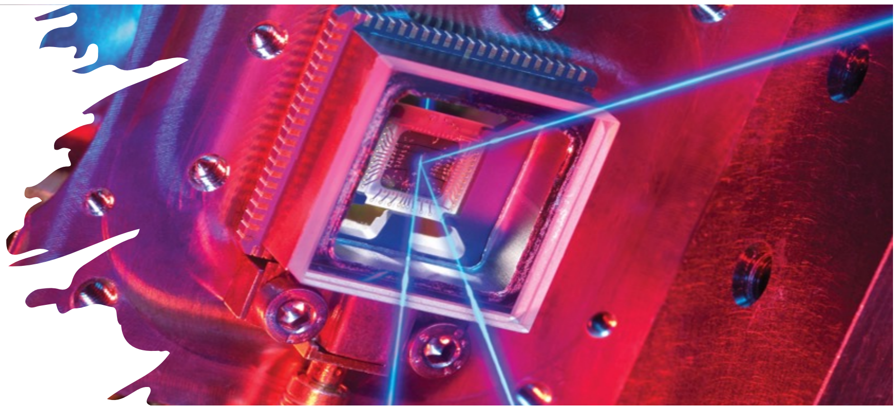
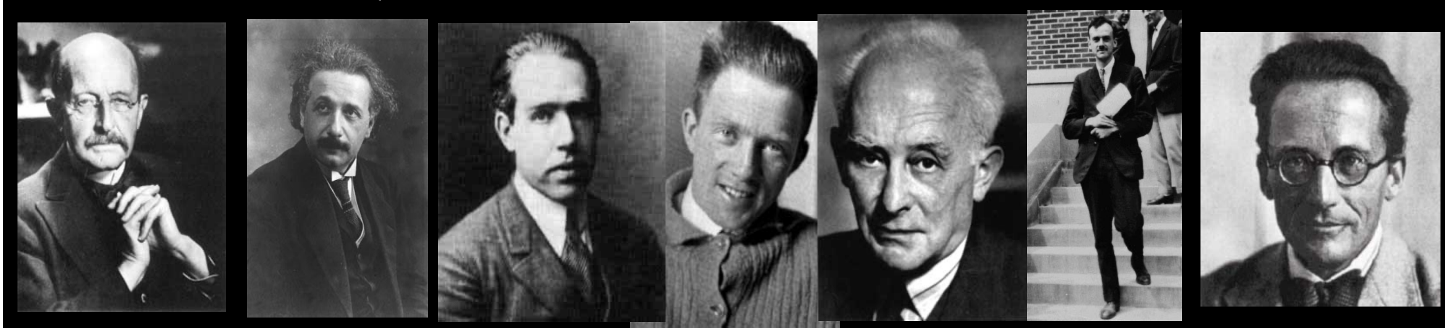
What's Quantum Technology?

Peter Knight
NQTP Strategic Advisory Board Chair
&
Roger McKinlay
NQTP Challenge Director



UK NATIONAL QUANTUM TECHNOLOGIES PROGRAMME

Quantum mechanics founders



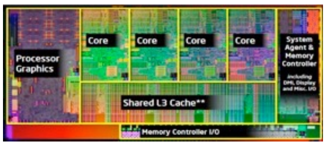
- Planck, Einstein, Bohr, Heisenberg, Born, Dirac, Schroedinger
- but how can quantum mechanical principles of coherence and entanglement be employed?

“"When two systems… enter into temporary physical interaction due to known forces between them, and …… separate again, then they can no longer be described in the same way as before, viz. by endowing each of them with a representative of its own. I would not call that one but rather the characteristic trait of quantum mechanics, the one that enforces its entire departure from classical lines of thought. By the interaction the two representatives [the quantum states] have become entangled." **.” Schroedinger, Camb Phil Soc**

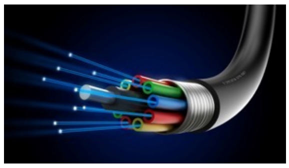
20^{th} century – the 1st quantum revolution

- Transformative outcomes across all of technology and society
- Industrial revolution, electricity etc. was built on classical physics
- Quantum physics, developed during the 1920s gave us much of our modern technology
- Examples:

Lasers



Microelectronics

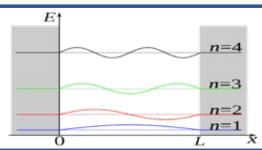


Broadband etc

Progress in quantum physics since 1990s is underpinning a 2nd quantum revolution with similar societal impact to 1st

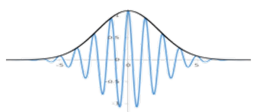
The strange world of quantum- highly counter-intuitive! First and second quantum revolutions

Quantization



All quantities are discrete, for example, the energy levels in an atom

Wave Nature of Matter



all objects (photons <u>and</u> particles) display both particle and wave properties

Lasers
semiconductors

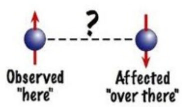
Superposition

Classical Bit	Quantum Bit (qubit)
0 or 1	0 and 1 0/1

quantum matter can be in two different states at the same time: measurement causes a collapse to one state.

Quantum 2.0

Entanglement



"connection" between separated particles where a measurement of one immediately affects the state of the other

UK has estimated ~5 year lead on time to technology insertion in key areas

UK NATIONAL QUANTUM PROGRAMME

A Brief Timeline

Launch The UK National Quantum Technologies Programme (NQTP)

2013 → 2014 → 2019 → 2023 → 2024 - 2034

PHASE 0:

Workshop at Chicheley Hall

PHASE 1:

Focus on converting research and excellence into technology prototypes and plugging the skills deficit

£380m investment over 5 years.

PHASE 2:

Focus on driving commercialisation and economic impact (investment, supply chain growth, international collaboration)

Additional £350m over 5 years plus £153m for industry-led activities.

National Quantum Computing Centre (NQCC) launched Sept 2020

PHASE 3

Publication of UK Quantum Strategy affirms UK continued commitment to quantum technologies for the next 10 years. Strategy provides an additional investment of £2.5 billion, starting in 2024

So far, NQTP has provided awards to over 123 businesses and 38 universities and RTOs collaborating in over 95 projects

THE UK NATIONAL QUANTUM TECHNOLOGIES PROGRAMME (NQTP): PARTNERS AND GOVERNANCE

Department for Science, Innovation & Technology

UK Quantum Strategy lead department

Parent department of UKRI and sponsor for NPL

UKRI Engineering and Physical Sciences Research Council

Funds research and training in quantum, including:
(1) a national network of research hubs;
(2) centres for doctoral training;
(3)-domestic and international research grants;
(4)-fellowships.

