Novel Sources and Systems for Space?

John-Mark Hopkins

EPIC
European Photonics Industry Consortium

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Fraunhofer CAP Introduction

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Fraunhofer Centre for Applied Photonics

- A UK research and technology organisation, RTO
- UK not for profit Ltd company
- Legally independant affiliate of Fraunhofer Society – Europe‘s leading independent research org.
- Operating according to tried and tested Fraunhofer model
- Providing professional R&D services
  - Sources (lasers)
  - Systems
- Active across many sectors
- Work with industry to translate technology into products

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Fraunhofer Centre for Applied Photonics

University of Strathclyde and Fraunhofer sign letter of intent for collaboration in photonics

Fraunhofer CAP launched 5 year package from founding partners including Scottish Gov. UoS. And Fraunhofer

2009 2010 2011 2012 2017

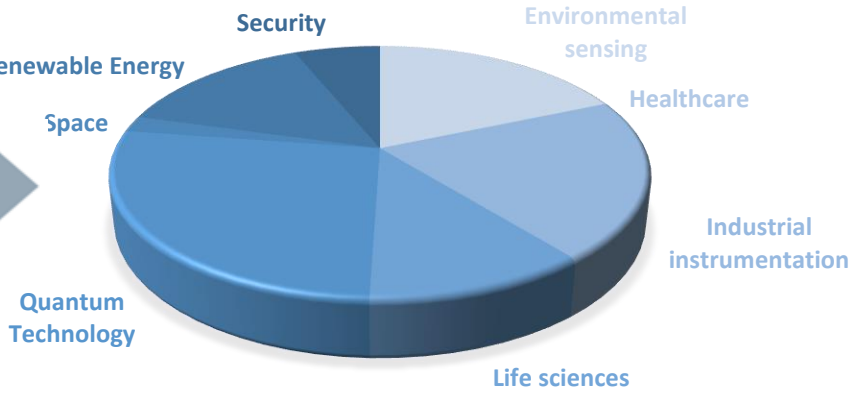
UK Gov. Invites Fraunhofer to explore closer connections with UK universities

General Election Coalition pursues Catapult concept

5 year business plan developed

Funding Renewed Fh-CAP builds a wide portfolio of projects and establishes itself as a delivery partner for UK industry

FRAUNHOFER CAP BUSINESS FIELDS BY PROJECT NUMBERS



- **Fraunhofer CAP activity is spread across many sectors – photonics as an enabling technology**

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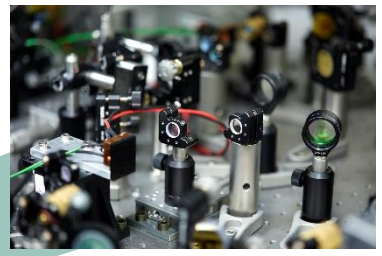
Fraunhofer Centre for Applied Photonics

- Lasers and Laser Systems Business Unit has projects in a number of markets
- 117 Projects to date
- Total project value

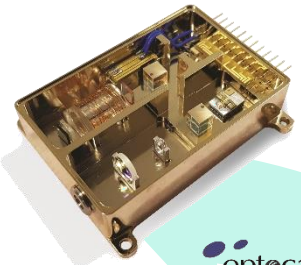
  44M GBP
- Total to Fraunhofer

  CAP >13M GBP

From this: laboratory bench-top



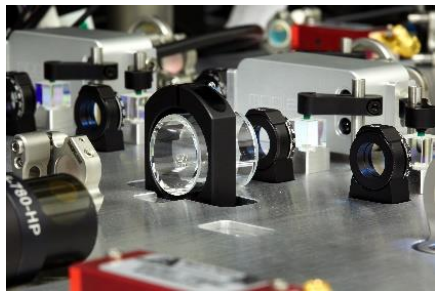
To this: Product



optocap

TRL 1 → TRL 2 → TRL 3 → TRL 4 → TRL 5 → TRL 6 → TRL 7 → TRL 8 → TRL 9

To this: engineered Proof of Concept



Fraunhofer CAP as a delivery partner

*TRL levels indicative only

Major themes:

- Asset monitoring
- Mid-infrared sensing
- Quantum Technologies

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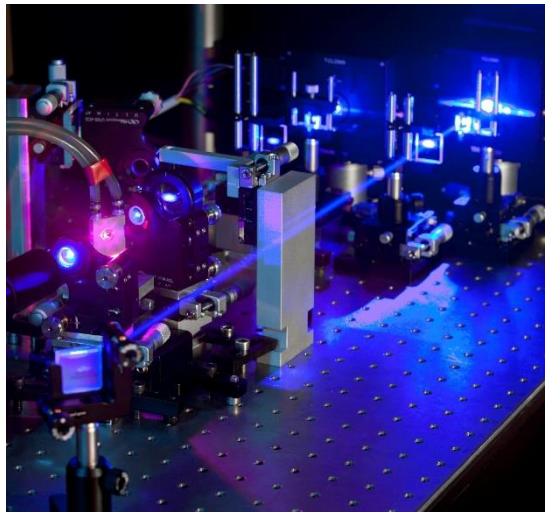
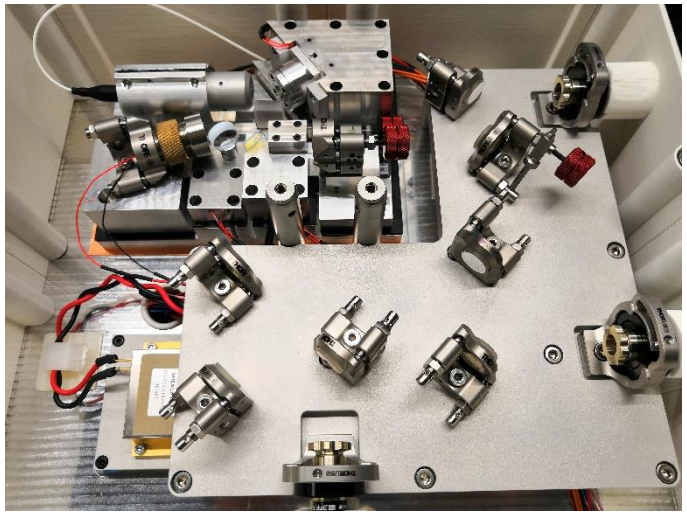
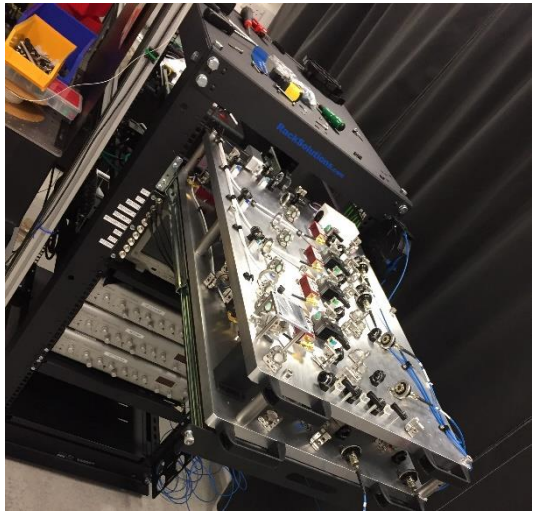
From benchtop to field deployment







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Towards Space

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Some of the capabilities at Fraunhofer CAP

Our job is to breadboard/engineer/prototype optical sources and systems so that industrial partners can ‘kick new technology down the stairs’ to test the viability in their applications environment

- LIDAR, LADAR and RADAR for Space
  - Low cost, compact LIDAR solutions also making use of single-photon detectors, Doppler, FMCW, hard-target LIDAR, Low return/single photon signal analysis …
- FSO Networks: Ultra-low power high-efficient transceivers and free space comms
  - Compact sources and systems for optical links, QKD, underwater comms/imaging and awareness, telescope design, beam steer and track…
- Low light cameras and sensors for gas analysis and environmental monitoring
  - Broadband absorption spectroscopy systems, QCLs, OPOs, SPADs, Raman systems, security and defence sensing, hyperspectral imaging, data acquisition and analysis…
- Quantum technologies, atomic clocks and atom interferometry
  - Compact single-frequency sources, flexible & tailored linewidth systems, optical networks/breadboards, full MOT, ECDLs, SDLs, DPSSL sources, QKD, Atom interferometry, entangled sources, diamond processing…
- Integrated photonics innovations making their way into space
  - Growing capability in wafer processing, ULI, low-cost disposable lab-on-chip, University partner – micro-LEDs and wafer-scale processing, on-chip Tx/Rx navigation system…

