UK NQT Hub in Sensors and Metrology

Kai Bongs, University of Birmingham

Appleton Space Conference 2015 - 3.12.2015

UK National Quantum Technologies Programme

- A **five-year £270M programme** announced by the UK government in the 2013 Autumn statement.
- Programme started October 2014.
- To exploit the potential of quantum science and develop a **portfolio of emerging technologies** with the potential to benefit the UK.
- Industry, government and academia working together to create opportunities for **UK wealth creation.**

Department for Business Innovation & Skills | EPSRC Pioneering research and skills | Innovate UK Technology Strategy Board | Knowledge Transfer Network | [dstl] | NPL National Physical Laboratory | CESG

UK NATIONAL QUANTUM TECHNOLOGIES PROGRAMME

Slide courtesy of D. Delpy

Atom-based QT sensors

Control

Lasers | Vacuum

System integration

University of Glasgow

University of Sussex

University of Southampton

M Squared

The University of Nottingham
UNITED KINGDOM · CHINA · MALAYSIA

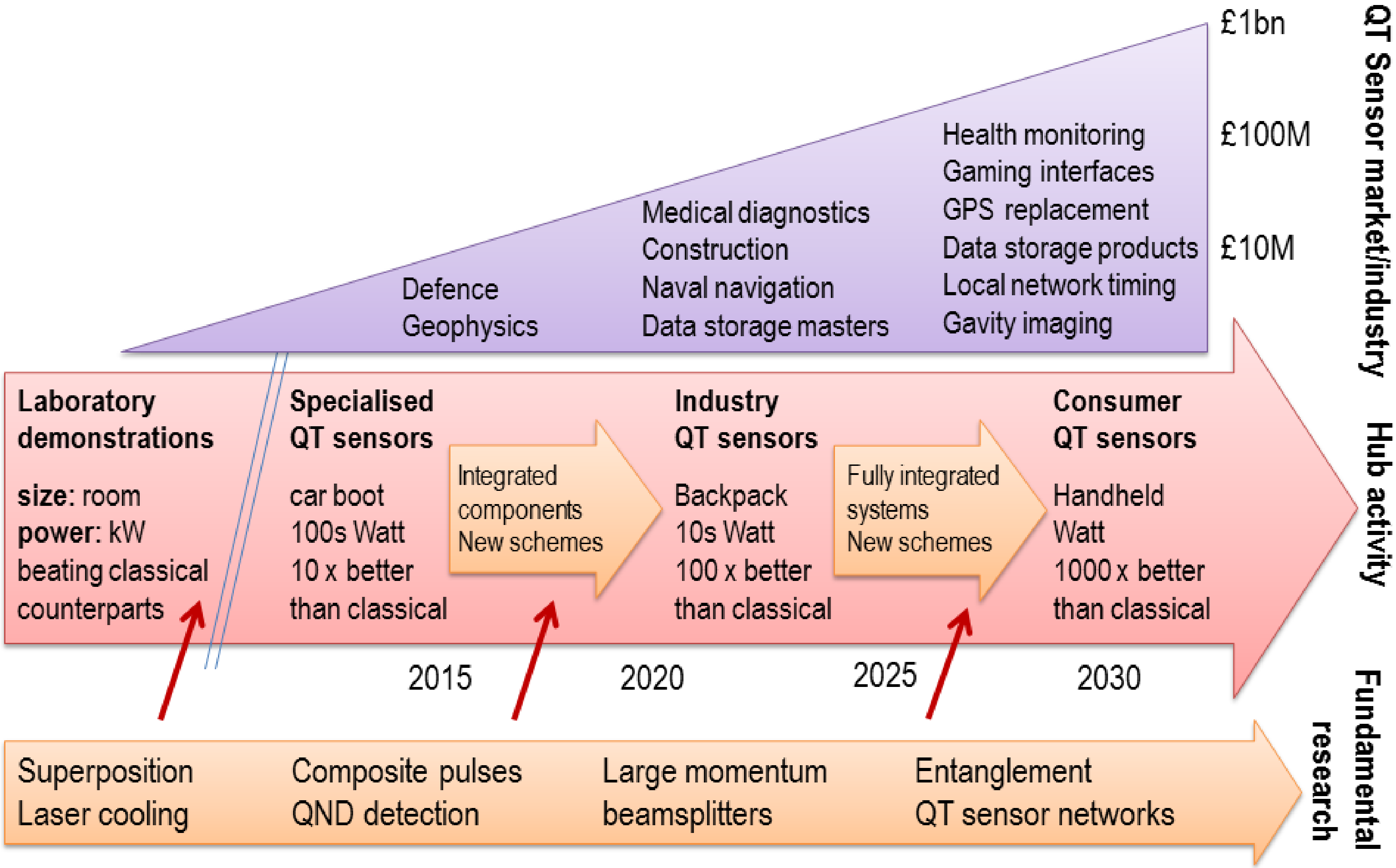
University of Strathclyde Glasgow

NPL National Physical Laboratory

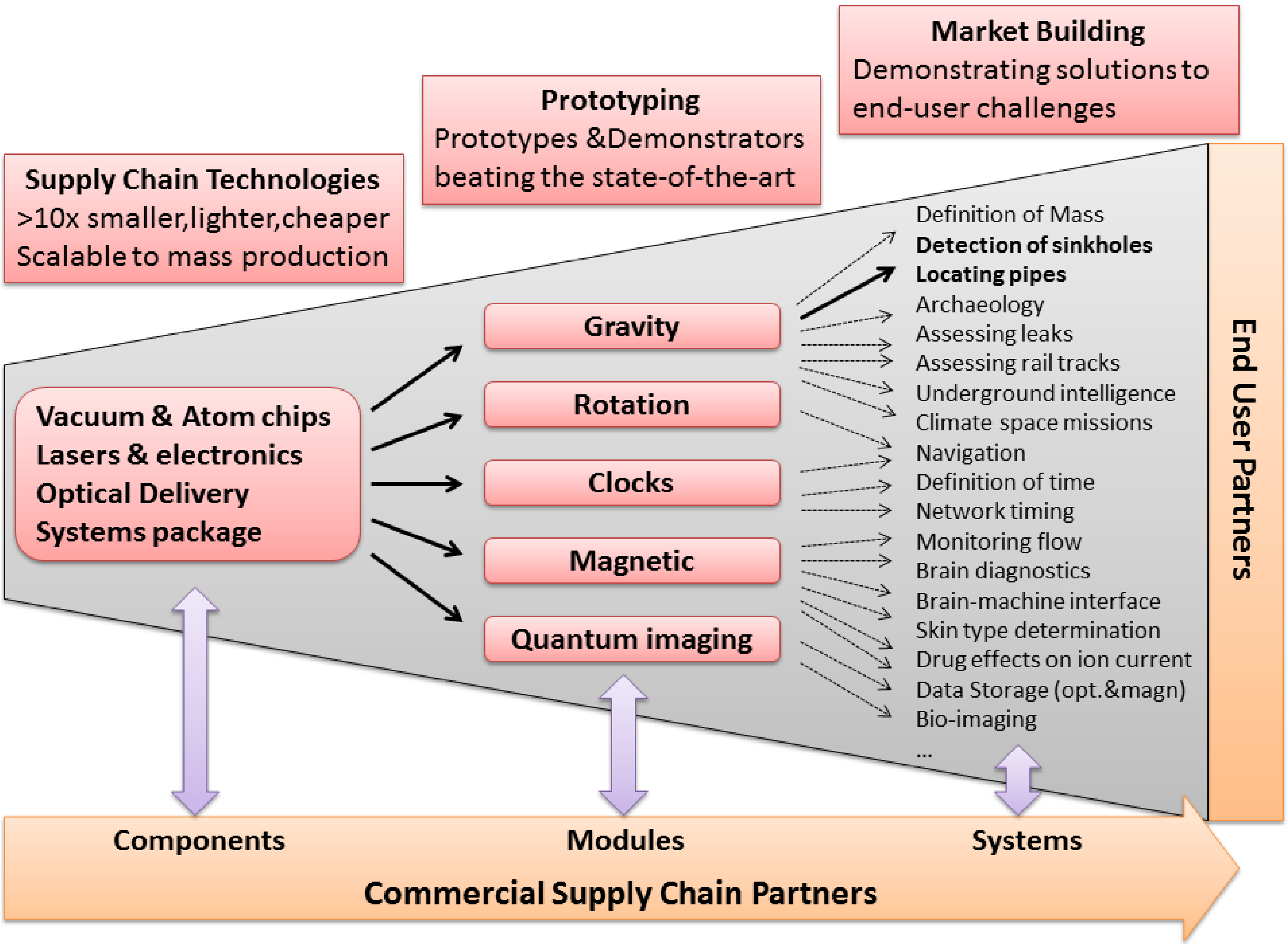
University of Birmingham

e2v

Quantum Sensor Roadmap



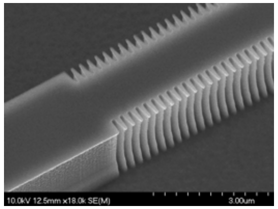
Activities and Links



Supply Chain

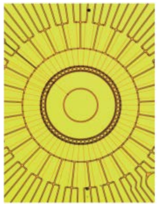
WP1: Lasers/electronics