UKRI Innovate UK

Delivering a national challenge programme to develop new commercial quantum products involving academia, industry and Government

UKRI Science and Technology Facilities Council

Delivering the Quantum Technologies for Fundamental Physics programme;

Home of the National Quantum Computing Centre

NPL National Physical Laboratory

Home of the Quantum Metrology Institute (QMI)

Leads activities to test, validate and commercialise new quantum R&D

Ministry of Defence

Government lead for defence applications of quantum technologies

[dstl]

Responsible for delivering MOD R&D programme in quantum technologies

Provides specialist technical support to national quantum programme partners

GCHQ

One of the UK's Intelligence and Security Agencies

Home of the National Cyber Security Centre (NCSC): conducts research and provides advice on 'post-quantum' security

COORDINATING BODIES

UK NATIONAL QUANTUM TECHNOLOGIES PROGRAMME

Programme Board

Provides coordination and strategic direction for the programme with representation from each of the partner agencies.. Chaired by Dame Lynn Gladden, Executive Chair, EPSRC.

Strategic Advisory Board

Provides independent advice to help steer the strategic direction of the programme and policy on quantum technologies, and is made up of eminent figures from across industry, academia and Government. Chaired by Sir Peter Knight.

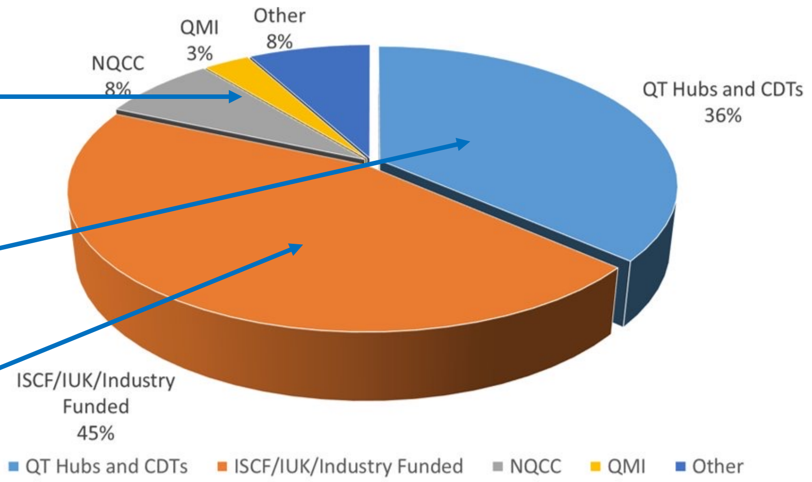
Research, Industry and Private Investment

The UK's National Quantum Technologies Programme is a £1bn 10-year investment in the sector.
years in to this phase

Infrastructure Bit

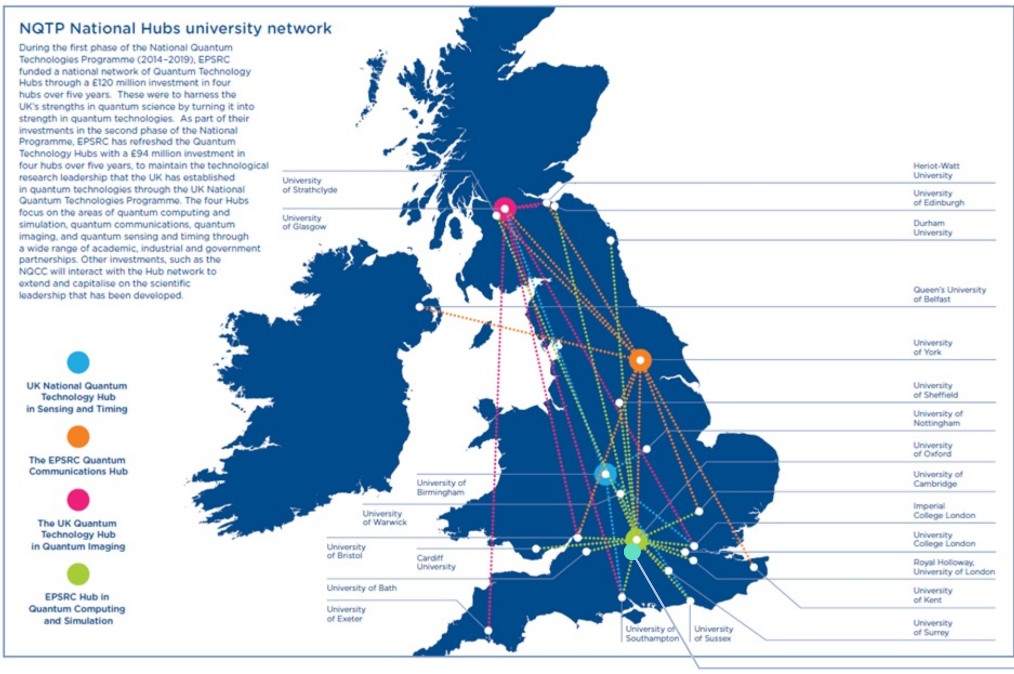
Commercialising Science Bit

Collaborative Industry bit



Hub refresh further £100m from '24, £70M TMF, plus others
And new Phase 3 from 2024 led by the Quantum Strategy

UK National Quantum Technologies Programme



125 MSc candidates	**>470** PhD candidates
120 Hub industry partners	**85** QT Apprenticeships
49 UK start-ups **590** employed	**>£245m** UK V/C funds raised
>40 UK Quantum Suppliers	**£1bn** UK public/private investment

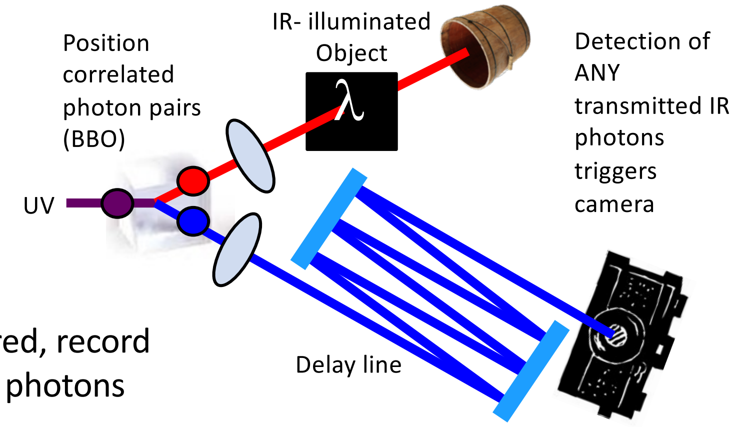
National Quantum Computing Centre

Applications - Imaging

Quantum Imaging

- Time Correlated Single Photon Counting uses single-photon source & accurate timing to scan objects and identify them at distances of 1km and greater.
- Several applications: target identification in free- space at kilometre distances; using remote multispectral depth information to extract structural and depth imaging eg highly scattering underwater environment
- Very promising for ranging/imaging applications: single-photon avalanche diode detector arrays, cameras where each pixel is a single-photon detector with single-photon sensitivity and picosecond temporal resolution.
- A variation: use correlated photon pairs for range-finding imaging, heralding the measurement with one photon and performing the range measurement with the other photon.