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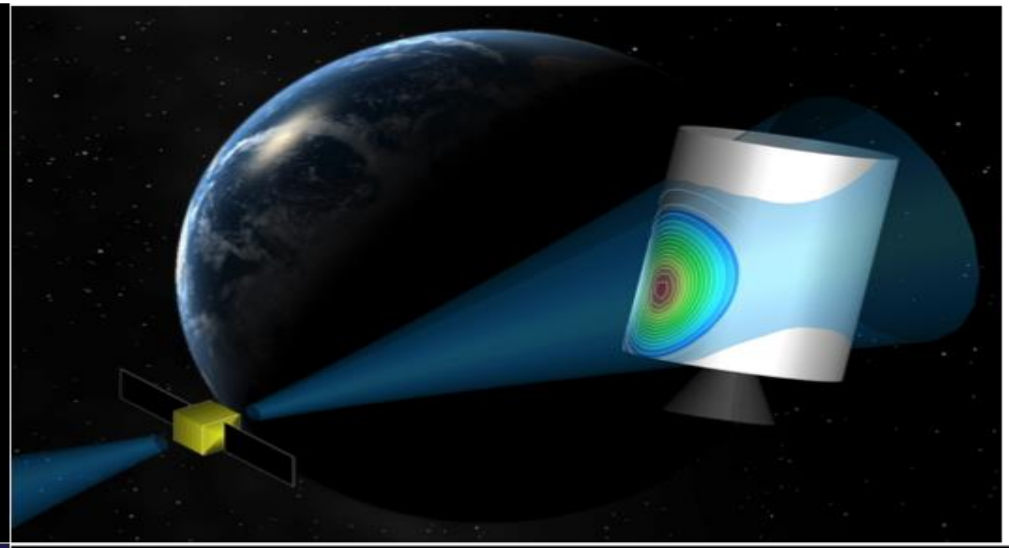
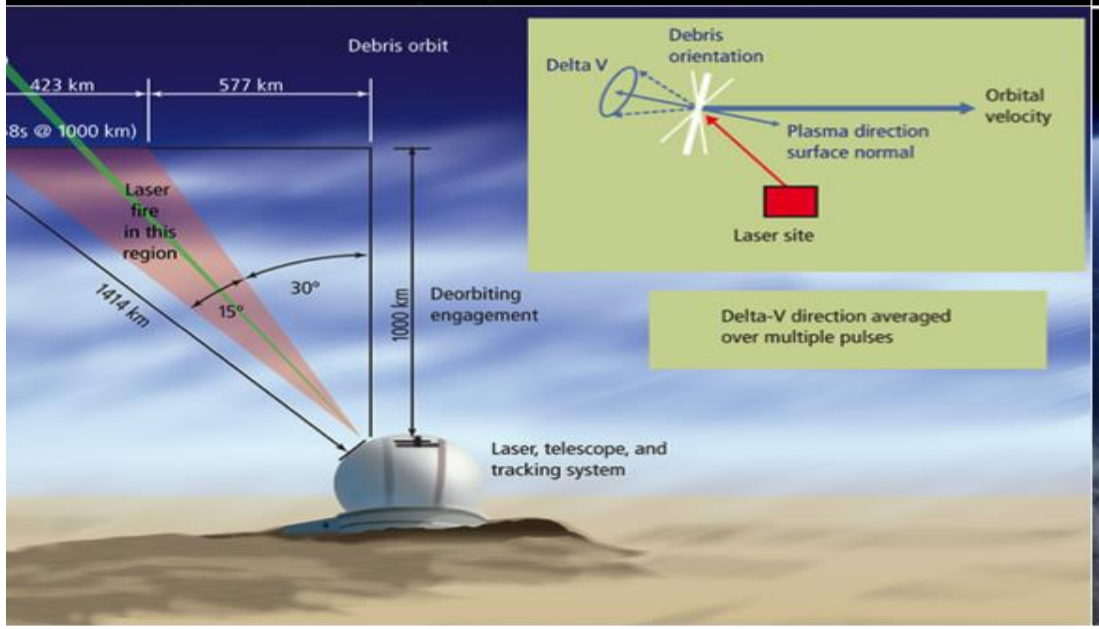
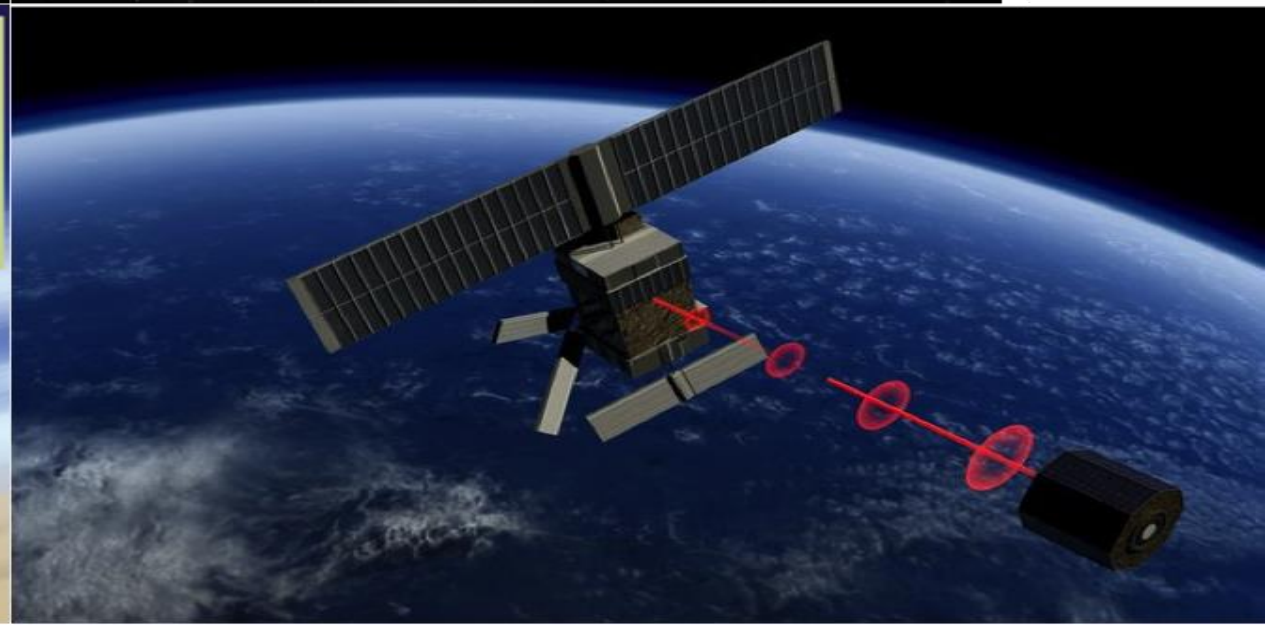
Active Debris Removal Concepts







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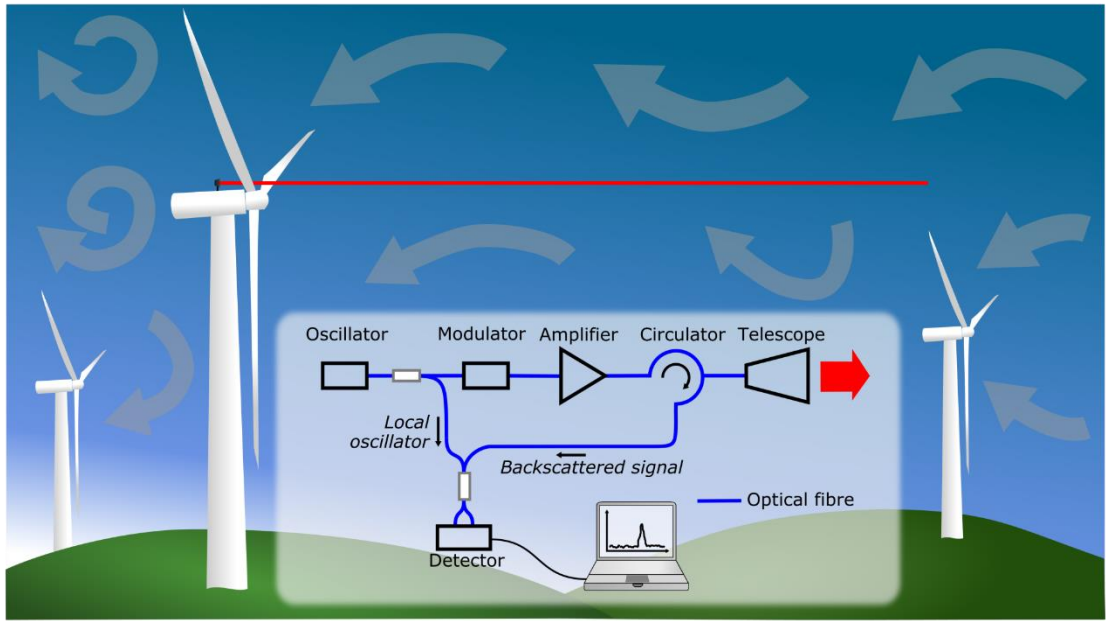
Fraunhofer CAP Capability in Lidar and Coherent Receivers

- FCAP has completed >10 coherent Doppler wind LIDAR projects from design, through feasibility to prototype development
- Development of LIDAR system collecting data from up to 10 km in range
- > 4 months of continuous field operation achieved by multiple different devices, gathering data in all weather
- Bespoke manufacturing of beam steering technology with 120 deg field of view and < 250 ms repointing time
- Telescope design (4 inch aperture) and specification to minimise RMS wavefront aberration to < λ/10, maximising fibre coupling efficiency and sensitivity
- First demonstration of an intersecting LIDAR system using a single laser source and bespoke amplifier to power 3 optical heads
- Optimisation of a heterodyne detection system and data production algorithm that copes with 90 dB RT loss



Coherent Doppler wind LIDAR measurement concept

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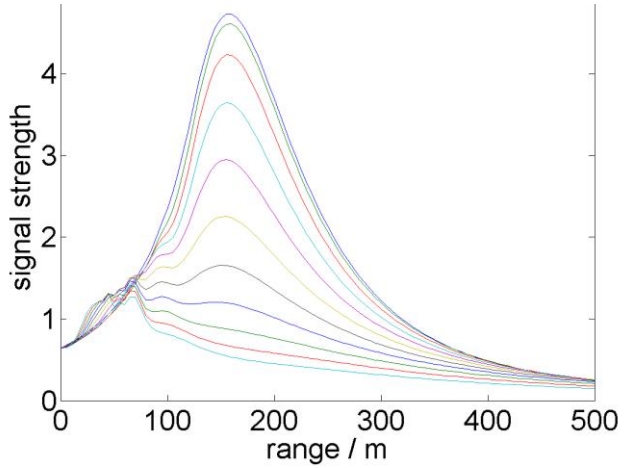
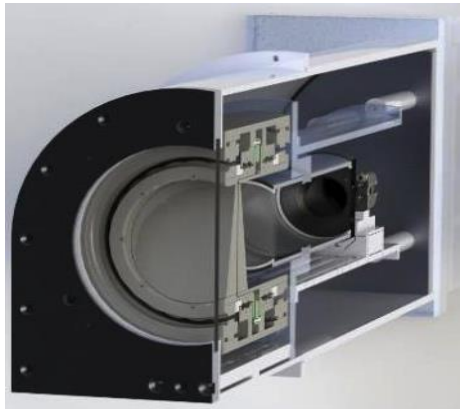
Coherent LIDAR transmitter/receiver/beam steering capabilities