Doug Paul, Glasgow
Douglas.Paul@glasgow.ac.uk

→ 100 kHz diode laser
System on a Chip



WP2: Atomics package
Mark Fromhold, Nottingham
Mark.Fromhold@nottingham.ac.uk

→ Atom/ion chips
Integrated optics
Vacuum

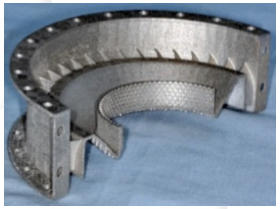


WP3: Custom lasers
Jennifer Hastie, Strathclyde
jennifer.hastie@strath.ac.uk

→ Semiconductor disk lasers
Femtosecond comb

WP4: Systems package
Moataz Attallah, Birmingham
M.M.Attallah@bham.ac.uk

→ Inertial stabilisation
Overall package by add. manufacturing



Demonstrators

WP5: Gravity sensors
Kai Bongs, Birmingham
k.bongs@bham.ac.uk

→ 1 nano-g in 10l volume
Towards gravity imager

WP6: Magnetic field sensors
Peter Krüger, Nottingham
Mark.Fromhold@nottingham.ac.uk

→ Highest sensitivity
From magnetic microscope to large scale

WP7: Rotation sensors
Tim Freegarde, Southampton
tim.freegarde@soton.ac.uk

→ 200 picoradian/s

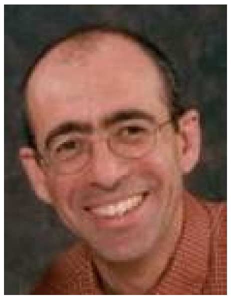
WP8: Clocks
Erling Riis, Strathclyde
e.riis@strath.ac.uk

→ 1 in 10^{13} in 1l volume
1 in 10^{16} in 10l volume

WP9: Quantum Imaging
Vincent Boyer, Birmingham
v.boyer@bham.ac.uk

→ Squeezed light source <20l

Market Building



WP10: Market Building

Costas Constantinou, Birmingham
C.Constantinou@bham.ac.uk
Martin Dawson, Fraunhofer UK
m.dawson@strath.ac.uk

UK network

Foster Dialogue

Knowledge Transfer

Demonstration activities

WP11: Gravity in Civil Eng.

