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Quantum Technology Hub
Sensors and Timing

Quantum Technology for a Future Gravity Mission

Kai Bongs

NCEO-CEOI e-conference

24.06.2020

University of Birmingham · University of Glasgow · Imperial College London · University of Nottingham UK | CHINA | MALAYSIA · University of Southampton · University of Strathclyde · University of Sussex

British Geological Survey Expert | Impartial | Innovative · NPL National Physical Laboratory · UK National Quantum Technologies Programme

Harnessing the Power of QT for Real-World Applications

>112 collaborative projects with industry

>73 companies invested money

>£100M project value
(in addition to initial £35.5M)

50 jobs in industry

>15 patent applications

>142 Records of invention

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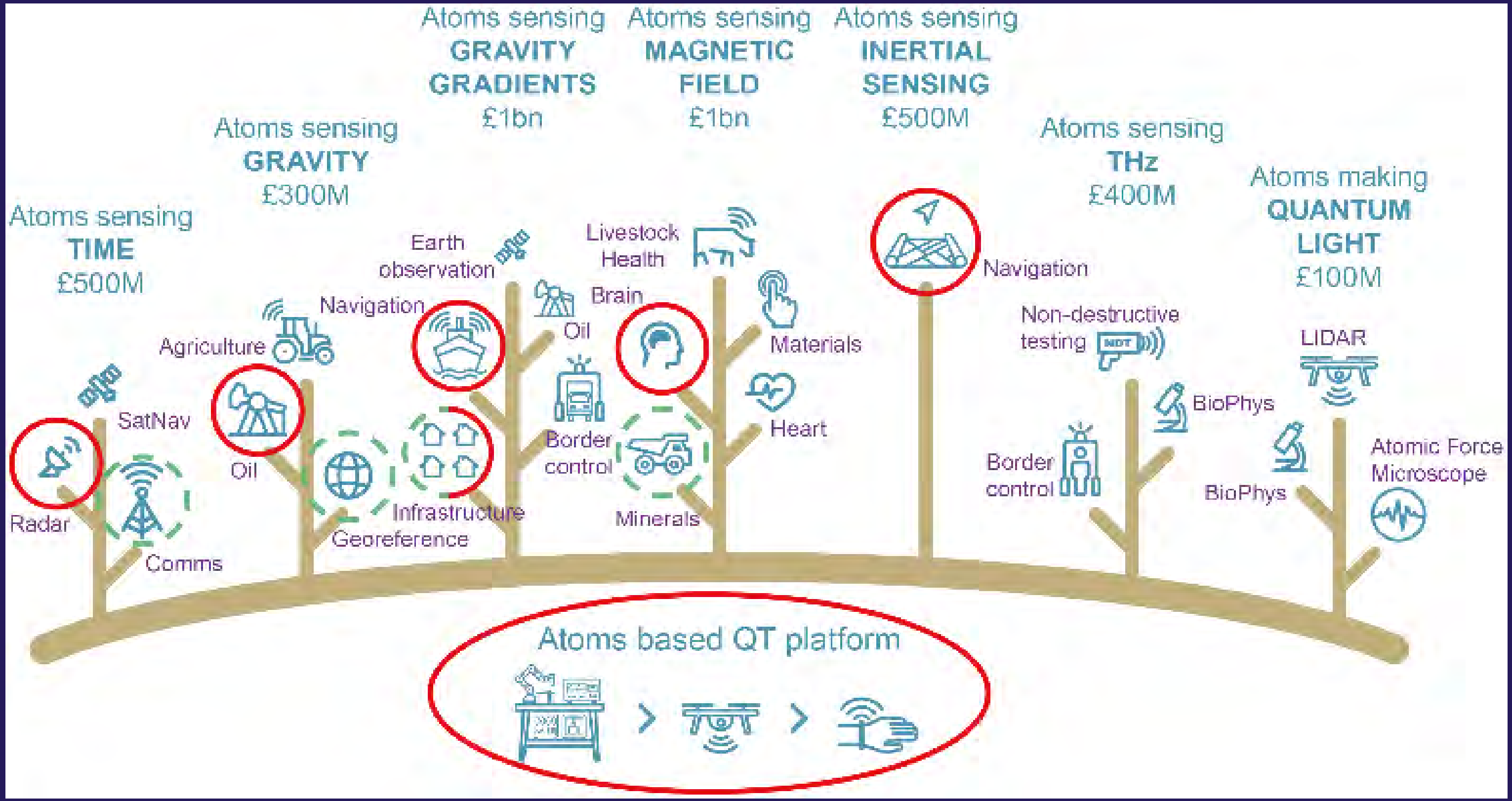
Harnessing the Power of QT for Real-World Applications



