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UK Quantum Technology Hub Sensors and Timing

Quantum sensing for gravity cartography

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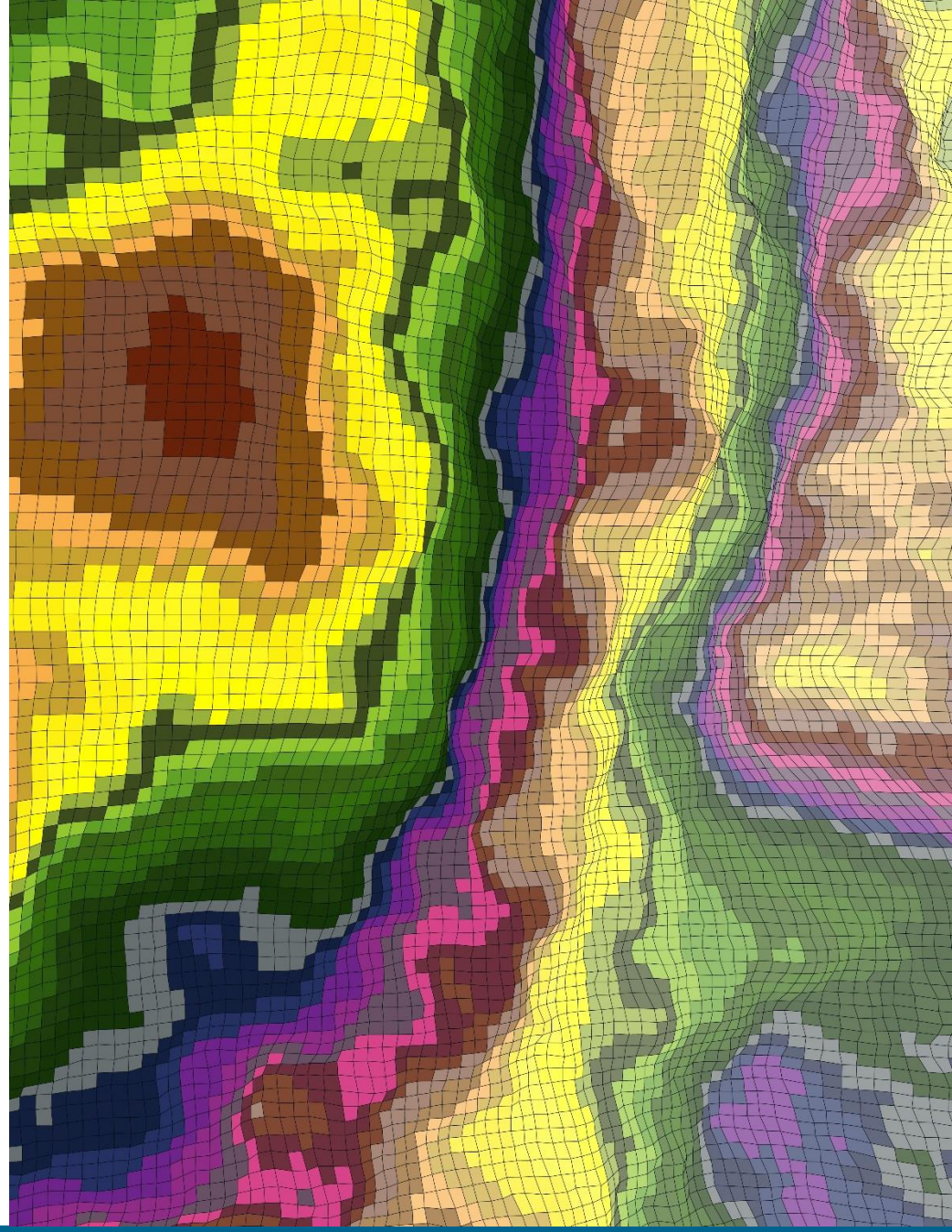
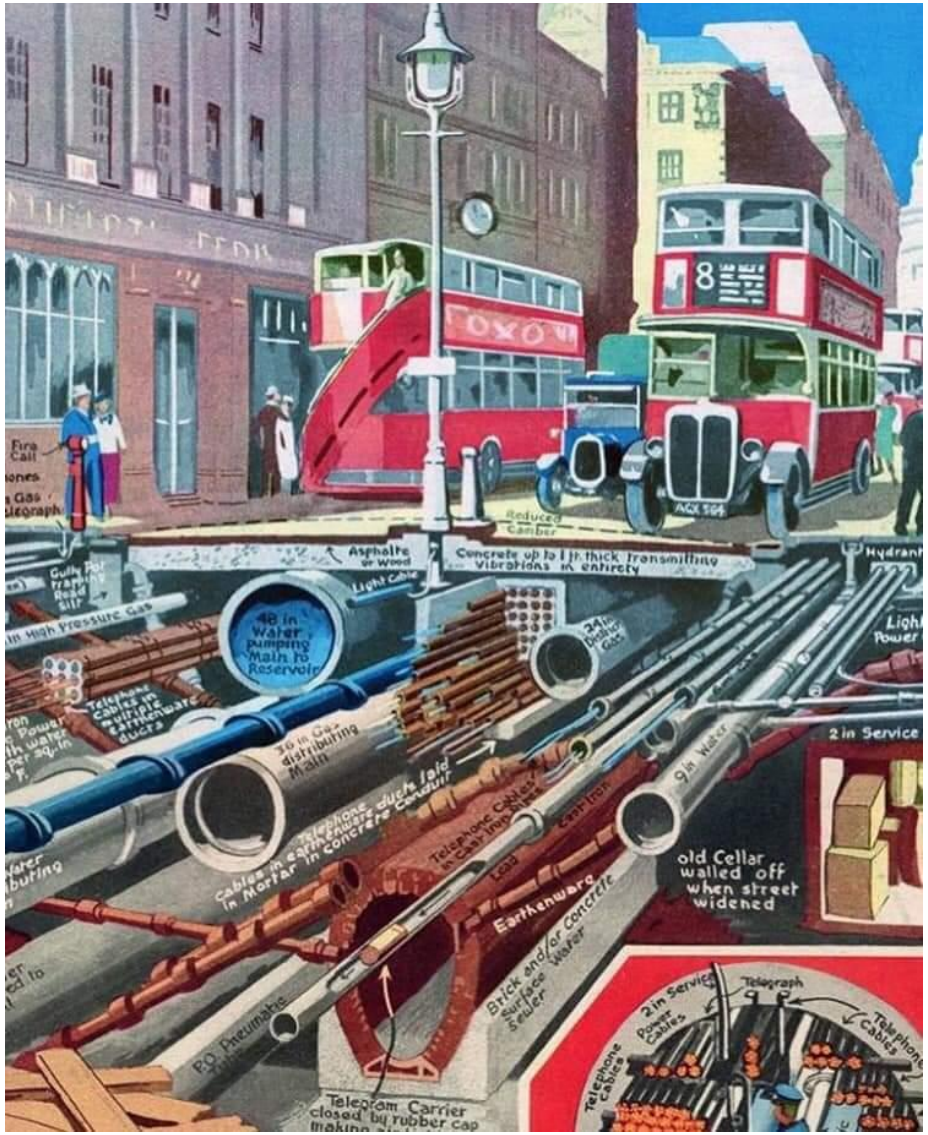