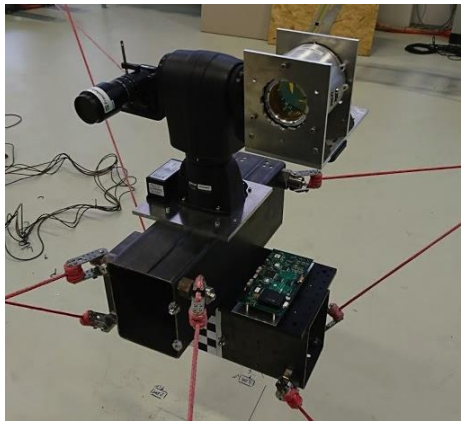
- Fraunhofer CAP has designed, built and integrated numerous coherent LIDAR transmitter/receivers
- We have designed and/or integrated of variety of beam-steering approaches
- for steering transmit beams and receiver field of view
- Turret beam steering for full hemisphere coverage
- Risley prism beam steering for < 250 ms beam re-pointing
- Galvonometer scanners for imaging
- Pan-tilt mounts for medium-low mass optical systems

2 inch telescopes used for coherent wind LIDAR



Simulated LIDAR signal strength versus range - multiple curves show diff levels of aberration caused by telescope





Rugged Risley prism beam scanning module developed in house and motion compensated platform under test at Fraunhofer IPA, Stuttgart

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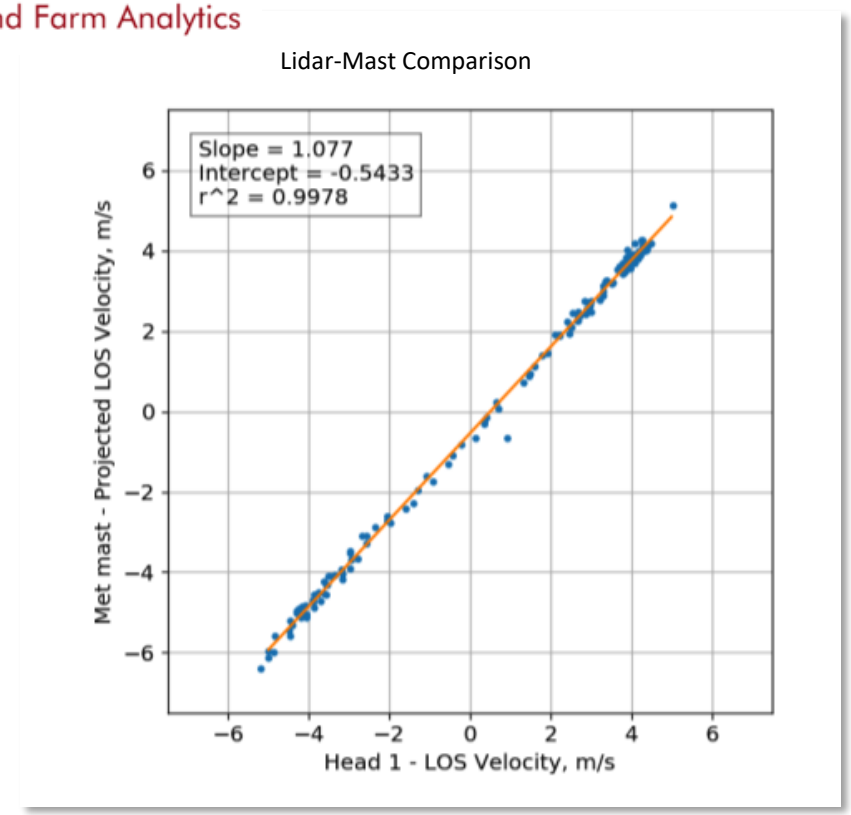
Multi-beam intersecting LIDAR prototype

Multi-beam coherent Doppler wind LIDAR prototype being tested by making comparison measurements with a calibrated met-mast

Wind Farm Analytics



Comparison test result used to check linearity and calibrate velocity offset value

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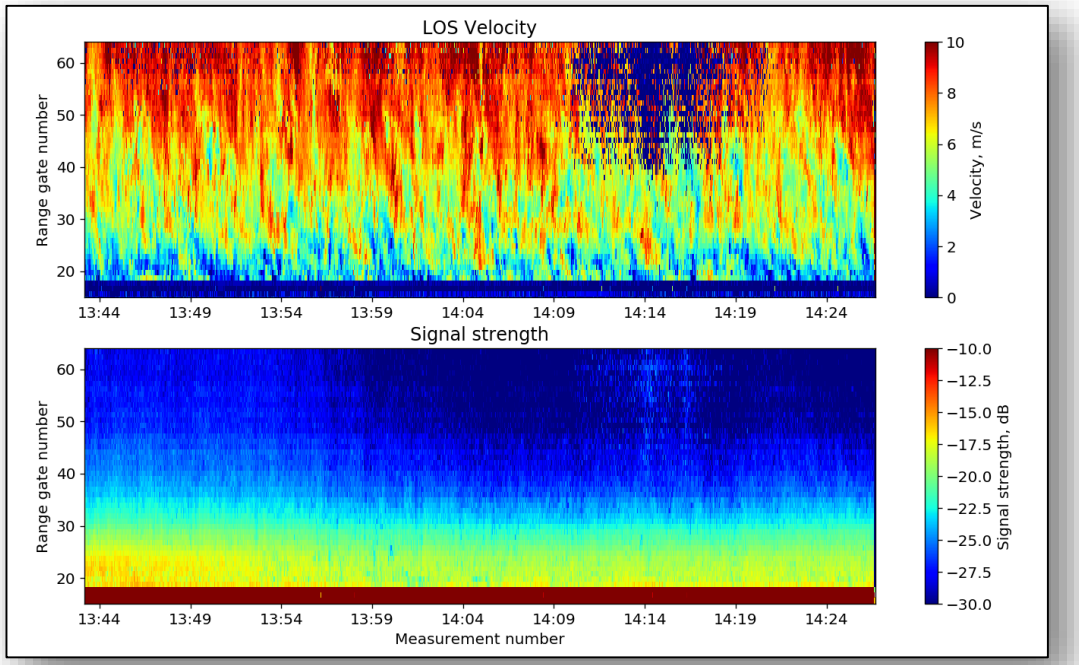
Low-cost Doppler wind LIDAR

Low-cost Doppler wind LIDAR prototype produced by Fraunhofer CAP. The beam is emitted through a fixed window, reducing system complexity and lowering the unit cost.



Example measurement data produced by the low-cost Doppler wind LIDAR prototype. The upper graph shows wind speed and the lower graph shows LIDAR signal strength.

