxford, UK and an industrial pilot line near Berlin, Germany enabling the accelerated transfer of our technology into industrial scale silicon solar cell production. In 2019, we announced plans to move into full commercial manufacturing.

Solar panels built with Oxford PV's perovskite solar cell technology will generate more power, critical for delivering more affordable clean energy, accelerating the adoption rate of solar and addressing climate change.

PROJECTS	
Quantum computing for materials modelling applications in photovoltaics	123

OXFORD QUANTUM CIRCUITS

www.oxfordquantumcircuits.com

OQC is a pioneer among quantum hardware companies. OQC has built the UK's most advanced superconducting quantum computer in the UK, the only one commercially available in the country. With its patented innovation, the Coaxmon, a unique 3D architecture bringing key componentry & wiring off-chip, OQC is building scalable quantum computers.

PROJECTS	
NISQ.OS	27

Reliable, high throughput production and characterisation of coherent superconducting devices	30

OXFORDSHIRE COUNTY COUNCIL

www.oxfordshire.gov.uk

Project contributions encompass:

- Exploring quantum gravimetry use cases, including: subsurface infrastructure, ground water levels monitoring, needed for flooding prevention, archaeology surveying as part of planning and mineral exploration.
- Liaising with internal and external stakeholders to define technical requirements for these use cases.
- Supporting demonstration of the technology, showcasing its capabilities in real world environment.
- Review trial outcomes and assess operational impact for the use cases.

PROJECTS	
Field Ready Absolute Quantum Gravimetry (ABGRAV)	33

PA CONSULTING SERVICES LIMITED

www.paconsulting.com

We believe in the power of ingenuity to build a positive human future in a technology-driven world. As strategies, technologies and innovation collide, we create opportunity from complexity.

Our diverse teams of experts combine innovative thinking and breakthrough use of technologies to progress further, faster. Our clients adapt and transform, and together we achieve enduring results.

An innovation and transformation consultancy, we are over 3,200 specialists in consumer, defence and security, energy and utilities, financial services, government, health and life sciences, manufacturing, and transport. Our people are strategists, innovators, designers, consultants, digital experts, scientists, engineers and technologists. We operate globally from offices across the UK, US, Europe and the Nordics.

PROJECTS	
High-BIAS2: High-Bandwidth Inertial Atom Source & Sensor	17

PHASECRAFT

www.phasecraft.io/

Phasecraft is a quantum software company whose goal is to get the most out of near-term quantum computers. One of our areas of focus is designing efficient quantum algorithms for solving hard problems in materials science. Phasecraft use our expertise in the theory of quantum computing to solve the hardest problems in this area. Our work on the Innovate UK project ranges from underpinning mathematics through to developing software on the Rigetti quantum hardware platform.

PROJECTS	
Quantum Computing Platform for NISQ Era Commercial Applications	20
Quantum computing for battery materials	51
Near-term quantum computing for solving hard industrial optimisation problems	110
Quantum computing for materials modelling applications in photovoltaics	123
Making noisy quantum processors practical	168
Feasibility of catalyst simulation on near-term quantum hardware	141

PHLUX TECHNOLOGY LTD

http://phluxtechnology.com

Phlux is developing high performance infrared sensors that will dramatically improve the performance of laser rangefinder, LIDAR, fibre sensing and imaging systems operating at wavelengths from 1000 nm to 1700 nm.

PROJECTS	
AIR SPAD - AlGaAsSb Infrared Single Photon Avalanche Diodes	94
QUantum communication Development with Increased Throughput for information Systems (QUDITS)	122

PHOTON FORCE LTD

www.photon-force.com

QuEOD Project lead Photon Force (PF) is an SME building on over a decade of successful research experience from Robert Henderson's CMOS Sensors & Systems Group at the University of Edinburgh. Our mission is to provide innovative single-photon sensitive detector technologies to facilitate advanced applications, with initial focus on the Biophotonics and Quantum technology fields. PF is a commercial supplier of CMOS time-resolved SPAD arrays and are presently designing next generation SPAD sensors. The team is ideally placed to continue UK leadership in next generation SPAD sensor architectures for quantum enhanced applications.

PROJECTS	
HYDRI - HYDrogen sensoR for Industry	59
Towards a Quantum enabled Cloud	62

Underwater Single Photon Imaging System	63
QT Assemble: Integrated Quantum Technology Programme	28
Quantum Electro-Optic Detector Technology (QuEOD)	29

POWERLASE LIMITED

www.powerlase-limited.com

Powerlase works with worldwide leading partners to successfully address the needs of the Electronics, Automotive, Aerospace, Defence, Shipbuilding, Oil and Gas, Nuclear Waste Management and Conservation industries. The high power, high energy laser technology offers solutions for Ablation, Surface Processing, Cleaning, Depainting, Polishing and Processing Composite Materials in industrial applications with demands of high production speed.

Customer-focused, with in-depth knowledge of applications providing solutions for materials processing, Powerlase enjoys significant expertise in designing and developing dynamic applications for ablation of Hot Stamped Tailored Blanks, high speed solar cell manufacturing, cleaning and depainting in the Automotive and Aerospace industries, cleaning of machine tools, ablation, cutting & drilling of composite materials, laser liftoff for flexible display manufacturing, ultra-fine polishing and industrial gas turbine manufacturing.

Our applications laboratory is based at the Crawley HQ. This state of the art lab is home to a number of physicists who are available to assist clients about their applications.

PROJECTS	
QuILT - Quantum element Interposition by Laser Transfer	126

POWERPHOTONIC LIMITED

www.powerphotonic.com

PowerPhotonic is a pioneer in the use of laser micro-machining for use in the manufacturing of precision micro-optics products for laser and optical applications.