Nicole Metje, Birmingham
n.metje@bham.ac.uk

Industry 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: semiconductor 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

Semicond.
Comp. Semi.
IQE

Exploration
ArkeX
BGS
BP
GeoDynamics
Halliburton
MicrogLacoste
Muquans
Reid Geophysics
Schlumberger

Healthcare
Elekta
NHS Trauma
Vertex

Transport
Network Rail
Texas Transp.Inst.
Transport for London

Laser
Coherent
Coldquanta
ELUXI
Gooch & Housego
HighFinesse
Sacher

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

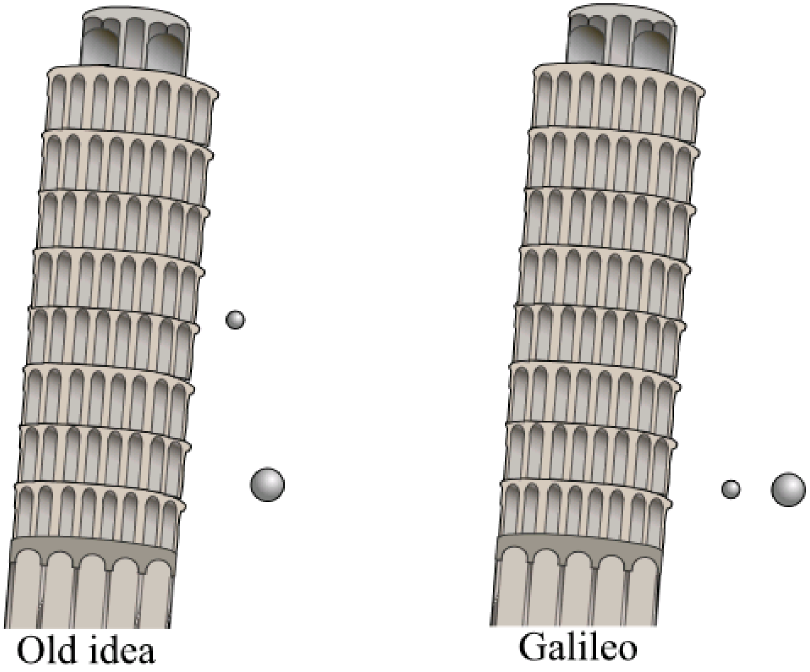
Other
Chemring
ESA
IBM
KTN
MTC
Oxford Instruments
Plextek
Procter & Gamble
Quantum Wave Fund
Qrometric
Rolls Royce
Royal Institute of Nav.
Samsung
Texas Instruments
TSB-KTP
Versysns Ventures
Witted

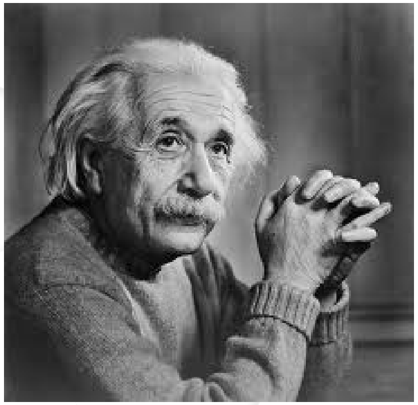
Space Opportunities?

- **“First user” in technology translation**
- **Fundamental Science**
- **Master Clocks**
- **Earth Exploration**
- **Potential of >4 missions at >£2bn total**