What's beneath your feet?

- We know surprisingly little about the underground infrastructure.
- Detection of underground infrastructure and hazards, most tech limited to top ~2 m.
- Can improve interventions and maintenance, reducing cost and impact on productivity.

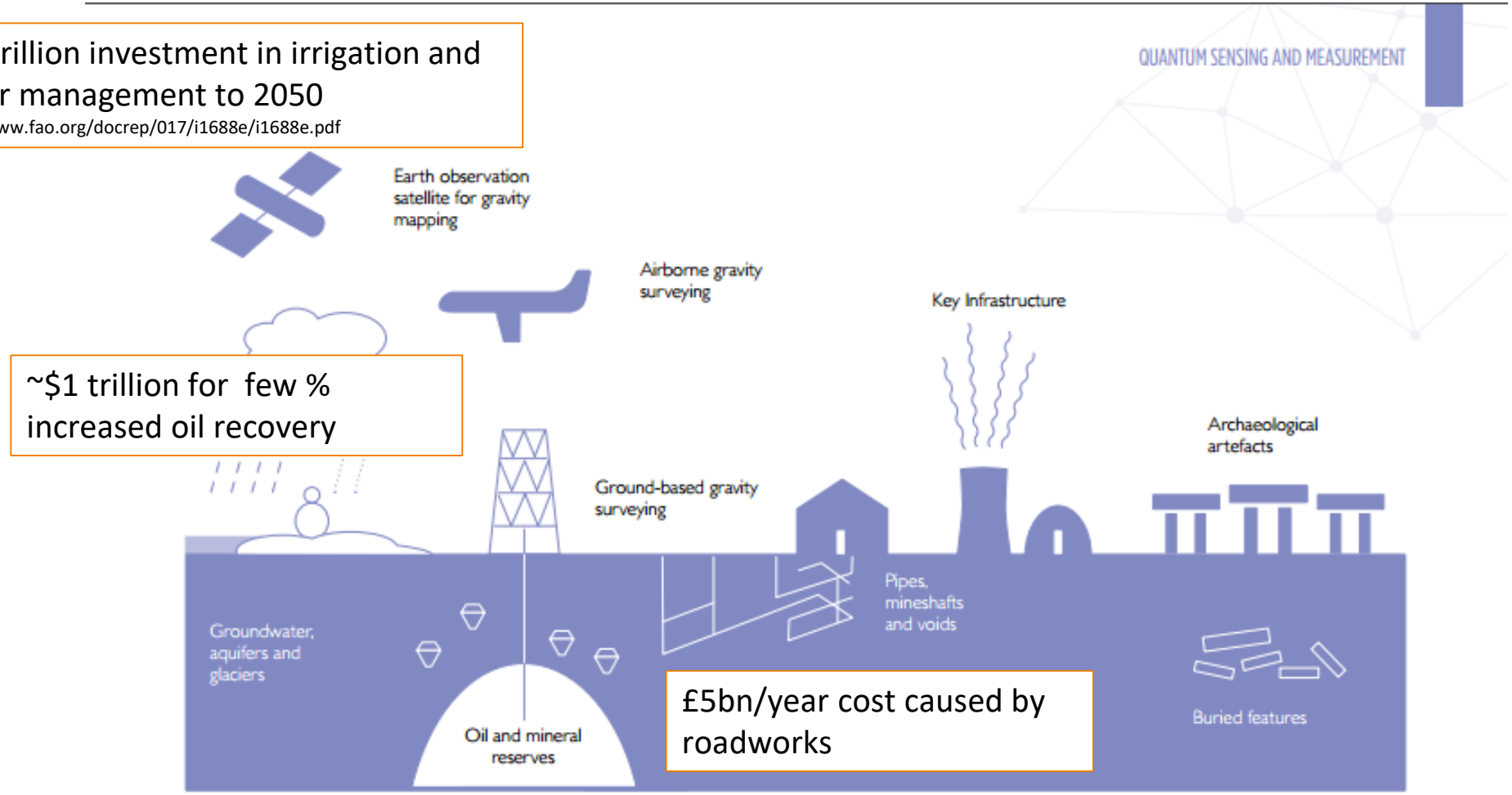


What's beneath your feet?

- Gravity exists between any two masses – potential for deeper detection of targets.
- Gravity is not attenuated - deeper pipes such as water, or leak-voids (sinkholes).
- Vibration can make gravity surveying impractical.

What can gravity be used for?