Ghost imaging: extreme covert imaging

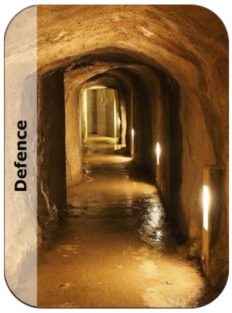


Illuminate object in the infra-red, record image using correlated visible photons

Photon counting -ultra-low exposure imaging

Applications - Sensing

What's Under your feet: Gravity – The Challenges

Improving Infrastructure Productivity			Seeing the Invisible	Situational Awareness
				
• 1.37m streetworks p.a. • 2.4m road openings • Projected costs p.a.: £3.19bn	• Surveys reduce risks • ROI on utility surveying $3.41-£20 • 5% of project budget for surveying ➔ reduce overspend to 25%	• 16% of utilities damaged by contractor in UK • Sinkhole occurrence increased fivefold in 2014	• 30% of exploratory bore holes drilled are successful • Exploration market ~£7bn	• Increasing black market for tunneling machinery in hostile & security critical environments

Imaging with Gravity

- Numerous applications in the societal challenge areas:
  - Security (hidden voids, dense objects)
  - Environmental monitoring (magma, buried material)
  - Prospecting: oil & gas
  - Space: attitude control


nature International weekly journal of science

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Archive > Volume 531 > Issue 7596 > Letters > Article

NATURE | LETTER

日本語要約

Measurement of the Earth tides with a MEMS gravimeter

R. P. Middlemiss, A. Samarelli, D. J. Paul, J. Hough, S. Rowan & G. D. Hammond

Affiliations | Contributions | Corresponding authors

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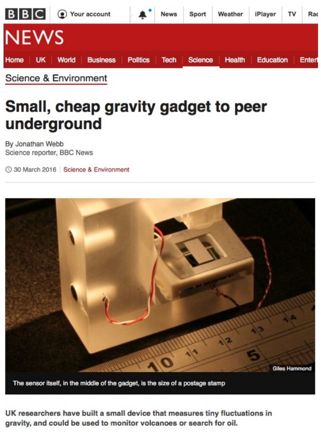
PDF | Citation | Reprints | Rights & permissions | Article metrics

The ability to measure tiny variations in the local gravitational acceleration allows, besides other applications, the detection of hidden hydrocarbon reserves, magma build-up before volcanic eruptions, and subterranean tunnels. Several technologies are available that achieve the sensitivities required for such applications (tens of microgal per hertz$^{1/2}$): free-fall gravimeters[1], spring-based gravimeters[1, 3], superconducting gravimeters[4], and atom interferometers[5]. All of these devices can observe the Earth tides[6]: the elastic deformation of the Earth's crust as a result of tidal forces. This is a universally predictable gravitational signal that requires both high sensitivity and high stability over timescales of several days to measure. All present gravimeters, however, have limitations of high cost (more than 100,000 US dollars) and high mass (more than 8 kilograms). Here we present a microelectromechanical system (MEMS) device with a sensitivity of 40 microgal per hertz$^{1/2}$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Science & Environment

Small, cheap gravity gadget to peer underground

By Jonathan Webb
Science reporter, BBC News

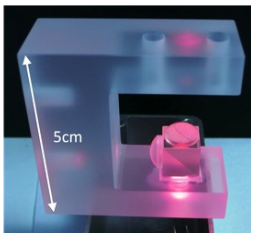
30 March 2016 | Science & Environment

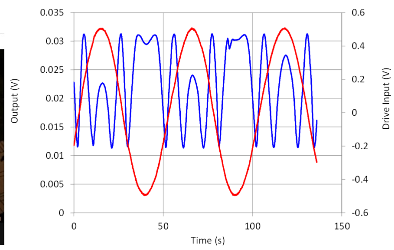
Giles Hammond

The sensor itself, in the middle of the gadget, is the size of a postage stamp

UK researchers have built a small device that measures tiny fluctuations in gravity, and could be used to monitor volcanoes or search for oil.