PowerPhotonic Ltd. was formed in 2004 to commercialize the technology from fundamental research undertaken at the world-renowned Institute of Photonics and Quantum Sciences at Heriot-Watt University in Edinburgh. With operations in the United Kingdom, North America and South East Asia, we are well positioned to support companies across the globe.

PROJECTS	
QT Assemble: Integrated Quantum Technology Programme	28

PQSHIELD LTD

www.pqshield.com

Formed as a spinout of the University of Oxford by cryptography researchers and specialists, PQShield has unrivalled domain expertise in the design and implementation of quantum-resistant cryptography for software and hardware applications.

PQShield is a major contributing participant to the National Institute of Standards and Technology (NIST) Post-Quantum Standardisation Process.

At PQShield, we help customers transition their product lines from legacy RSA and Elliptic Curve cryptography to quantum-secure standards by offering ready-made and tailored IP for secure elements, IoT firmware, PKI and server technologies, and end-user applications.

PROJECTS	
The quantum data centre of the future	61

PROCTER & GAMBLE TECHNICAL CENTRES LIMITED

www.pg.co.uk

Procter & Gamble, a globally trusted household brand based upon the principles of challenging convention, being innovation-led and contributing to society by helping to positively shape culture.

PROJECTS	
Quantum Terahertz Imager using Coherent control (QuanTICo)	49

QINETIQ LIMITED

www.qinetiq.com

QinetiQ is a company of scientists and engineers committed to listening, understanding and responding to our customers' needs. This enables us to use our depth of experience and our unique science and engineering expertise to equip them with powerful solutions to their most pressing challenges.

PROJECTS	
Pioneer Gravity: Gravity sensors for infrastructure productivity, situational awareness and seeing the invisible	14
CIFS - Calcium Ion Frequency Standard	56
QECCO: Quantum End-to-end Compilation for Combinatorial Optimisation	146

QLM TECHNOLOGY LIMITED

www.qlmtec.com

Qlmtec is the SPLICE project manager and inventor of the single-photon gas lidar technology. QLM leads on the camera R&D and on commercial exploitation.

PROJECTS	
Single Photon Lidar Imaging of Carbon Emissions (SPLICE)	23
Quantum Electro-Optic Detector Technology (QuEOD)	29
AIR SPAD - AlGaAsSb Infrared Single Photon Avalanche Diodes	94
Photon Absorption Spectroscopy CAmera for Leaks (PASCAL)	117
Q3MD: single photon sensitive detector for methane gas detection operating at 3μm	120
UP-conversion of Single-photons for ENvironnmental SEnsing [UP-SENSE]	135

QUANTROLOX LIMITED

quantrolox.com

A practically useful quantum computer will need many thousands of qubits – the fundamental building blocks of quantum computers. Due to imperfections in control instruments, fabrication and design, qubits have subtle variations requiring different sets of control parameters to render each one usable. An intricate process is required to be able to reach a practically useful quantum computer. As the number of qubits is increased, the challenge of tuning and characterising them grows significantly.

Successful tuning, optimising and stabilising of many thousands of qubits, regardless of their variability, requires intelligent automation. A big parameter space must be explored efficiently, data interpreted, patterns recognized and decisions made in real time. Current solutions that depend on human expertise are not good enough and will not scale.

QuantrolOx is building automated machine learning based control software for quantum technologies to tune, stabilise, and optimise qubits. QuantrolOx's software is technology agnostic and applicable to all types of quantum technologies, however initially the company is targeting solid-state qubits where the team has already demonstrated substantial practical benefits.

PROJECTS	
Realistic machine learning based ultra fast simulator for semiconductor spin qubit devices	131

QUANTUM DICE LIMITED

www.quantum-dice.com

Quantum Dice is an award-winning, fast growing quantum technology startup backed by world leading innovation from the University of Oxford.

Providing random number generation (QRNGs) which generate unbiased, true random numbers. RNGs are essential components of modern communication technologies which generate cryptographically secure keys in a wide range of commercial settings.

The founders were the winning team in July 2019 of Oxford University Innovation's inaugural StEP Ignite Programme.

PROJECTS	
Establishing the Need - Finding the future market for UK Quantum Random Number Generators	69
Developing the first Space-suitable Quantum Random Number Generator	83
QUANTUM 4 IOT	86
Assurance for quantum random number generators	25
Compact Source-Device Independent QRNG	178
High-speed self-certifying Quantum Random Number Generator for simulationsn	103

QUANTUM MOTION TECHNOLOGIES LIMITED

quantummotion.tech

Quantum Motion Technology is developing a revolutionary technology platform; not just a qubit, but a scalable array of qubits based on the ubiquitous silicon technology already used to manufacture the chips in smartphones and computers. The Company is developing fault tolerant quantum computing architectures that are compatible with the CMOS process. Fault tolerant quantum processors will support the most powerful quantum algorithms, targeting solutions to currently intractable problems in fields as diverse as chemistry, medicine and artificial intelligence.

PROJECTS	
Multicore NISQ Processors on Silicon Chips	39
Global Spin Qubit Control	179
Quantum PDK	181
Altnaharra: Cryoelectronics for Quantum Circuits	54
Quantum Pixel (QuPix)	80

QURECA LTD

qureca.com

QURECA Ltd. provides a range of professional services, business development, and the solution to the quantum workforce skills bottleneck: the first online platform for quantum training and resourcing, to support individuals and businesses to be part of the quantum revolution.

In 2019, the Royal Society described QURECA Ltd. as

the company that "fills the gaps in the existing quantum community, creating a society ready for quantum through a common language."

There is a clear need to be realistic in identifying the emerging technologies opportunities that will transform society. The ecosystem for quantum technologies is full of gaps but QURECA Ltd. aims to provide all the resources needed in the community, in order to build a stronger network of stakeholders.

