UNIVERSITY OF BIRMINGHAM

UK National Quantum Technology Hub Sensors and Metrology

Space activities in the UK QT Hub in Sensors and Metrology

Raffaele Nolli

ZARM, Bremen, 24/10/2017

Outline

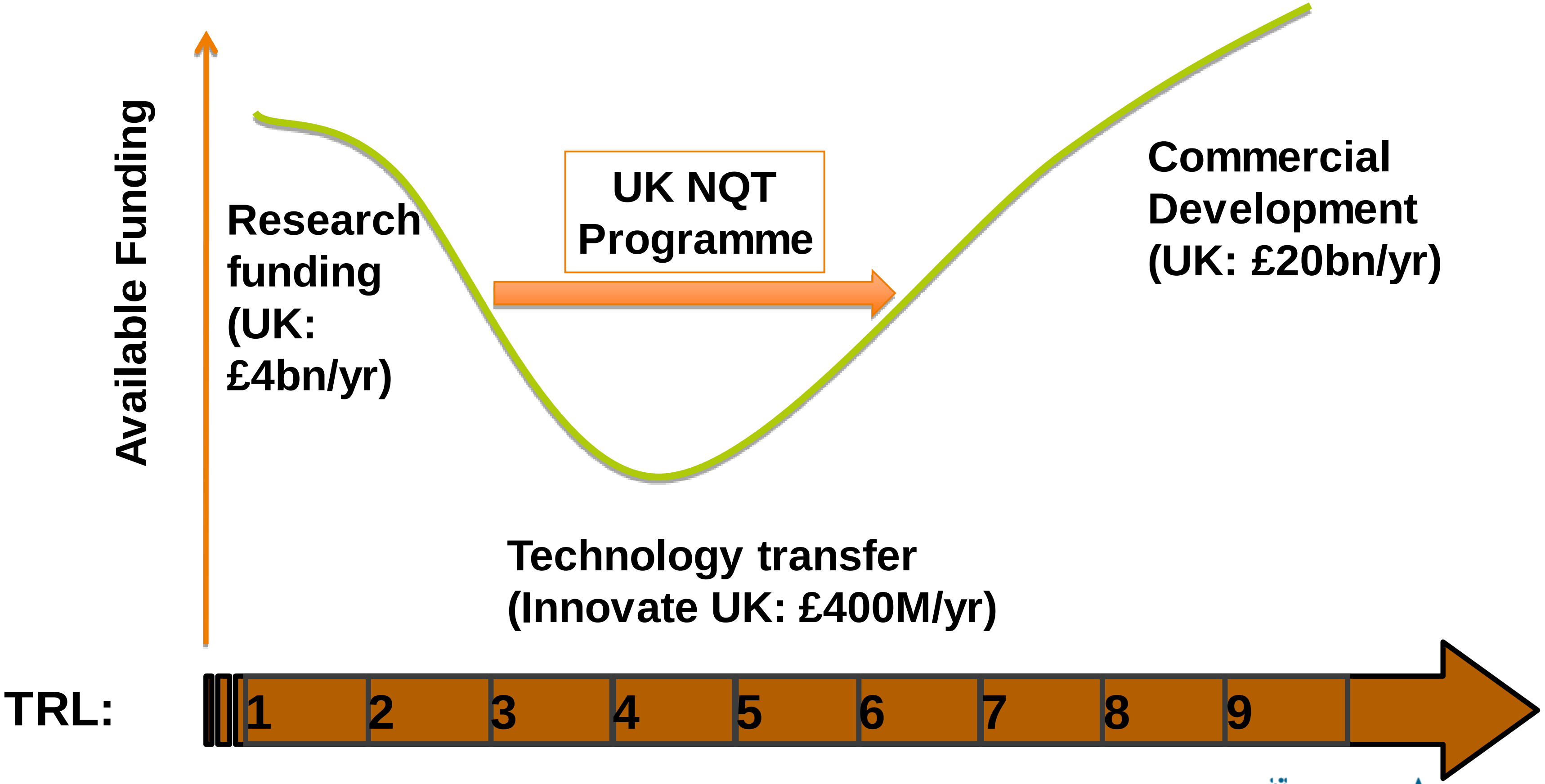
- The UK National Quantum Technology Hub
- Gravity
- Clocks
- Key research areas in the group
- Focus on Space applications

The QT Hub in Sensors and Metrology

Part of the UK National Quantum Technologies Programme (≈ £400M). Four hubs:

- **Sensors and Metrology**
- **Quantum Enhanced Imaging**
- **Networked Quantum Information Technologies**
- **Quantum Communication Technologies**

The QT Hub in Sensors and Metrology



The QT Hub in Sensors and Metrology

New academic-industrial collaborations

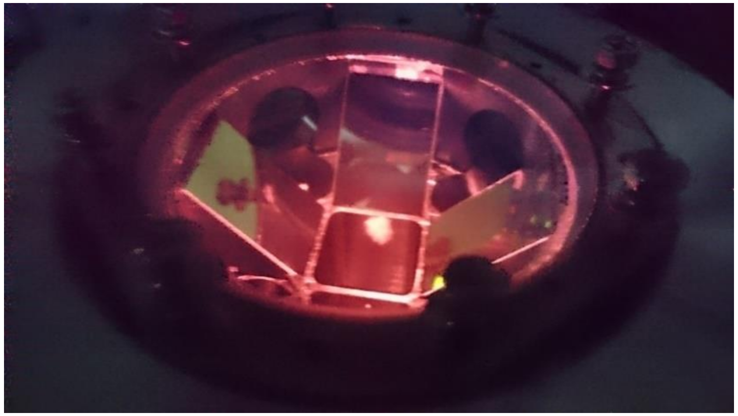
Translating scientific development into marketable technologies

Developing skilled workforce and production practices

The QT Hub in Sensors and Metrology

We develop atom based sensors

Exploiting atomic physics to produce clocks, magnetometers, gravity sensing, inertial sensing…



10^8 rubidium atoms in a magneto-optical trap

The QT Hub in Sensors and Metrology

- **Birmingham led hub in quantum sensing**
- 12 academic and over 120 industrial partners
- **Partnership projects with Universities of Liverpool, Durham, Warwick, Oxford and UCL**
- **Total of £80M over 5 years (EPSRC: £35M, Dstl: £15M, Industry: £30M)**
- **Connect across the value chain, strong industry collaboration**
- **1000m^2 Technology Transfer Centre for co-location**

- GOAL: Promote Science to Market

120 Industrial partners

Dstl: **gravity imager & optical clock developments, field trials**
e2v: **vacuum, imaging, systems engineering**
MSquared: **electronics, lasers, system integration**
NPL: **clock and magnetometer development and system validation**
Kelvin Nanotechnologies: **semicond. laser systems, MOT/atom/ion chips**
Chronos: **timing signal generation**
RAL: **space applications**

Defence
AWE
BAE systems
GEM Elettronica
MBDA
Sandia
Selex
Thales
TMD
UTC Aerospace

Healthcare
Elekta
NHS Trauma
Vertex

Exploration
ArkeX
BGS
BP
GeoDynamics
MicrogLacoste
Muquans
Reid Geophysics

Semicond.
Comp. Semi.
IQE

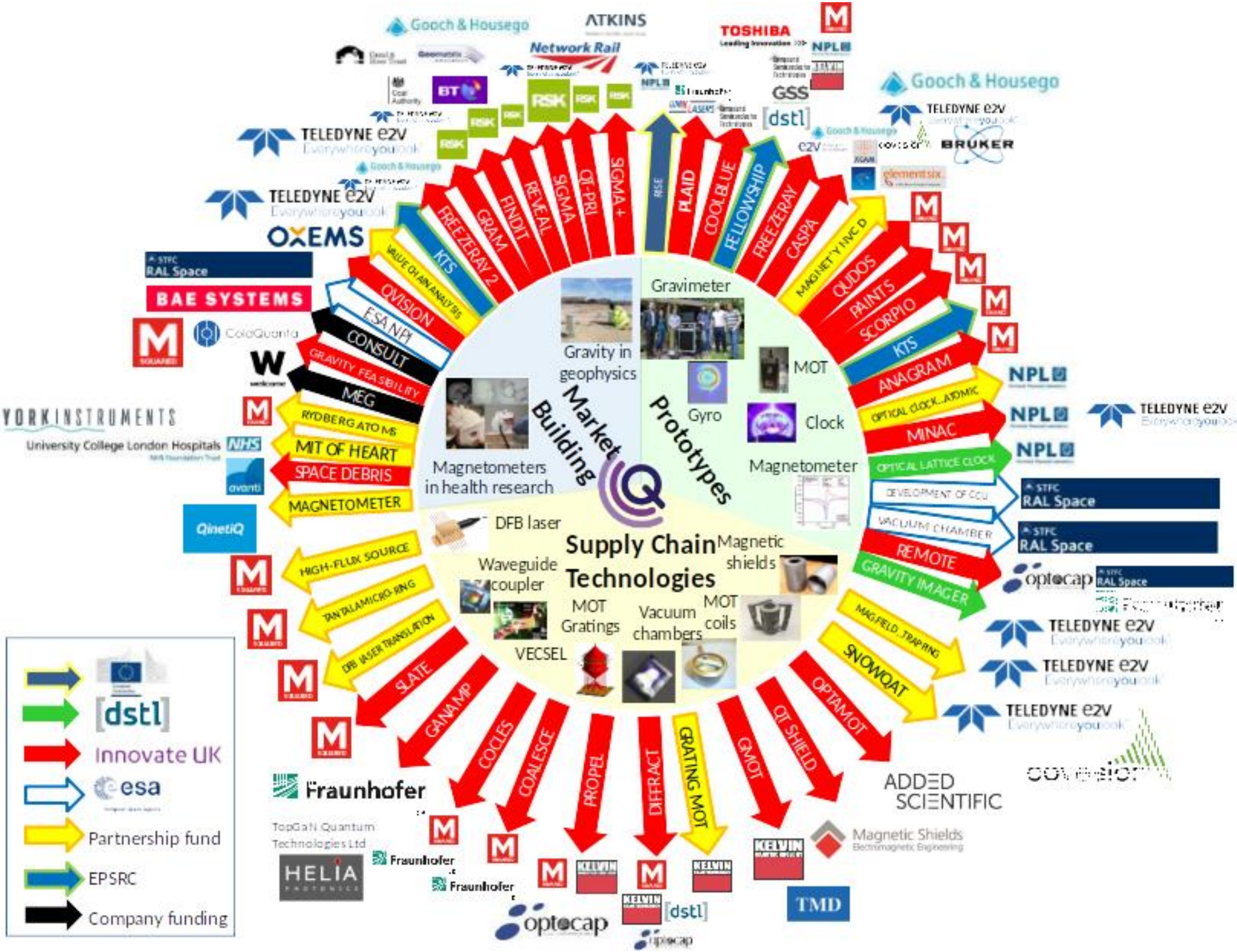
Laser
Coherent
Coldquanta
ELUXI
HighFinesse
Sacher

Transport
Network Rail
Texas Transp.Inst.
Transport for London

Infrastructure
Balfour Beatty
Cardno
Drill Line
ICE
Infotec
JK Guest
Macleod Simmonds
RSK
Severn Trent Water
Stratascan
Subscan
Subsurface Utility Eng.
T2 Utility Engineers
UKSTT
URS Infrastruc. and Env.
UTSI Electronics

Other
Chemring
ESA
ES Technology
IBM
KTN
MTC
Oxford Instruments
Procter & Gamble
Quantum Wave Fund
Qrometric
Rolls Royce
Royal Institute of Nav.
Samsung
Texas Instruments
TSB-KTP
Versysns Ventures
Witted