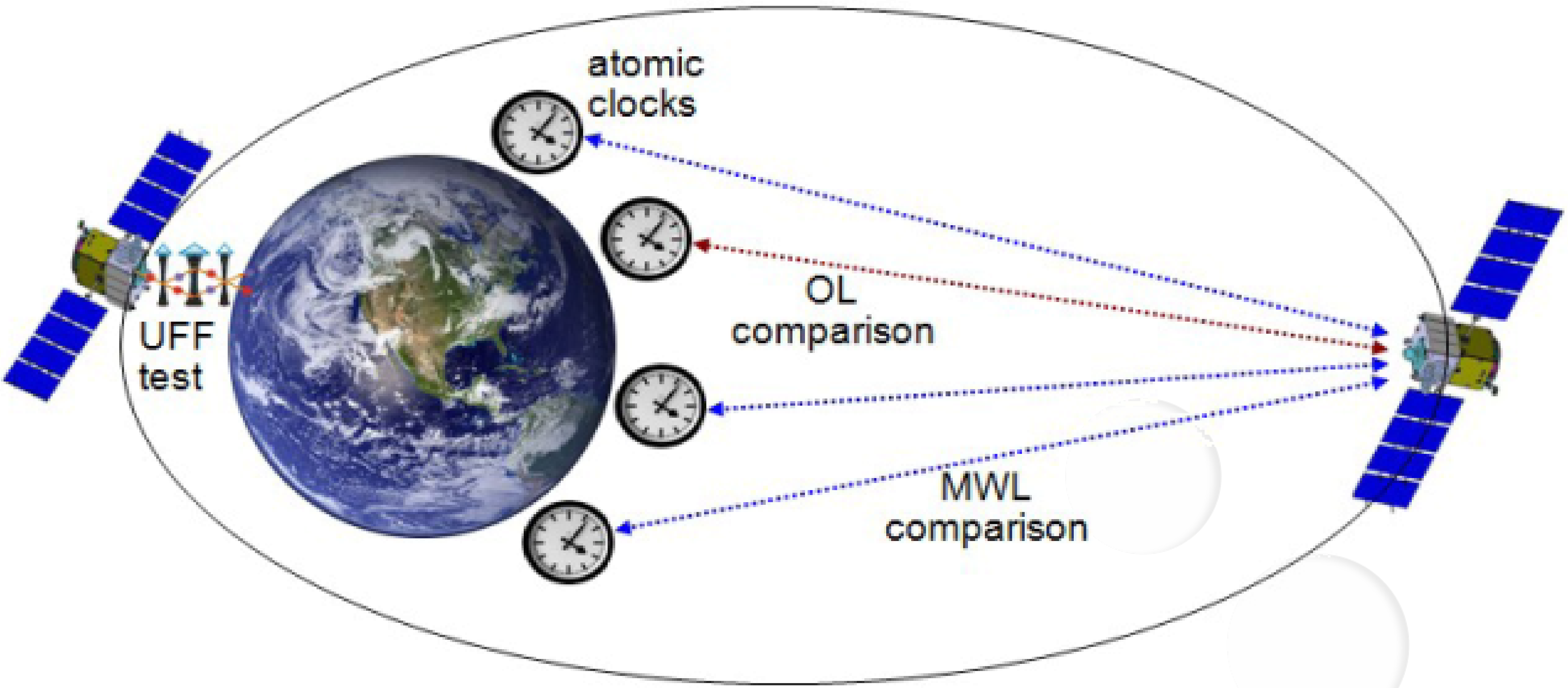
Einstein Equivalence Principle

Motivated by the incompatibility of General Relativity and Quantum Mechanics, a high priority experimental approach is to conduct an Equivalence Principle Test on objects in a single quantum state.