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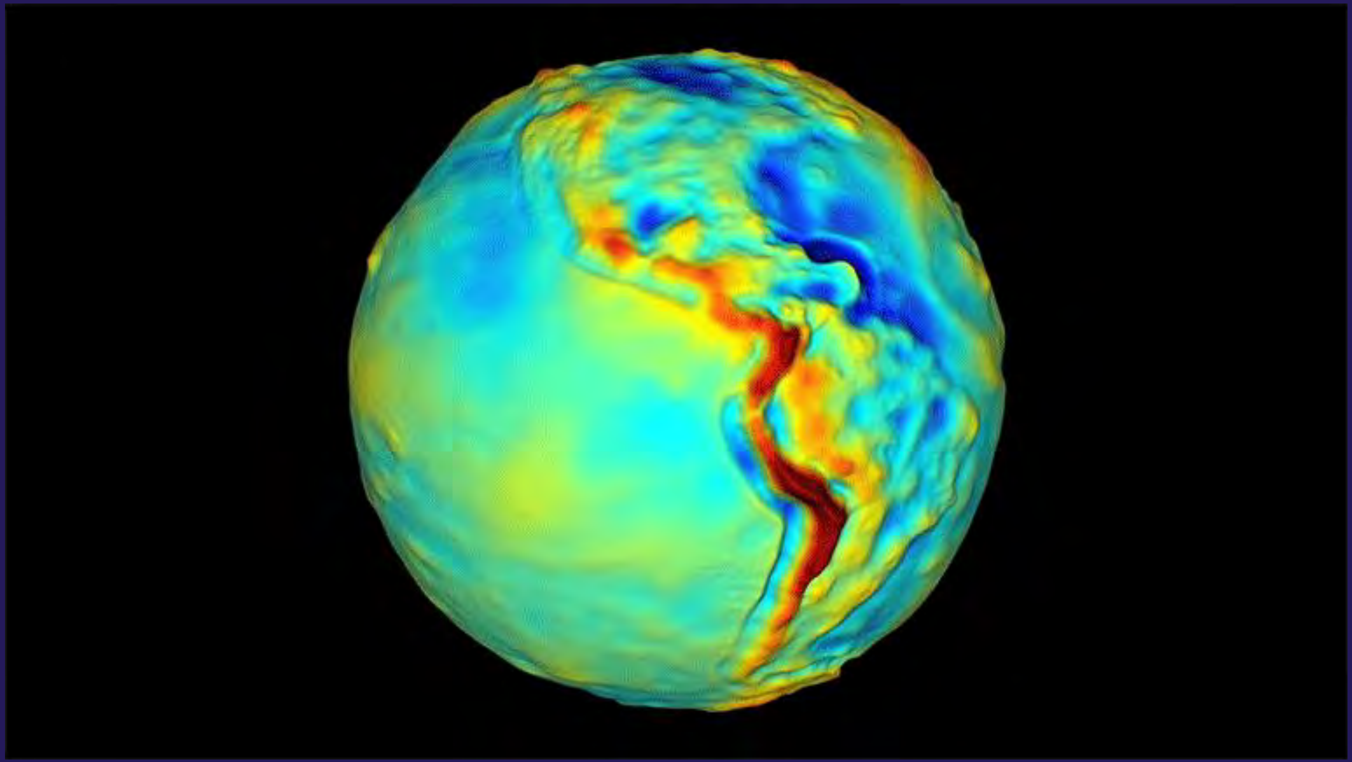
Quantum Sensors for Observing the Earth’s Gravity Field



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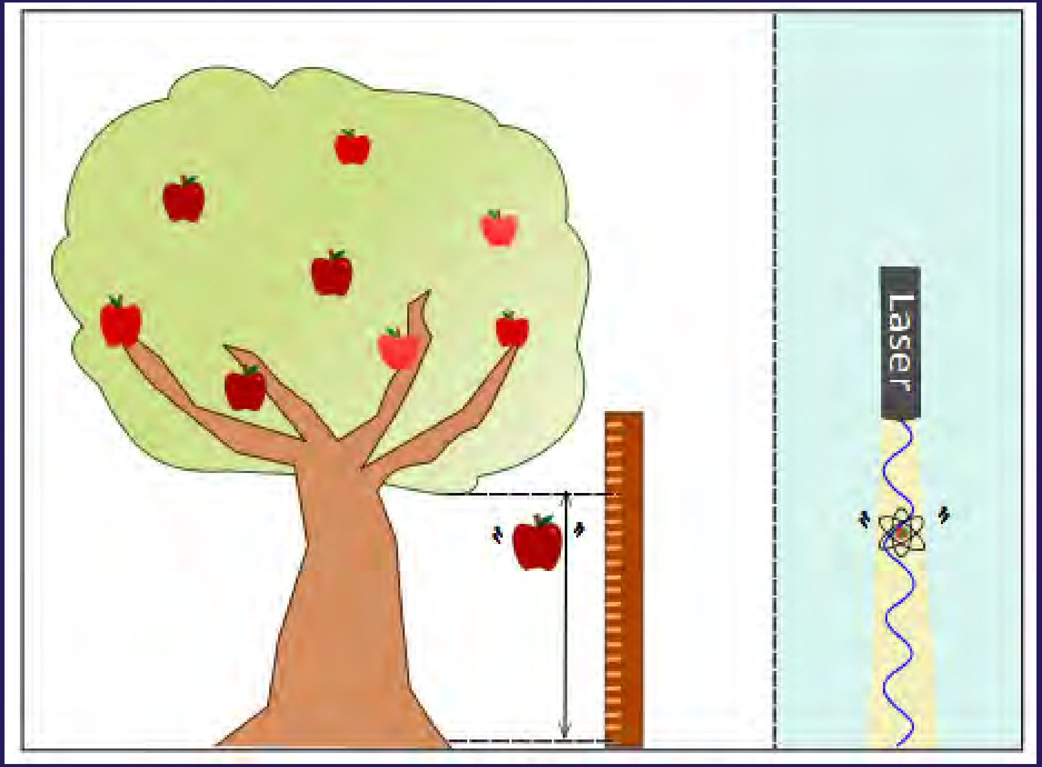
Operational Principle: Falling Atoms Measured by a Laser Ruler