Market Building
Gravity in geophysics
Magnetometers in health research
Prototypes
Gravimeter
MOT
Gyro
Clock
Magnetometer
Supply Chain Technologies
DFB laser
Waveguide coupler
MOT Gratings
VECSEL
Vacuum chambers
MOT coils
Magnetic shields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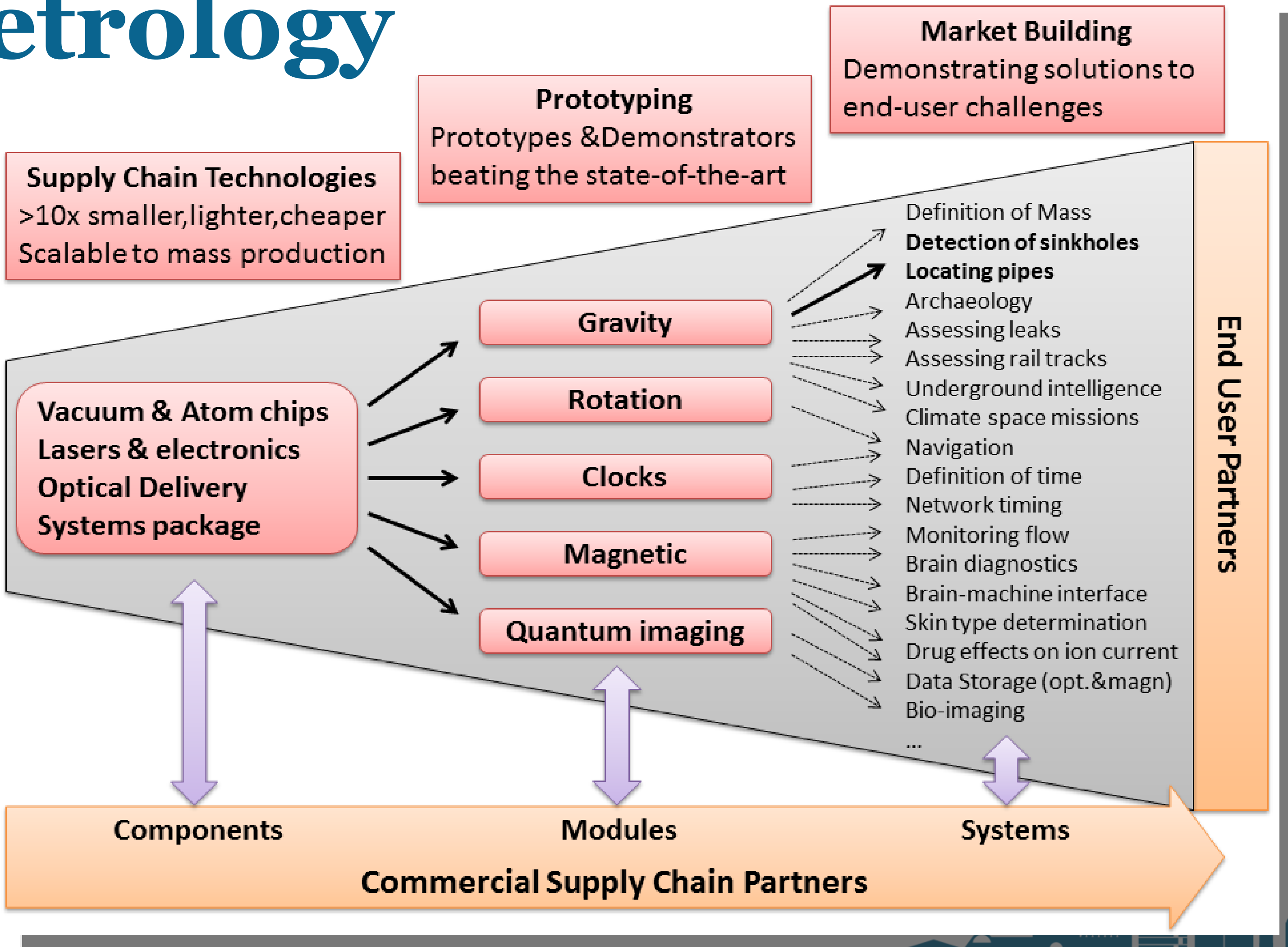
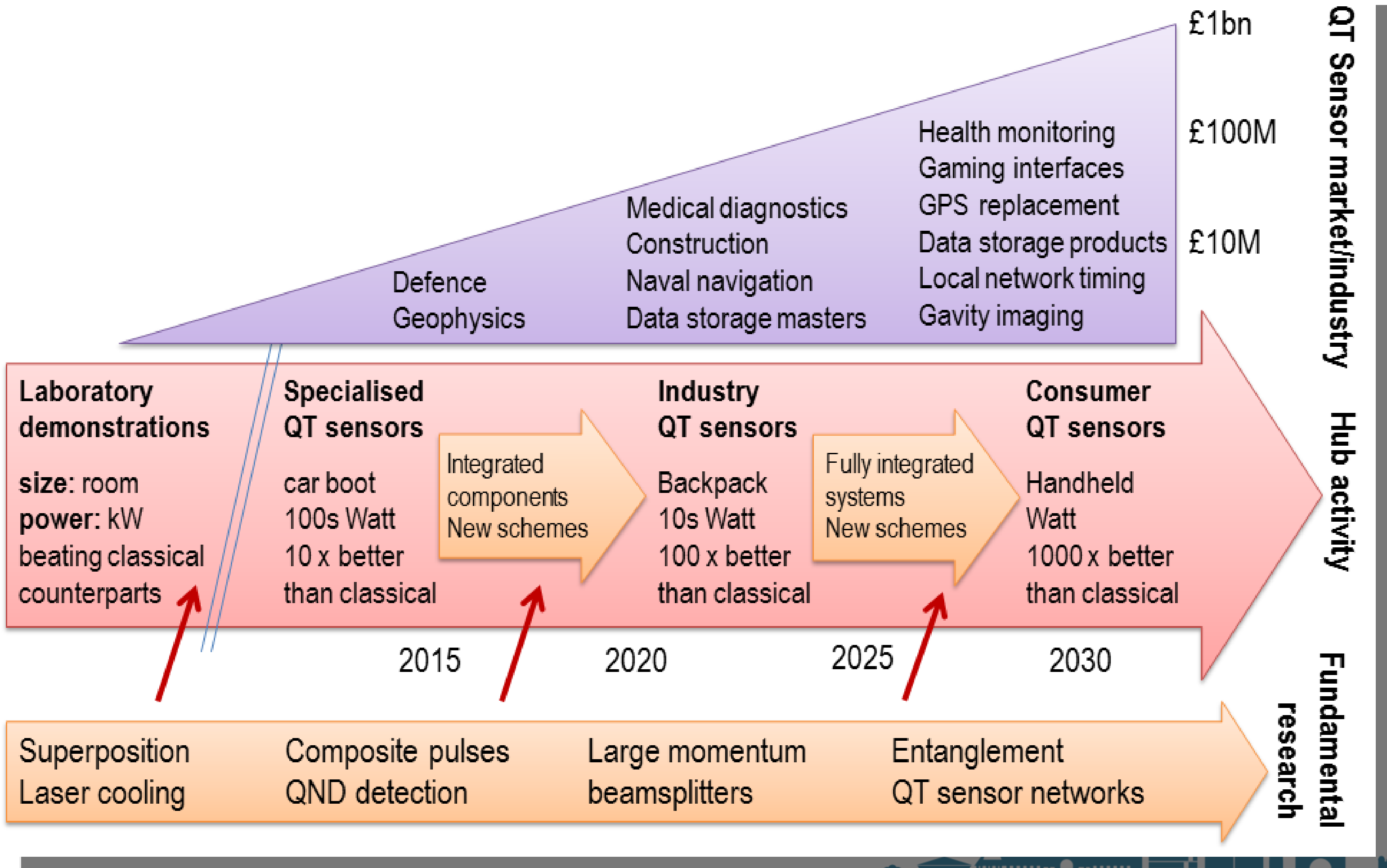
VECSEL
FREEZERAY 2
GRAM
FINDIT
REVEAL
SIGMA
QT-PRI
SIGMA +
RISE
PLAID
COOLBLUE
FELLOWSHIP
FREEZERAY
CASPA
MAGNETY NVC D
QUDOS
PAINTS
SCORPIO
KTS
ANAGRAM
OPTICAL CLOCK...ATOMIC
MINAC
OPTICAL LATTICE CLOCK
DEVELOPMENT OF CCU
VACUUM CHAMBER
REMOTE
GRAVITY IMAGER
MAG FIELD_TRAPPING
SNOWQAT
OPTAMOT
QT SHIELD
GMOT
GRATING MOT
DIFFRACT
PROPEL
COALESCE
COCLES
GANAMP
SLATE
DFB LASER TRANSLATION
TANTALA MICRO-RING
HIGH-FLUX SOURCE
MAGNETOMETER
SPACE DEBRIS
MIT OF HEART
RYDBERG ATOMS
MEG
GRAVITY FEASIBILITY
CONSULT
ESA NPI
QVISION
VALUE CHAIN ANALYSIS
KTS
Gooch & Housego
ATKINS
Network Rail
TOSHIBA
NPL
BT
RSK
GSS
dstl
TELEDYNE e2V
BRUKER
elementsix
OXEMS
RAL Space
BAE SYSTEMS
ColdQuanta
YORK INSTRUMENTS
University College London Hospitals NHS
avanti
QinetiQ
Fraunhofer
TopGaN Quantum Technologies Ltd
HELIA
optocap
KELVIN
TMD
Magnetic Shields
ADDED SCIENTIFIC
esa
innovate UK
Partnership fund
EPSRC
Company funding

The QT Hub in Sensors and Metrology



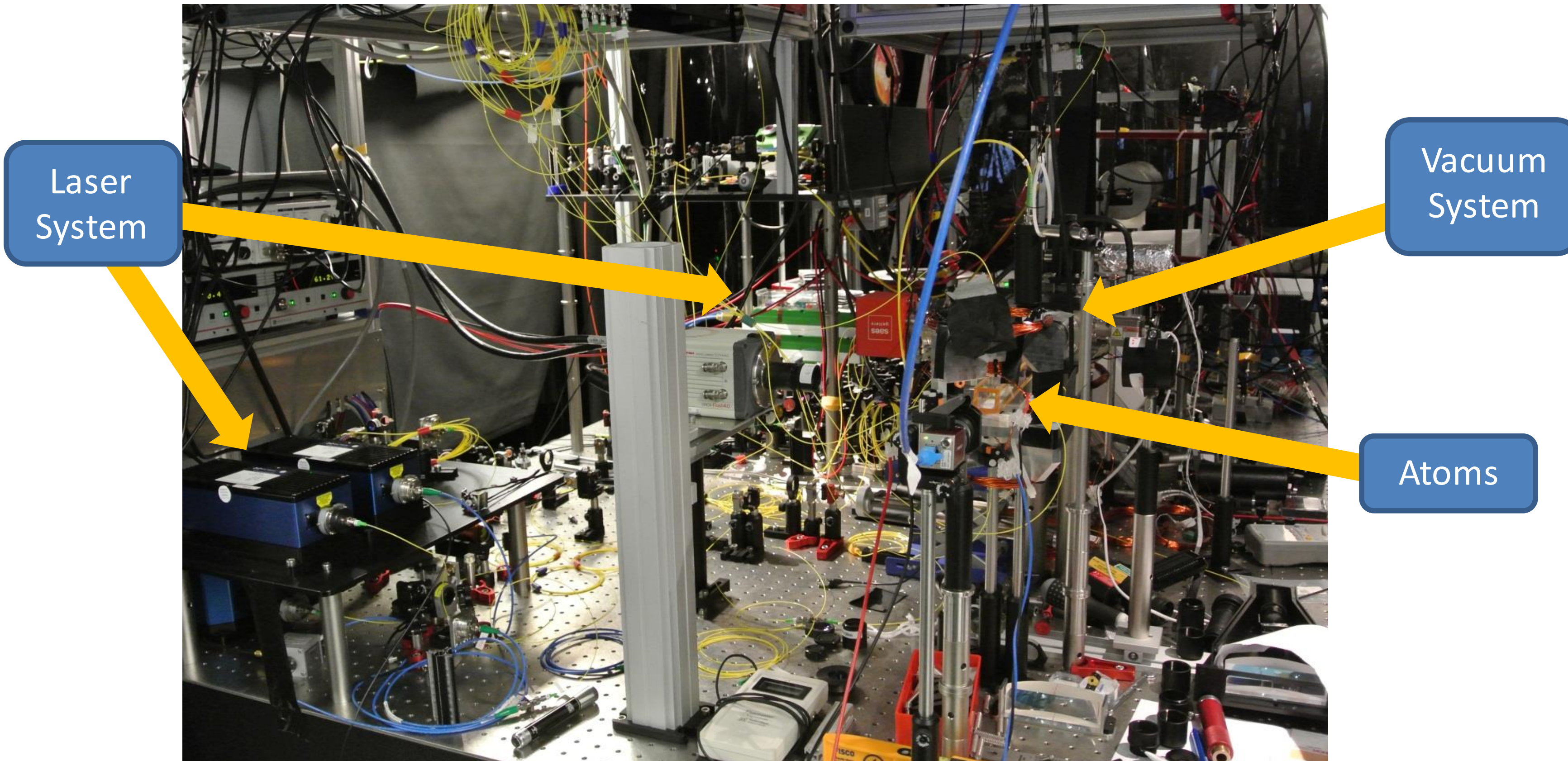
The QT Hub roadmap



From experiment to instrument

Laboratory environment		Portable (space!!) devices
≈ m^3, 10^3 kg	Volume, weight	≈ 10^{-2} m^3, 10 kg
No restrictions	Energy/Power	Batteries, 10-100 Whr
£100k-1M	Cost	≈ £10k
Protected environment	Robustness	External stress

From experiment to instrument



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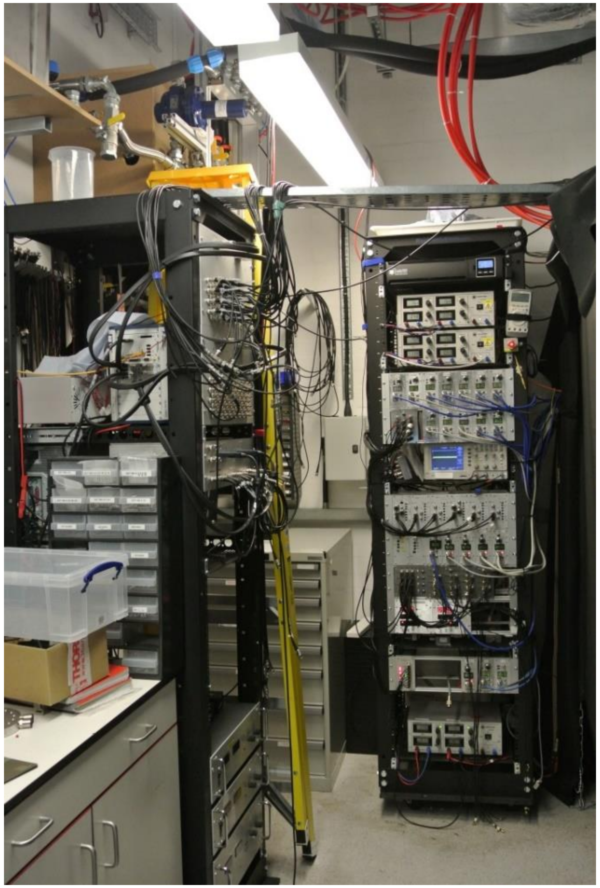
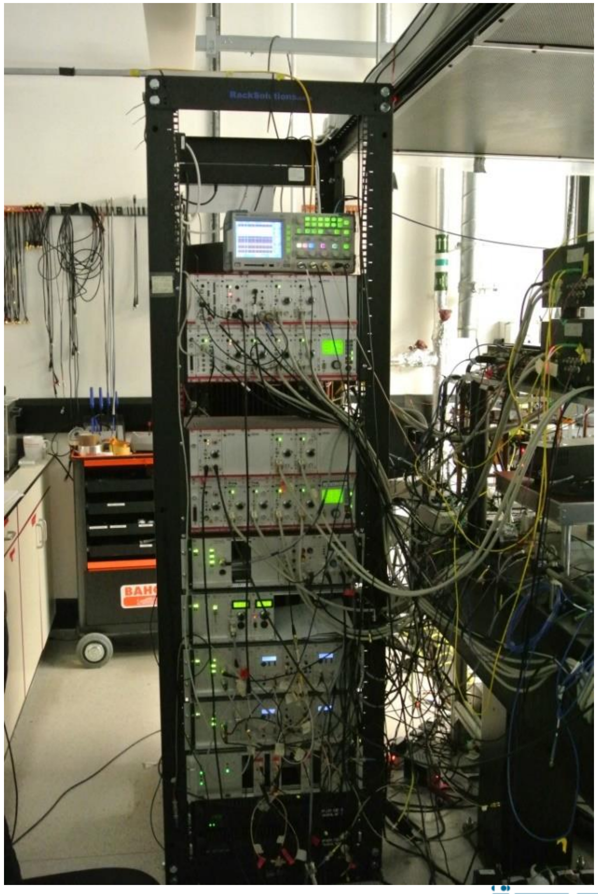
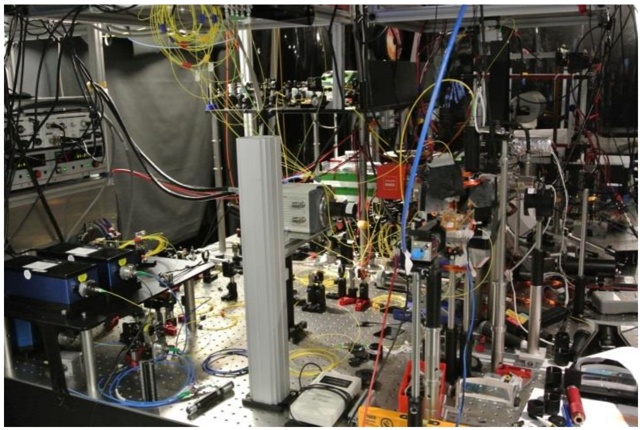