PROJECTS	
Developing an error corrected quantum processor solution for commercial quantum computing	57

QONTROL LTD

https://qontrol.co.uk

Scalable control electronics for chip-scale photonics and quantum photonics.

We want to make controlling complex photonic and quantum photonic devices easy and economical. From our headquarters in Bristol, UK, we design the things you need to make your devices and systems work. All our products are designed and assembled by us, in Bristol, and manufactured in the UK and EU.

PROJECTS	
H3Lo-QP: High-voltage High-IO High-transmission Low-temperature Quantum Photonics	173

RAHKO

www.rahko.ai

Rahko is a quantum drug discovery company. Rahko is combining computational quantum chemistry, quantum machine learning and quantum computing to build the world's first quantum drug discovery pipeline to enable the discovery of better, safer drugs - faster and cheaper than traditional drug discovery by orders of magnitude.

PROJECTS	
QUANTIFI - QUANTum computIng For heterogeneous catalytIc materials solutions.	50
Quantum technology - mapping and map integration for buried assets (QT-MIBA)	48

REDWAVE LABS

www.redwavelabs.com

RedWave Labs design and manufacture high quality custom electronics, specialising in photonics. RedWave Labs' core product areas are laser controllers and optimised OEM subsystems for photonics and quantum technologies. Redwave Labs' design capabilities range from low noise laser control systems to RF control up to 10 GHz. Commercialised designs include field proven digital systems from simple microcontrollers to high-speed FPGA.

PROJECTS	
3QN: Towards A New UK Industry for Novel Quantum Receivers in Nascent Satellite QKD Global Markets	12
High-BIAS2: High-Bandwidth Inertial Atom Source & Sensor	17
Sidewinder	42
HYDRI - HYDrogen sensoR for Industry	59
Underwater Single Photon Imaging System	63
Dual-FISH	68
QT Assemble: Integrated Quantum Technology Programme	28
PAssively STabilised Laser (PASTEL)	115
Photon Absorption Spectroscopy CAmera for Leaks (PASCAL)	117
Q3MD: single photon sensitive detector for methane gas detection operating at 3μm	120
High Quantum Efficiency Detectors	72

RICARDO UK LIMITED

ricardo.com

Ricardo plc is a world-class environmental, engineering and strategic consulting company listed on the London Stock Exchange.

With more than 100 years of engineering excellence, we provide exceptional levels of technical expertise in delivering leading-edge and innovative cross-sector sustainable solutions to solve our clients' most complex strategic and operational challenges.

PROJECTS	
Feasibility study of using Quantum Sensors when developing new batteries and when recycling batteries	99

RIGETTI UK LIMITED

www.rigetti.com

Rigetti Computing is leading the Innovate UK project to launch the UK's first commercially available quantum computer, which will be made available to UK partners and customers via the cloud. The first version of the computer will be available by early 2022 and is based off of Rigetti's superconducting qubit architecture. Rigetti is responsible for providing the quantum chips for the computer and assembling and deploying the system, which will be built in Oxford Instruments' ProteoxLX dilution refrigerator.

PROJECTS	
Quantum Computing Platform for NISQ Era Commercial Applications	20
Practical improvements to the performance of quantum simulation for drug-protein binding	76
Advancing the practical implementation of quantum error correction with fault-tolerant syndrome extraction	93
Near-term quantum computing for solving hard industrial optimisation problems	110
Quantum Powered Sensemaking of People and Places	129
Quantum Unsupervised Learning for Anti-Money Laundering Detection	152
Quantum Machine Learning for Financial Data Streams	150

RIVERLANE

www.riverlane.com

Riverlane builds ground-breaking software to unleash the power of quantum computers.
Deltaflow.OS® is an operating system for quantum computers inspired by heterogeneous architectures. By empowering quantum programmers to implement fast operations at the right level in the stack, Deltaflow.OS® increases performance by several orders of magnitude.

PROJECTS	
Autonomous quantum technologies (AutoQT)	55
Developing an error corrected quantum processor solution for commercial quantum computing	57
Quantum Enhanced Computing Platform for Pharmaceutical R&D - QuPharma	60
The quantum data centre of the future	61
Practical improvements to the performance of quantum simulation for drug-protein binding	76
NISQ.OS	27
Advancing the practical implementation of quantum error correction with fault-tolerant syndrome extraction	93
Hybrid compilation framework to accelerate quantum application development (CATALYST)	172
The Quantum Accelerator for Materials Design (QuAMaD)	155

ROLLS-ROYCE PLC

www.rolls-royce.com

Rolls-Royce pioneers cutting-edge technologies that deliver clean, safe and competitive solutions to meet our planet's vital power needs.

PROJECTS	
Developing an error corrected quantum processor solution for commercial quantum computing	57
Hybrid compilation framework to accelerate quantum application development (CATALYST)	172
The Quantum Accelerator for Materials Design (QuAMaD)	155

RSK

rskgroup.com

Practical solutions to global challenges.
Since its establishment in 1989, RSK has grown into a leading integrated environmental, engineering and technical services business. We provide end-to-end services to help organisations achieve their aspirations in a sustainable and efficient manner.

RSK strives to be a company of which its staff members are proud to be part. Working across a wide array of sectors, we are committed to supplying high-quality services tailored to the needs of our clients, adhering consistently to our guiding principles and strict health and safety standards.