Quantum Sensor Ingredients

The Nobel Prize in Physics 1997

"for development of methods to cool and trap atoms with laser light"


S. Chu

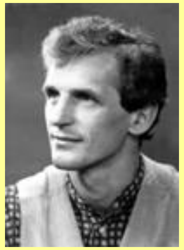

C. Cohen-Tannoudji


W.D. Phillips

The Nobel Prize in Physics 2001

"for the achievement of Bose-Einstein condensation in dilute gases of alkali atoms"


E. A. Cornell


W. Ketterle

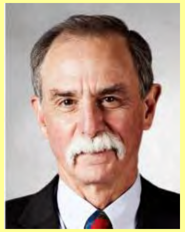

C. E. Wieman

Preparing probe particles

The Nobel Prize in Physics 2012

"for ground-breaking experimental methods that enable measuring and manipulation of individual quantum systems."


S. Haroche


D. J. Wineland

Manipulating probe particles

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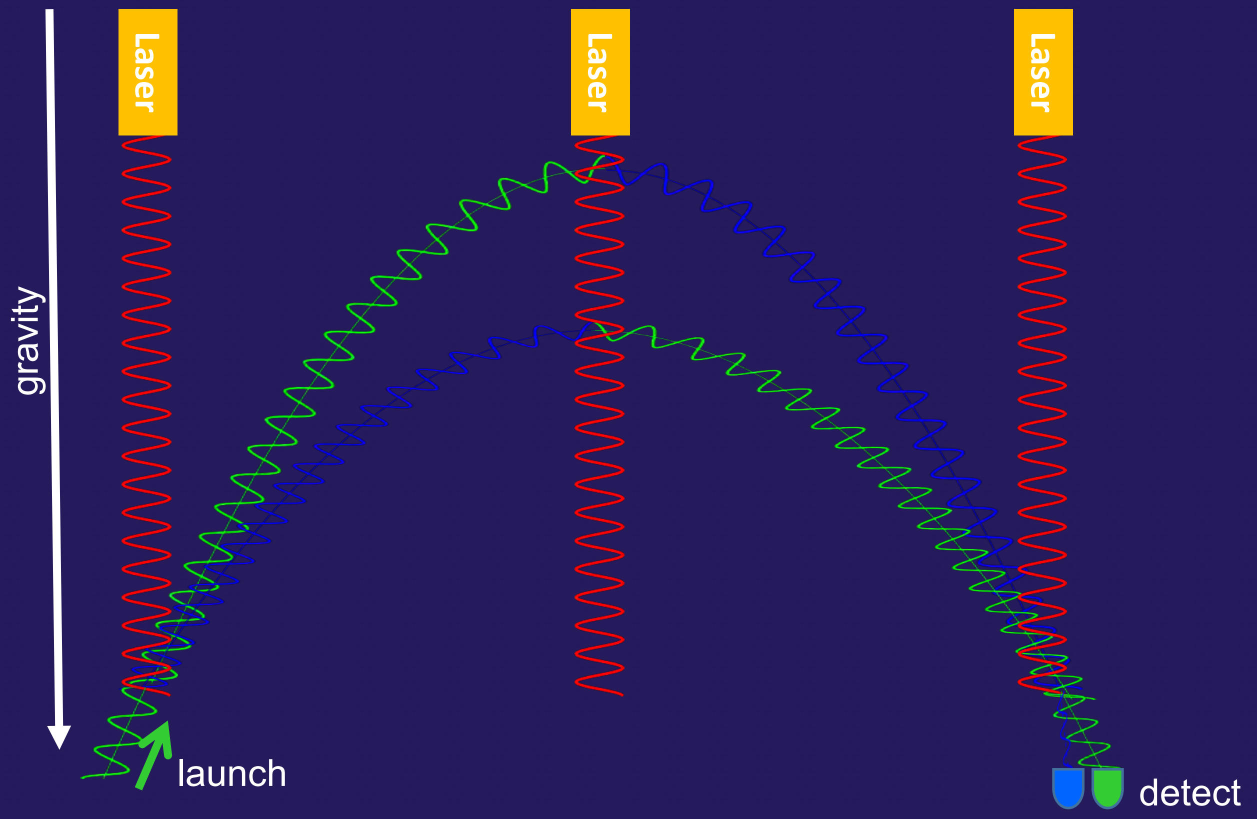
Quantum Sensor Ingredients: Atom Interferometer