>$1 trillion investment in irrigation and water management to 2050
http://www.fao.org/docrep/017/i1688e/i1688e.pdf



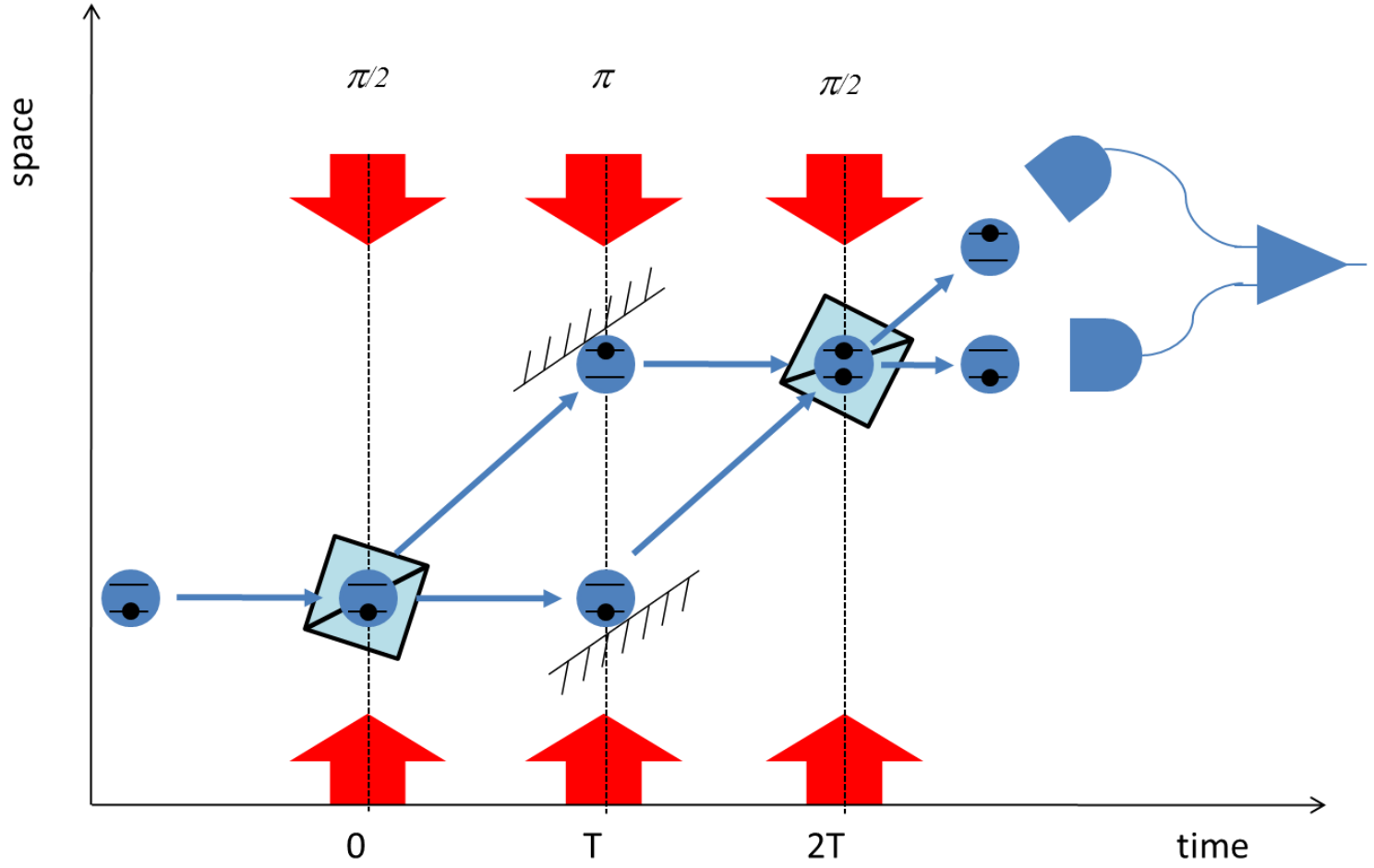
~$1 trillion for few % increased oil recovery

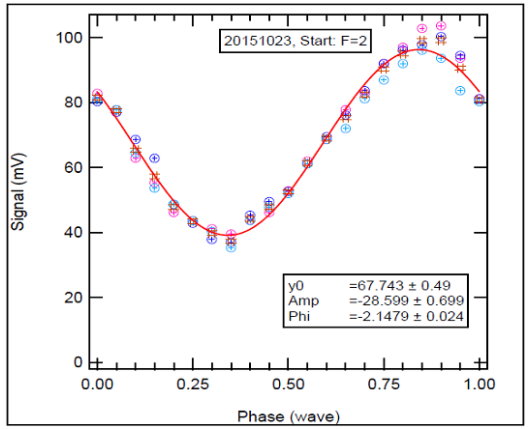
£5bn/year cost caused by roadworks

Image, Quantum Blackett Report: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/564946/gs-16-18-quantum-technologies-report.pdf

Quantum sensing of gravity

- Atom interferometry – interchange roles of light and matter.