PROJECTS	
Pioneer Gravity: Gravity sensors for infrastructure productivity, situational awareness and seeing the invisible	14
Quantum technology - mapping and map integration for buried assets (QT-MIBA)	48

SAMSUNG ELECTRONICS (UK) LIMITED

www.samsung.com/uk

Samsung Electronics is a global leader in technology, opening new possibilities for people everywhere. Through relentless innovation and discovery, we are transforming the worlds of TVs, smartphones, wearable devices, tablets, digital appliances, network systems, medical devices, semiconductors and LED solutions. Samsung is also leading in the Internet of Things space through, among others, our Smart Home and Digital Health initiatives.
Since being established in 1969, Samsung Electronics has grown into one of the world's leading technology companies, and become recognized as one of the top 10 global brands. Our network now extends across the world, and Samsung takes great pride in the creativity and diversity of its talented people, who drive our growth.

PROJECTS	
The Quantum Accelerator for Materials Design (QuAMaD)	161

SATELLITE APPLICATIONS CATAPULT

sa.catapult.org.uk

The Satellite Applications Catapult (SAC) is one of a network

of UK technology and innovation companies which aim to drive economic growth through the commercialisation of research. The SAC's aim is to support UK industry by accelerating the growth of satellite applications and to contribute to capturing a 10% share of the global space market predicted by 2030.

SAC is achieving this by exploiting the innovation potential in the UK industrial and academic communities, by being a focal point where small and medium enterprises, large industry and end users can work together with researchers to challenge barriers, explore and develop new ideas, and bring these to commercial reality.

PROJECTS	
Viable Satellite Free Space Optical Quantum Key Distribution Technologies (ViSatQT)	52

SCIENTIFIC LIMITED

www.torrscientific.co.uk

Torr Scientific Limited is an innovative company that brings together a unique range of expertise, skills and equipment from the worlds of thin film vacuum coating, vacuum instrumentation and electron-optics.

The company manufactures Vacuum Optics and X-ray and Electron Optical (XEO) Components. Torr Scientific was established in 1998 and the employees of the company have many years of experience in the UHV and Electron-Optical industries.

Products are manufactured in cleanroom conditions and facilities include vacuum furnaces, TIG welding, helium leak testing, e-beam and sputter coating systems, UV-Vis-NIR spectrophotometer, Interferometer, glassshop and machine shop.

Please browse this website for further details about Torr Scientific's large range of UHV Viewports, AR coatings, optics, X-Ray anodes, CVD diamond and vacuum components.

PROJECTS	
QTEAM: Quantum Technologies Enabled by Additive Manufacturing	128

SECQAI

www.secqai.com

A team of physicists, scientists & developers who are creating leading Quantum Hardware to provide the basis for a secure future.

We believe in the need for collaborative work with our customers to continue technological advancement, working hand-in-hand with academia to develop innovative solutions to customer problems.

PROJECTS	
A novel, quantum model for NLP: a step towards AGI.	139

SEEQC UK LIMITED

seeqc.com

Seeqc is developing the first fully digital quantum computing platform for global business. Seeqc combines classical and quantum technologies to address the efficiency, stability and cost issues endemic to quantum computing systems, applied via a unique chip-scale architecture for digital readout and control.

PROJECTS	
NISQ.OS	27
Reliable, high throughput production and characterisation of coherent superconducting devices	30
Project IN-QUEST: Innovative Quantum-Enabling Sub-Kelvin Technology	36
Autonomous quantum technologies (AutoQT)	55
Quantum Enhanced Computing Platform for Pharmaceutical R&D - QuPharma	60
Performance Magnetic Shielding For Commercial Quantum Technologies	75
Development of cryo-CMOS to enable the next generation of scalable quantum computers	58

SEMIWISE LIMITED

www.semiconductorwise.com

Semiwise offer CMOS technology and transistor design IP ideal for Internet of things (IoT), Artificial Intelligence (AI) and Low Power (LP) CMOS chip design. This dramatically increases performance and reliability, while reducing statistical variability, leakage and manufacturing costs.

Semiwise is aiming at the development and commercialization of innovative low power CMOS transistor level IP that improves performance and variability and drastically reduces power in both forthcoming and existing technology generations.

The IP is ideal for Internet of Things (IoT) applications solving important shortcomings in the current CMOS technology. The IP was initially generated within GSS. It currently consists of 8 granted patents and 6 patents at different stages of prosecution. The generation of the IP was facilitated by a service agreement with the Silicon Valley company Nif/T, LLC which developed and

prosecuted the patents.

PROJECTS	
Development of cryo-CMOS to enable the next generation of scalable quantum computers	58

SENETAS

www.senetas.com

Senetas provided their 100Gbps ETQD compliant High Speed Encryptors with long range optical transceiver for the project. This facilitated testing of Toshiba QKD systems using extremely high-speed links over distances in excess of 80km.

PROJECTS	
Agile Quantum Safe Communications (AQuaSec)	13

SENKO ADVANCED COMPONENTS (EURO) LIMITED

www.senko.com

SENKO Advanced Components design and manufacture precise, user-friendly, and application-focused fiber optic connectors that allow network operators to achieve the performance and reliability necessary to support the world's unquenchable demand for data.

As you would expect from a Japanese company, precision is paramount to our offering, and we take pride in providing the global communications market with reliable and repeatable components that guarantee business-critical, error-free transmission.

We understand the challenges that network operators face in building networks that are not just quick and easy to construct, but also easy to manage and maintain over the complete lifecycle of the network. For this reason, SENKO pays special attention in developing connectors that are easy to identify and access even in when placed in the densest and demanding of applications.

The world demands high-performance connectivity 'always and everywhere'. Our application-focused approach ensures that connectors are optimised for the environment whether it be inside a controlled data centre, or high up on a remote antenna mast.

SENKO connectivity is driving next-generation applications that consume unparalleled amounts of data. Super-computing, AI and Big Data are just a few of the applications that demand data rates as high as 400G, 800G, 1,6TB or beyond. Our VSFF (Very Small Form Factor) connectivity is the first of its kind to deliver twice as many optical channels within the standard footprint of legacy transceivers.