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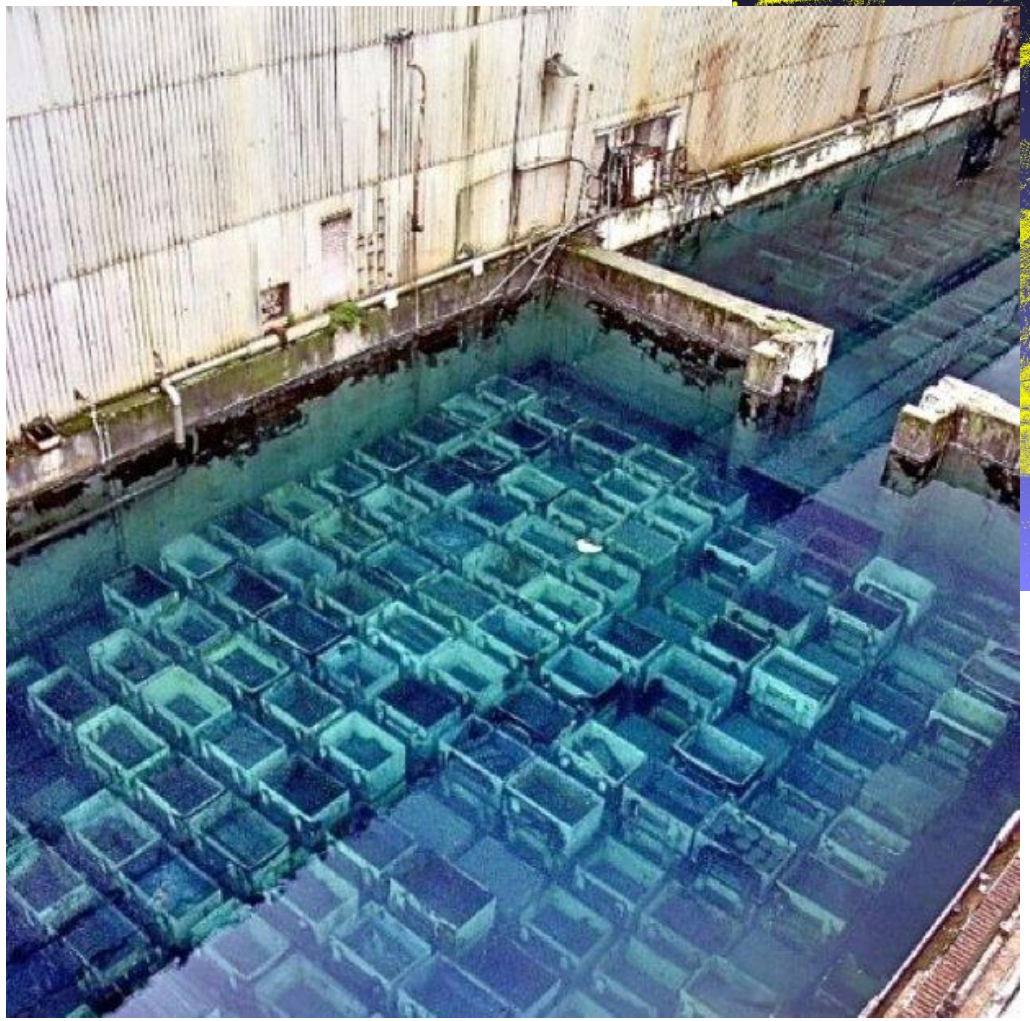
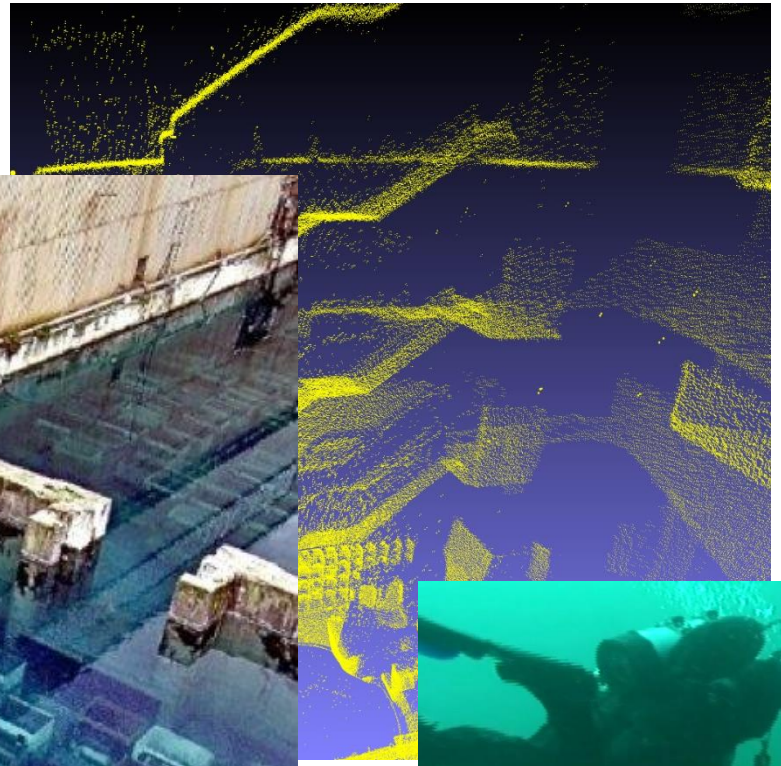
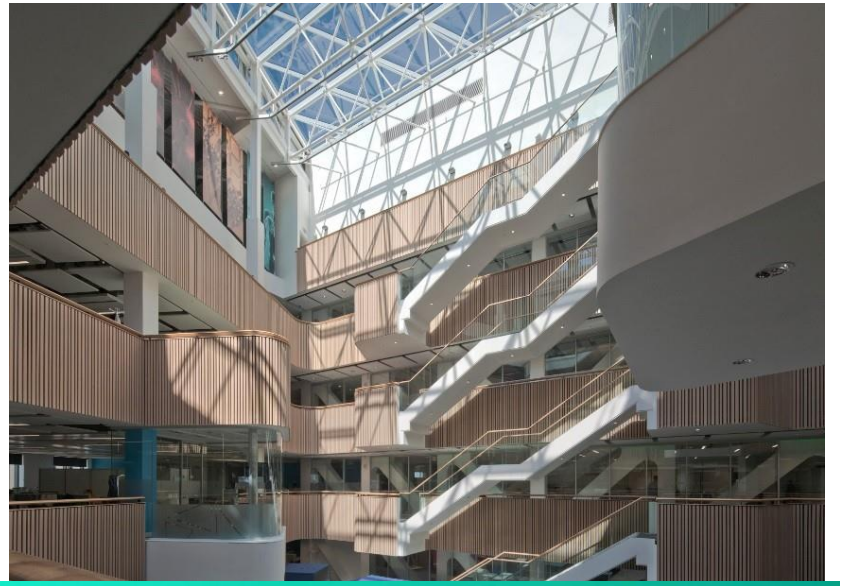
FCAP LIDAR Activity







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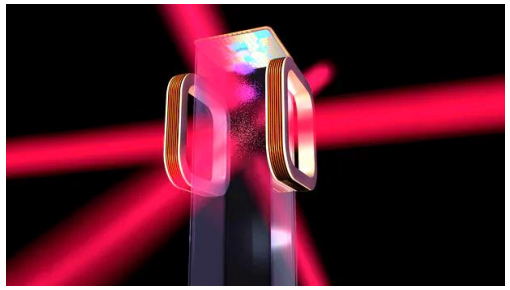
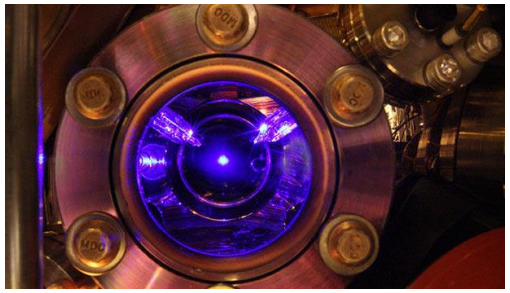
Quantum Technology strengths at Fh-CAP

Atom Sensors



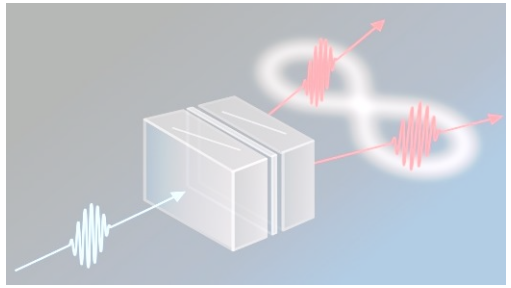
- 10 projects

Optical Clocks



- 10 projects

Quantum Info



- 5 projects

Photon Detectors

- 7 projects

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TELEDYNE TECHNOLOGIES Everywhereyoulook™
THALES
PHOTON FORCE
inex microtechnology
SMG SILICONMICROGRAVITY
QinetiQ
TopGaN lasers blue laser technology
PA
M SQUARED
UNIKLASERS
RedWave Labs
BT
ArQit
RSK
ColdQuanta
HELIA PHOTONICS
TMD
EMERSON
ALTRAN
Geomatrix EARTH SCIENCE LTD
Magnetic Shields Electromagnetic Engineering
wideblue making technology happen

FCAP support 25 QT company partners

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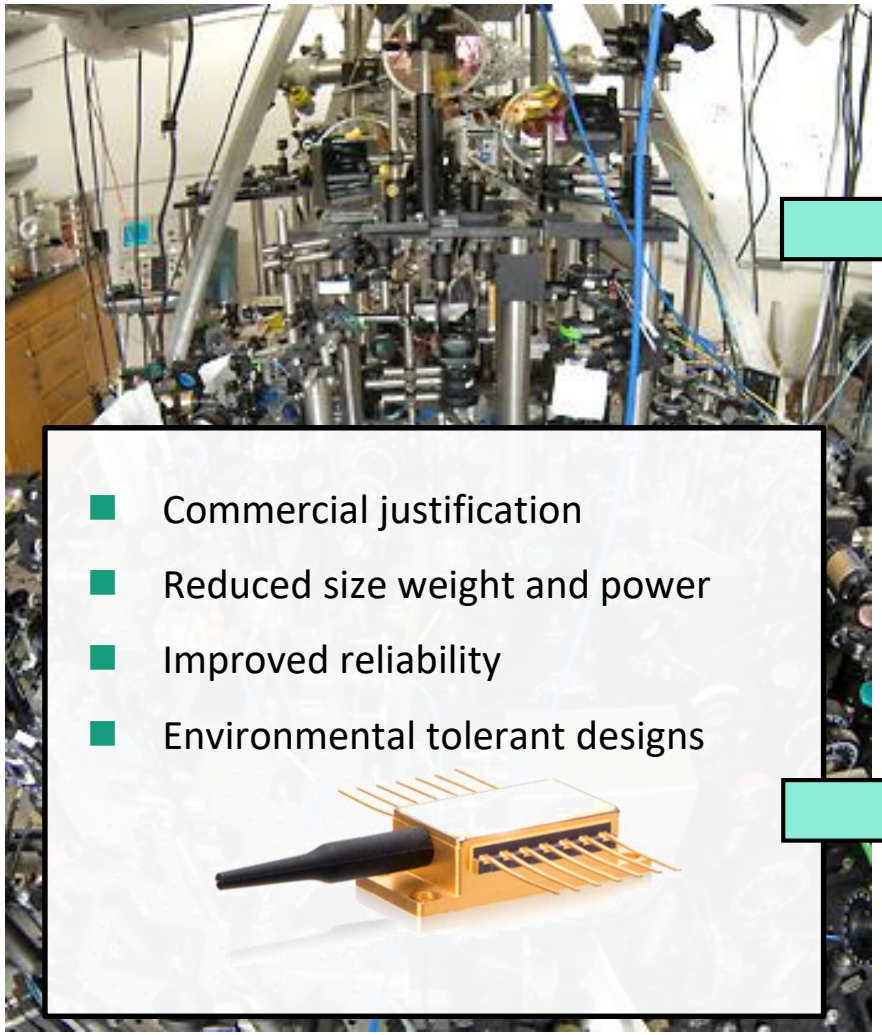
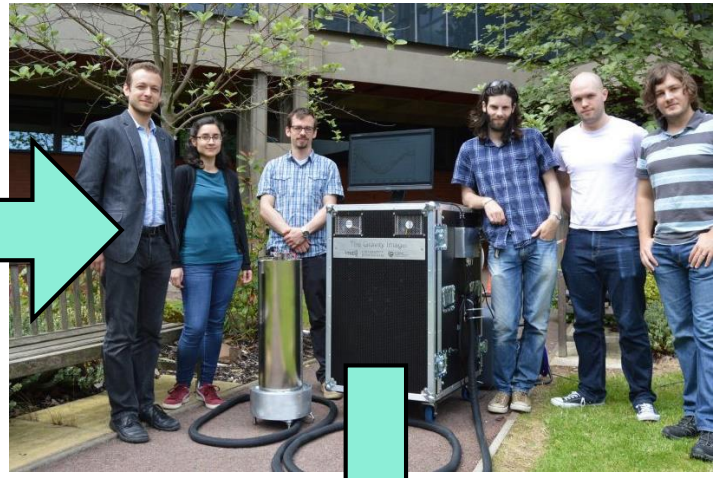
Quantum systems – out of the lab