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The Physics

$$\Delta\phi = \boxed{k_z T^2 g_z = \pi \frac{\Delta z}{\lambda}}$$

➔ Dropping object next to laser ruler

Advantages over classical instruments:

- Ideal test mass (no fabrication tolerances or ageing)
- Measurement versus frequency (“absolute”)
- Large potential for sensitivity increase
- Intrinsic differences possible (suppression of systematics)

Harnessing the Power of QT for Real-World Applications

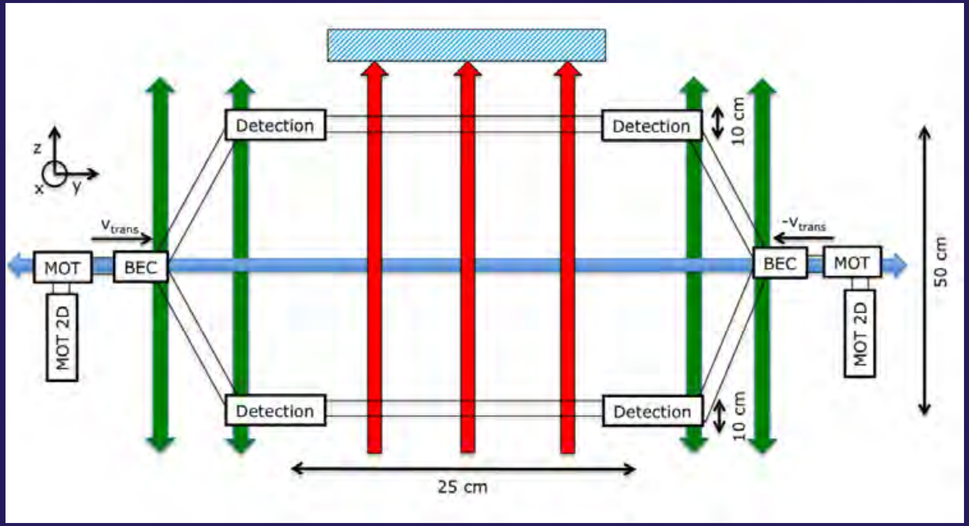
$$\Delta g = \frac{1}{kT^2\sqrt{N}}$$

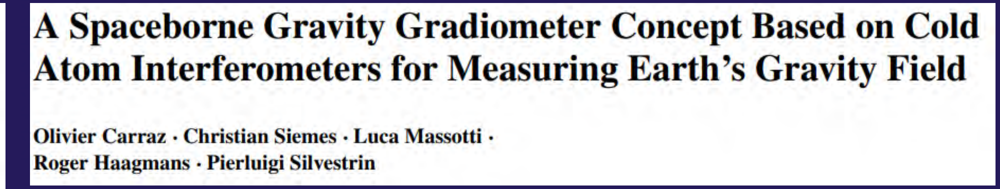
Large T → large sensitivity

T=100ms N=10^6	T=1s N=10^6	T=10s N=10^6	T=1s N=10^6 100 pulses	T=1s N=10^8 1000 pulses
6 10^{-9} m/s^2	6 10^{-11} m/s^2	6 10^{-13} m/s^2	6 10^{-13} m/s^2	3 10^{-14} m/s^2

GRACE reference:
ONERA Superstar Accelerometer: 10^{-10} m/s^2

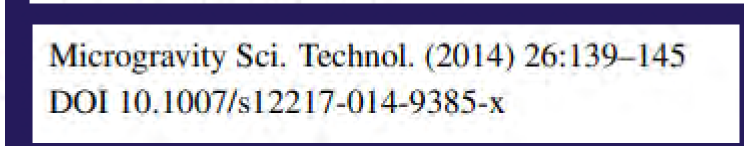
Cold Atom Space Gravity Gradiometer Concept





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



Microgravity Sci. Technol. (2014) 26:139–145
DOI 10.1007/s12217-014-9385-x

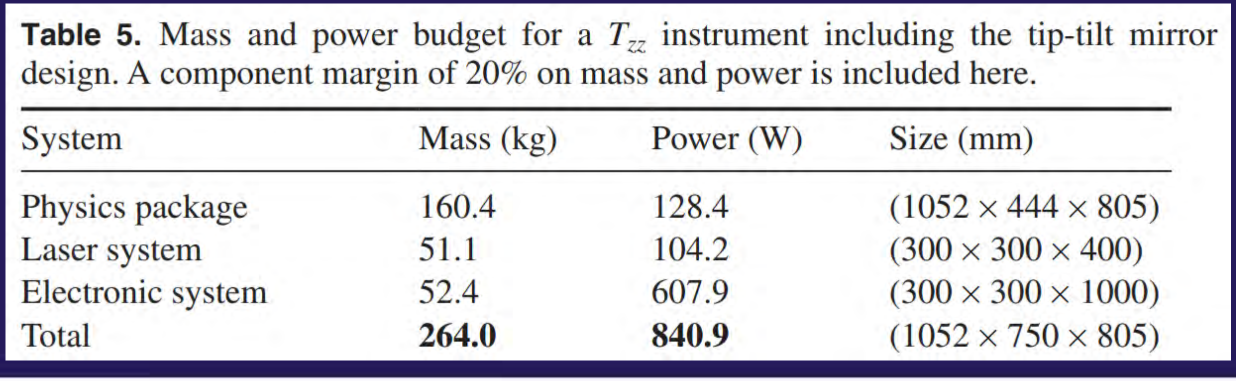


Table 5. Mass and power budget for a T_{zz} instrument including the tip-tilt mirror design. A component margin of 20% on mass and power is included here.