Atom interferometry fringes at UoB, 2015

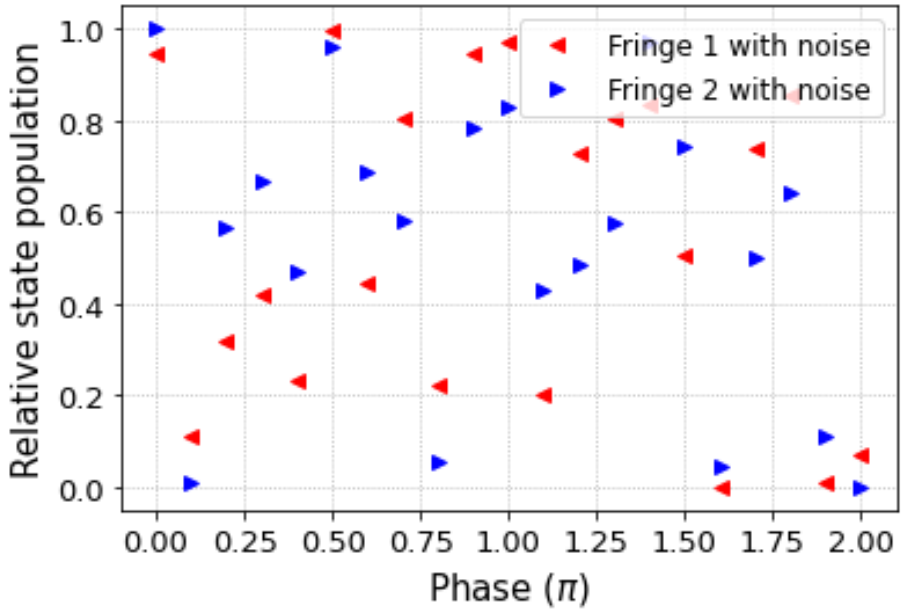
Phase difference:

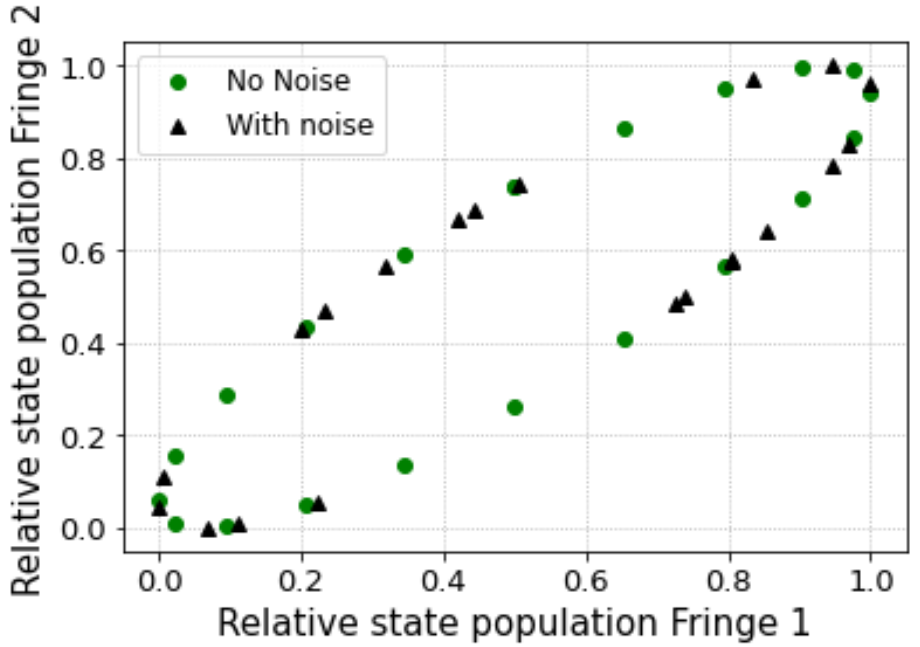
$$\emptyset_{\boldsymbol{g}} = k_{\mathrm{eff}} g T^2$$