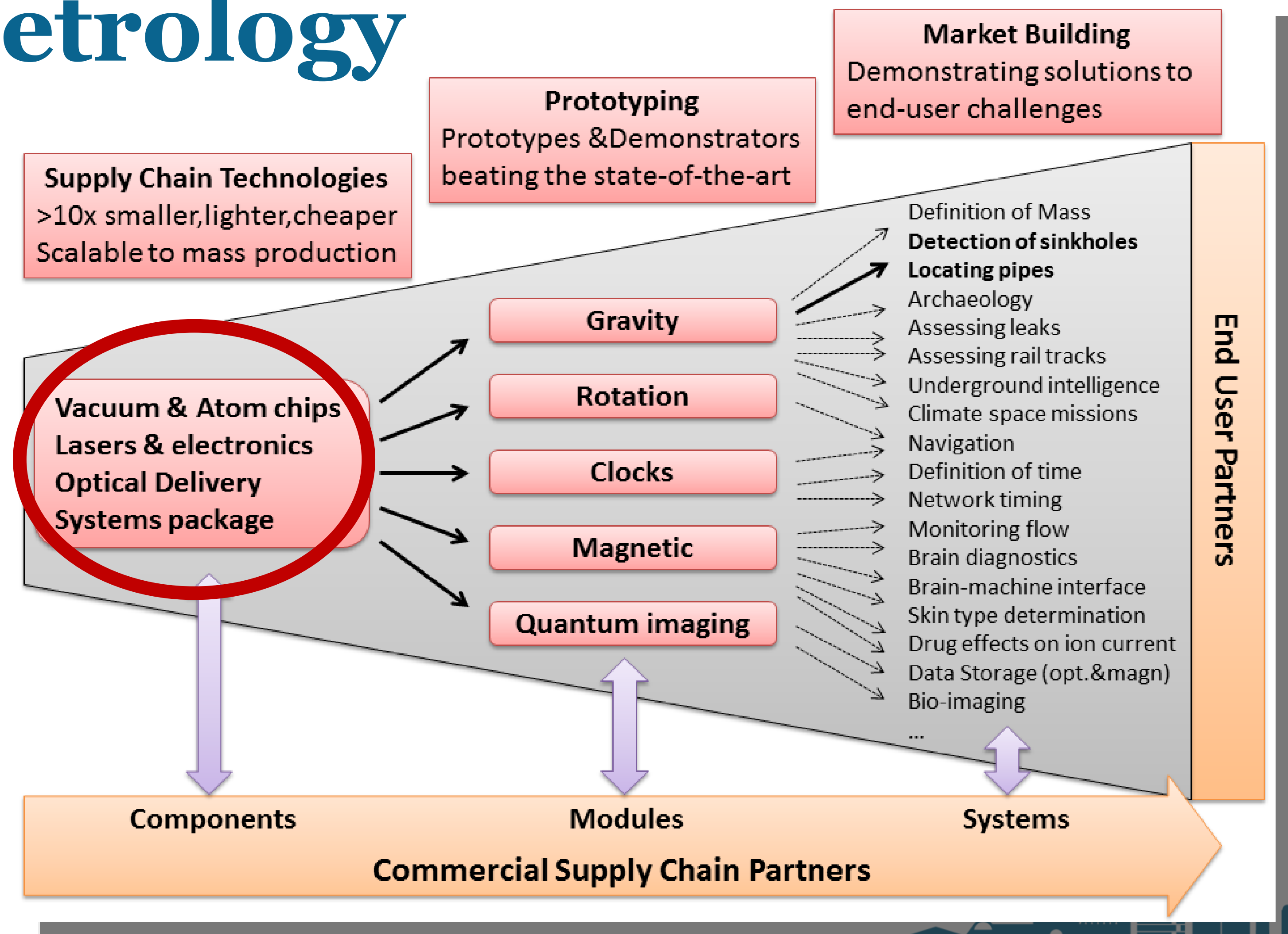
From experiment to instrument



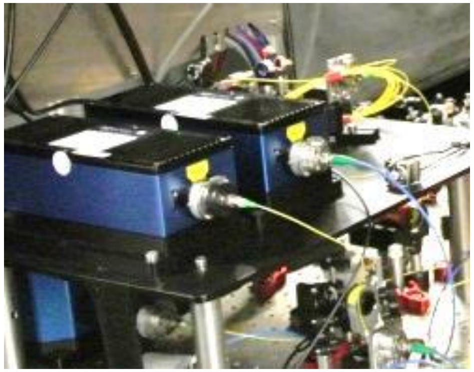
iSense project (indoor)