STE-QUEST



Clocks in Space

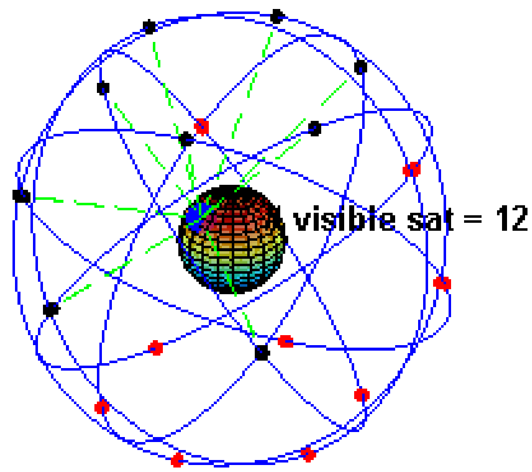
Time-evolution of
Fundamental constants

$$\alpha = e^2/4\pi\varepsilon_0\hbar c$$

Master Clock in Space

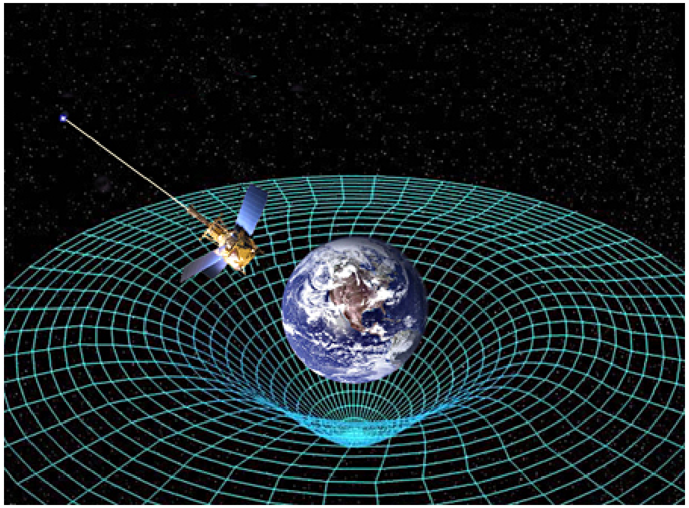
Timekeeping

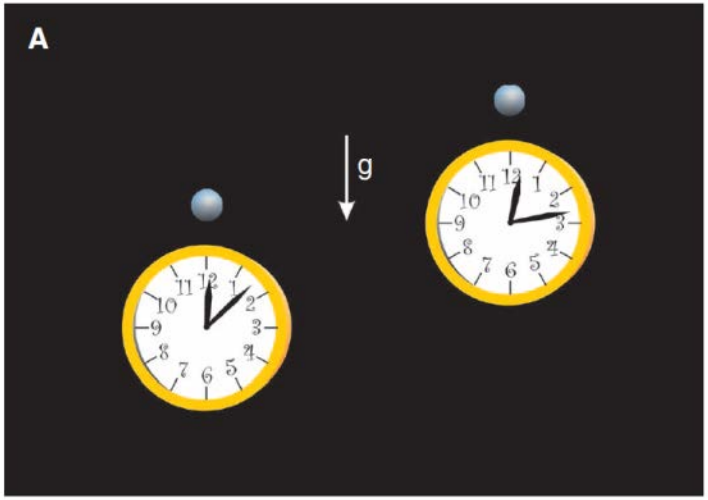
Satellite Navigation



Clocks in Space

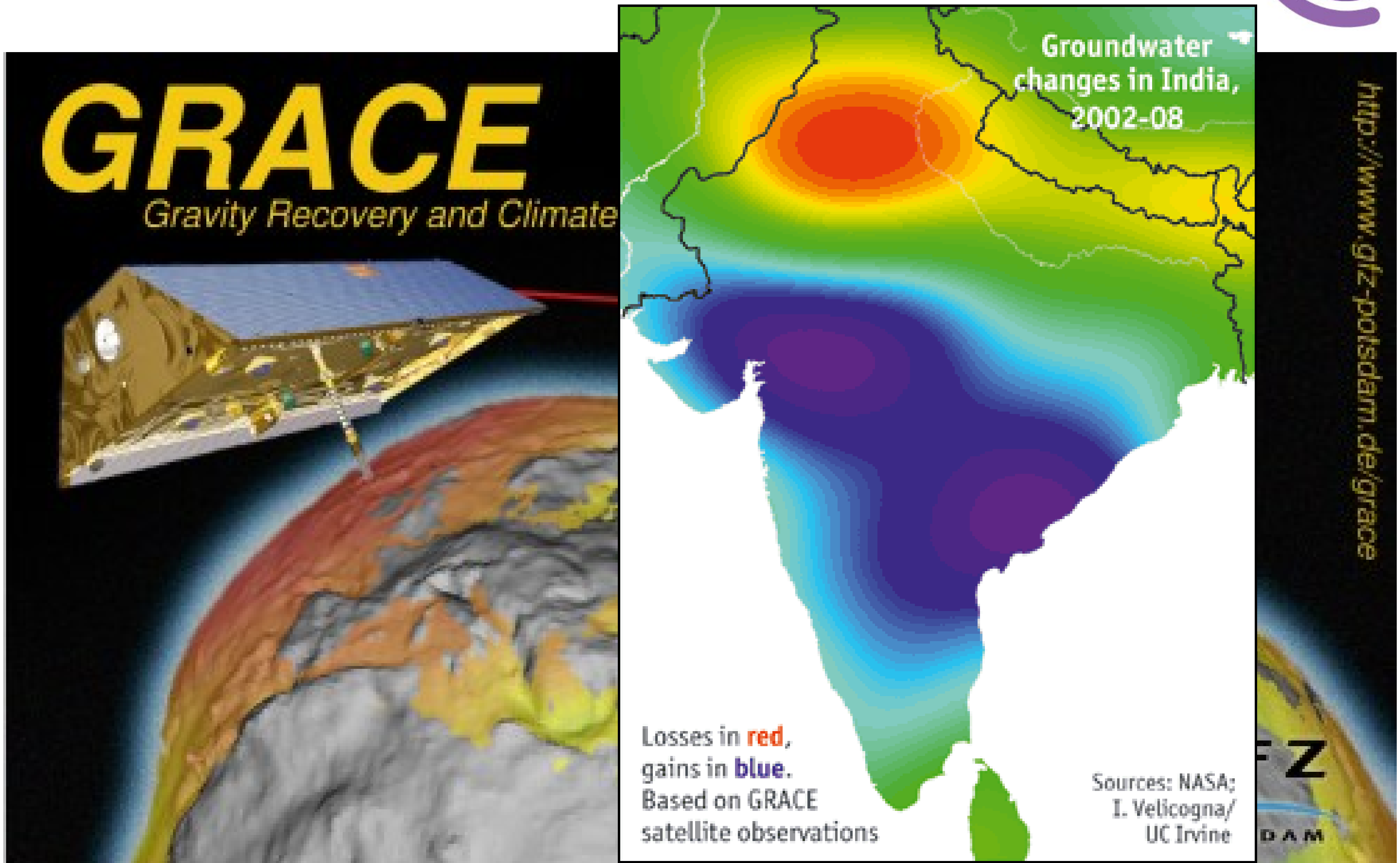
Relativistic Geodesy





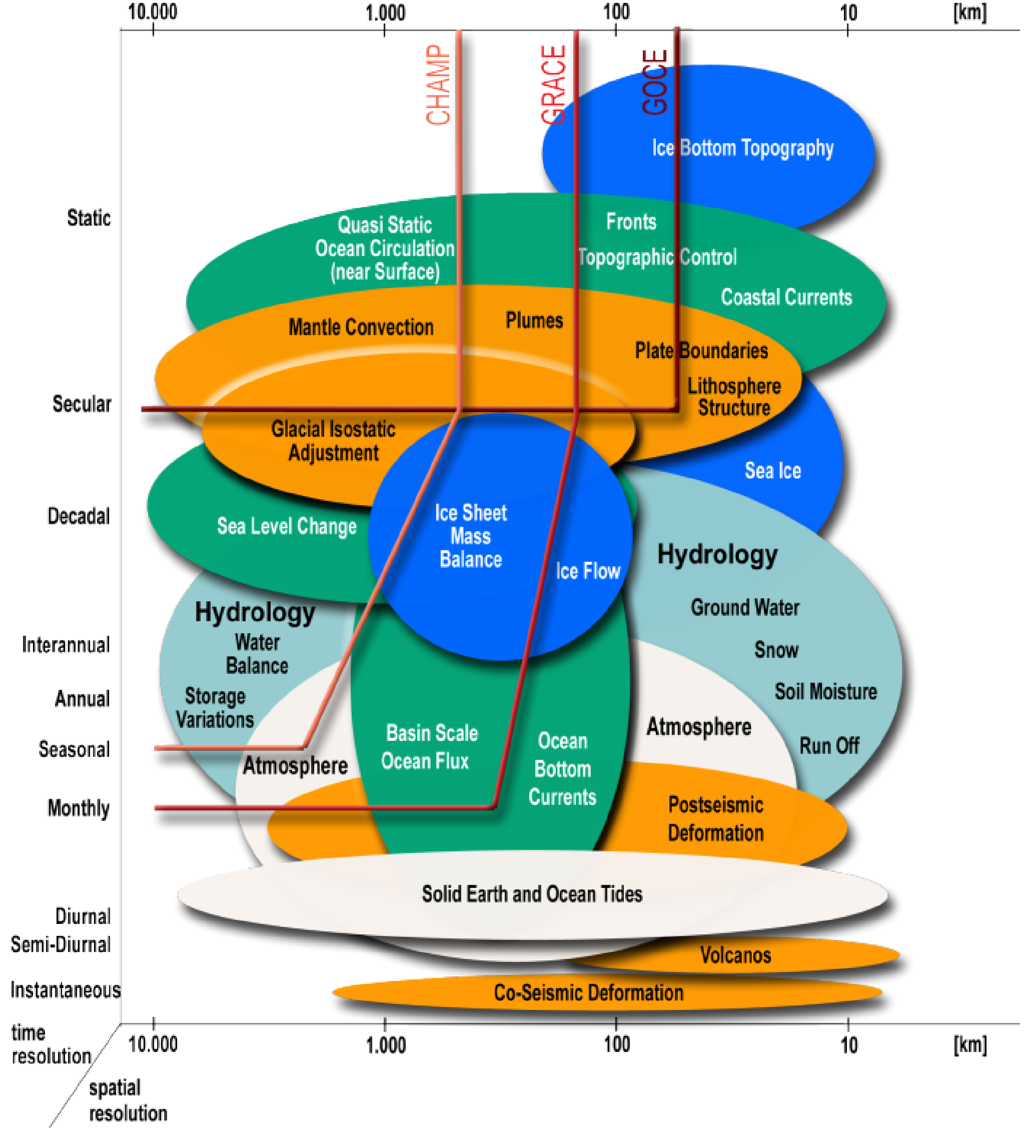
Science **329,** 1630 (2010);