System	Mass (kg)	Power (W)	Size (mm)
Physics package	160.4	128.4	(1052 × 444 × 805)
Laser system	51.1	104.2	(300 × 300 × 400)
Electronic system	52.4	607.9	(300 × 300 × 1000)
Total	**264.0**	**840.9**	(1052 × 750 × 805)

Concept study and preliminary design of a cold atom interferometer for space gravity gradiometry

A Trimeche[1], B Battelier[2], D Becker[3],
A Bertoldi[2], P Bouyer[2], C Braxmaier[4,5], E Charron[6],
R Corgier[3,6], M Cornelius[4], K Douch[7,8], N Gaaloul[3],
S Herrmann[4], J Müller[7], E Rasel[3], C Schubert[3], H Wu[7]
and F Pereira dos Santos[1]

Class. Quantum Grav. **36** (2019) 215004 (40pp)

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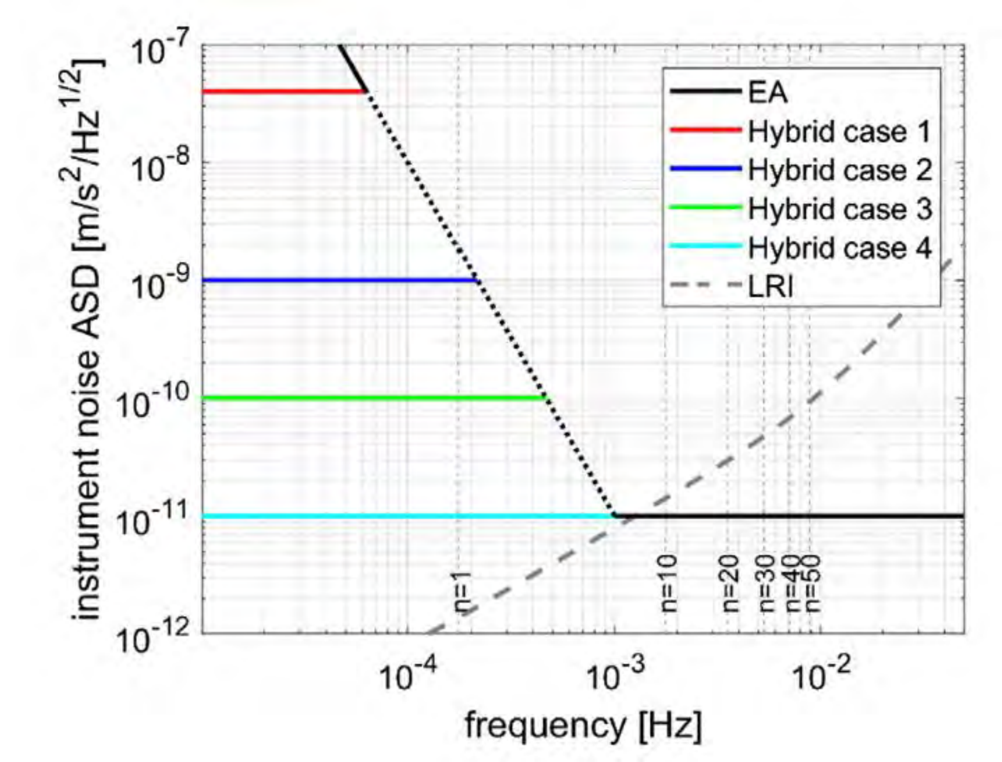
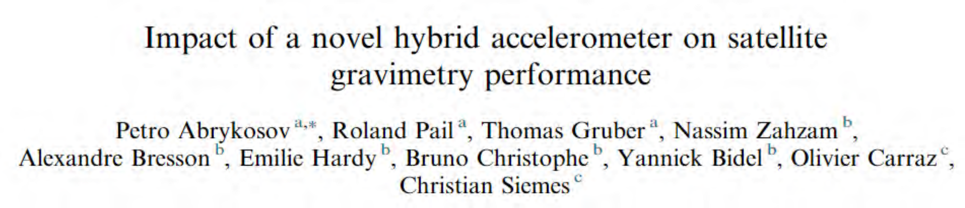
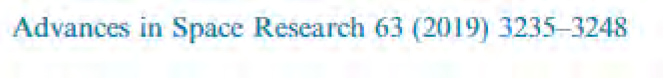
Hybrid EA-Cold Atom Space Concept





Impact of a novel hybrid accelerometer on satellite gravimetry performance

Petro Abrykosov[a,*], Roland Pail[a], Thomas Gruber[a], Nassim Zahzam[b], Alexandre Bresson[b], Emilie Hardy[b], Bruno Christophe[b], Yannick Bidel[b], Olivier Carraz[c], Christian Siemes[c]