≈120L, 50 kg, 240 W

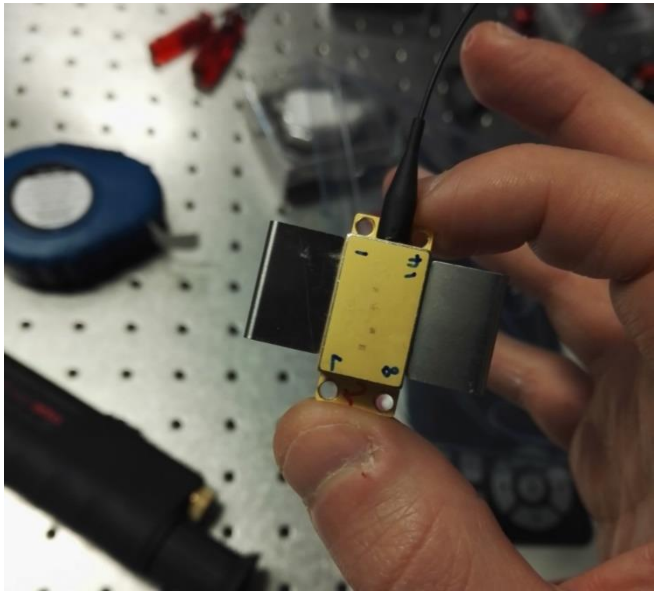
The QT Hub in Sensors and Metrology



Fibre-coupled DFB lasers



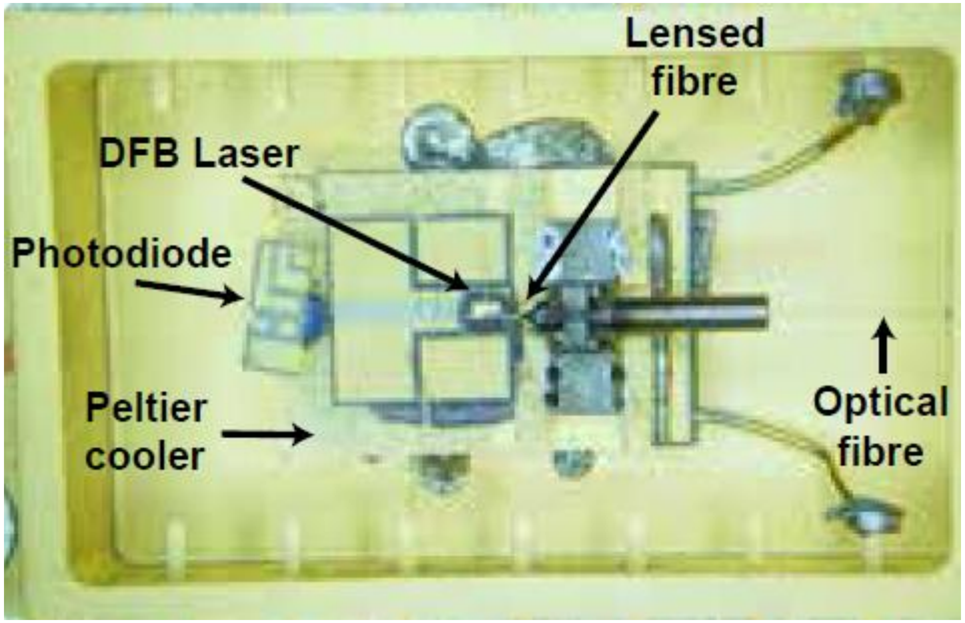
- Nanofabricated DFB



- Reduced size
- Drastically reduced cost

University of Glasgow
SQUARED
KELVIN NANOTECHNOLOGY
optocap

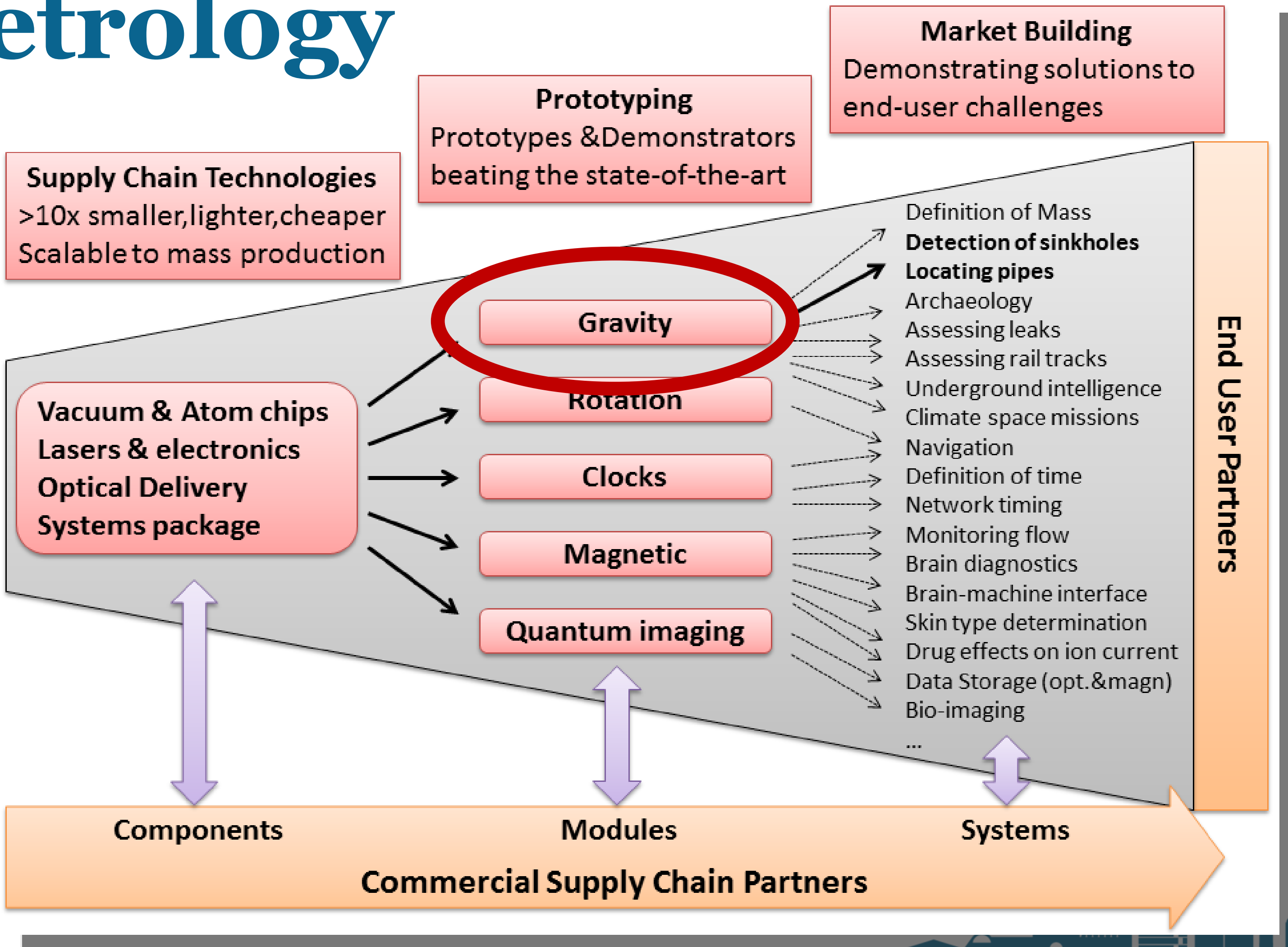
Fibre-coupled DFB lasers



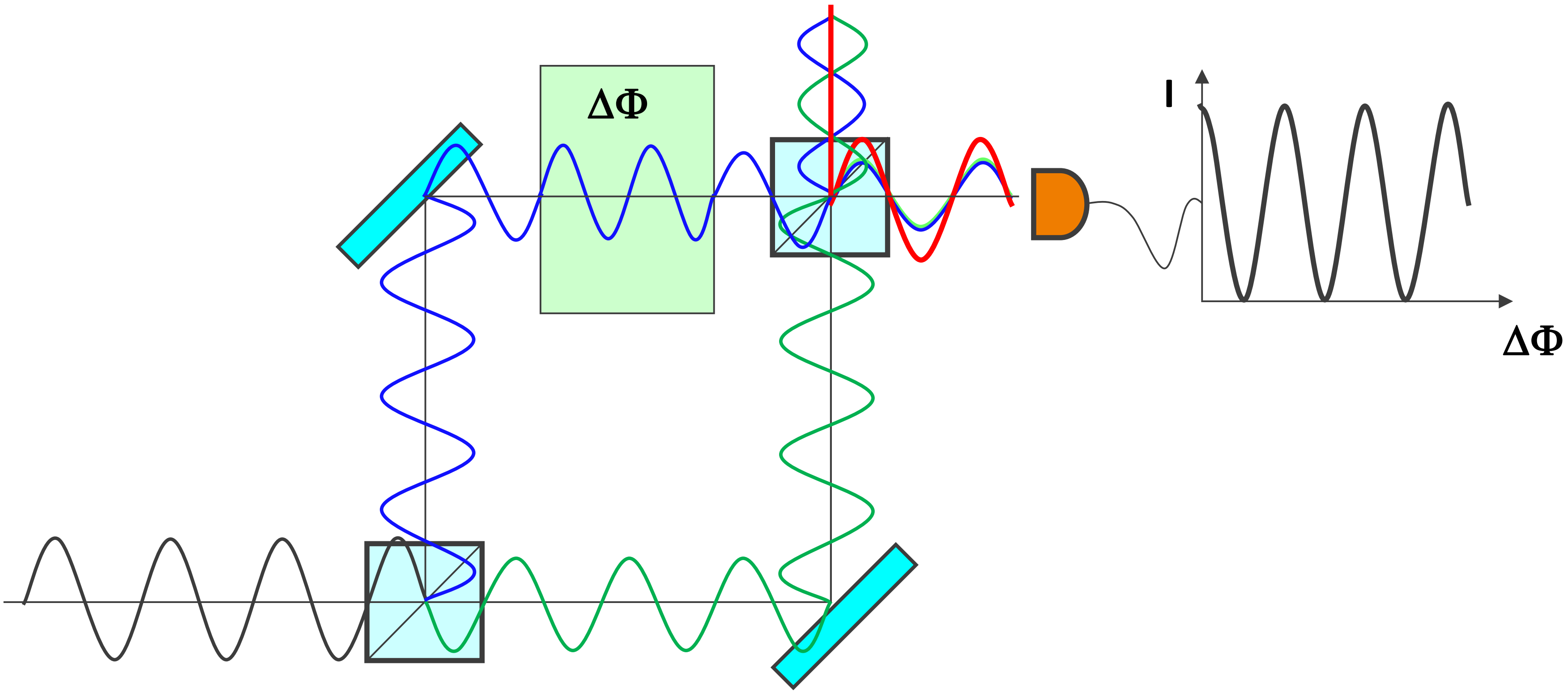
20.83 mm

- Miniaturised (14-pin butterfly package)
- Durable
- Low power consuming

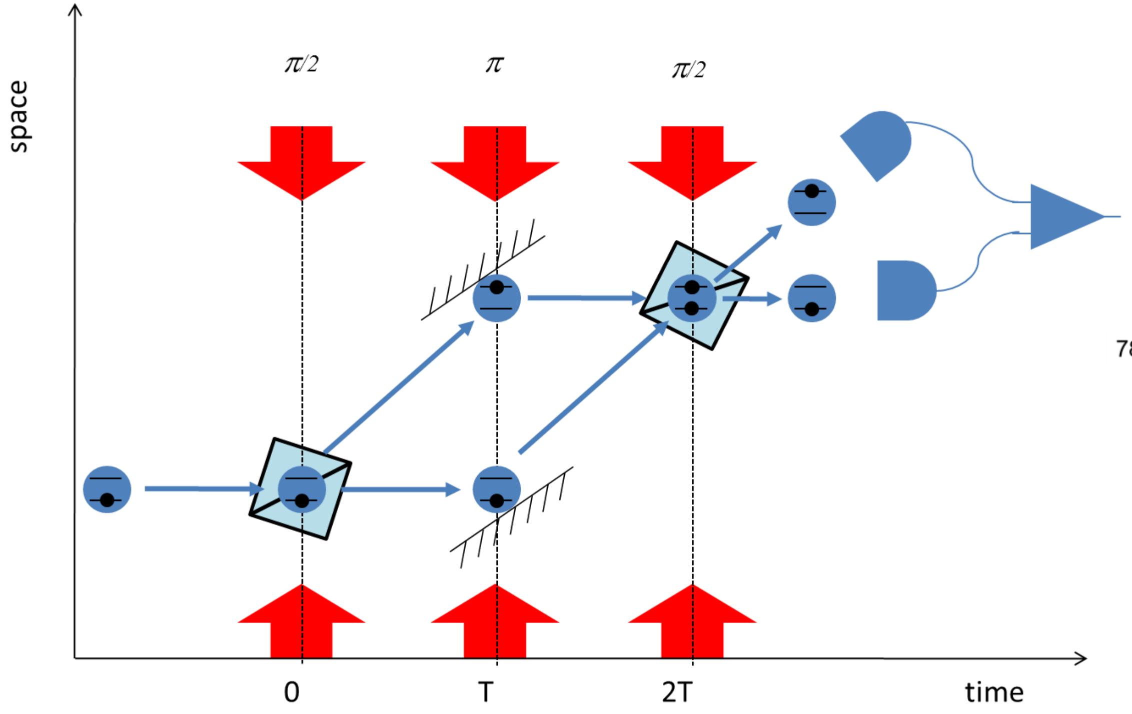
The QT Hub in Sensors and Metrology

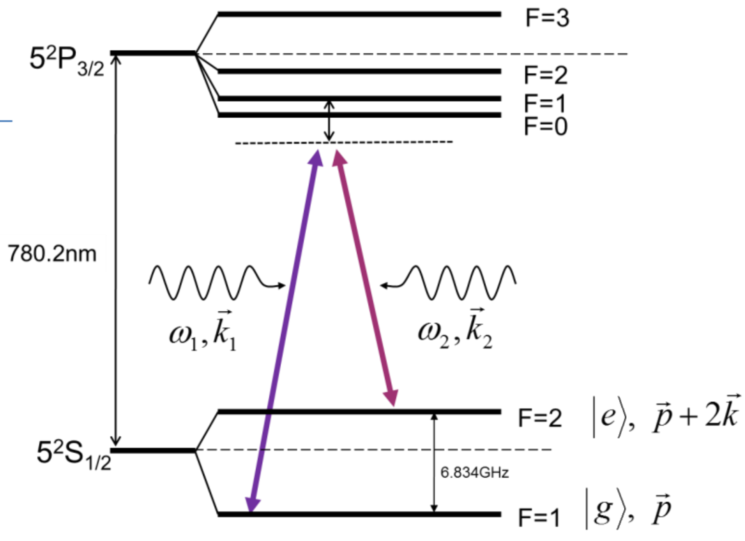


Optical interferometer…



...atomic interferometer





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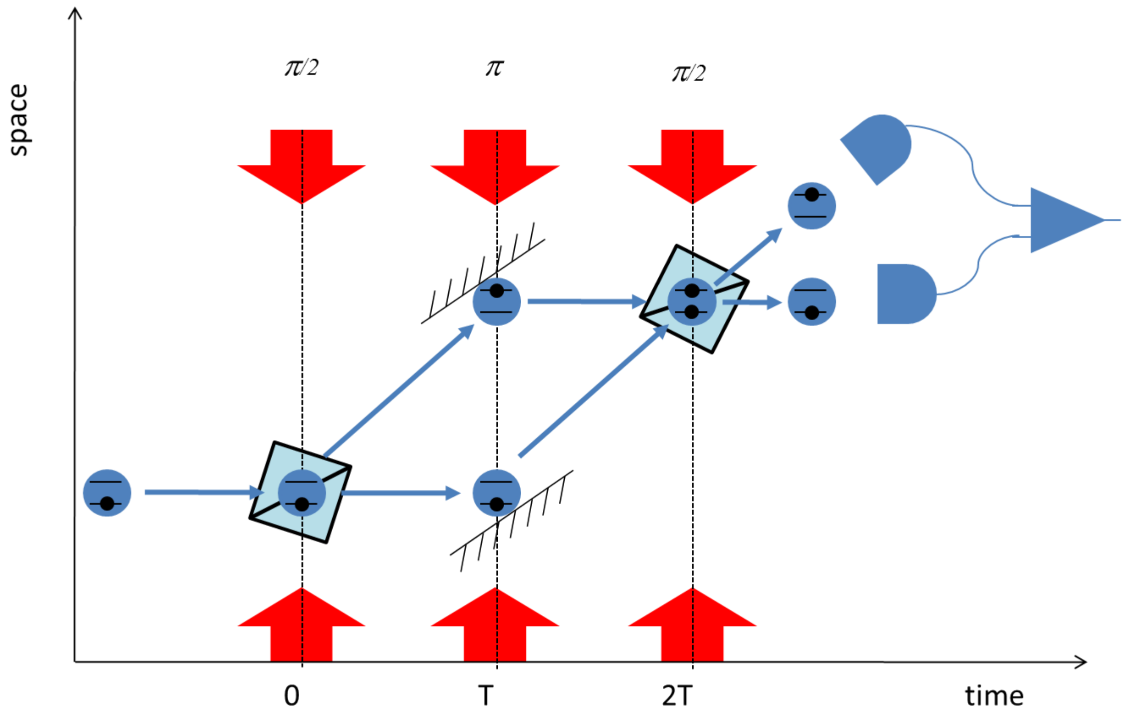
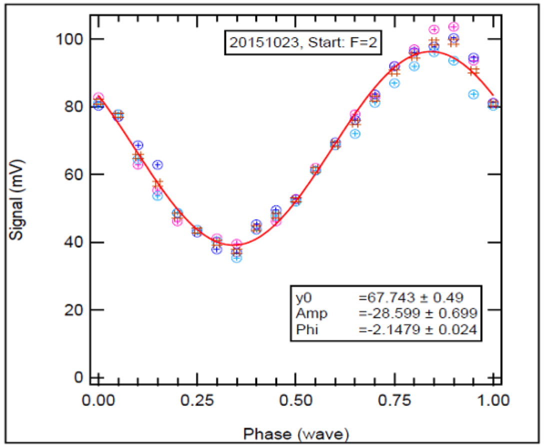
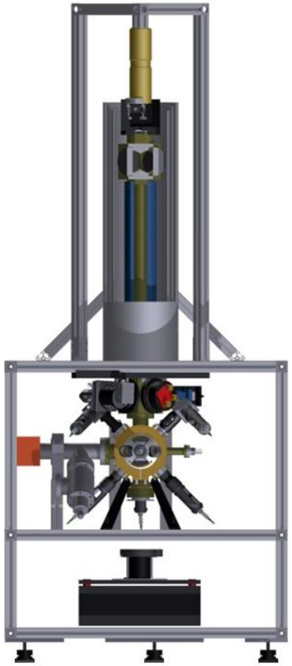


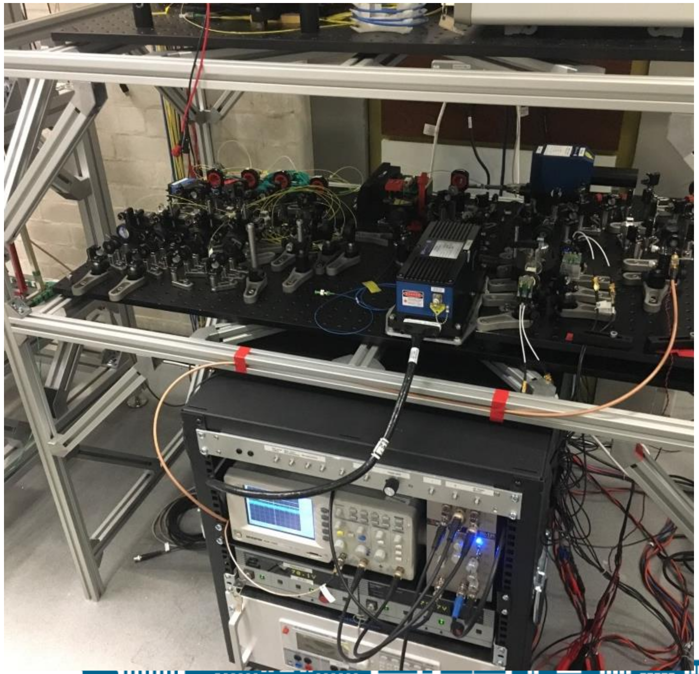


Transportable Gravimeter

Laboratory system built for absolute comparisons and to act as future reference platform for the hub