Whatever your connector requirements or application, SENKO is here to help you. We value every connection.

PROJECTS	
Quantum Photonic Integrated Circuit Packaging (QPICPAC)	125

SIA PARTNERS UK PLC

www.sia-partners.com

Sia Partners is a next generation management consulting firm and pioneer of Consulting 4.0.
We offer a unique blend of AI and design capabilities, augmenting traditional consulting to deliver superior value to our clients. Counting 2,400 consultants in 38 countries, we expect to achieve USD 420 millions in turnover for the current fiscal year.

With a global footprint and expertise in more than 30 sectors and services, we optimize client projects worldwide. Through our Consulting for Good approach, we strive for next-level impact by developing innovative CSR solutions for our clients, making sustainability a lever for profitable transformation.

From its conception, Sia Partners has adhered to the following missions:

- Offer solid, value-creating advice based on profound analyses of our clients' businesses (competitive developments, regulatory impacts, and organizational redesigns)
- Promote the management consulting 'pure player' model, remaining independent from the IT industry
- Gradually develop the company sector by sector, ever in pursuit of excellence

Convinced of the relevance of its positioning, Sia Partners boasts strong development and aims to become a leading independent management consulting company in Europe.

PROJECTS	
Developing an error corrected quantum processor solution for commercial quantum computing	57

SILICON MICROGRAVITY LIMITED

www.silicong.com

Silicon Microgravity Limited (SMG) is a technology company focused on the inertial navigation and gravity markets.

Over 10 years of research and development, first at Cambridge University's Nanoscience Department and then carried on inside SMG, has gone in to our resonant MEMS technology. Today SMG's team of scientists and engineers are based in our Technology Centre in Waterbeach, just north

of Cambridge, England.

SMG focuses on two markets. The inertial navigation market where our MEMS accelerometers and gyroscopes presently under development will provide higher accuracy, smaller form factor and lower cost than existing sensors. Then the gravity sesning market where our MEMS gravity accelerometer sensor can detect changes down to 10 nanoG.

PROJECTS	
Pioneer Gravity: Gravity sensors for infrastructure productivity, situational awareness and seeing the invisible	14
Quantum Hive gravity system	124
QUAMINEX - A drone deployed integrated gravity/ magnetics measurement system for mineral exploration	174

SIVERS PHOTONICS

www.sivers-semiconductors.com/sivers-photonics

Sivers Photonics manufactures III-V compound semiconductor lasers devices critical to high growth, optical communications, sensing, and wireless markets. Our optical communications devices are a key component of cloud storage and cloud communications; passive optical networks (PON), including fibre-to-the-home; 5G fronthaul; and emerging Quantum technologies. Our optical sensing devices enable autonomous and assisted driving vehicles; consumer biometrics; hazard and metrology; security; and augmented and merged reality applications. Our optical wireless devices are critical to free-space optical communications using light.

PROJECTS	
MAG-V : Enabling Volume Quantum Magnetometer Applications through Component Optimisation & System Miniaturisation	16
Quantum sensors for end-of-line battery testing	21
Single Photon Infrared Imaging, Detection and Ranging (SPIDAR)	22

SKYLARK LASERS LIMITED

www.skylarklasers.com

Skylark is a leading-edge photonics company specializing in the development and production of CW single frequency DPSS lasers. Our proprietary BRaMMS Technology platform delivers outstanding spectral performance with some of the highest output powers in the market. We are trusted by clients in research and industry worldwide.

PROJECTS	
Pioneer Gravity: Gravity sensors for infrastructure productivity, situational awareness and seeing the invisible	14
QT Assemble: Integrated Quantum Technology Programme	28
NX Micro COTS laser system for quantum gravity Gradiometry	158

SONARDYNE INTERNATIONAL LIMITED

www.sonardyne.com

Sonardyne has been writing the future of underwater technology for over 50 years. We engineer, manufacture, service and support solutions that transform what's possible in offshore energy, maritime defence and ocean science. We own your challenges and deliver on the promises we make.

Through investment in people, technology and footprint, we have built one of the most capable, dynamic and responsible businesses in the marine technology space. As a vertically integrated company with everything under one roof, we – together with our trusted supply chain and strategic partners – can tackle your subsea project in ways no other solutions provider can.

PROJECTS	
Underwater Single Photon Imaging System	63

STANDARD CHARTERED BANK

www.sc.com/en

Standard Chartered is working with the University of Edinburgh and Rigetti to advance quantum-based machine learning methods, including generative and predictive models, for applications in the finance sector.

PROJECTS	
Quantum Computing Platform for NISQ Era Commercial Applications	20
Quantum Machine Learning for Financial Data Streams	150

STFC - LABORATORIES

www.ukri.org/councils/stfc/

The Science and Technology Facilities Council (STFC) is a world-leading multidisciplinary science organisation, and our goal is to deliver economic, societal, scientific and international benefits to the UK and its people – and more broadly to the world. Our strength comes from our distinct but interrelated functions.

We provide access to world-leading, large-scale facilities across a range of physical and life sciences, enabling research, innovation and skills training in these areas. We

work with partners to build National Science and Innovation Campuses based around our National Laboratories to promote academic and industrial collaboration and translation of our research to market through direct interaction with industry.

STFC's mission is to deliver world-leading national and international research and innovation capabilities and, through those, discover the secrets of the Universe. Our major research and innovation campuses at Harwell, Daresbury and research facilities across the UK and overseas support fundamental research in astronomy, physics, computational science and space science.