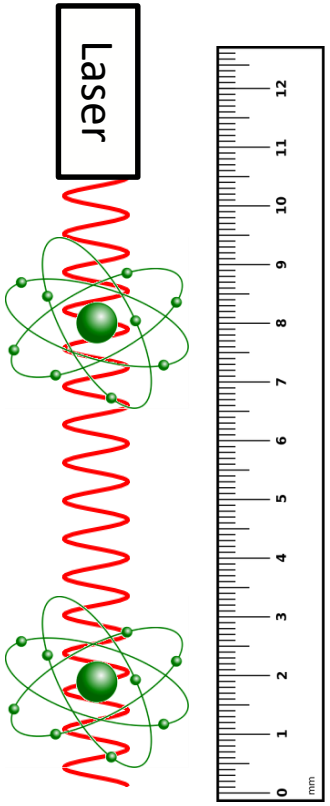
Review: Bongs, K. *et al.* Taking atom interferometric quantum sensors from the laboratory to real-world applications. *Nat Rev Phys* **1,** 731–739 (2019)

Quantum sensing of gravity gradients

- Simultaneously measure on two clouds with a common ‘laser ruler’.

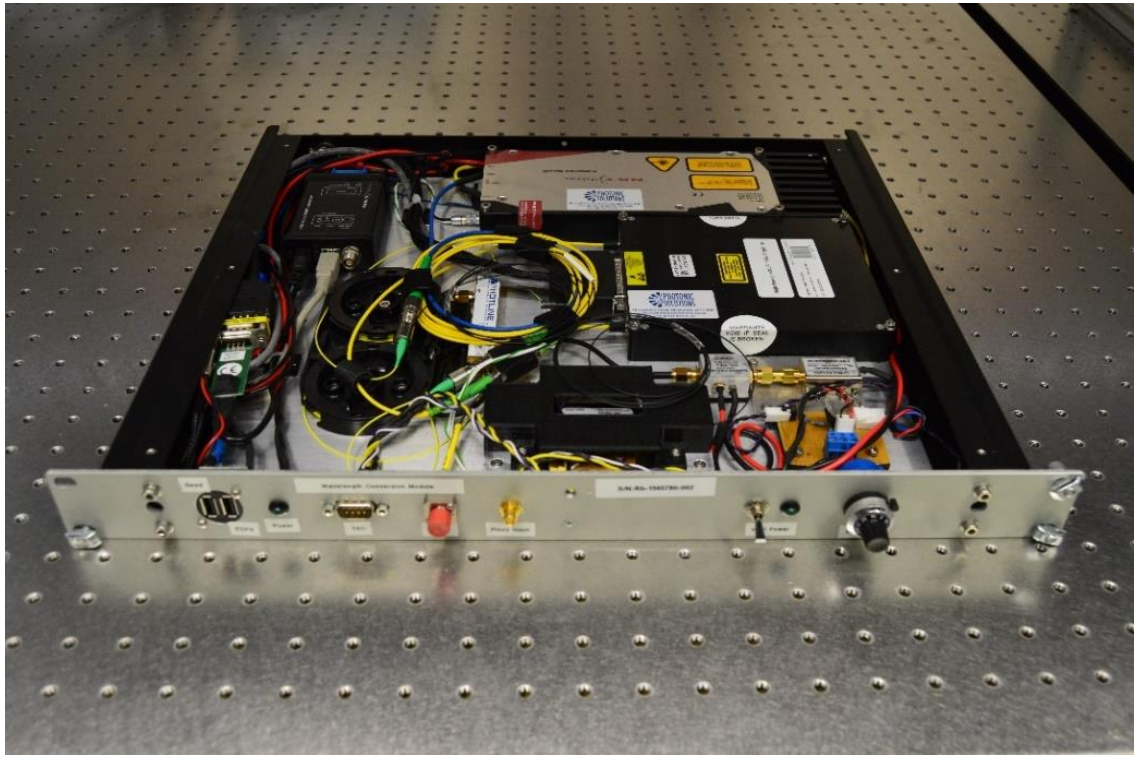




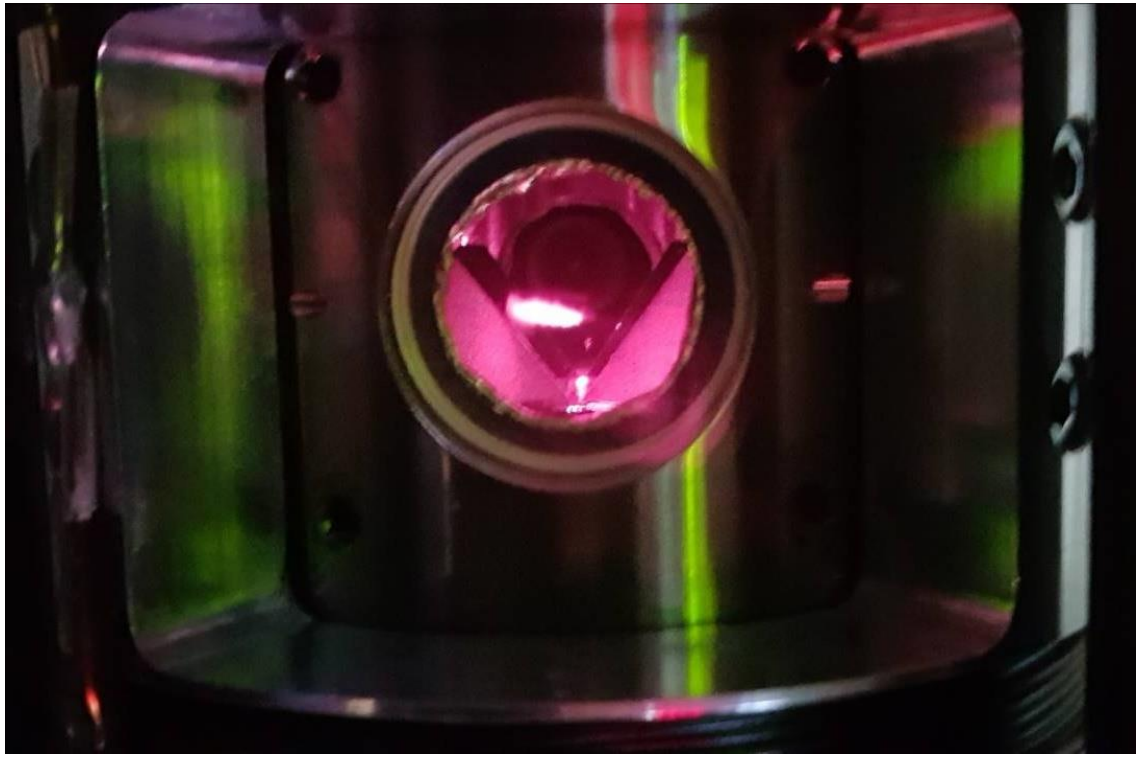


Improving field readiness

- Key technology choices:
  - Telecom fibre laser systems; robust preparation of atom clouds