- Commercial justification
- Reduced size weight and power
- Improved reliability
- Environmental tolerant designs



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Cold atom interferometry

ATOM SENSORS

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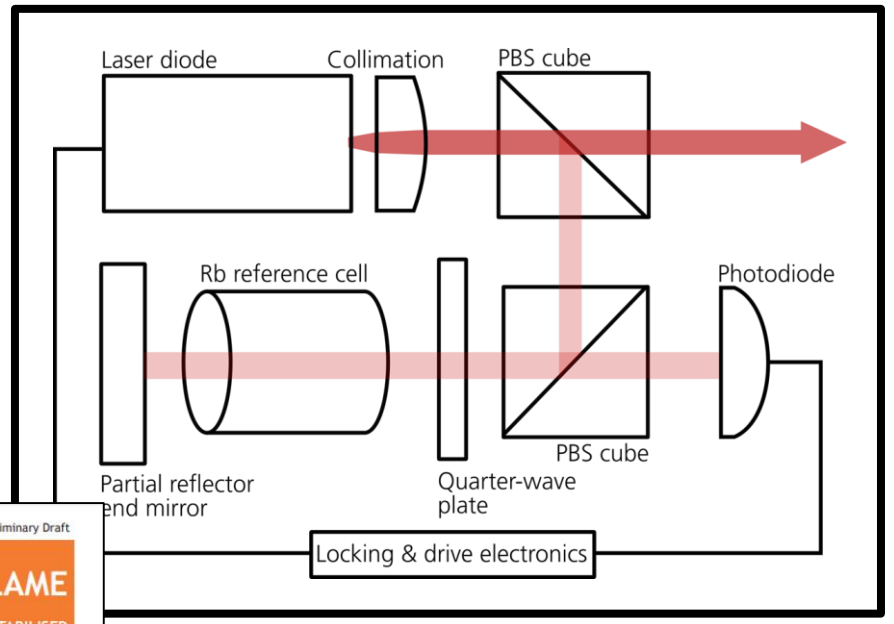
Flame: Compact 780nm Frequency Stabilized Saturation spectroscopy module



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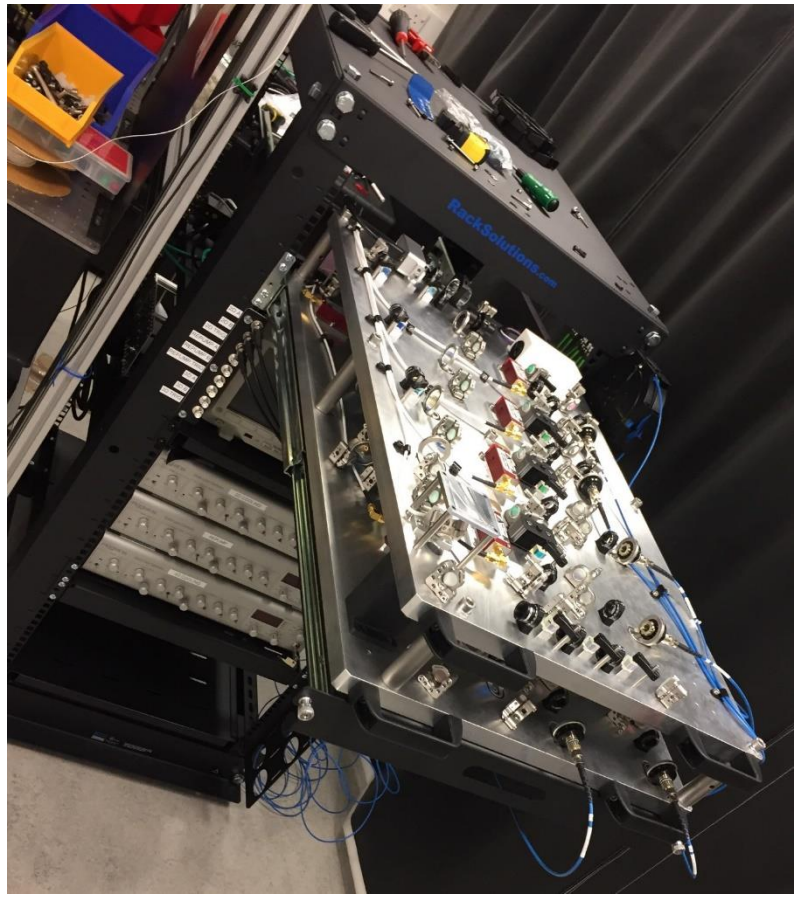
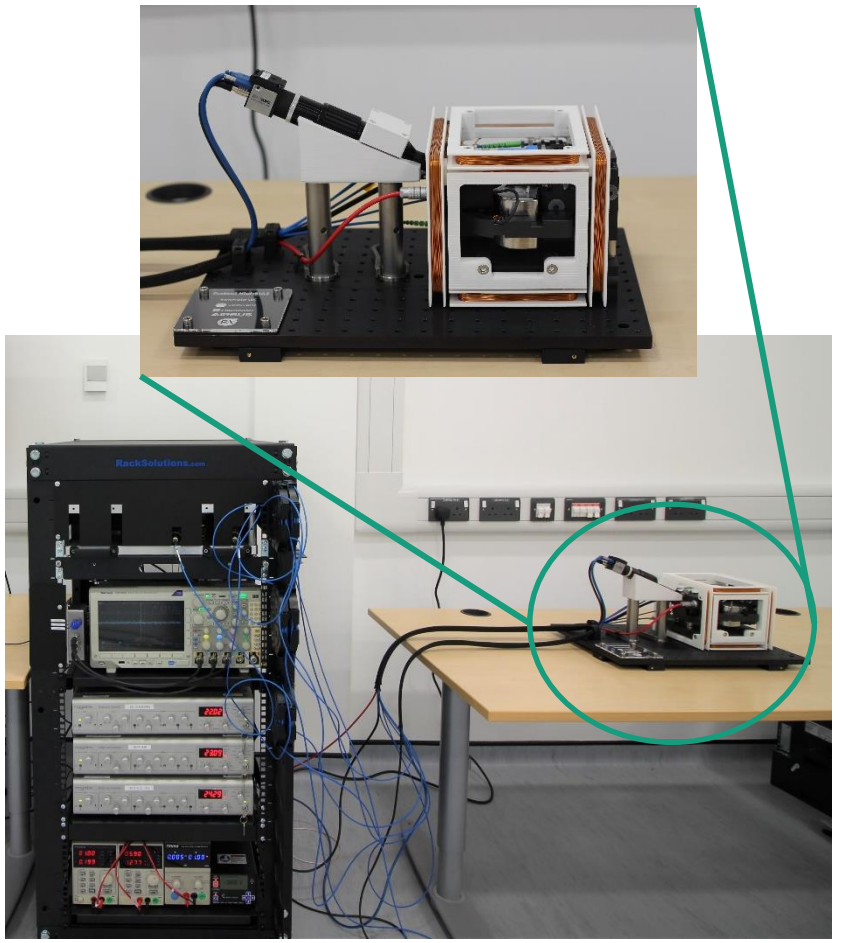
Inertial sensing

Innovate UK funded project to develop high-flux source of cold atoms for inertial sensing

- Full rubidium cooling system
  - Lasers and stabilisation
  - Beam delivery optics
  - Fibre delivery system
  - Sequencing and timing electronics
  - ‘Relatively’ low overall system SWaP
- Moved to Airbus for testing and characterisation





- Atom number – 3 x 10^7, 3D MOT loading rate – 6 x 10^7/s, Lifetime – 16 s
- Reduced overall system SWaP compared to competing systems

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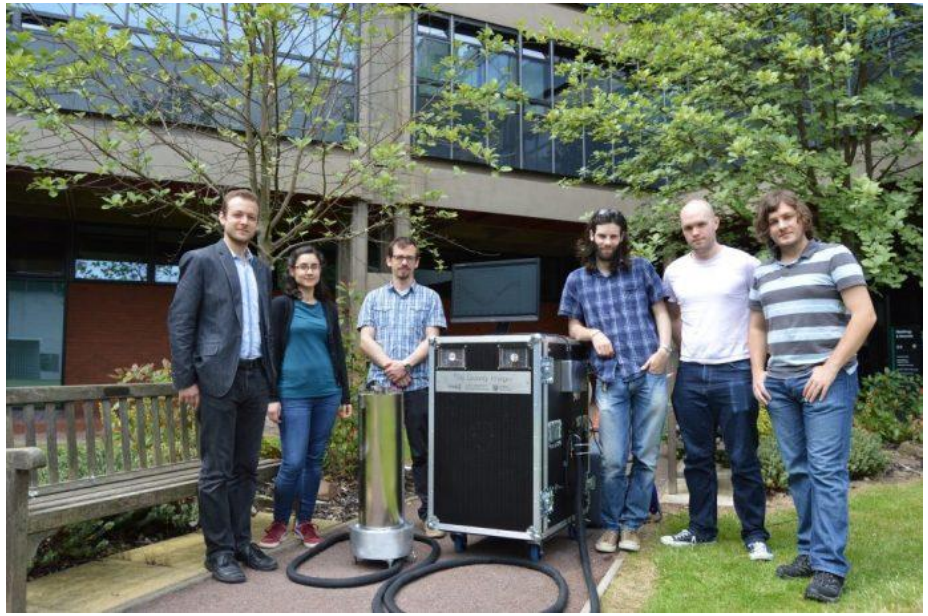
Gravity sensing