Participate in calibration campaigns to benchmark performance



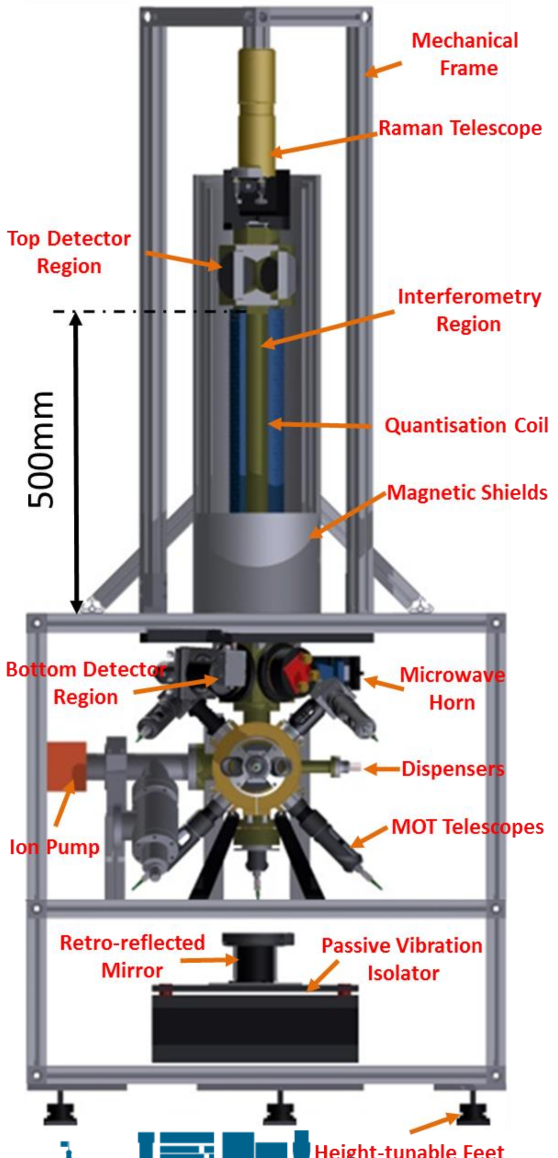


T. Gravimeter

Rubidium atoms, six-beam, vertical launch via moving molasses

Performance in TTC 2nd floor laboratory:

- Experimental cycle: 1.5s
- ~10^8 atoms launched
- Temperature <10 µK
- Sensitivity 2 x 10^{-8} g in 600s
- limited by mirror motion (vibration and air currents)



T. Gravimeter


Herstmonceux Castle

NERC
SCIENCE OF THE ENVIRONMENT

First campaign at Space Geodesy Facility, Herstmonceux, for calibration with FG5-X gravimeters

Herstmonceux Castle

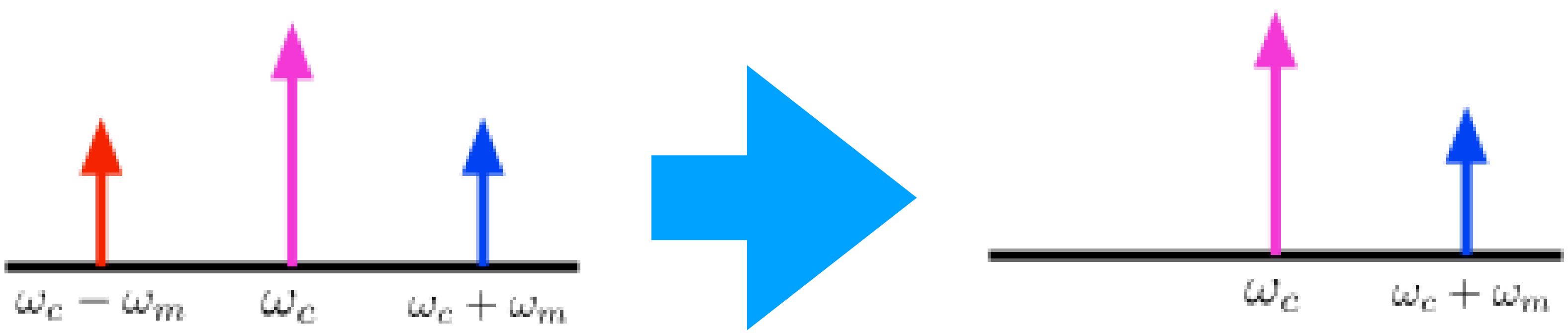
T. Gravimeter

Aim for long term comparison and to understand benefit of continuous data acquisition for satellite laser ranging

T. Gravimeter

Herstmonceux Castle

Implement single side band techniques to remove systematics and biases versus EOM scheme



Double SideBand (DSB)

Full-Carrier Single SideBand (FC-SSB)

T. Gravimeter

Herstmonceux Castle

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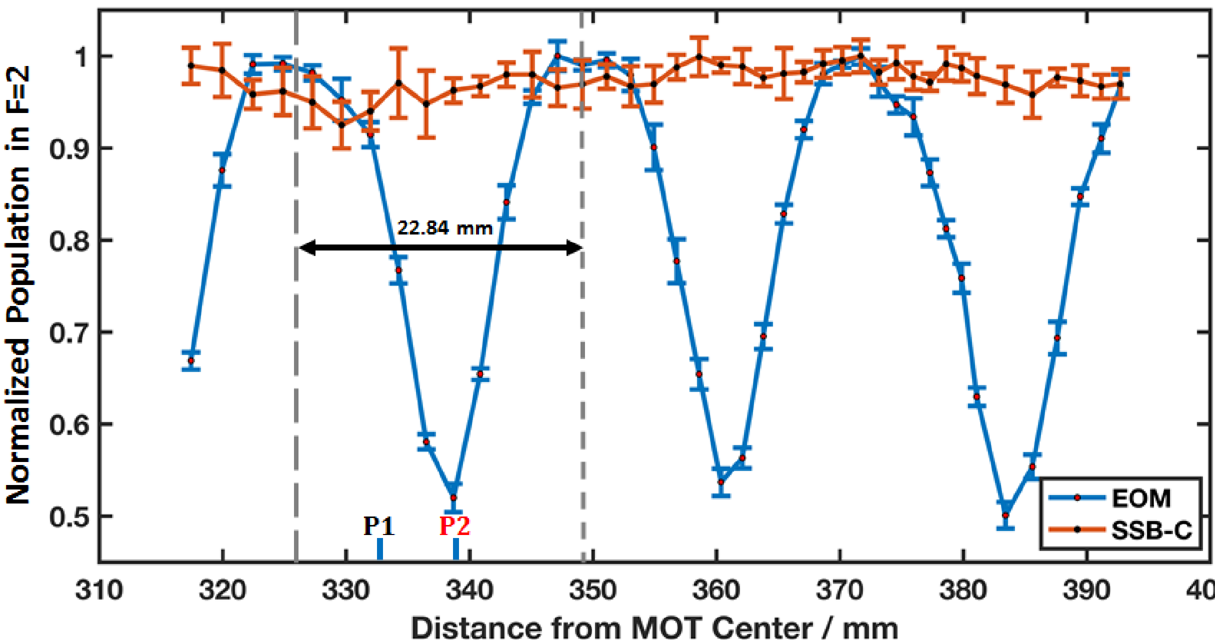

Herstmonceux Castle

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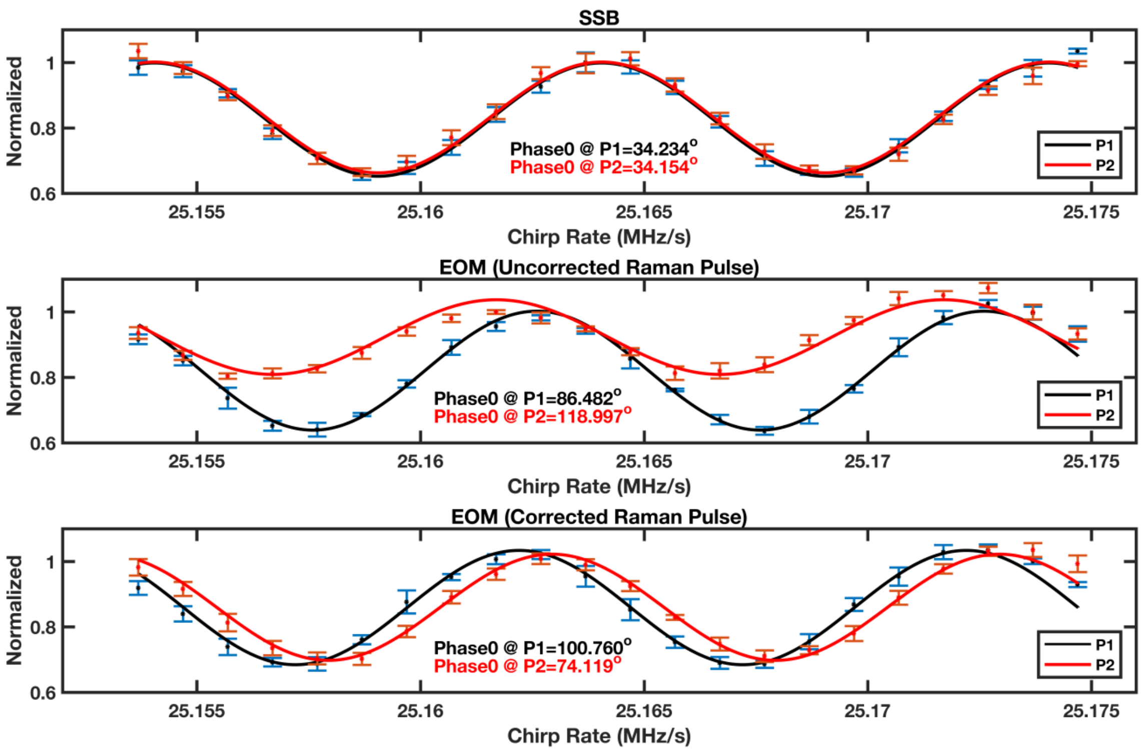


Portable gradiometer

Increase portability

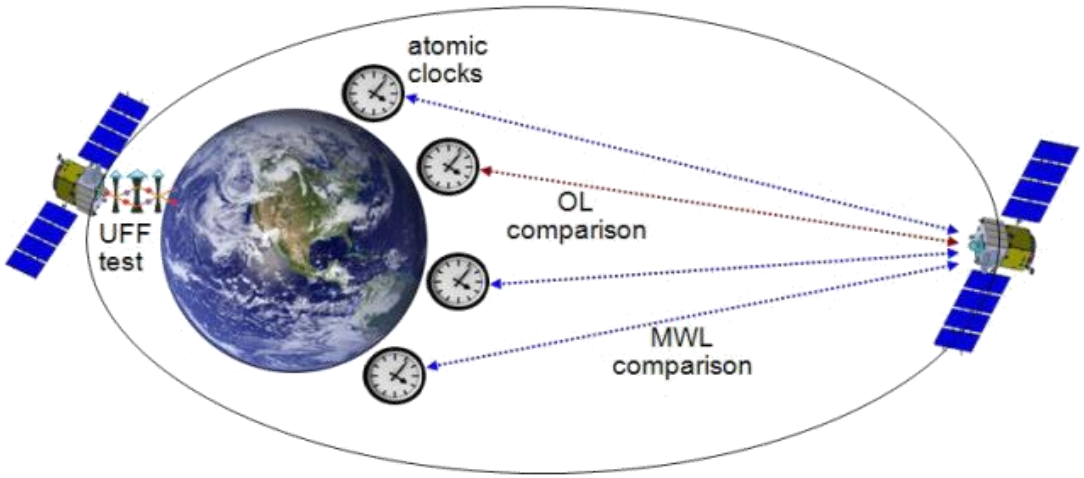
- Decrease size and weight of apparatus
- Integrating and simplifying sub-systems

Space applications

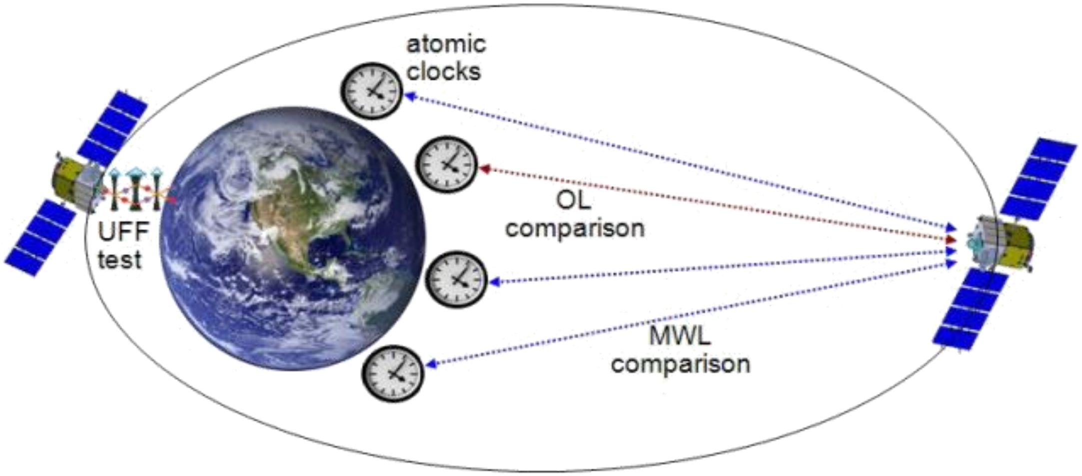
Fields of interest:

- Atomic clocks
- Gravity sensing **(mapping/environmental studies)**
- Fundamental Physics **(tests of the equivalence principle, gravitational wave detection, fundamental constants)**