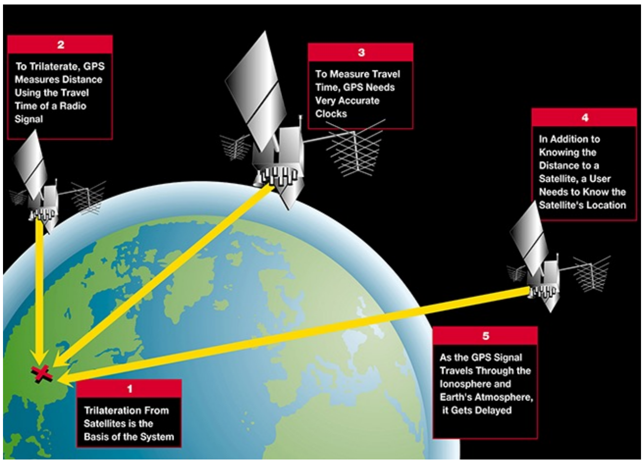
MEMS demonstrator

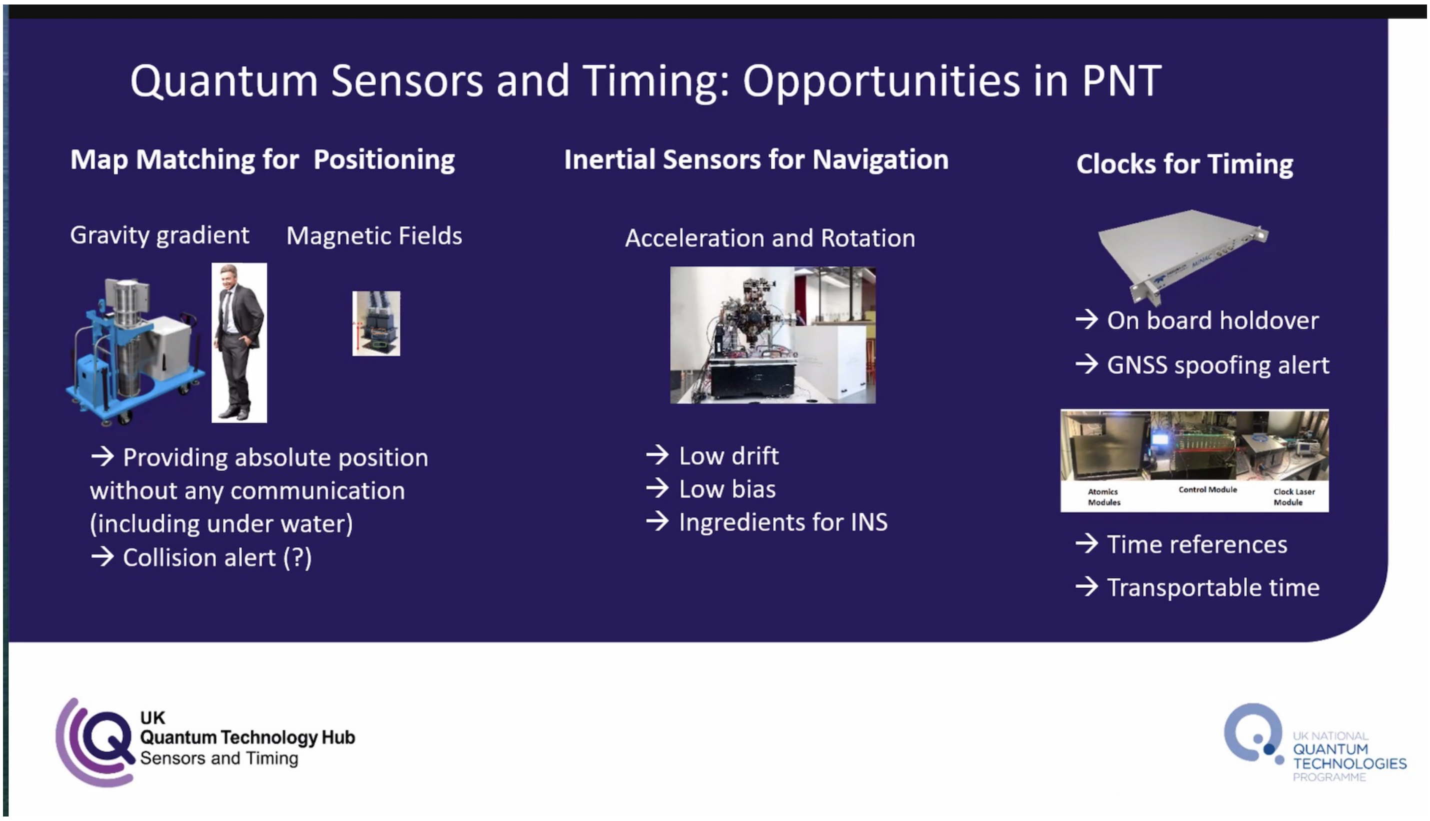




Interferometer fringes

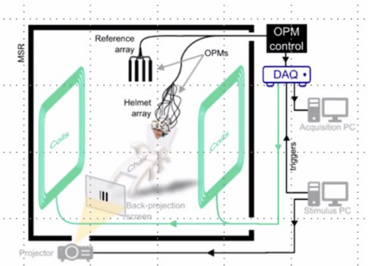
Where am I? Quantum Navigation





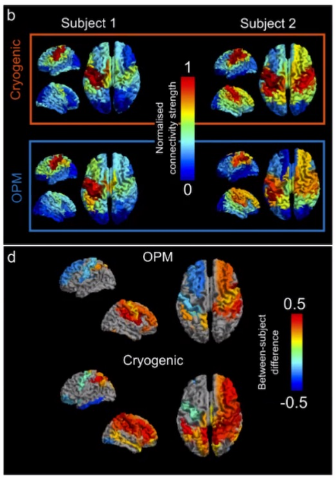
What’s in your head: MEG

Quantum-Magnetoencephalography – Spin off from QT



Cerca:
Joint venture spin-off between Magnetic Shields and Nottingham University
Founded in 2020

First systems delivered internationally
£6M turnover in first year
>£50M requests for quotations



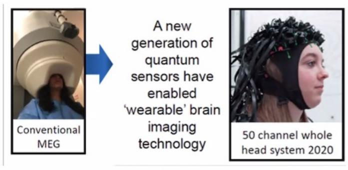
Impact Opportunities:

Epilepsy: 60M people worldwide

Dementia: 1% GDP

Schizophrenia: 1% of population

Trauma: 100.000 / year in UK

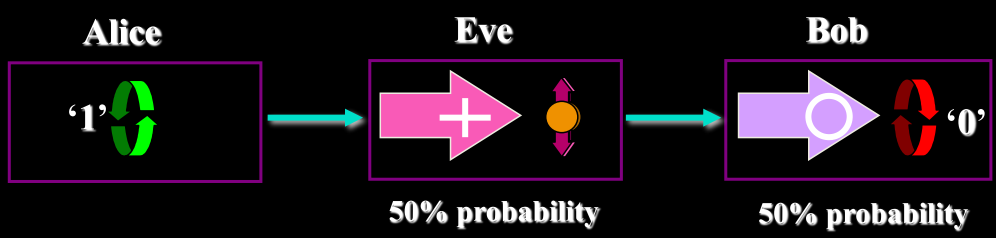


UK Quantum Technology Hub Sensors and Timing

UK NATIONAL QUANTUM TECHNOLOGIES PROGRAMME

Communications

Eavesdropping (Intercept & resend)



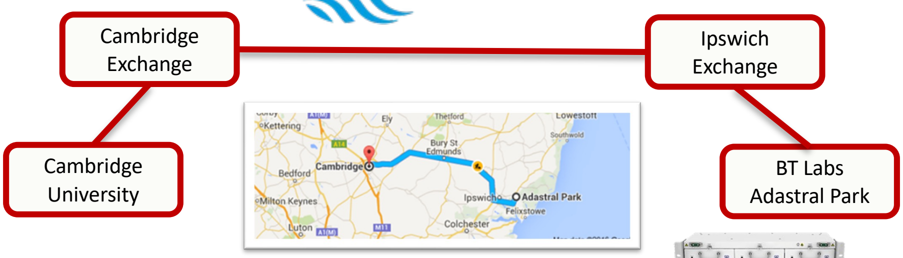
In quantum physics, the act of measurement disturbs what you are measuring, so an eavesdropper reveals themselves and in any case can only access partial information