Development of a transportable gravity gradiometer

- Lead for all laser development
  - Multiple architectures developed including full supply chain
  - Field testing of instruments requiring environmental testing



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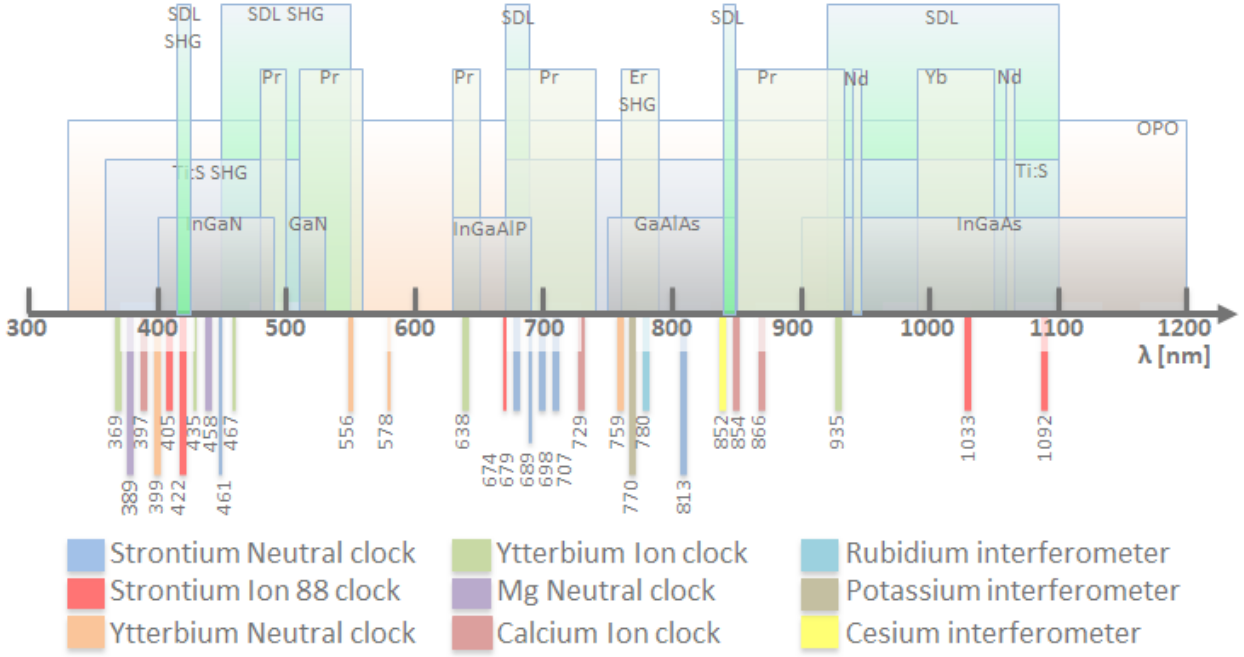

Laser systems for strontium

OPTICAL CLOCKS

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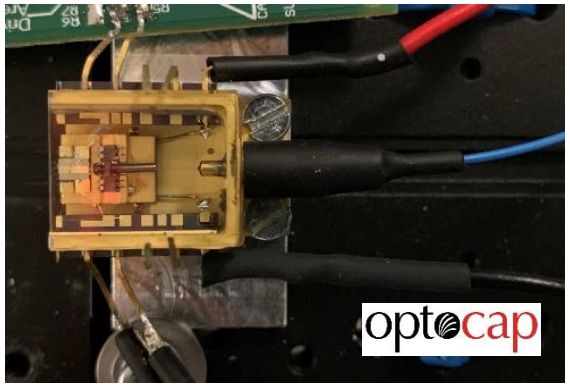
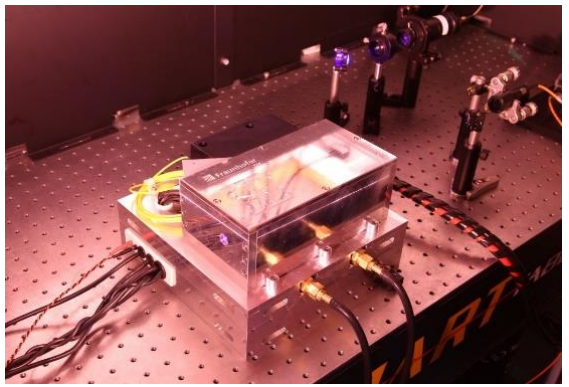
Sources for optical clocks

European Space Agency

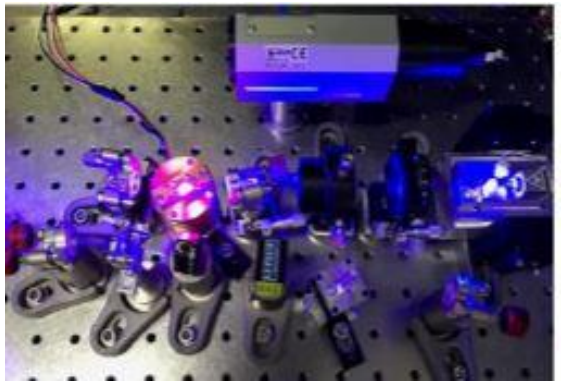
National Physical Laboratory



- Reduce temporal uncertainty
  - Navigation
  - Telecommunications
  - Science



- Fraunhofer CAP are the leader of two ESA collaborative programmes to develop new sources for optical clocks:
  - Development of High Reliability Lasers at 461 nm and 689 nm (Sr Lattice) and 422 nm (Single Trapped Sr Ion)
  - Development of a High Power, High Spectral Purity Red-Detuned Lattice Laser at 813nm for Neutral Strontium
- Other lasers
  - Compact ECDL & tapered amplifier packages (blue & 780nm CW and pulsed)
  - Semiconductor Disk Lasers (Direct red & Blue)
  - Novel Diode-pumped solid-state lasers



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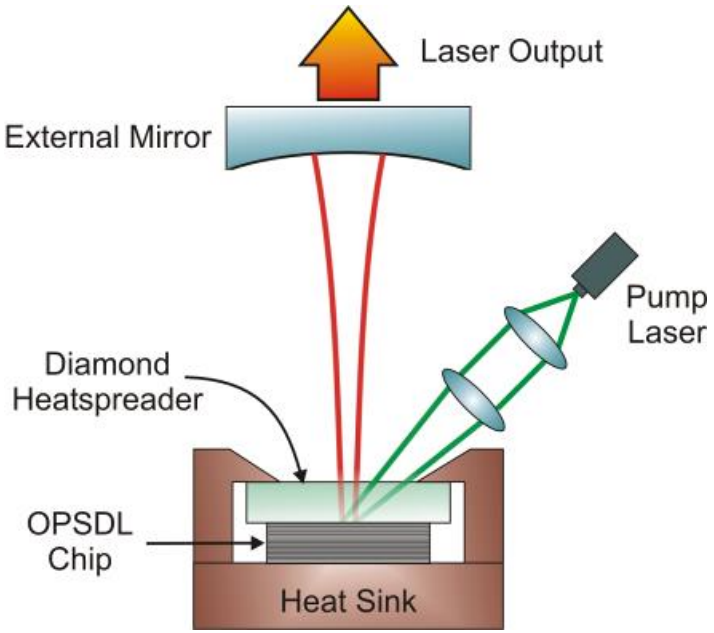
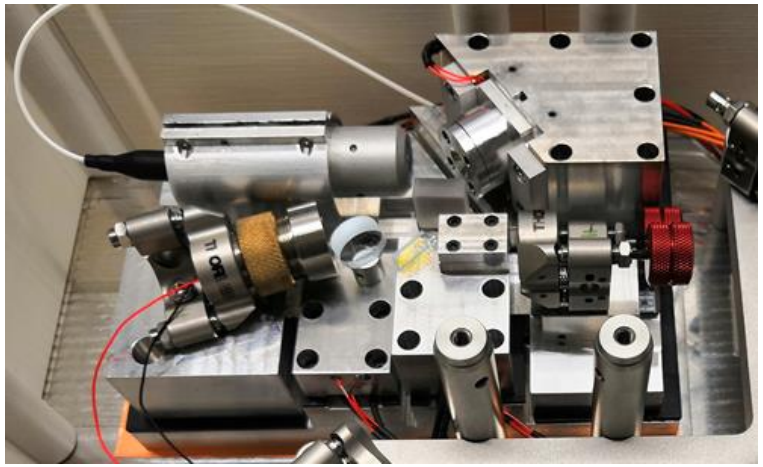
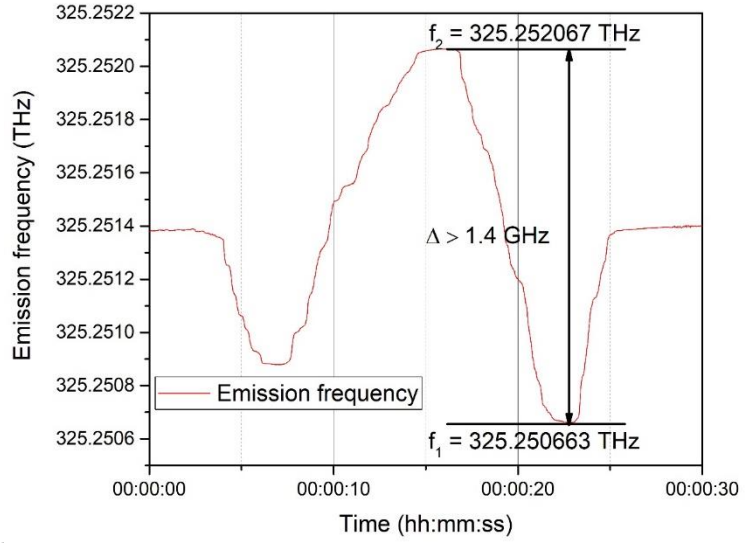
High power 461 nm SDL