The Space-Time Explorer and QUantum Equivalence Principle Space Test

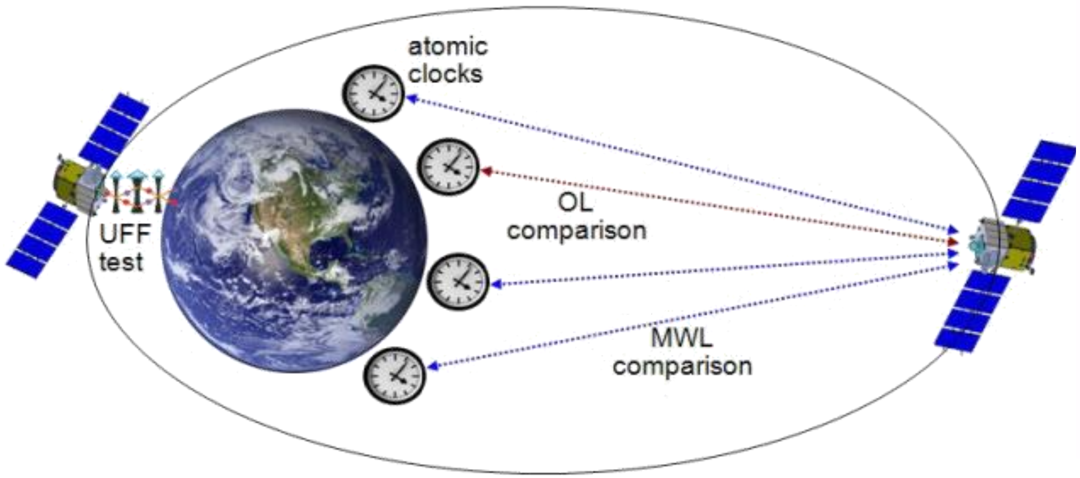


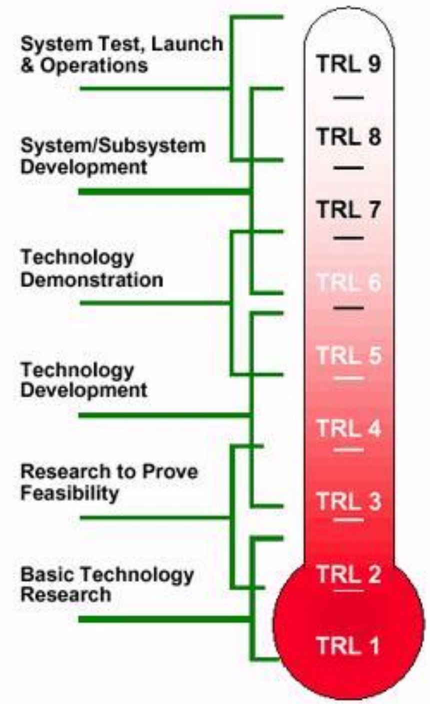
STE-QUEST



- **performing precision measurements with high accuracy atomic sensors, including clocks and AI**
- **Investigation of fundamental physics questions and of Einstein's Equivalence Principle.**

STE-QUEST





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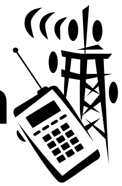
Applications of precision clocks

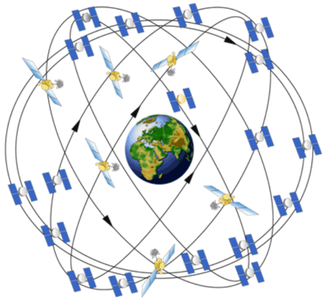
Network synchronisation



Time references for data encryption

Financial time-stamping

Next generation GNSS



Geodesy applications

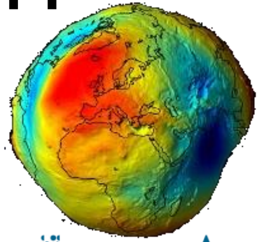


Photo: ESA/GOCE

Space Optical Clock

- **Portable apparatus, 970 L and 300 kg**
- **Atomics package developed in Birmingham and relocated to PTB (Braunschweig)**
- **Model for future deployment on the ISS**

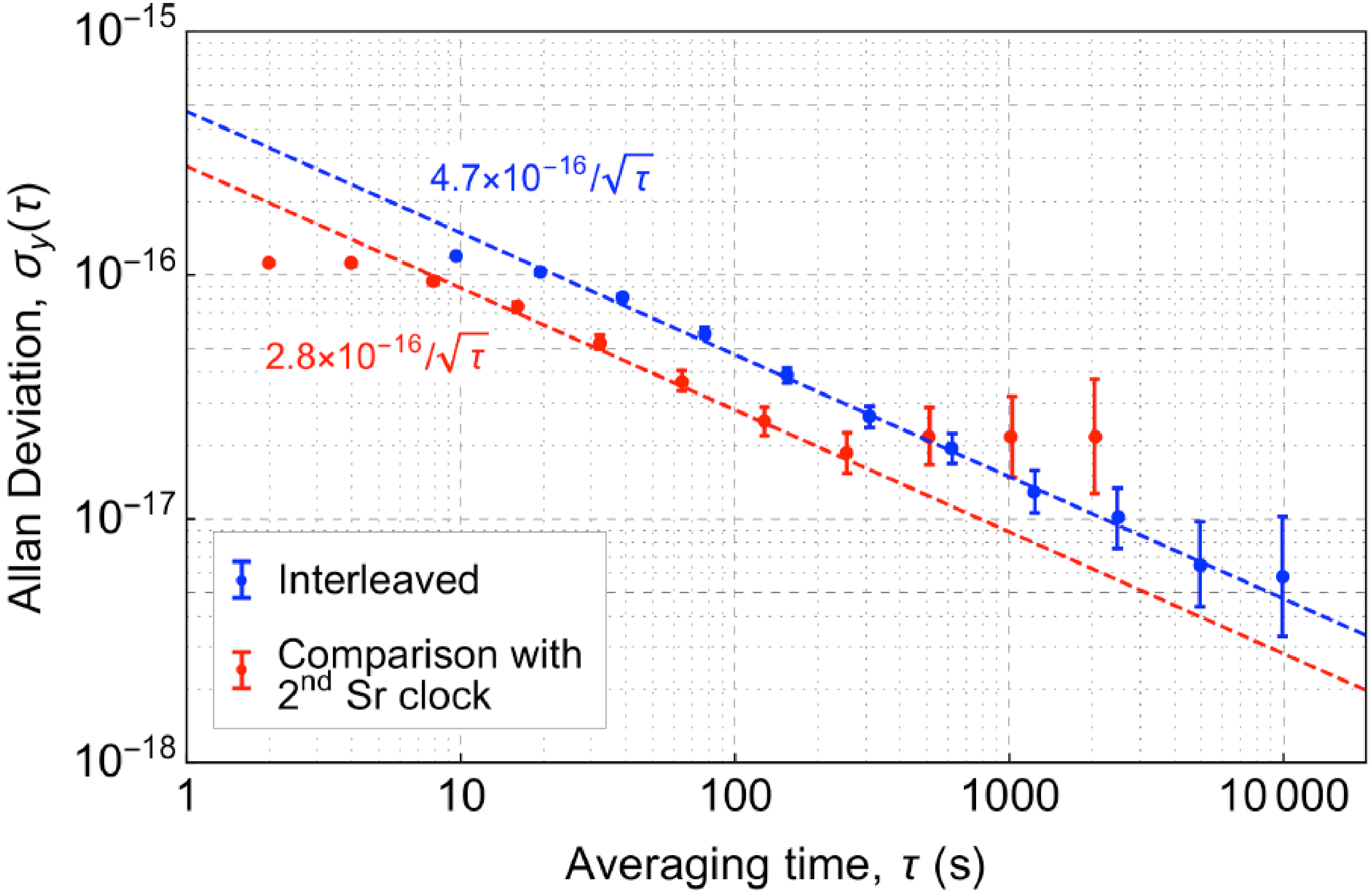
Space Optical Clock

Main goals:

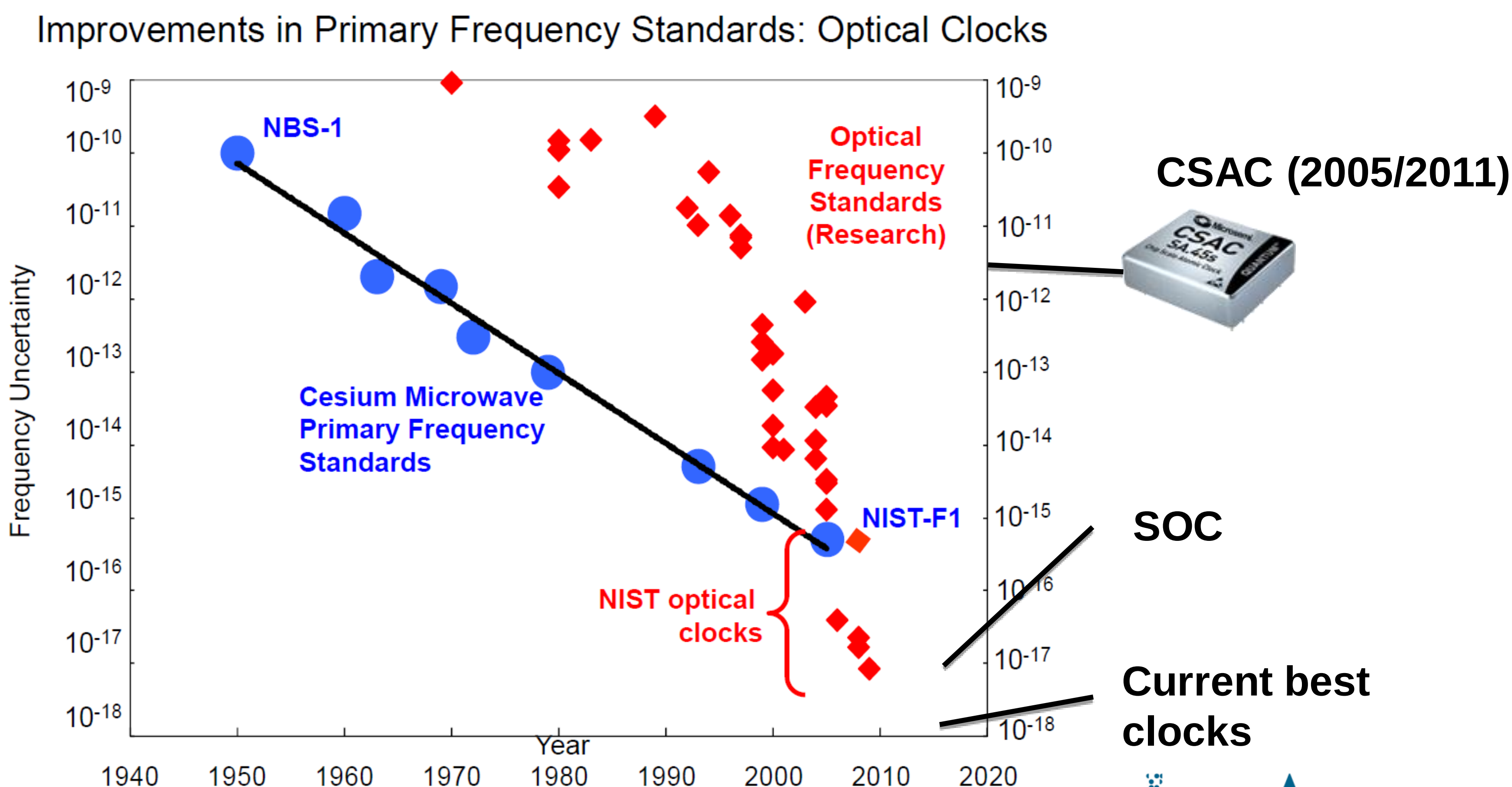
- Testing Einstein Equivalence principle
- Relativistic geodesy

HEINRICH HEINE UNIVERSITÄT DÜSSELDORF
PTB
Leibniz Universität Hannover
l'Observatoire de Paris SYRTE
INRiM ISTITUTO NAZIONALE DI RICERCA METROLOGICA
UNIVERSITY OF BIRMINGHAM
NPL National Physical Laboratory
TOPTICA PHOTONICS
KAYSER-THREDE
EADS astrium
MenloSystems GmbH
KAYSER ITALIA
LTF Université de Neuchâtel unine
csem centre suisse d'électronique et de microtechnique
EPFL ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Space Optical Clock