PROJECTS	
Next Generation Satellite QKD - Creating a UK Sovereign Capability for Manufacturing Satellite QKD Payloads	19
Safire	41
Space-certified Nonlinear Optics for Rugged Quantum Lasers (SNORQL)	44
Developing an error corrected quantum processor solution for commercial quantum computing	57
Quantum Enhanced Computing Platform for Pharmaceutical R&D - QuPharma	60
High-speed self-certifying Quantum Random Number Generator for simulationsn	103
INTERCOM: A high-performance ion-photon interface to enable multi-core trapped ion quantum computing	106
Miniature Packaged Ion Traps	109
QTEAM: Quantum Technologies Enabled by Additive Manufacturing	128
Realistic machine learning based ultra fast simulator for semiconductor spin qubit devices	131
Developing valuable operational healthcare applications using quantum computing techniques	140
A next-generation quantum computing based approach to enzyme targeted drug discovery	136
The Quantum Accelerator for Materials Design (QuAMaD)	155
Security-first Federated Quantum Machine Learning for Genomics	153
Quantum Unsupervised Learning for Anti-Money Laundering Detection	152
Feasibility Study on Quantum Optimization of Aircraft Container Loading	142
Investigating the use of quantum computing and quantum machine learning to reduce carbon emissions in aviation	144

STL TECH LIMITED

www.stl-tech.co.uk

Innovation as a service. STL provide technology, engineering, and product development expertise to support the ambitions of our clients.

Formed in 2016, STL was born out of a market need for cutting edge engineering capabilities. Based in the heart of Bristol's growing deep tech sector, STL provide innovators with the tools, technologies, and expertise needed to turn high-level concepts, into successful commercial enterprises.

Our experts have the experience and technical knowledge to fully understand the core of your technology. STL will collaborate with your team to develop a detailed technology road map that accounts for all of your needs and requirements. We will then implement a robust development programme to iterate prototypes and ultimately deliver advanced hardware and software products that can be used to accelerate your growth.

PROJECTS	
Single Photon Lidar Imaging of Carbon Emissions (SPLICE)	23
CompaQT	97

SURECORE LIMITED

www.sure-core.com

SureCore has identified a need in the market for low power memory to support several emerging major technologies such as IoT, wearable and medical applications that mandate "keep alive" memory.

Standard SRAM is not reliable below 0.9V, but sureCore's single supply rail, Ultra-Low Voltage SRAM IP allows operating voltage to scale in tandem with the logic. sureCore's IP delivers at a record-setting 0.6V across process, voltage and temperature. It provides an unprecedented 20MHz cycle time at 0.6V scaling to over 300MHz at 1.21V. Test chip results revealed an up to 80% savings in dynamic power consumption and an up to 75% reduction in static power.

Key is sureCore's patented "smart-Assist" technology that allows robust operation down to the retention voltage. Further architectural improvements include subdividing the memory into up to eight banks, which, in conjunction with enhanced sleep modes, provide greater system level flexibility. As well as operating in peripheral power off, light and deep sleep modes, each bank can also be independently controlled for active or in light sleep, deep sleep or power off modes.

sureCore's 40nmULP process technology memory compiler was launched in June 2016 and has been proven in silicon. The company also has a 28nm FDSOI compiler and is currently working on additional compilers at various technology nodes.

For the first time, devices in 'Keep Alive' mode can deliver useful processing power at unprecedented low power levels. The huge reduction in power consumption will enable

devices to keep going for far longer enabling sureCore to establish itself as the Architects of Low Power Memory.

40nm is a mature node that is a sweet spot that enables solutions for IoT and wearable devices to be cost effectively designed and produced, which is why sureCore has targeted 40nm for its low power IP as it provides a huge global potential market.

PROJECTS	
Development of cryo-CMOS to enable the next generation of scalable quantum computers	58

SYNOPSYS (NORTHERN EUROPE) LIMITED

www.synopsys.com

Synopsys technology is at the heart of innovations that are changing the way we live and work. The Internet of Things. Autonomous cars. Wearables. Smart medical devices. Secure financial services. Machine learning and computer vision. These breakthroughs are ushering in the era of Smart, Secure Everything—where devices are getting smarter, everything's connected, and everything must be secure.

Powering this new era of technology are advanced silicon chips, which are made even smarter by the remarkable software that drives them. Synopsys is at the forefront of Smart, Secure Everything with the world's most advanced tools for silicon chip design, verification, IP integration, and application security testing. Our technology helps customers innovate from Silicon to Software, so they can deliver Smart, Secure Everything.

Since 1986, Synopsys has been at the heart of accelerating electronics innovation with engineers around the world having used Synopsys technology to successfully design and create billions of chips and systems that are found in the electronics that people rely on every day.

PROJECTS	
Development of cryo-CMOS to enable the next generation of scalable quantum computers	58

TATA STEEL UK LIMITED

www.tatasteeleurope.com

Tata Steel is one of Europe's leading steel producers, with steelmaking in the UK and Netherlands, and manufacturing plants across Europe. The company supplies high-quality steel products to the most demanding markets, including construction and infrastructure, automotive, packaging and engineering. Tata Steel works with customers to develop new steel products that give them a competitive edge.

The Tata Steel group is among the top global steel companies with an annual crude steel capacity of 33 million tonnes. It is one of the world's most geographically-diversified steel producers, with operations and a commercial presence across the world. The group's turnover (excluding its South East Asia operations) in the year ending March 2019 was US $22.67 billion.

PROJECTS	
MAG-V : Enabling Volume Quantum Magnetometer Applications through Component Optimisation & System Miniaturisation	16

TELEDYNE E2V

www.teledyne-e2v.com

Teledyne e2v is a global leader in specialised components and subsystems for innovative solutions in medical, science, aerospace, defence and industrial applications.