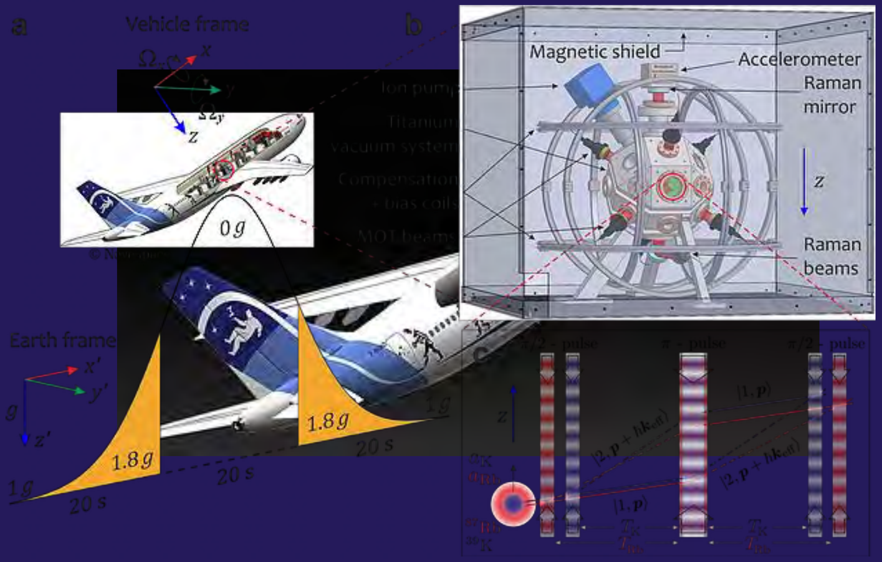


Advances in Space Research 63 (2019) 3235–3248

Cold Atoms in Space Heritage: ICE Experiment

ICE (first flight 2008)

- Dual matter-wave inertial sensor in microgravity environment generated by parabolic flight
- Simultaneous cold-atom interferometers of rubidium and potassium.
- Test of the weak equivalence principle