Applications of precision clocks



Space applications

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Gravity mapping

GRACE, GOCE missions

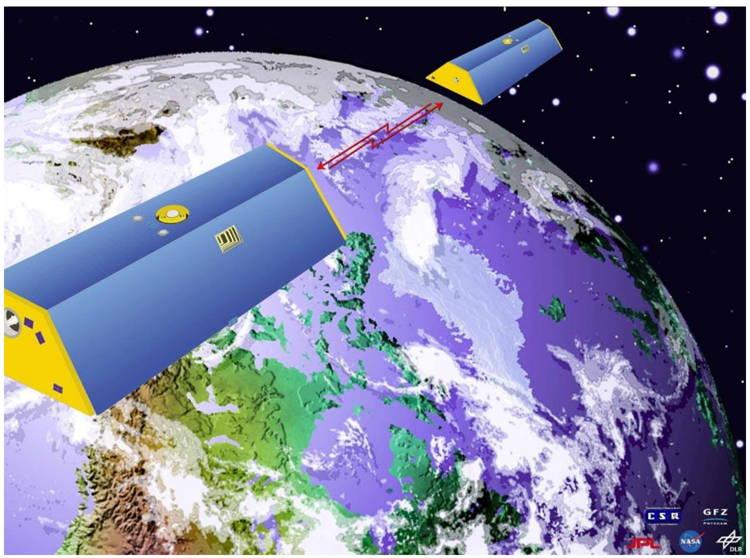


Image from NASA

Image from ESA

Gravity mapping

GRACE, GOCE missions

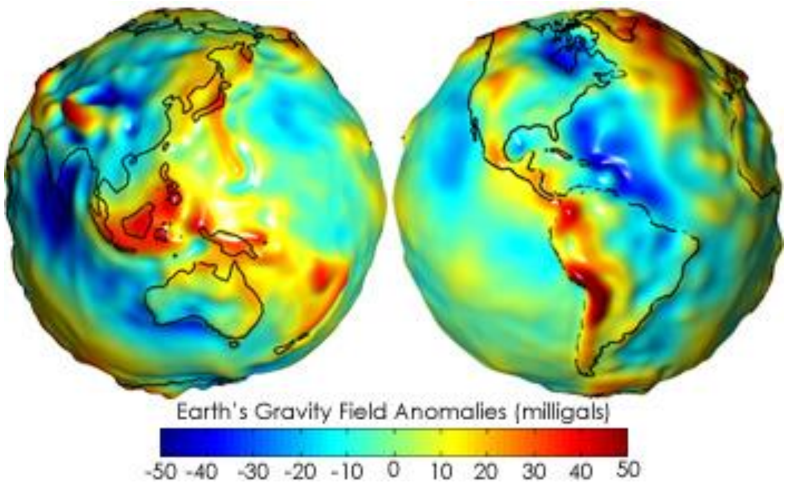


Image from NASA

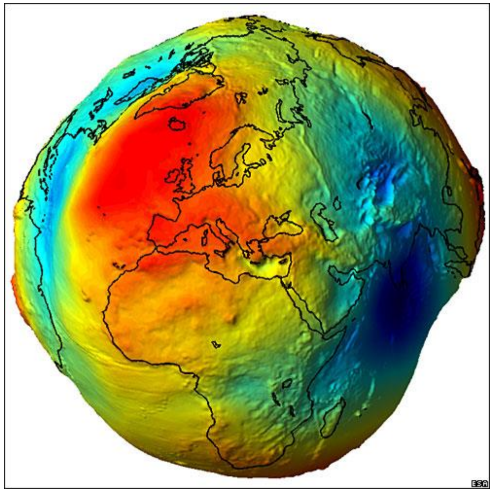
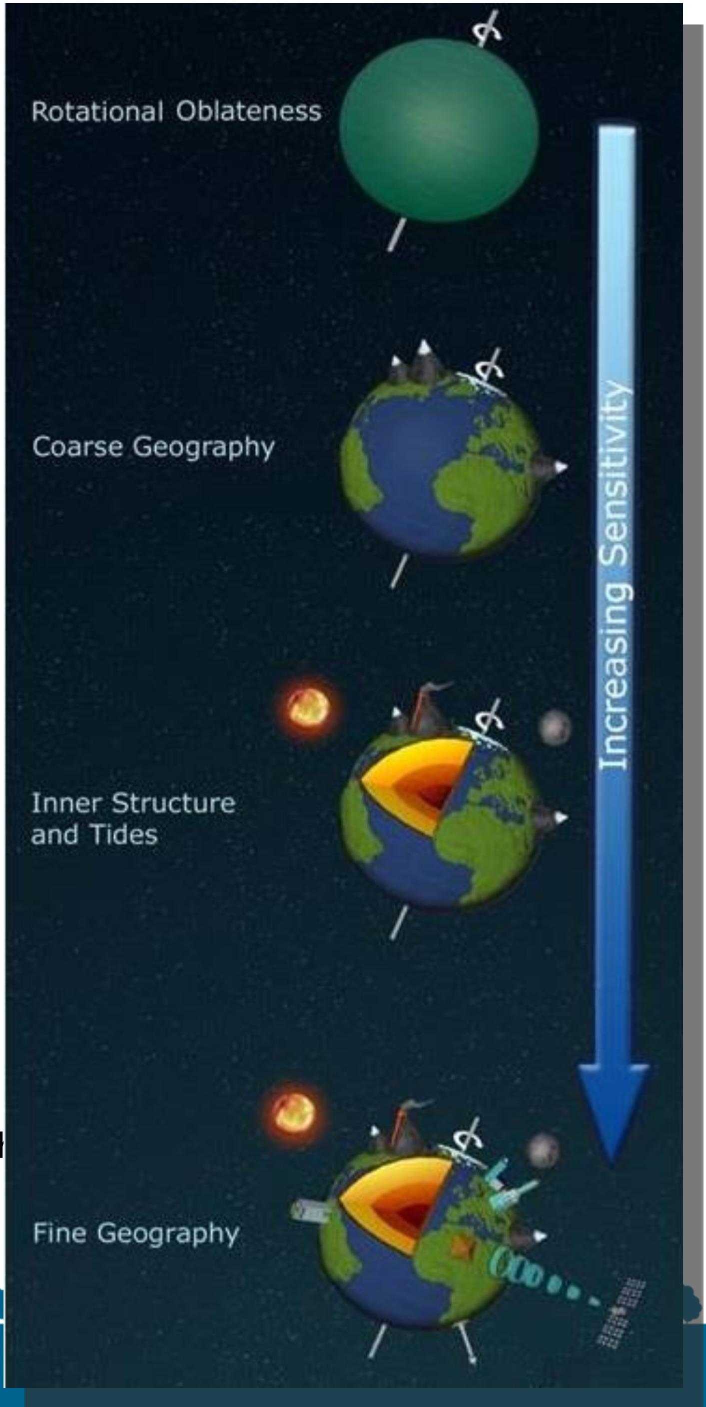


Image from ESA

Gravity mapping

Classical sensing to map gravity field anomalies:

- **Geoid map**
- **Water/ice sheet distribution**
- **Ocean currents and heat transport**
- **Geodynamics of Earth's interior**



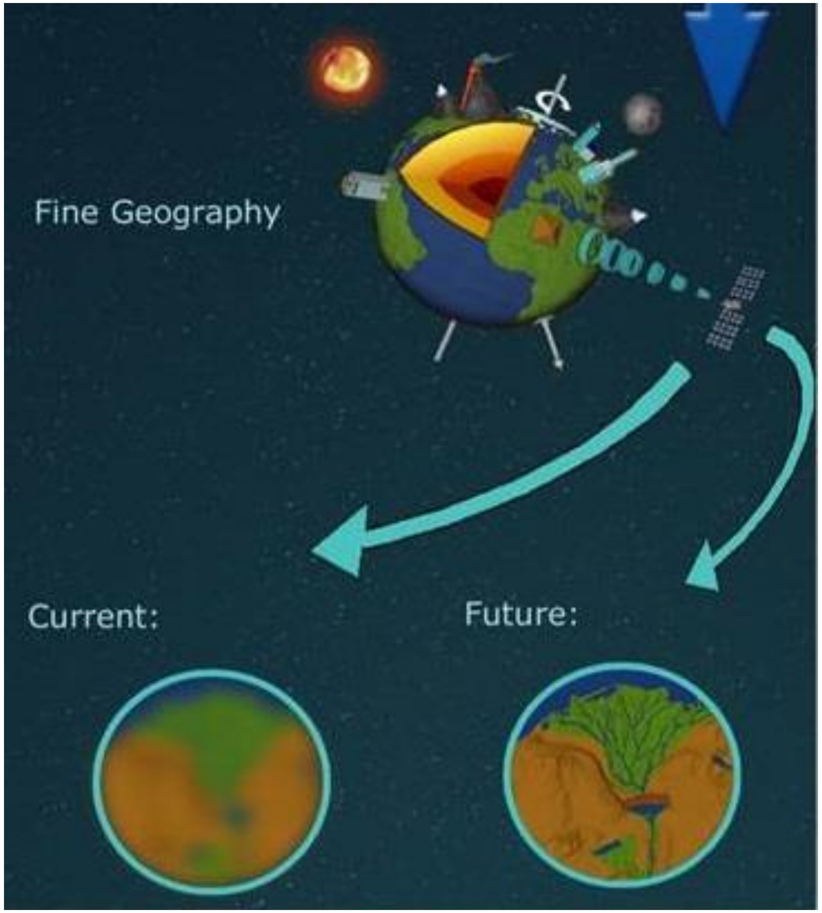
Ψ in the sky
K Bongs, M Holynski & Y Singh
Nature Physics 11, 615 (2015)

Gravity mapping

spatial resolution ≈ 100 km

QT gravity sensing to increase spatial and temporal resolution

≈10 factor improvement in resolution, more localised information



Ψ in the sky
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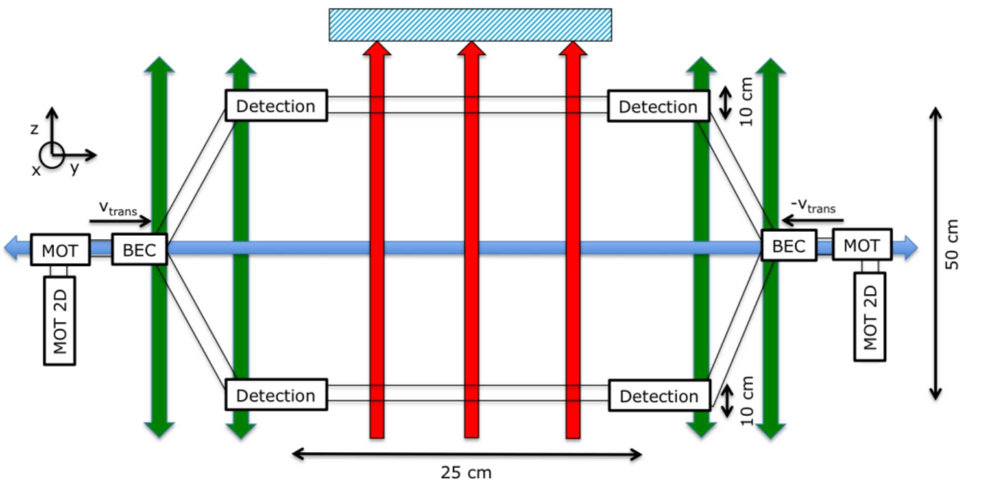
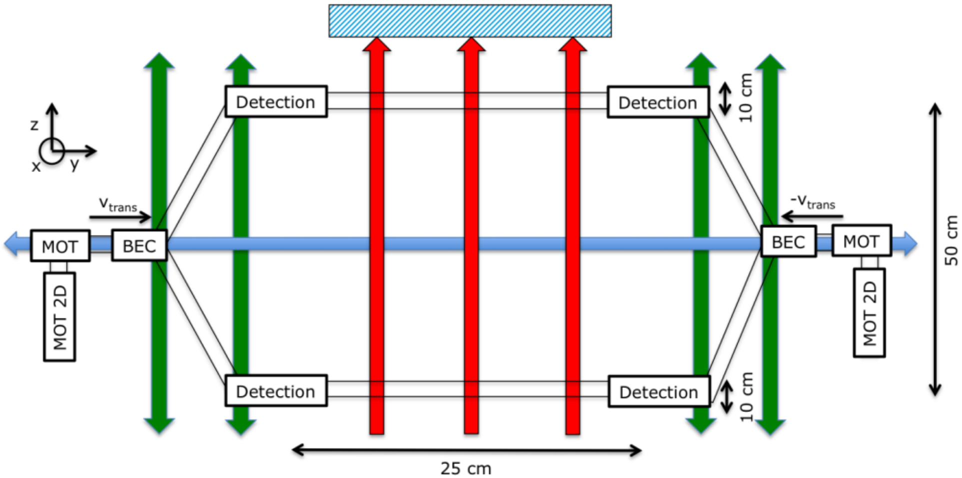
Compact Vacuum Chamber for an Earth Gravity Gradiometer based on Laser-cooled Atom Interferometry



A spaceborne gravity gradiometer concept based on cold atom interferometers for measuring Earth's gravity field

Olivier Carraz · Christian Siemes · Luca Massotti · Roger Haagmans · Pierluigi Silvestrin

The CVC project



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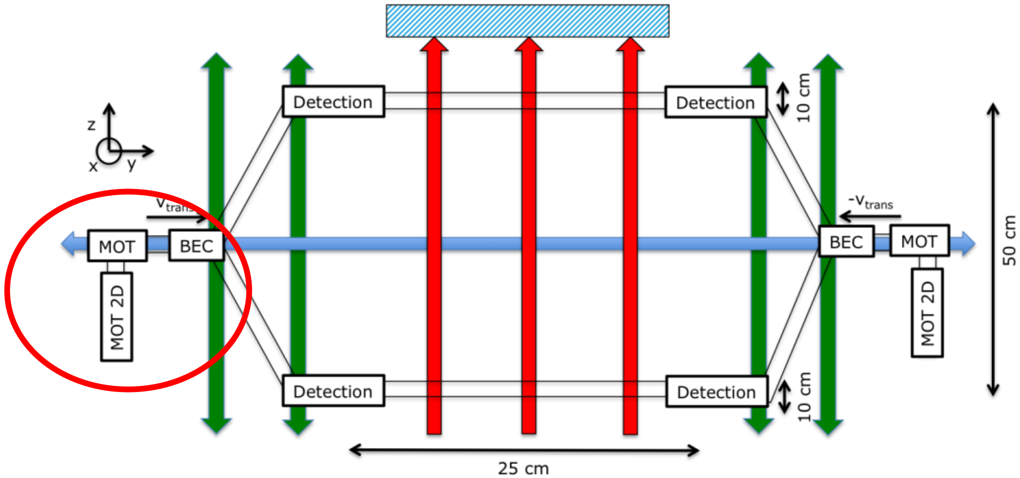
sensitivity ↑ time of measurement

esa RAL Space UNIVERSITY OF BIRMINGHAM ZARM

The CVC project



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$\Delta g \propto T^{-2}$

Lower noise environment

BEC interferometry

=

Lower expansion rates

UNIVERSITY OF BIRMINGHAM

Cold Atoms Space PAyload

TELEDYNE e2V
Everywhereyoulook™

(Consortium Leader)

UNIVERSITY OF BIRMINGHAM

Innovate UK

CLYDE SPACE

Gooch & Housego

UNIVERSITY OF Southampton

XCAM

covesion

AIRBUS DEFENCE & SPACE

CASPA

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UNIVERSITY OF BIRMINGHAM

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Gooch & Housego

CLYDE SPACE

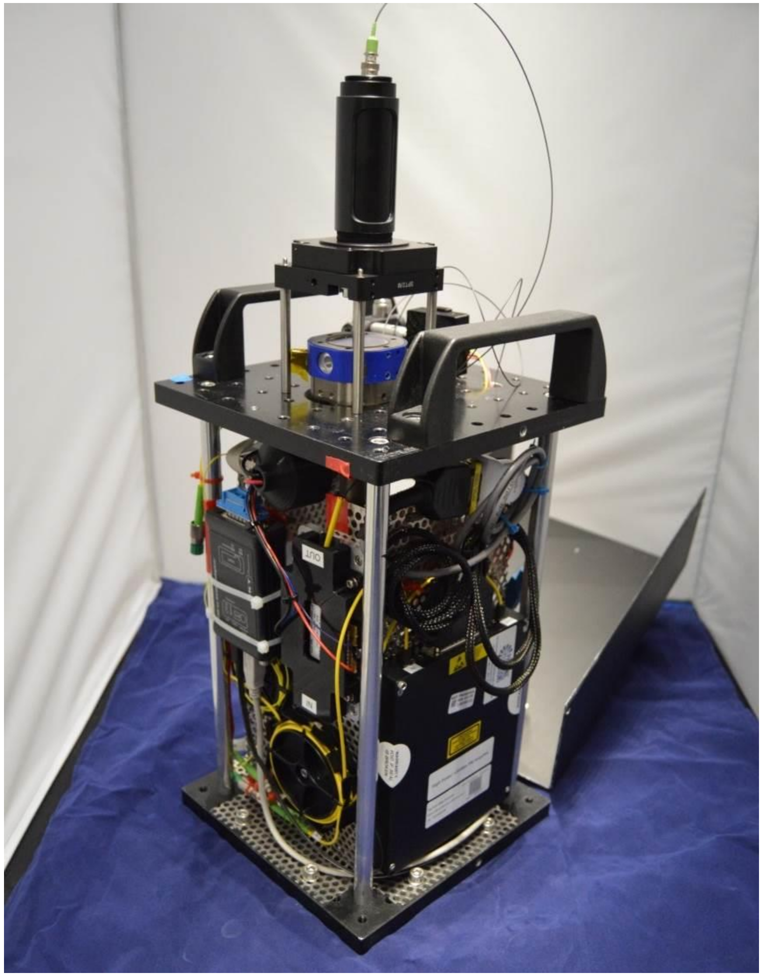
UNIVERSITY OF Southampton

XCAM

covesion

AIRBUS DEFENCE & SPACE

Compact MOT system



Atom number: 10^7
Atomic species: ^{87}Rb

Components:

- □Vacuum chamber
- □Laser system
- □Laser control
- □Power supply
- □Packaging

SWAP:

- □Volume: 20 L
- □Weight: 10 kg
- □Power: 80 W

CASPA

Produce a Cold Atoms Space Payload for in orbit Technology demonstration based on CubeSat (4U of 6U spacecraft)

- **Increase TRL for cold atoms space applications**
- **Miniaturising and integrating**
- **Autonomy, durability and resilience for prolonged operation**

CASPA

TELEDYNE e2V Everywhereyoulook™

CLYDE SPACE

Innovate UK

XCAM

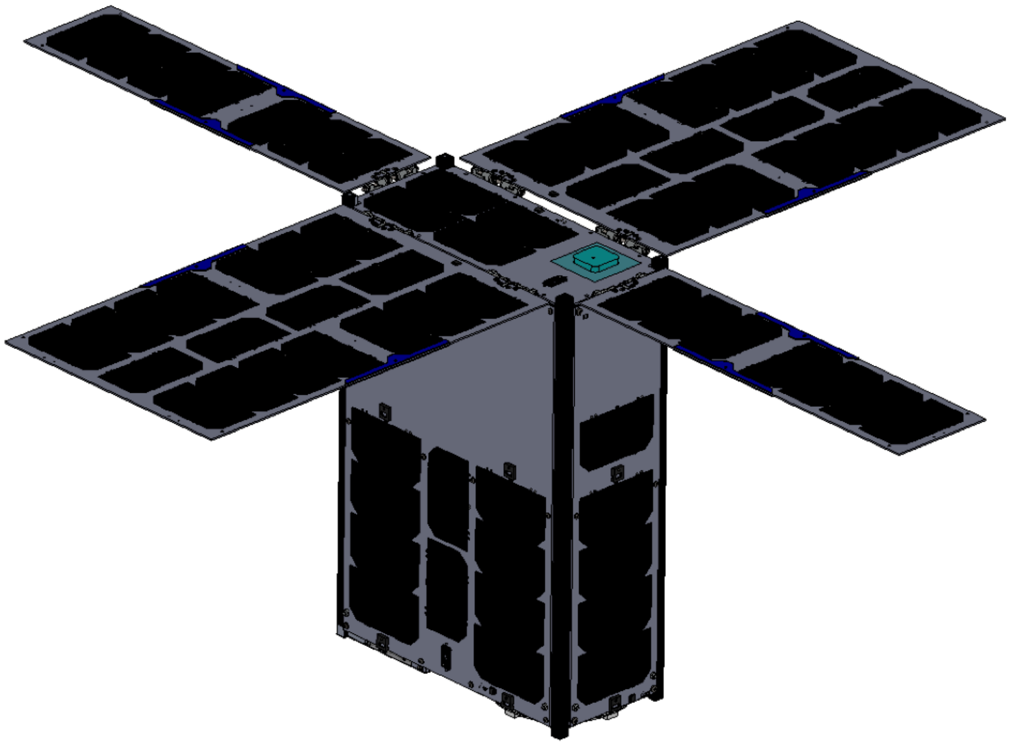
UNIVERSITY OF BIRMINGHAM

AIRBUS DEFENCE & SPACE

Gooch & Housego

UNIVERSITY OF Southampton

covesion



Payload requirements on a 6U CubeSat: < 4 kg, 4U, <40 W

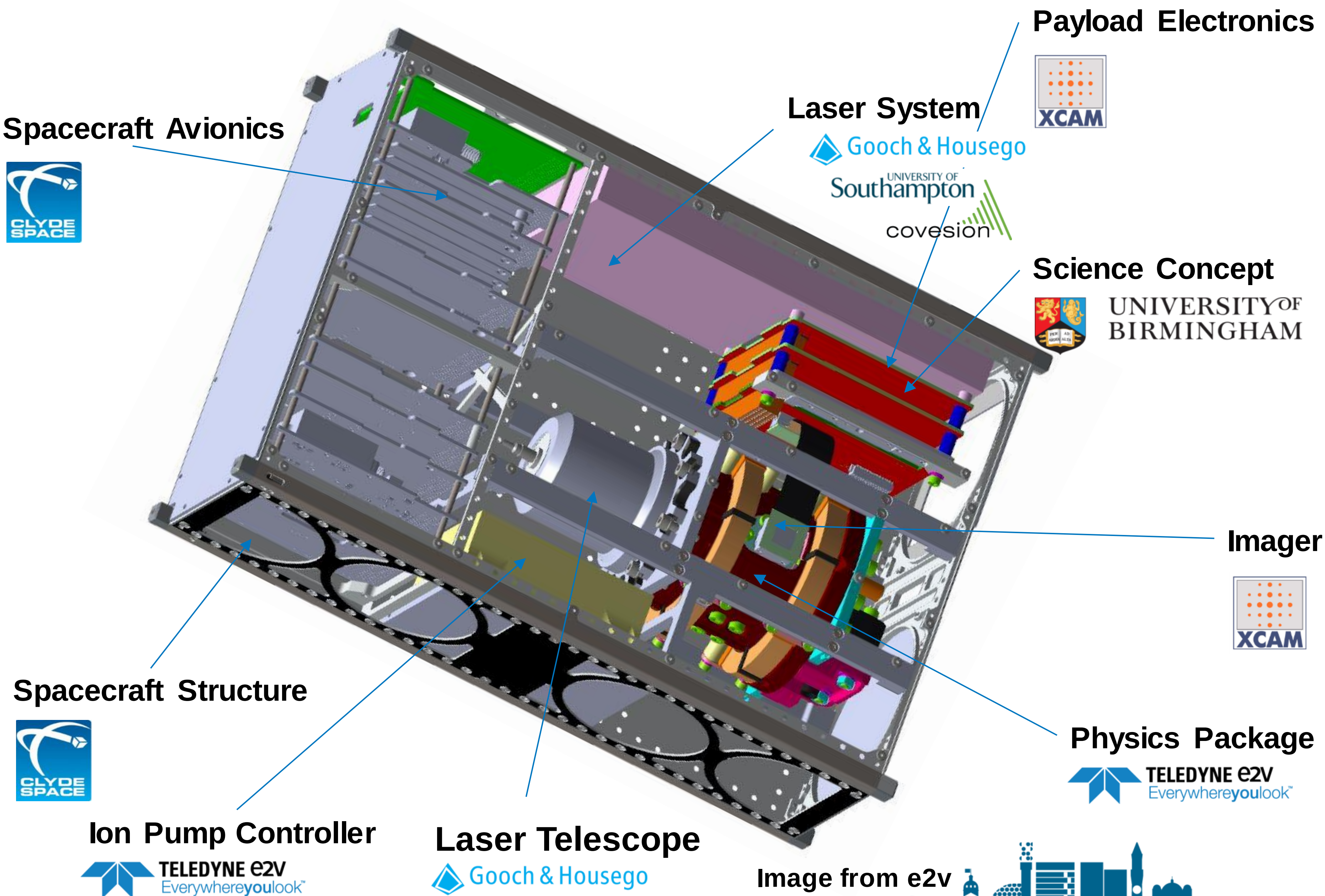
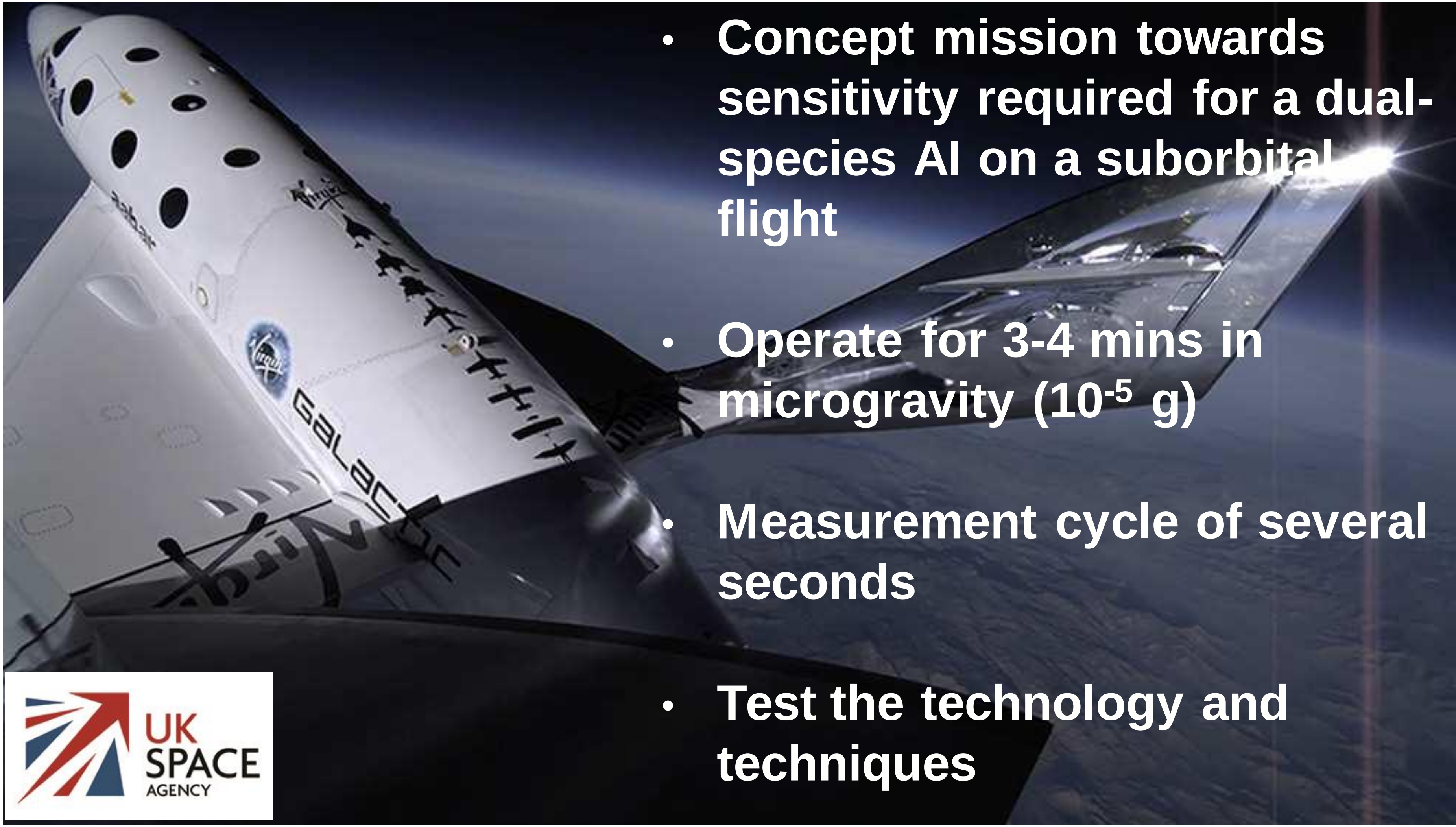


Image from e2v

Study for AI on suborbital flights



- Concept mission towards sensitivity required for a dual-species AI on a suborbital flight
- Operate for 3-4 mins in microgravity (10^{-5} g)
- Measurement cycle of several seconds
- Test the technology and techniques

UK SPACE AGENCY

UNIVERSITY OF BIRMINGHAM

UK National Quantum Technology Hub Sensors and Metrology

TELEDYNE e2v Everywhereyoulook™

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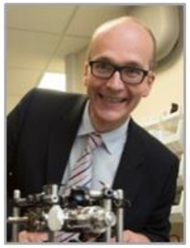
Trym Systems Ltd

UoB Gravity Sensing

UNIVERSITY OF BIRMINGHAM MUARC

Hub Director



Prof Kai Bongs

Team lead

Dr Michael Holynski

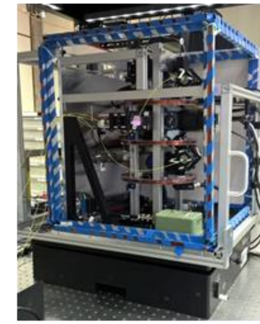
AI Rapid Test Facility

Clemens Rammeloo

Dr Alex Wilson

Rustin Nourshargh

Georgios Voulazeris



[dstl] *Gravity Imager*

Dr Aisha Kaushik

Dr Jamie Vovrosh

Andrew Lamb

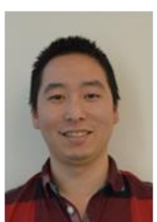
Dr Anthony Rodgers

Ben Stray

Luuk Earl

S&T Test bed

Dr Yu-Hung Lien



Lingxiao Zhu

Space Projects

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Recruiting: PhD students, Post-docs

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