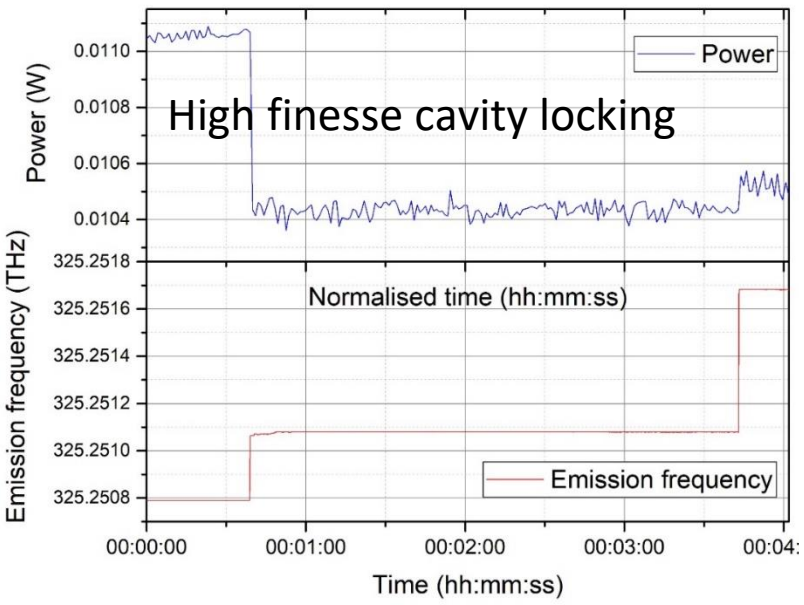


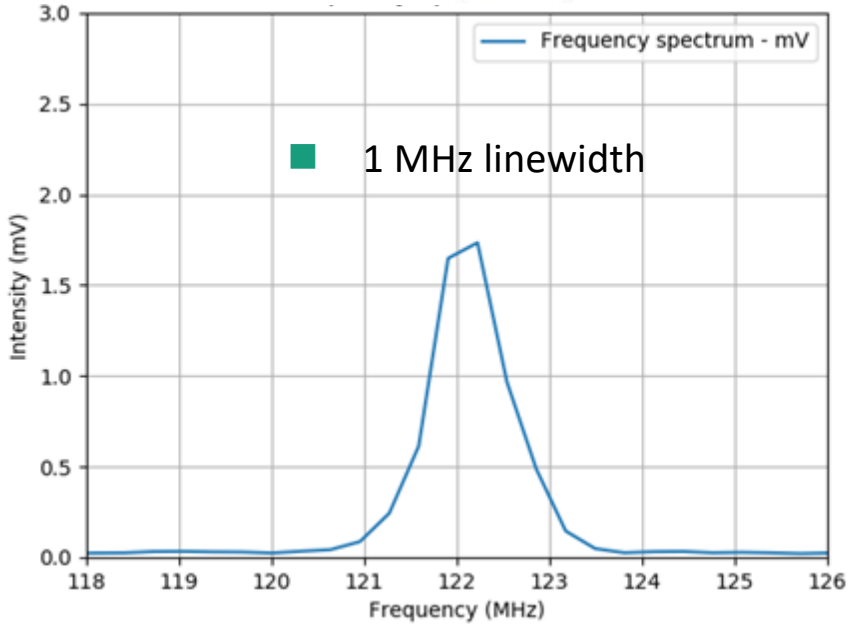
- High Brightness
- Wavelength flexible
- External cavity
- Efficient
- Small footprint



1.4 GHz smooth tuning







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Steps to Optical Integration

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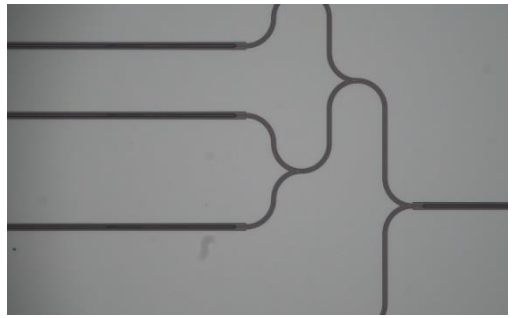
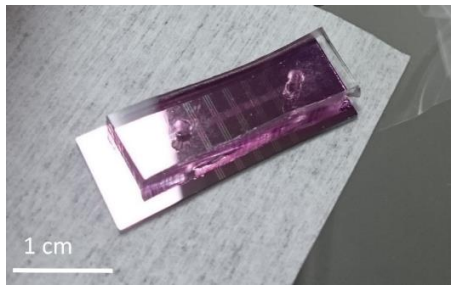
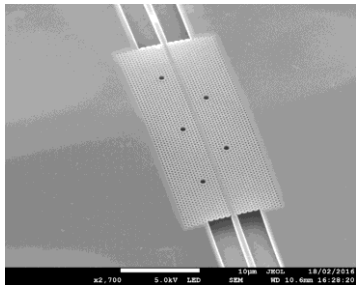
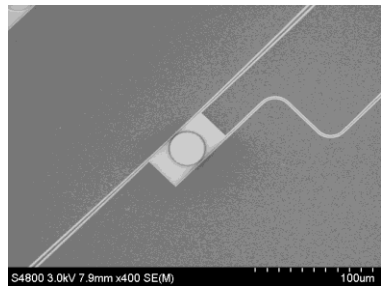
Photonics Integration capabilities

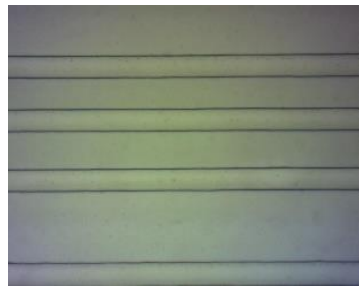
- Waveguides fabricated via e-beam lithography or direct write laser lithography and dry etching
- Silicon on insulator, glass, polymer
- Designed in house. Access cleanroom at IOP (same building) or send out designs (e-beam)
- Waveguides, photonic crystals, ring resonators
- Biosensors / microfluidics
- Nanoscale accuracy transfer printing