Hardware based encryption may be secure if operated properly. But pay attention to human factors concerning use

https://www.ncsc.gov.uk/information/quantum-key-distribution from my colleagues at GCHQ

Long distance Quantum Key Distribution with **Trusted Nodes: secure communications**

QUANTUM COMMUNICATIONS HUB



Testbed between BT Labs at Adastral Park and Cambridge University

Adva FSP 3000

In quantum physics, the act of measurement disturbs what you are measuring, so an eavesdropper reveals themselves and in any case can only access partial information

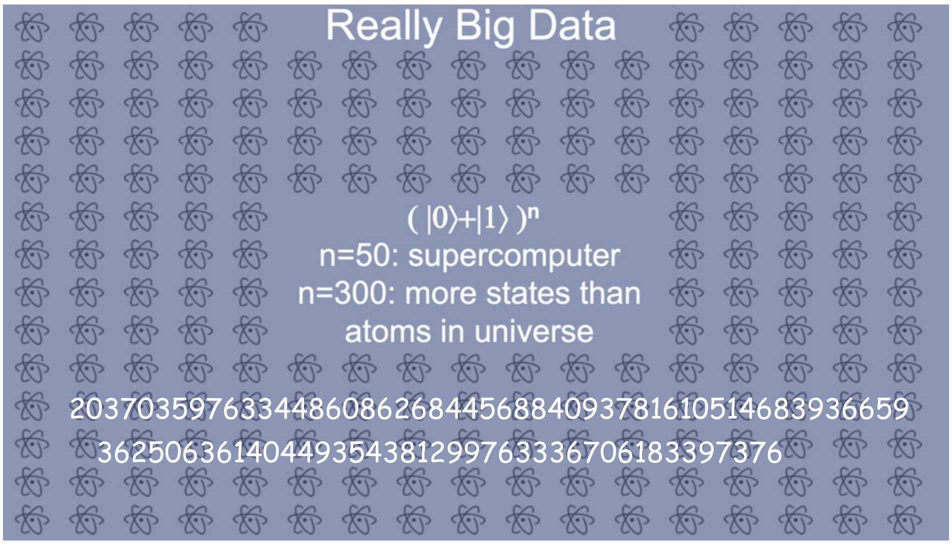
But .....

Computing

Basic idea of Quantum Computing

- Computation with n Qubits.
- Main difference: build **coherent superposition** of states
- State space grows exponentially with number n of qubits: 2^n
- Behaves like a massively parallel computer
- Solves problems in much fewer steps in carefully constructed algorithms: see https://quantumalgorithmzoo.org

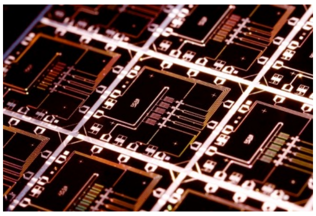
QUBIT scale (adapted from John Martinis)- add one bit *doubles* the size



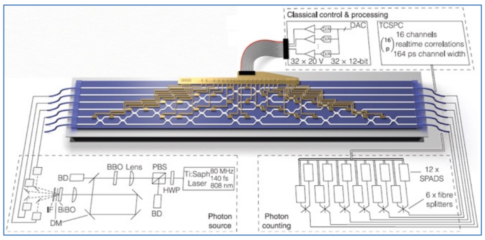
Google's 53 qubit processor gives $2^{53} = 10^{16}$

(Only 144,115,188,075,855,872 states)

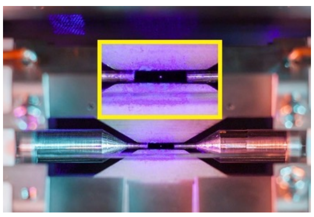
Quantum Computer Hardware Startups



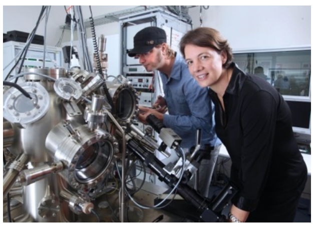
Superconducting
Intel, IBM, Google, Rigetti



Optical
Xanadu, PsiQuantum



IONQ



Semiconductor
Silicon Quantum Computing

Quantum Computing and the Crypto apocalypse

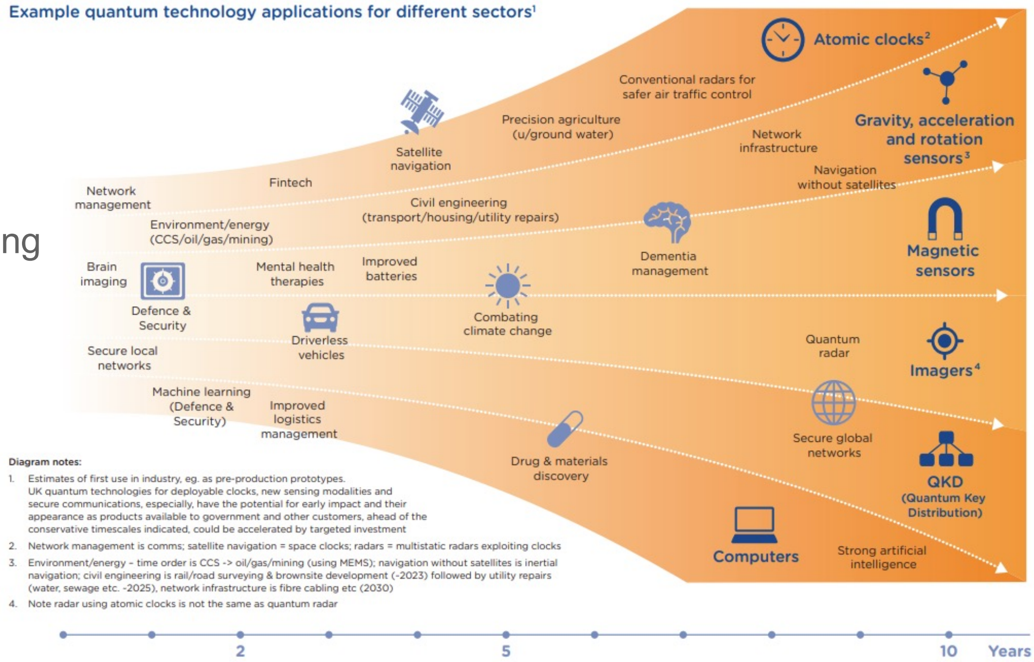
- Quantum computing changes whole nature of information processing
- Changes complexity classes: what was thought “hard” (nonpolynomial) may become “easy” (polynomial). Destroys our confidence in the security of the internet!
- Quantum Computing is NOT just about faster…Quantum can do things assumed impossible in a normal time.
- Yet ”Hardness” assumptions underpin internet and comms security: *problem!*
- Shor (1994): **Factoring** hard classically becomes “easy” with a quantum computer
- Will render all public key infrastructure vulnerable. No RSA, TLS….Affects us all!
- Quantum computer at scale will emerge in a decade (best estimate);
- Need to retool all crypt primitives within that time to be quantum resistant.