Teledyne e2v offers:

- RF Power solutions for: defence electronic countermeasures, radiotherapy cancer treatment machines, radar systems, satellite communications amplifiers, industrial heating, cargo screening, ProWave® industrial processing systems, missile control safety and arming devices, and digital television transmitters.
- Imaging solutions including CCD and CMOS sensors and cameras, for space and earth observation imaging, science and life science imaging, machine vision, ophthalmology and dental x-ray systems.
- Semiconductor solutions for aerospace and defence programmes requiring: lifecycle management, hi-rel microprocessors, high speed data converters, high reliability ICs with lifetime continuity of supply, assembly and test services and MRAMs

PROJECTS	
3QN: Towards A New UK Industry for Novel Quantum Receivers in Nascent Satellite QKD Global Markets	12
Pioneer Gravity: Gravity sensors for infrastructure productivity, situational awareness and seeing the invisible	14
KAIROS	15

TETHERED DRONE SYSTEMS LTD

tethereddronesystems.co.uk

Tethered Drone Systems Ltd, world leading innovation providing continuous and autonomous flight with secure high-speed data transmission for multiple payloads via the fibre optic cable and powered tether.

PROJECTS	
Agile Quantum Safe Communications (AQuaSec)	13

THALES UK LTD

www.thalesgroup.com

Thales UK Ltd has been a key part of the UK supply chain for sophisticated Optronic sensors for hazardous conditions for over century. With 6,500 UK employees based on 12 sites, UK R&D investment is over £50 million and over £500 million is spent annually on the UK supply chain. Thales Glasgow develops and manufactures advanced optical sensors systems, primarily for defence and security (D&S) markets. Our product lines include ultra-high resolution cameras from the visible through to IR long wave, laser rangefinders, and laser designators.

PROJECTS	
Single Photon Infrared Imaging, Detection and Ranging (SPIDAR)	22

THE PUBLIC SERVICE CONSULTANTS LIMITED

www.thalesgroup.com

We exist to improve public services, for organisations, society and individuals.

The PSC is a team of public service consultants united by the belief that better public services are the key to a stronger society. Dedicated to the sector, we work closely and collaboratively with ambitious leaders and teams to solve complex challenges and deliver high-value change. Our expertise has been recognised by the Financial Times, The Economist, The Guardian, and the Health Service Journal.

As specialists, we choose to work only in public services and are proud to partner with inspiring leaders and teams across healthcare, central government, education, and beyond.

PROJECTS	
Developing valuable operational healthcare applications using quantum computing techniques	140

TOKAMAK ENERGY LTD

www.tokamakenergy.co.uk

Our mission is to deliver clean, secure, affordable fusion energy in the 2030s. We have an unrivalled track record designing and operating spherical tokamaks; the optimal route to commercial fusion energy. We are pioneers in transformative high temperature superconducting magnet technology for fusion and other applications.
Fusion energy and our scalable technology could be rolled out across the world as a solution to one of humanity's greatest challenges: providing clean, sustainable energy and energy security for all.

PROJECTS	
Quantum Optical Neural Networks for Quench Prevention	151

TOPGAN QUANTUM TECHNOLOGIES

topganlasers.com

TopGAN Quantum Technologies (TGQT) is a R&D design house based in Edinburgh with a focus on GaN laser diode and laser systems for quantum technologies. TGQT develop GaN laser diodes that meet the wavelength, power and linewidth requirements for optical atomic clocks (and other cold-atom sensors) to enable commercialisation opportunities through a lower cost laser module.

PROJECTS	
369GaN	32
STREAMLINE	45
Blue FLAME	67
Platipas - Passive Platform Development for Visible Wavelengths	118

TOSHIBA EUROPE LTD

www.toshiba.eu

Toshiba lead and support a number of projects, including:

SPIDAR: Toshiba Europe Limited are a leading innovator of quantum photonic devices and systems. At their Cambridge Research Laboratory they have developed high performance QKD systems to protect data communications with guaranteed security, and quantum devices including the first telecom GHz-rate single photon detectors and the first entangled light emitting diodes. They manufacture commercial QKD systems in the UK, and are advancing technologies for quantum networks, devices, and imaging.

AQuaSeC: Toshiba's QKD technology offers the highest key rates and longest fibre reach available today. Furthermore, our multiplexing technology also allows the quantum signals to be sent on the ordinary data carrying fibres like in the trial with the National Composites Centre and the Centre for Modelling and Simulation in Bristol. Toshiba have also miniaturised QKD technology onto a semiconductor chip manufactured using standard semiconductor fabrication

techniques, this allows mass production of highly uniform devices bringing quantum technology into everyday life.

PROJECTS	
Agile Quantum Safe Communications (AQuaSec)	13
Next Generation Satellite QKD - Creating a UK Sovereign Capability for Manufacturing Satellite QKD Payloads	19
Single Photon Infrared Imaging, Detection and Ranging (SPIDAR)	22
Assurance for quantum random number generators	25
UK National Foundry for Quantum Components (QFoundry)	31

UNIKLASERS LIMITED

www.uniklasers.com

UniKLasers is a leading-edge photonics company specialising in the development and production of CW single frequency DPSS lasers. UniKLasers proprietary BRaMMS Technology® platform delivers outstanding spectral performance with some of the highest output powers in the market. We are trusted by clients in research and industry worldwide.

PROJECTS	
QT Assemble: Integrated Quantum Technology Programme	28
Pioneer Gravity	14

UNITED KINGDOM ATOMIC ENERGY AUTHORITY

https://ccfe.ukaea.uk

As the UK's national fusion lab, the UK Atomic Energy Authority's mission is to lead the commercial development of fusion power and related technology, and position the UK as a leader in sustainable fusion energy. We are meeting the scientific and engineering challenges that come with such a grand ambition.