Earth Observation



The Economist, Sep 10th 2009

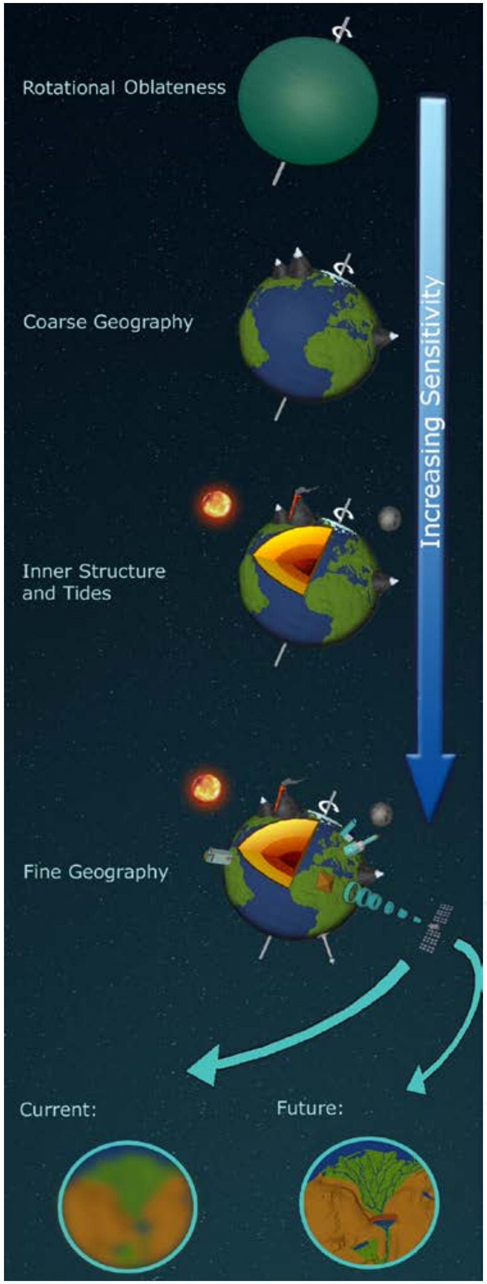
Earth Observation



Source: Applications and Implementations of Atom-Based Inertial Quantum Sensors, ESA contract n. 21583/08/NL/HE, Subcontract n. C08-023 AO/1-5421/07/NL/HE, St14.April 2009