The Industry Story

Only a product away…

- Computing
- Secure communication
- Sensing and timing - PNT
- Imaging

Example quantum technology applications for different sectors[1]



Catalytic Funding

The numbers

THE UK QUANTUM TECHNOLOGY CHALLENGE

7 years strategy (2018-2025)

TO DATE

£174M UK government investment awarded to

139 business-led projects involving

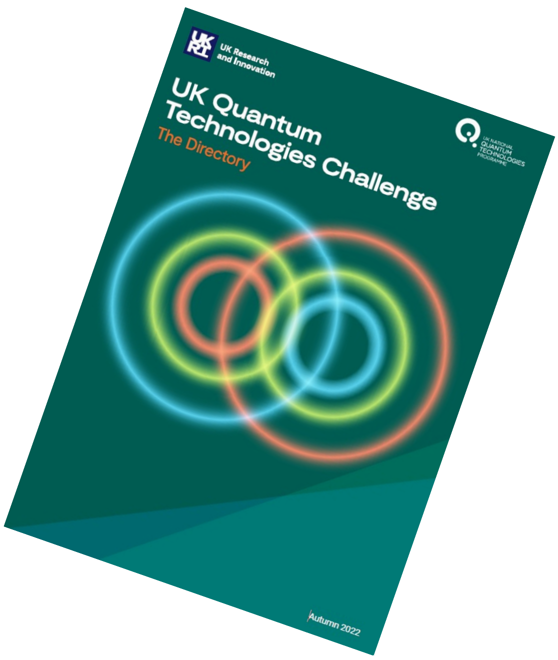
141 UK companies in collaboration

THE UK QUANTUM LANDSCAPE

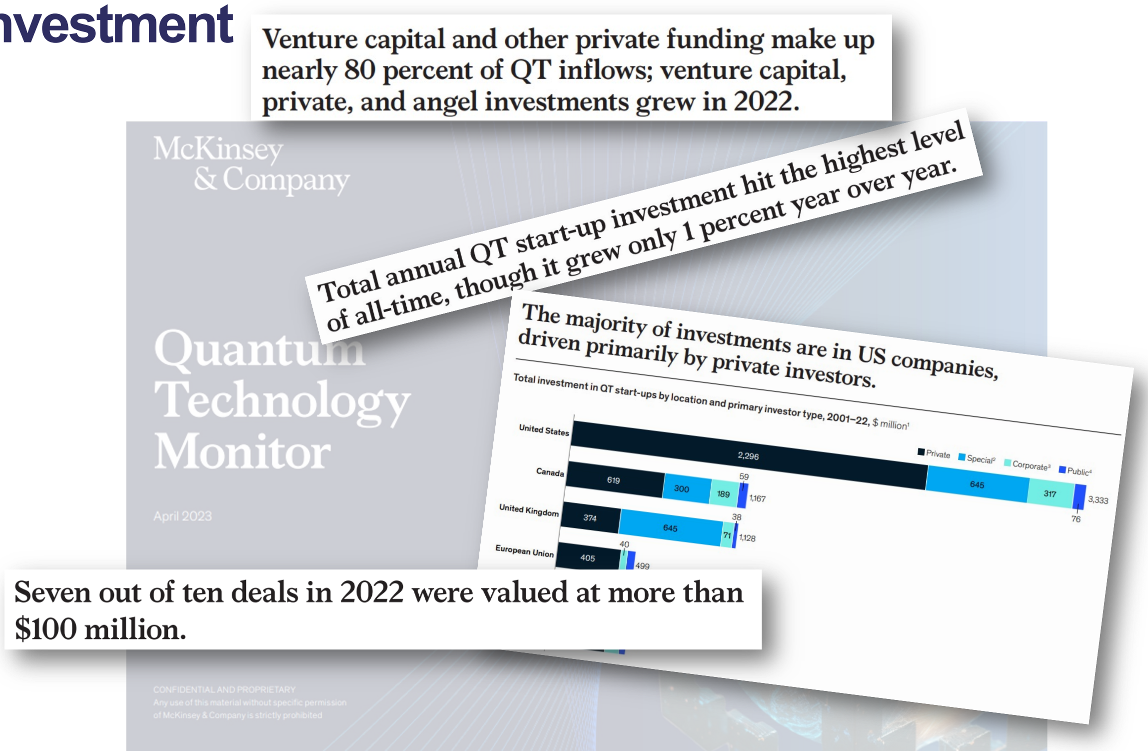
Over **£390M** private investment since 2018

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

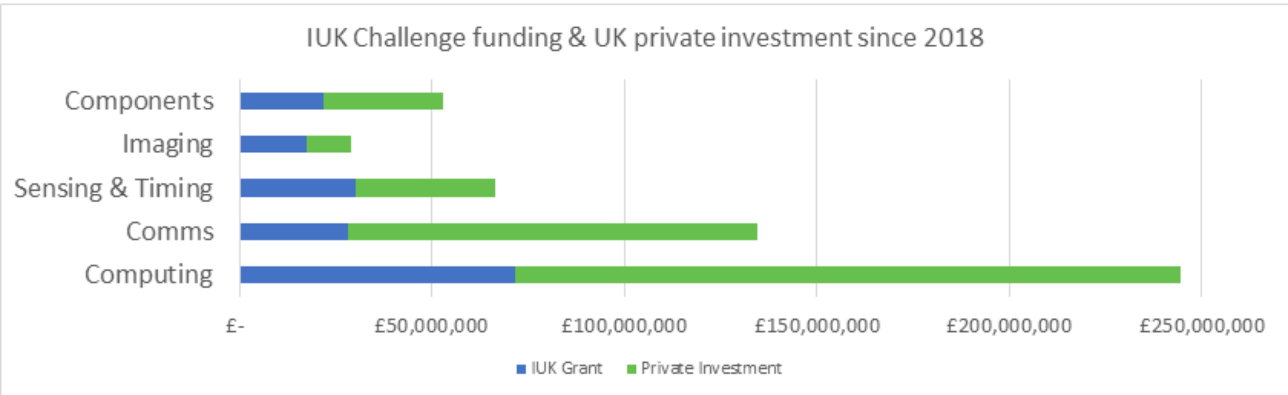
One of the UK's **6** fastest growing sectors in 2020