UKAEA is made up of four main facilities: Culham Centre for Fusion Energy (CCFE), Remote Applications in Challenging Environments (RACE), Materials Research Facility (MRF), and - in partnership with STFC - the Oxfordshire Advanced Skills (OAS) apprentice training centre.

As part of CCFE, we operate the world's largest fusion device – the Joint European Torus, or JET – on behalf of the European fusion consortium EUROfusion.
Connect with us to hear more about our world-class research and career opportunities and to discuss commercial opportunities.

PROJECTS	
Feasibility study to quantify the potential of using quantum algorithms to simulate MHD effects in liquid metals	143
Quantum Optical Neural Networks for Quench Prevention	151

UNITIVE DESIGN & ANALYSIS

www.unitivedesign.co.uk

On project QuanTICo: Unitive Design specialise in the design and development of imaging systems and are the project lead for QuanTICo (Quantum Terahertz Imager using Coherent control), a disruptive imaging technology based on research carried out by Durham University. The commercial value of the technology is high speed, low noise THz imaging which can deliver benefits in market sectors from food and drink, and renewable energies to the non-destructive evaluation and testing industries. THz imaging enables inspection of materials which are difficult to see using other techniques, such as those which are optically opaque but largely transparent to ionising radiation.

PROJECTS	
Quantum Terahertz Imager using Coherent control (QuanTICo)	49

UNISYS LIMITED

www.unisys.com

We are a global technology solutions company that powers breakthroughs for the world's leading organizations. These solutions — digital workplace, cloud, applications & infrastructure, enterprise computing and business process solutions — help people overcome obstacles and not only reach their greatest potential but go beyond it.

PROJECTS	
Feasibility Study on Quantum Optimization of Aircraft Container Loading	142

UNIVERSAL QUANTUM LTD

https://universalquantum.com

Universal Quantum is building the world's first million-qubit quantum computer. Its unique, electronic quantum computing modules are based on silicon technology where individual modules are connected using ultrafast electric field links to form an architecture that truly scales. Based near Brighton in the UK, Universal Quantum is backed by top VCs, has 15+ years of quantum computing experience and is a proud member of the Tech Talent Charter.

PROJECTS	
Developing an error corrected quantum processor solution for commercial quantum computing	57
Development of cryo-CMOS to enable the next generation of scalable quantum computers	58
NISQ.OS	27

VECTOR PHOTONICS LIMITED

www.vectorphotonics.co.uk

Vector Photonics' PCSELs are the first, major break-through in semiconductor laser technology for 30 years. The company is a spin-out from one of the world's leading academic groups in Photonics at the University of Glasgow. Its proprietary technology, developed since 2012, places Vector Photonics at the heart of the rapidly growing datacenter industry.

PCSELs (Photonic Crystal Surface Emitting Lasers) are low cost, robust with high speed and power. This combination of key characteristics gives them a huge advantage over present-day, commonly used VCSELs (Vertical Cavity Surface Emitting Lasers), which compromise wavelength range and power, and EEL lasers (Edge Emitting Lasers), which are high- cost and fragile.

PCSELs have other advantages too. They emit light from the top surface, like VCSELs, making them easy to package and incorporate into PCBs and electronic assemblies. They are also made in a similar way to EELs, so existing, experienced, supply chain capability and capacity can be utilised.

PROJECTS	
ADRENALIN (lAser Diodes in the veRy nEar iNfrared for quantum AppLIcatioNs)	92
QUantum communication Development with Increased Throughput for information Systems (QUDITS)	122

VORSUS LTD

Vorsus Quantum provides a full suite of technology services to enable business organisations quantum ready.

PROJECTS	
Persistent Homology on near-term Quantum Computers	116

WAVE PHOTONICS LTD

www.wavephotonics.com

Wave Photonics is taking a computational approach to integrated photonics design.

We are building a platform providing optimised designs and streamlined integration between the supply chain.

PROJECTS	
A quantum photonics PDK	66
Photonic chips as a platform for DIY QKD	85
Silicon Nitride for Quantum Computing (SiNQ)	154

WIDEBLUE

www.wide-blue.com

Wideblue is an integrated product design, product development and manufacturing consultancy. Our product design team are experts in industrial design, mechanical engineering, electronic design, software development, photonics, image processing and manufacturing. Multi-disciplinary technical skills are backed up by a proven design process and strong project management. Wideblue design consumer products, medical devices, scientific instruments and specialist technical systems. Our strength is developing integrated systems which are commercially viable products. An in-house manufacturing start-up facility helps clients to bridge the gap between proto

PROJECTS	
3QN: Towards A New UK Industry for Novel Quantum Receivers in Nascent Satellite QKD Global Markets	12
Compact optics for high performance portable atomic timing and quantum sensors	34
Towards a Quantum enabled Cloud	62
Grating-based lattice optical clock (G-BLOC)	101

ZAIKU GROUP LTD

www.zaikugroup.com

Zaiku Group is a collaborative Deep-tech R&D commercial venture on a mission to bring together talented people in mathematics and deep science. Our areas of interests include; Quantum Computing, Pure Mathematics, Distributed Systems, Artificial Intelligence, Blockchain Security, Homomorphic Encryption, and Neuromorphic Computing.

PROJECTS	
Sakurai: A Quantum Error Mitigation Platform-as-a-Service for Privacy-Preserving Genomics Data Analysis	90
Security-first Federated Quantum Machine Learning for Genomics	153

Delivered by Innovate UK

UK Research and Innovation (UKRI)
Polaris House
North Star Avenue
Swindon SN2 1ET
T: 01793 444000
E: communications@ukri.org
www.ukri.org

UK NATIONAL QUANTUM TECHNOLOGIES PROGRAMME