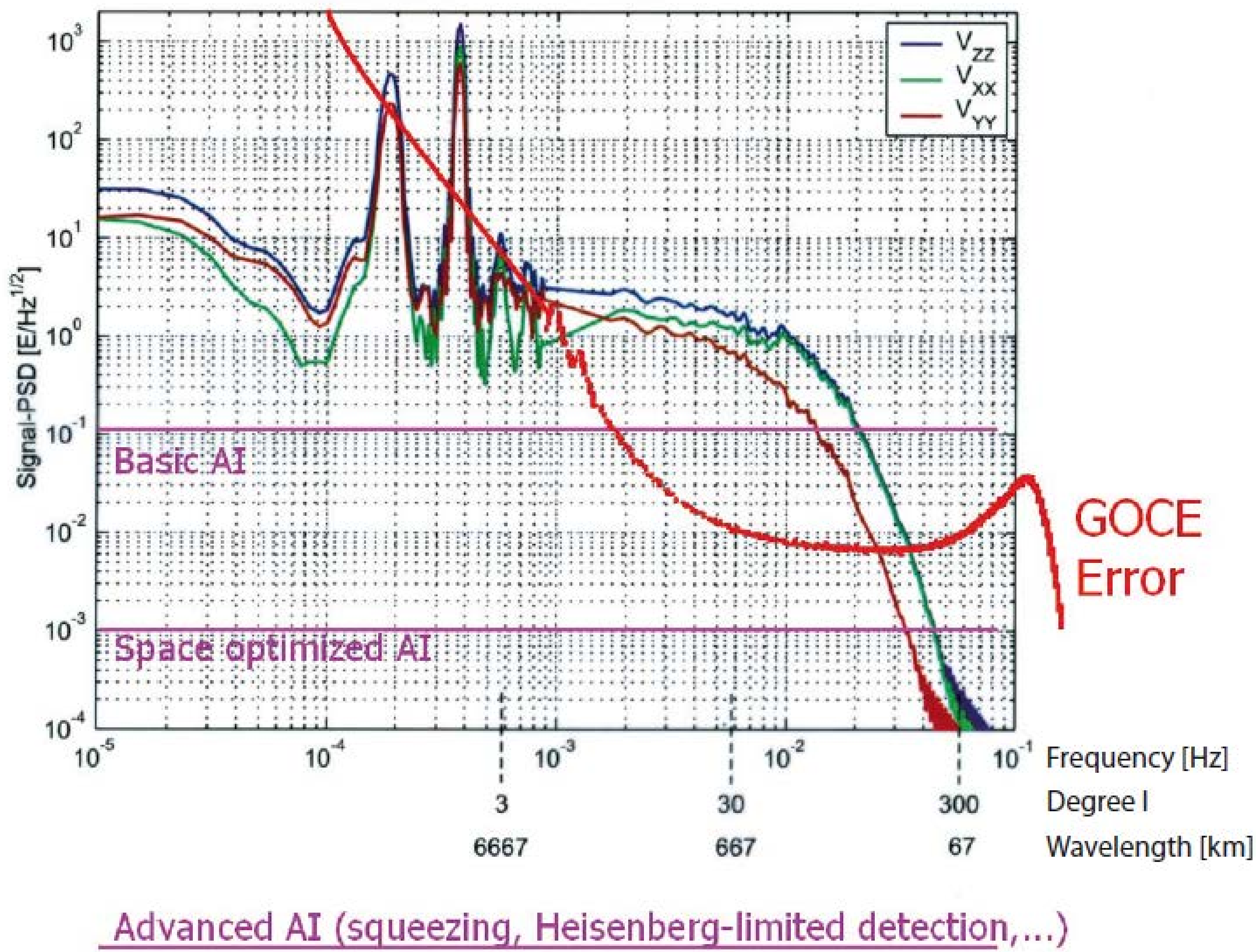
Earth Observation

- GRACE and GOCE have proven that gravity can provide unique data to help to assess global climate and water challenges
- There is a risk of loosing this data after GRACE goes out of service in the early 2020s.
- QT Gravity promises finer resolution – local information – for future missions



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

Potential of Atom Interferometers



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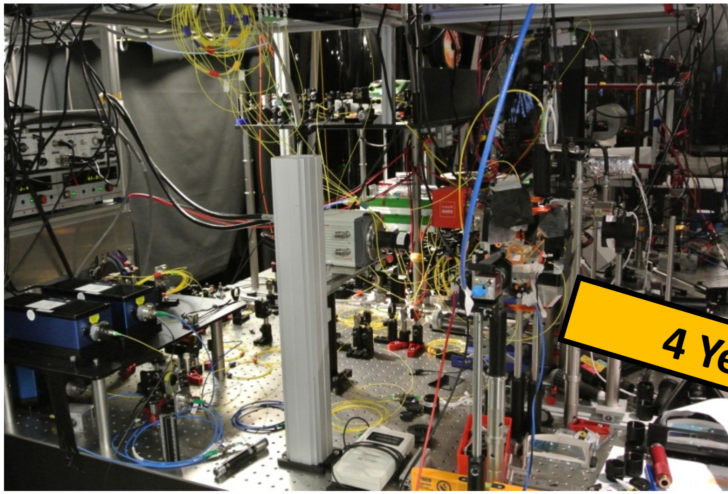
Source: Applications and Implementations of Atom-Based Inertial Quantum Sensors, ESA contract n. 21583/08/NL/HE, Subcontract n. C08-023 AO/1-5421/07/NL/HE, St14.April 2009