Private Investment



Where the investment is going

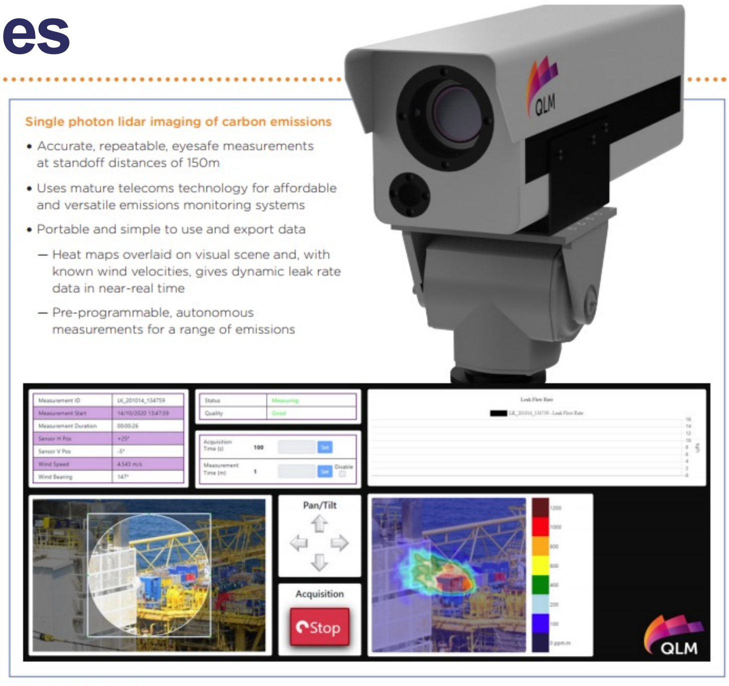


Integrators and Primes (QLM)

Single photon generation and detection opens the door to imaging systems which cannot be achieved using conventional means, including

- Portable, robust multi-gas imagers for gas emissions in infrastructure
- Vision through obscurance for lidar systems and imaging
- Non-line of sight imaging of obstacles

UK Research and Innovation



www.thespliceproject.com

Quantum companies in focus

Nu Quantum

Based: Cambridge

Technology chain: Components

Profile:

Start-up. Only company world-wide developing **room temperature single-photon sources** and **detectors** to enable the next generation of commercially-viable photonic quantum technologies, **quantum networking, computing**

Key projects
AirQKD
Assurance for QRNGs
ViSatQT

Computing Comms Sensing &Timing Imaging

VCs

Quantum companies in focus

Riverlane

Based: Cambridge

Technology chain: Software & services

Profile:

Start-up. Builds ground-breaking software to unleash the power of **quantum computers.** Deltaflow.OS is an **operating system** for quantum computers inspired by heterogeneous architectures

Key projects
NISQ.OS
AutoQT
QPharma

Computing Comms Sensing &Timing Imaging Components

UK Research and Innovation

Customers!

ORCA Computing

ORCA Computing Ltd.

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 fibre-based photonic quantum computing platform…

Quantum companies in focus

Covesion

Based: Southampton

Technology chain: Components

Profile:

Established SME. World leading designer, manufacturer of frequency conversion crystals – can change the wavelength of laser, single photon sources to suit user specifications or applications

Key projects
MIRUS
QT Assemble
SNORQL

Computing Comms Sensing &Timing Imaging Components

UK Research and Innovation

Collaborations

High-BIAS^2

- Lead: ColdQuanta
- 2020-2023
- Advancing the development of a cold atom-based Quantum Positioning System
- Enabling resilient navigation systems without the need for GNSS

ColdQuanta The Quantum Atomics Company

BAE SYSTEMS

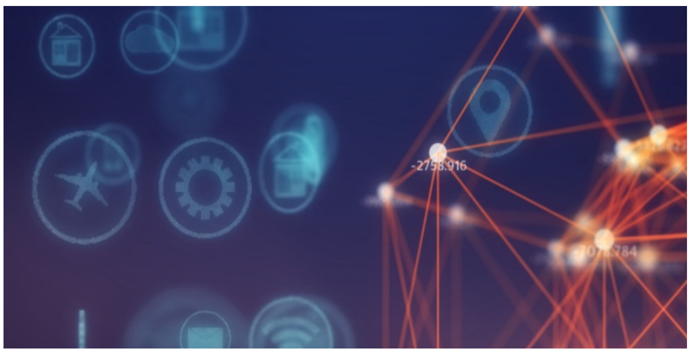
PA

ALTER TECHNOLOGY

Fraunhofer

UK CALEDONIAN PHOTONICS

RedWave Labs



UK Research and Innovation

Not just Start-Ups

Quantum companies in focus

Alter technologies

Based: Central belt, Scotland

Technology chain: Systems, packaging

Profile:

Large enterprise. package design and precision assembly services for a wide range of optoelectronic, microelectronic and MEMS devices. Offer end to end semiconductor manufacturing from wafer singulation to assembled product.