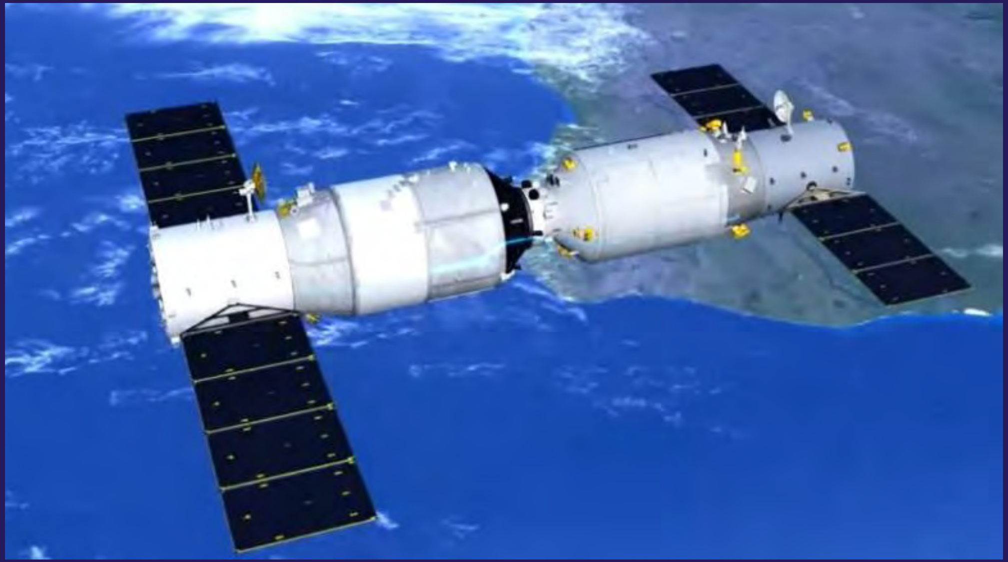
Cold Atoms in Space Heritage: CACES

- ***CACES** - Cold Atom Clock Experiment in Space (2017)*

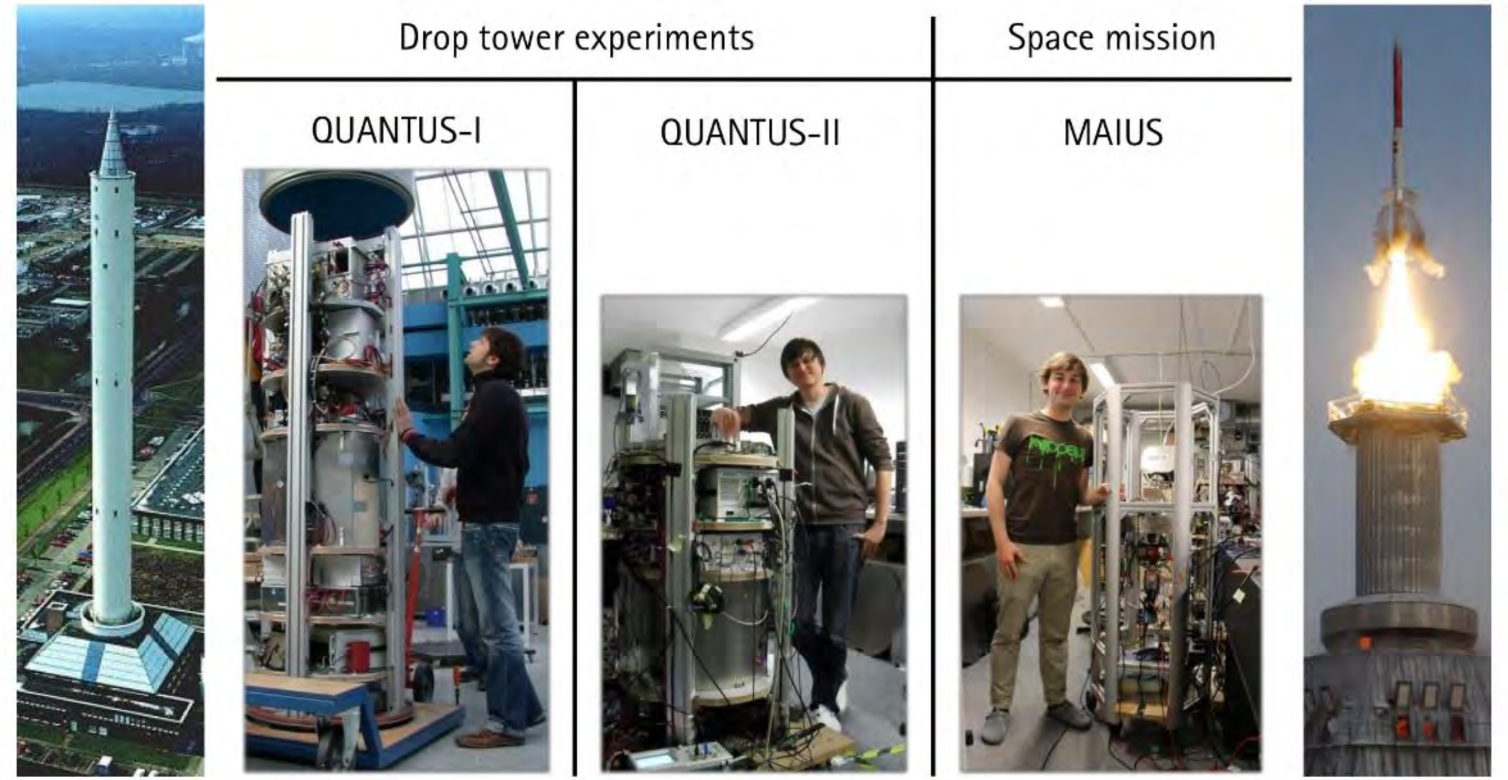
Rubidium based cold atoms clock on space laboratory Tiangong-2.