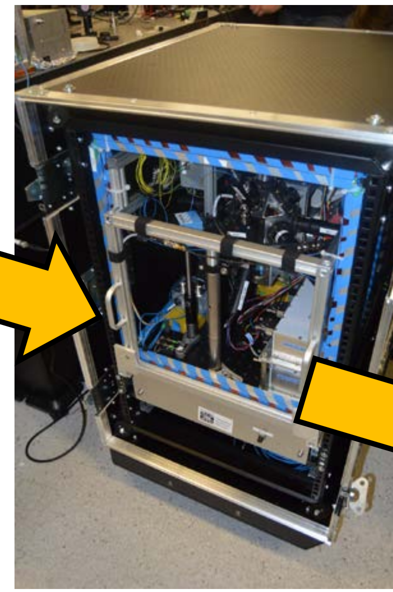
The challenge

THE PAST



~2000L, 100s kg, 1-2kW

NOW



~120L, 50kg, 240W

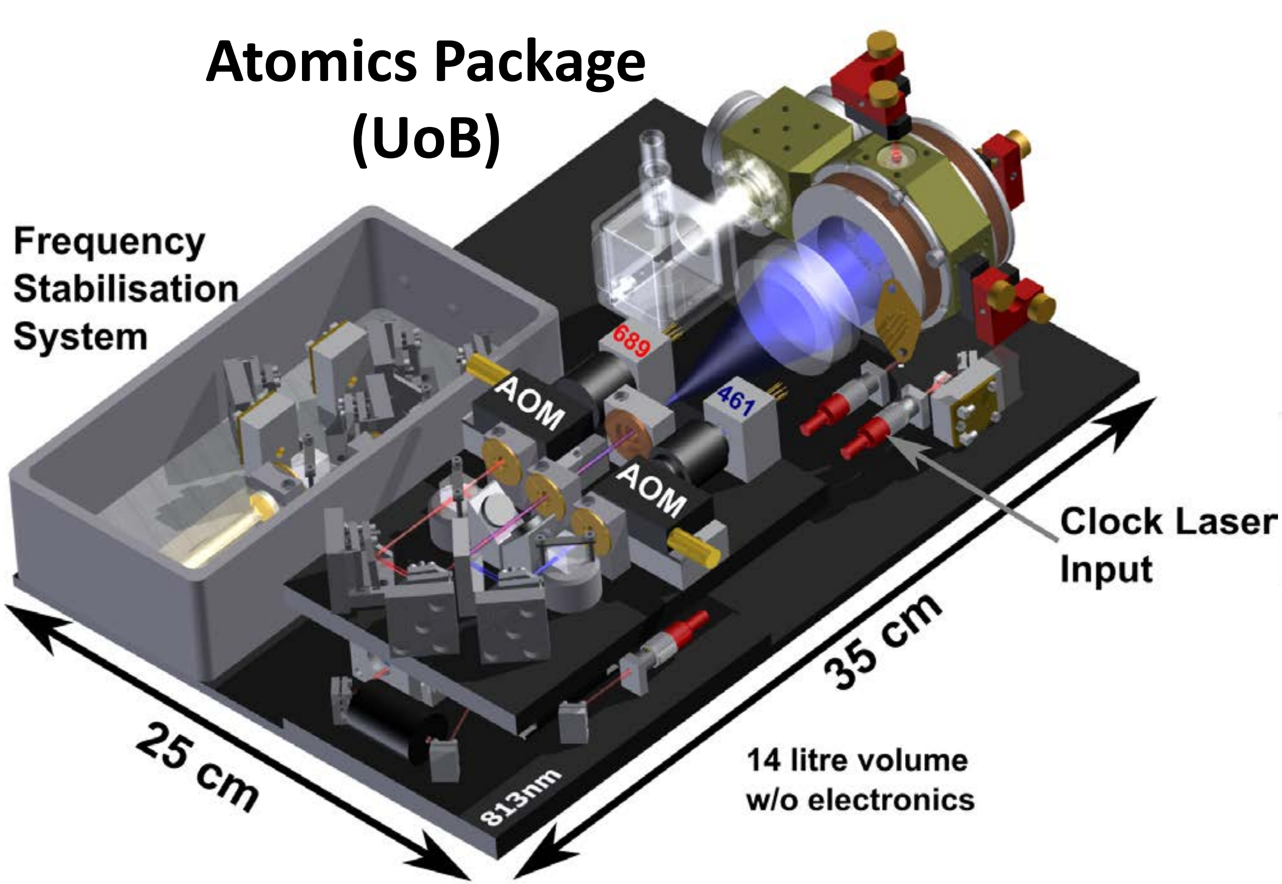
TARGET

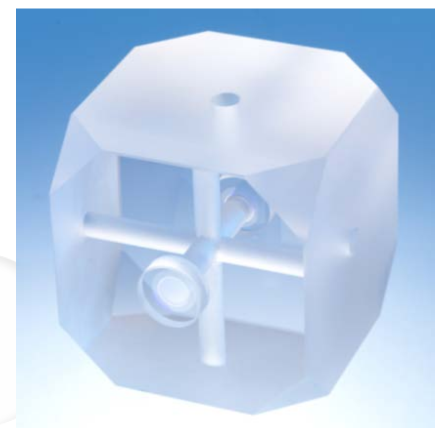
~2L, ~10kg, ~80W
(Per sensor head)

In this contract we will:

- Achieve significant further miniaturisation
- Without loss of performance, and with increased robustness

WP8 Example:
Miniature Optical Lattice Clock





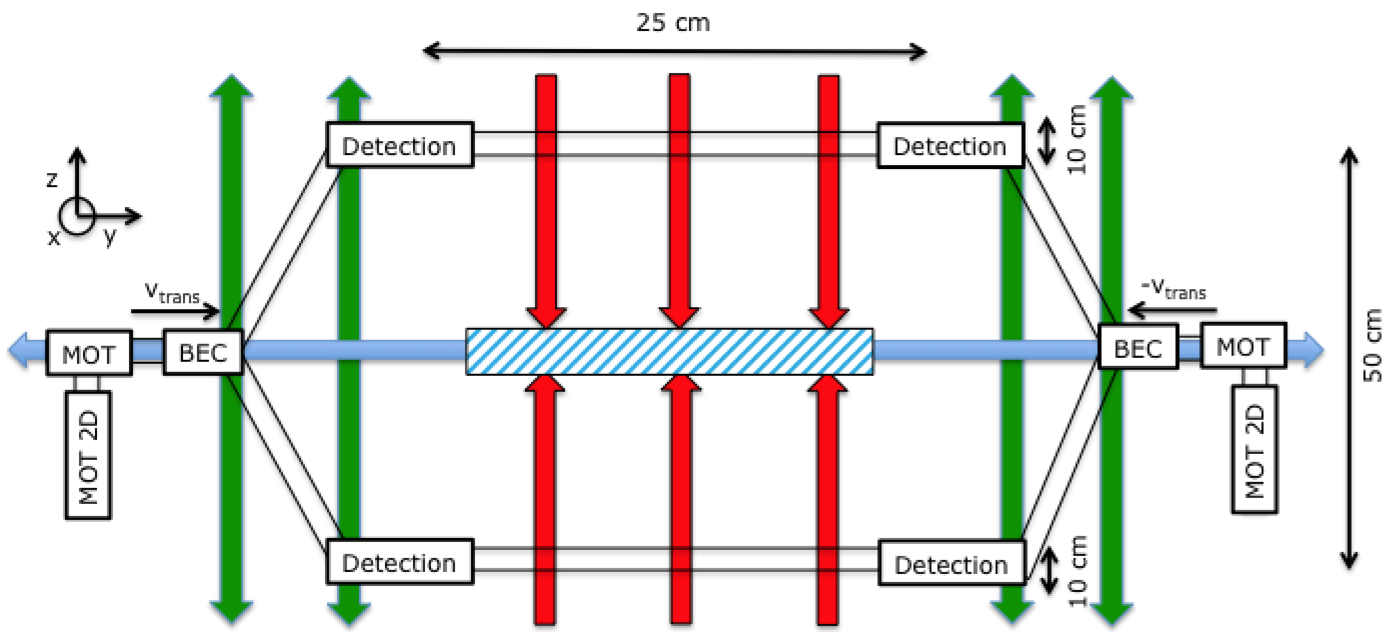
Clock Laser (NPL)

SA Webster and Gill, *Force-insensitive optical cavity*, Opt. Letters **36** (2011)

ESA NGGM Project

4000112182/14/NL/RA

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

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Collaboration

- **We are open to collaboration**
- **Let us know what suits you**
- **Contact**
  Jo Smart (j.c.smart@bham.ac.uk)