ALTER TECHNOLOGY

Key projects
High-BIAS2
QT Assemble
Pioneer Gravity

Computing Comms Sensing &Timing Imaging

Quantum companies in focus

Oxford Instruments

Based: Oxford

Technology chain: Component (Platform)

Profile:

Established large enterprise, designs, supplies and supports market-leading cryogenic and high flux superconducting magnetic research platforms. They are a globally **leading supplier** of **dilution fridge** platforms for **quantum computing**

OXFORD INSTRUMENTS

Key projects
NISQ-Era Platform
FABU
QuPharma

Computing Comms Sensing &Timing Imaging Components

BAE SYSTEMS

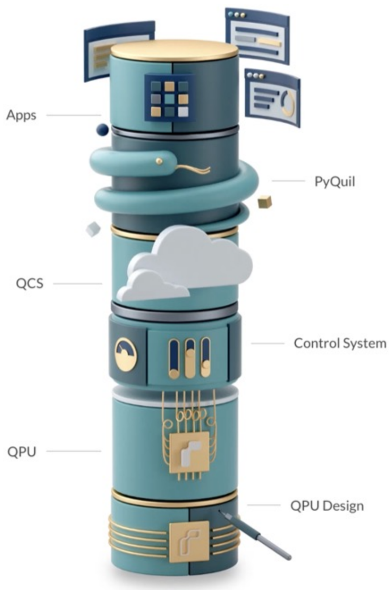
bp

QINETIQ

BT

TOSHIBA

Full Stack



Deployment of full stack Rigetti platform in the UK

Accessible via the cloud

End use applications and new engagements

UK Research and Innovation

rigetti

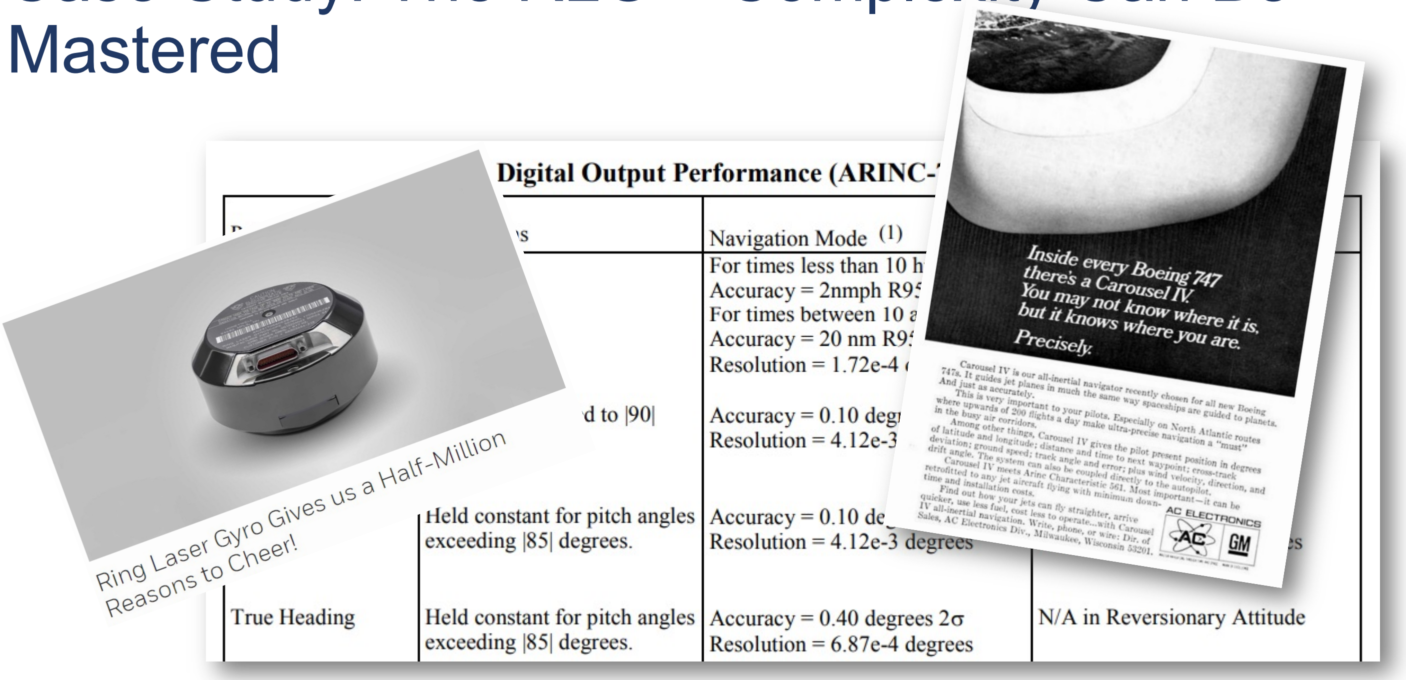
Standard Chartered

OXFORD INSTRUMENTS

THE UNIVERSITY of EDINBURGH

PHASECRAFT

Case Study: The RLG – Complexity Can Be Mastered



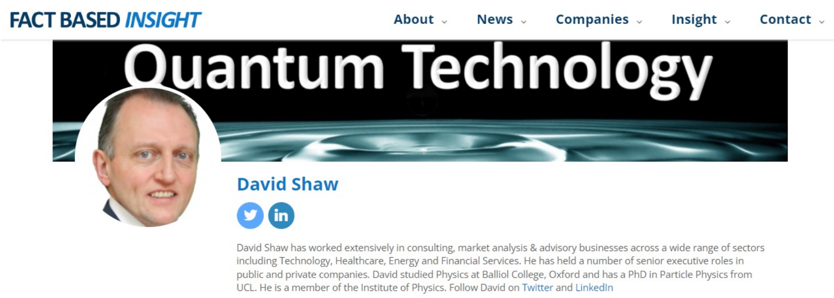
The Classic Engineering Goals

- Smaller
- Cheaper
- More robust
- More reliable
- Lower noise
- More efficient
- **For computing – Scalable!**

Nuts and Bolts

- Materials
  - Silicon – Compound Semiconductors – Glass
- Fabrication
  - Nano – 2D Materials – heterogenous – 3D structures
  - Silicon meets glass.

▪ Optical
  ▪ Gratings, cavities, optical waveguides, lasers, lasers, lasers, lasers..



Variables: A Lifetime of Work

- The Physics:
  - Electron spin.
  - Photon polarization
  - Atoms, Ions, artificial atoms/ defect-centres
- Qubit Type:
  - Trapped Ion
  - Neutral atom
  - Silicon
  - Photonic

- Not just qubits.
  - Architecture
  - Error correction
  - Control/calibration
  - Gate control
  - Environment
  - Connectivity
  - Substrate

Conclusions on the Industry Story

- We’ve created an ecosystem in which companies are starting and growing.
- We’re attracting global companies to the UK.
- We’re seeing products and revenue.
- The £2.5B commitment from UK Government shows commitment for the long term.

conclusions

- UK is in top 3 world-wide
- 20 year £3.5Bn investment
- applications
- *Beware of Export Regulation consequences*

- you have nothing to do but mention the quantum theory, and people will take your voice for the voice of science, and believe anything- Bernard Shaw, Geneva (1938)