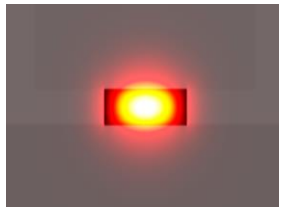


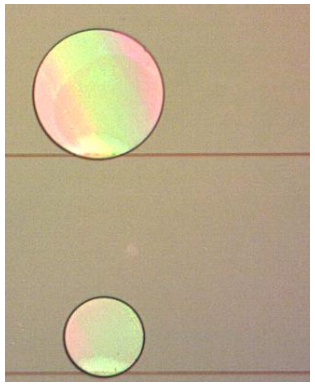


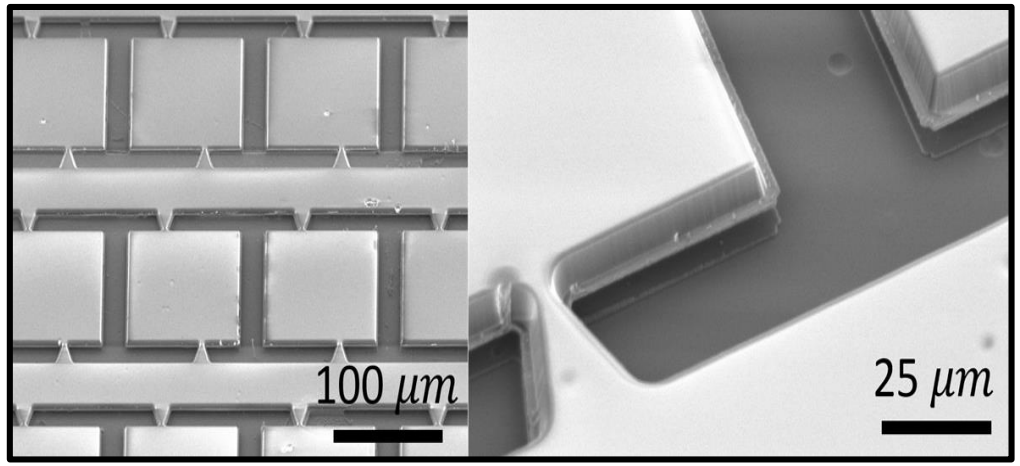












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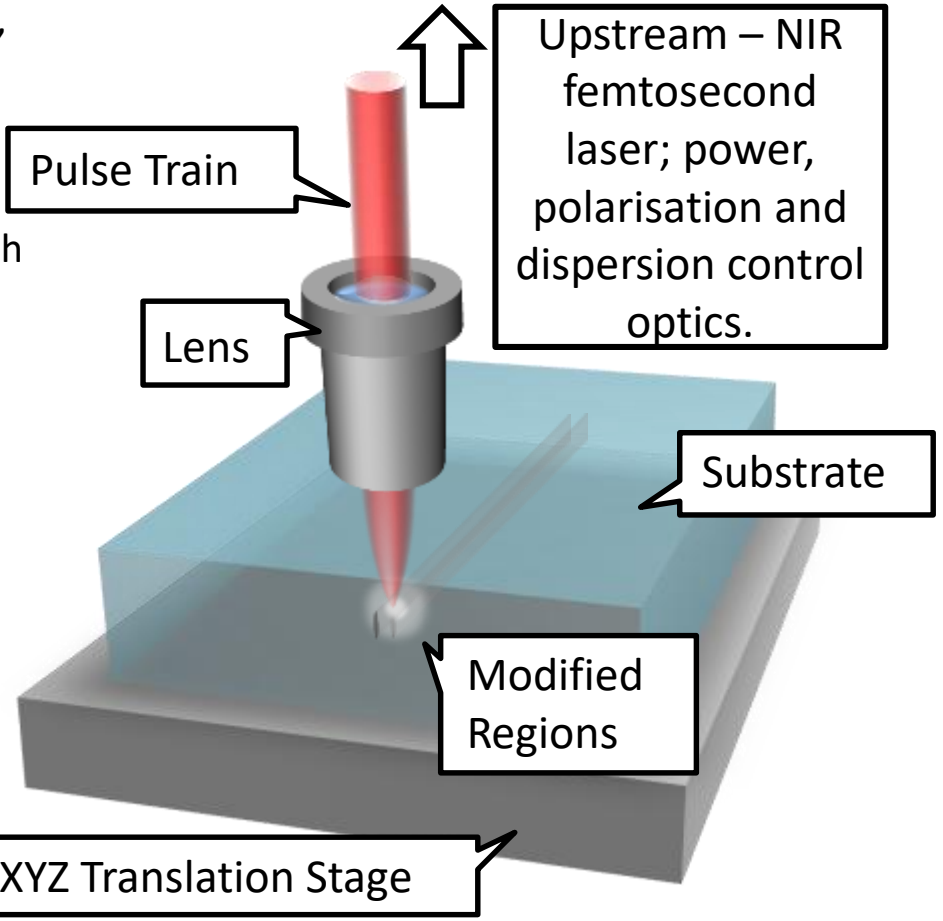
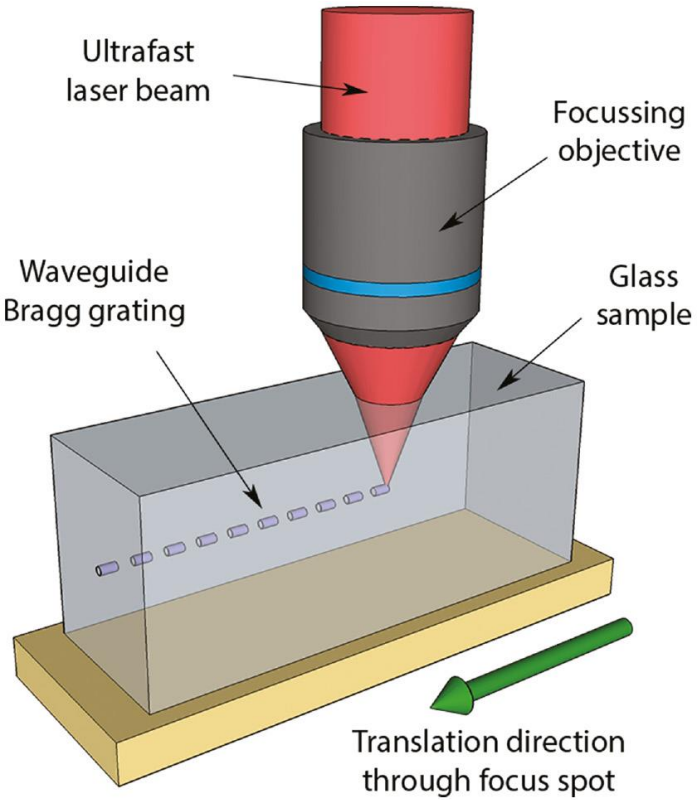
Ultrafast Laser Inscription for QT

- NIR femtosecond fibre laser – 1030nm, 250 fs to >10 ps, single shot to 40 MHz, up to 20 µJ pulses, up to 10W.
- High precision stages with large working area – 200 by 200 mm with submicron precision
- Direct Laser writing – surface and subsurface structuring (ULI, Ultrafast laser Inscription)





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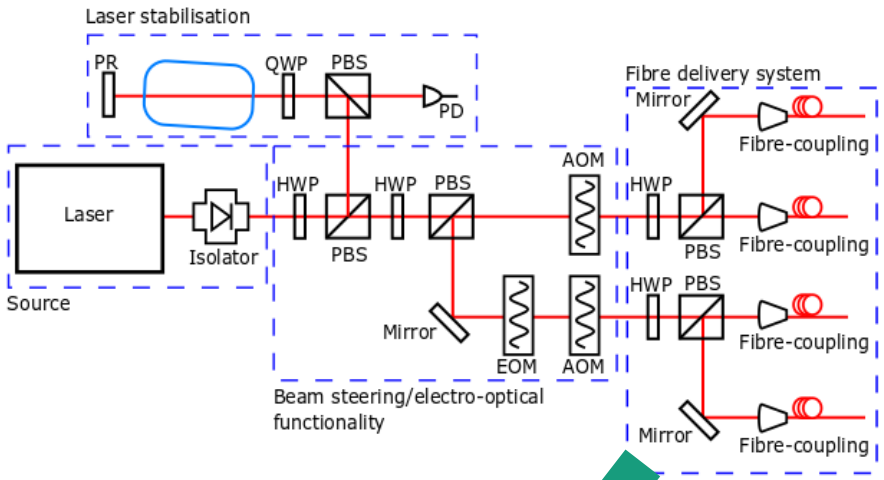
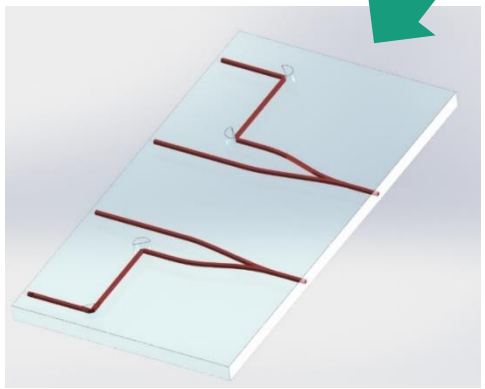
Ultrafast Laser Inscription for QT: Combination of integrated components

- Writing of 3D waveguides for beam delivery
- Waveguide lasers
- Chip scale photonics devices
  - Integrating elements on chip (sources, isolators, AOMs, fibre-coupling, etc.)
- Integration of elements such as isolators and AOMs into beam delivery systems

Potential benefits

- Low size, weight and power
- Inherent robustness





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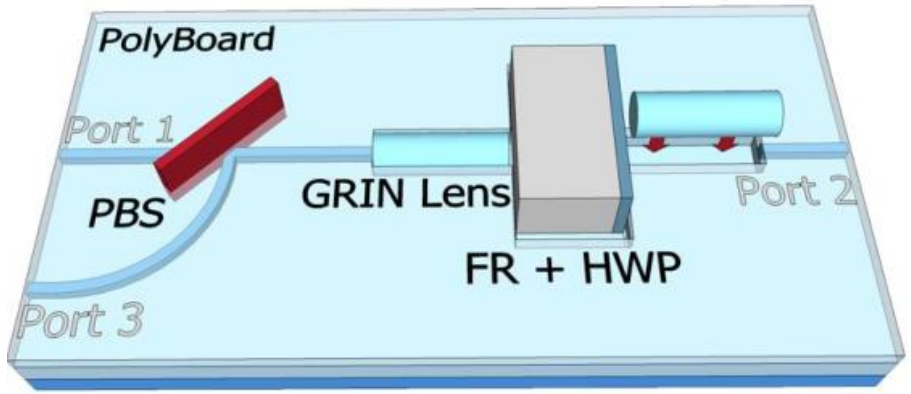

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Thank you!

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What's next?

- What can we do for you?
  - Didn't have time to talk about other developments at Fraunhofer CAP: gas sensing, oil monitoring, QKD, underwater imaging, Diamond devices, Nuclear Raman sensing, low-cost distributed fibre sensing…
  - We are technology agnostic and want to hear your challenges
  - We are a credible partner for Quantum systems
  - We can develop rapid testing and qualification for 'New Space' with an applications appropriate focus
  - We can help unlock funding for the higher risk R&D ideas that have stayed in your 2nd drawer
  - We are still growing and are aiming to improve in all aspects of photonics for space and integrated optics development
  - We can signpost other UK capabilities/partners or other members of the Fraunhofer family to engage with
- What can you do for us?
  - Engage with us, share your challenges, include us in your consortium deliberations, come and visit and enjoy the beautiful blue skies of Glasgow, some local hospitality and help us get our joint space ideas off the ground!

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Some of the capabilities at Fraunhofer CAP

Our job is to breadboard/engineer/prototype optical sources and systems so that industrial partners can ‘kick new technology down the stairs’ to test the viability in their applications environment

- LIDAR, LADAR and RADAR for Space
  - Low cost, compact LIDAR solutions also making use of single-photon detectors, Doppler, FMCW, hard-target LIDAR, Low return/single photon signal analysis …
- FSO Networks: Ultra-low power high-efficient transceivers and free space comms
  - Compact sources and systems for optical links, QKD, underwater comms/imaging and awareness, telescope design, beam steer and track…
- Low light cameras and sensors for gas analysis and environmental monitoring
  - Broadband absorption spectroscopy systems, QCLs, OPOs, SPADs, Raman systems, security and defence sensing, hyperspectral imaging, data acquisition and analysis…
- Quantum technologies, atomic clocks and atom interferometry
  - Compact single-frequency sources, flexible & tailored linewidth systems, optical networks/breadboards, full MOT, ECDLs, SDLs, DPSSL sources, QKD, Atom interferometry, entangled sources, diamond processing…
- Integrated photonics innovations making their way into space
  - Growing capability in wafer processing, ULI, low-cost disposable lab-on-chip, University partner – micro-LEDs and wafer-scale processing, on-chip Tx/Rx navigation system…

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This presentation was presented at EPIC Meeting on New Space 2019

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