国家航天局
China National Space Administration

中国航天科技集团公司
China Aerospace Science and Technology Corporation

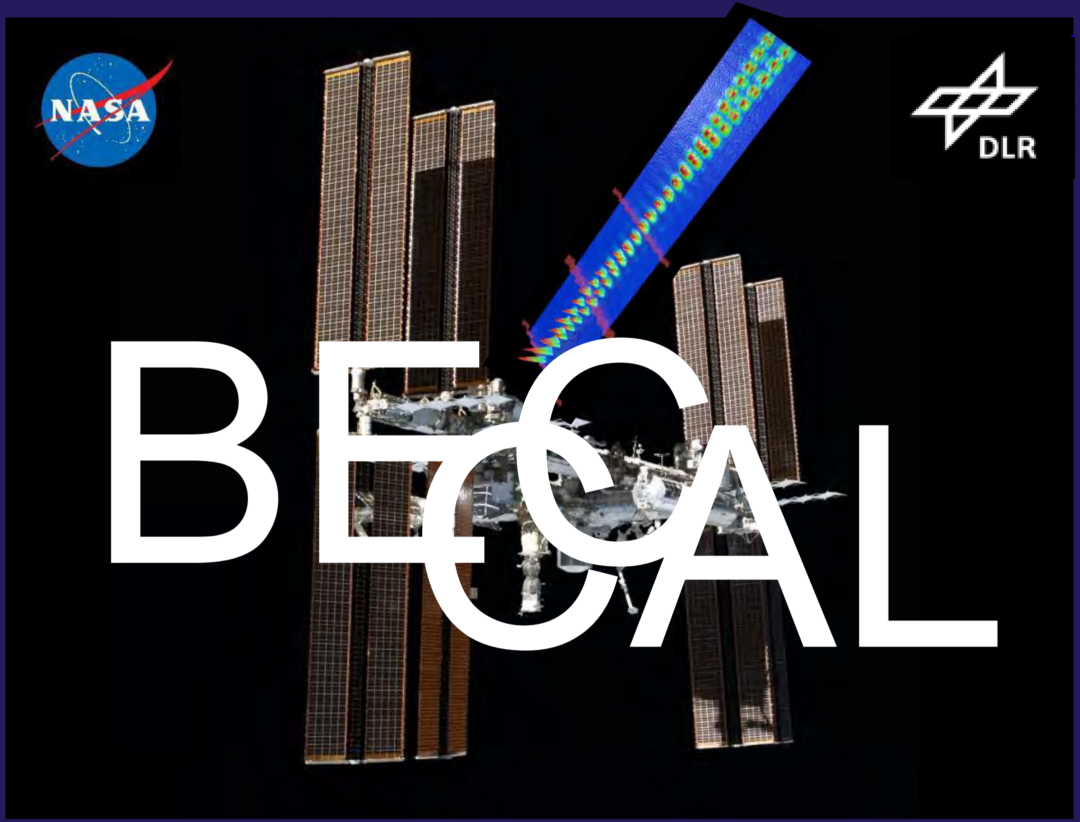


Cold Atoms in Space Heritage: QUANTUS



Images courtesy of Ernst Rasel

Cold Atoms in Space Heritage: BECCAL



Images courtesy of Ernst Rasel

What can Quantum Sensors Offer in Addition to Precision?

So far cold atom space sensor concepts have focused on the promise for ultimate precision

→ The instrument concepts are 100’s of kg and close to kW power
→ Mission costs are on the 100’s of €M scale

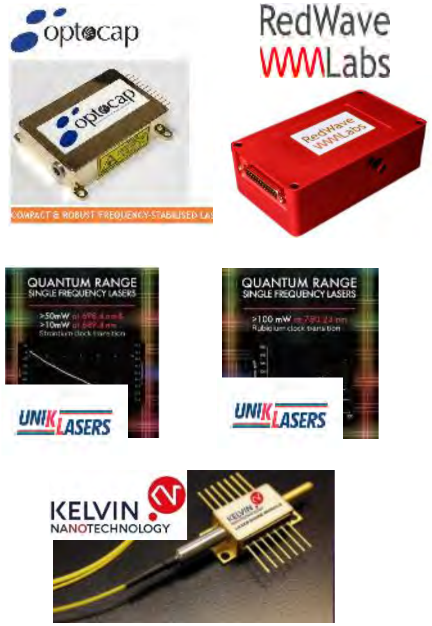
Quantum Technology developments aim at reducing SWAP-C, while just being “good enough”

→ Can sensors close to GOCE-sensitivity, but at 10% of the cost help?
→ How does “temporal” versus “spatial” resolution affect applications?

QT Hub Collaborations: Emerging Products

Alkali cells

Frequency doubler



Lasers for atom cooling and clocks

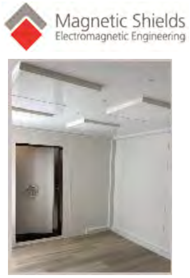
QT vacuum systems

Precision current drivers

Grating MOT chips

Sequencers

Compact MOT



Magnetically shielded room

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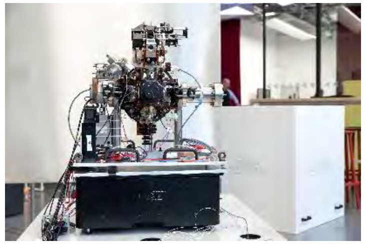
QT Hub Collaborations: Emerging Products

M SQUARED

Quantum Gravimeter

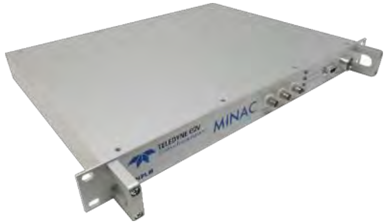
In collaboration with Birmingham



Quantum Accelerometer

In collaboration with Imperial College London

TELEDYNE IMAGING
Everywhereyoulook™



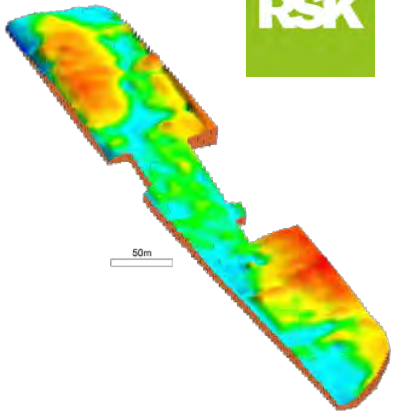
Quantum MW Clock

In collaboration with NPL

Quantum Gravity Gradiometer for Civil Engineering

In collaboration with Birmingham

RSK



Gravity Mapping Techniques and Data Interpretation

In collaboration with Birmingham

The QT Hub Journey: Reducing SWAP-C

Gravity Imager 1 (GI1)

Flying Cold Atoms

Gravity Imager 3

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UK QT Sensor Developments: 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

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

UK Research and Innovation

TELEDYNE e2V Everywhereyoulook

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UK QT Sensor Satellite Proposal – see Talk Tomorrow

Thursday 25th, 12:15
Future EO: Concept for a Cold Atom Gravity Explorer (CAGE) Mission
(Marton Kiss-Toth - Teledyne e2v and Mike Salter - STFC – RAL Space)

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