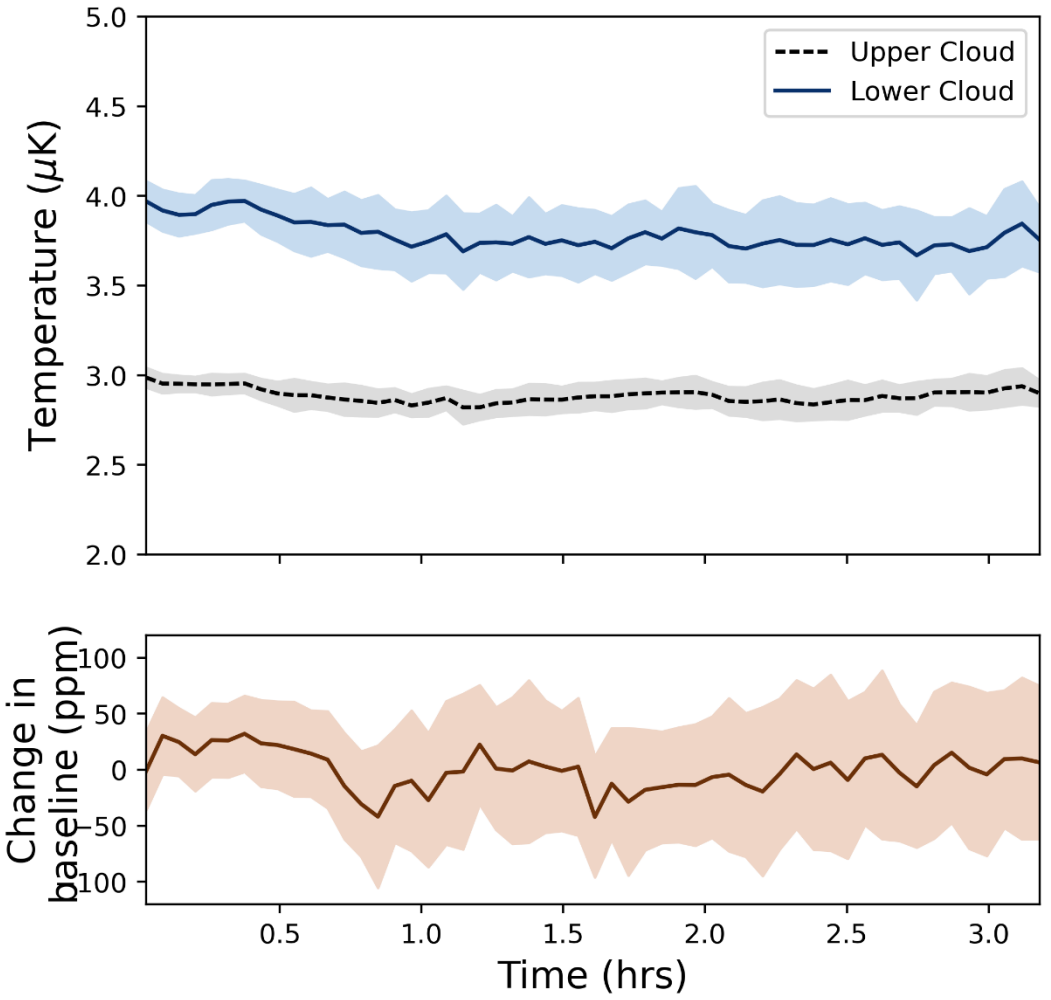
UoB telecom laser for atom interferometry

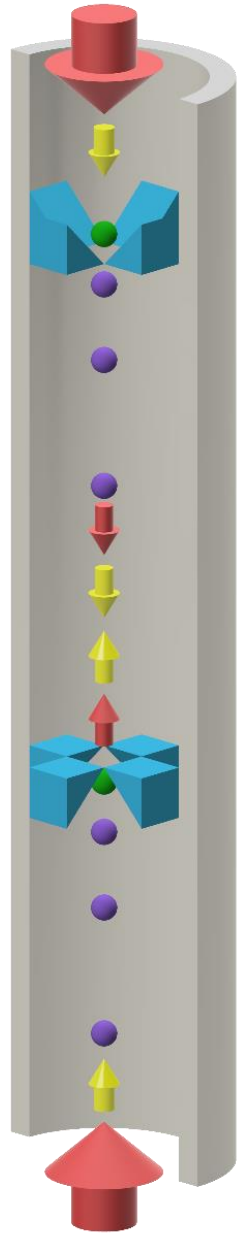


10^9 rubidium atoms in a prism MOT at UoB

Hourglass gravity gradiometer

- Robust concept, with cylindrical form factor
- Stable and can operate in the field for months without realignment

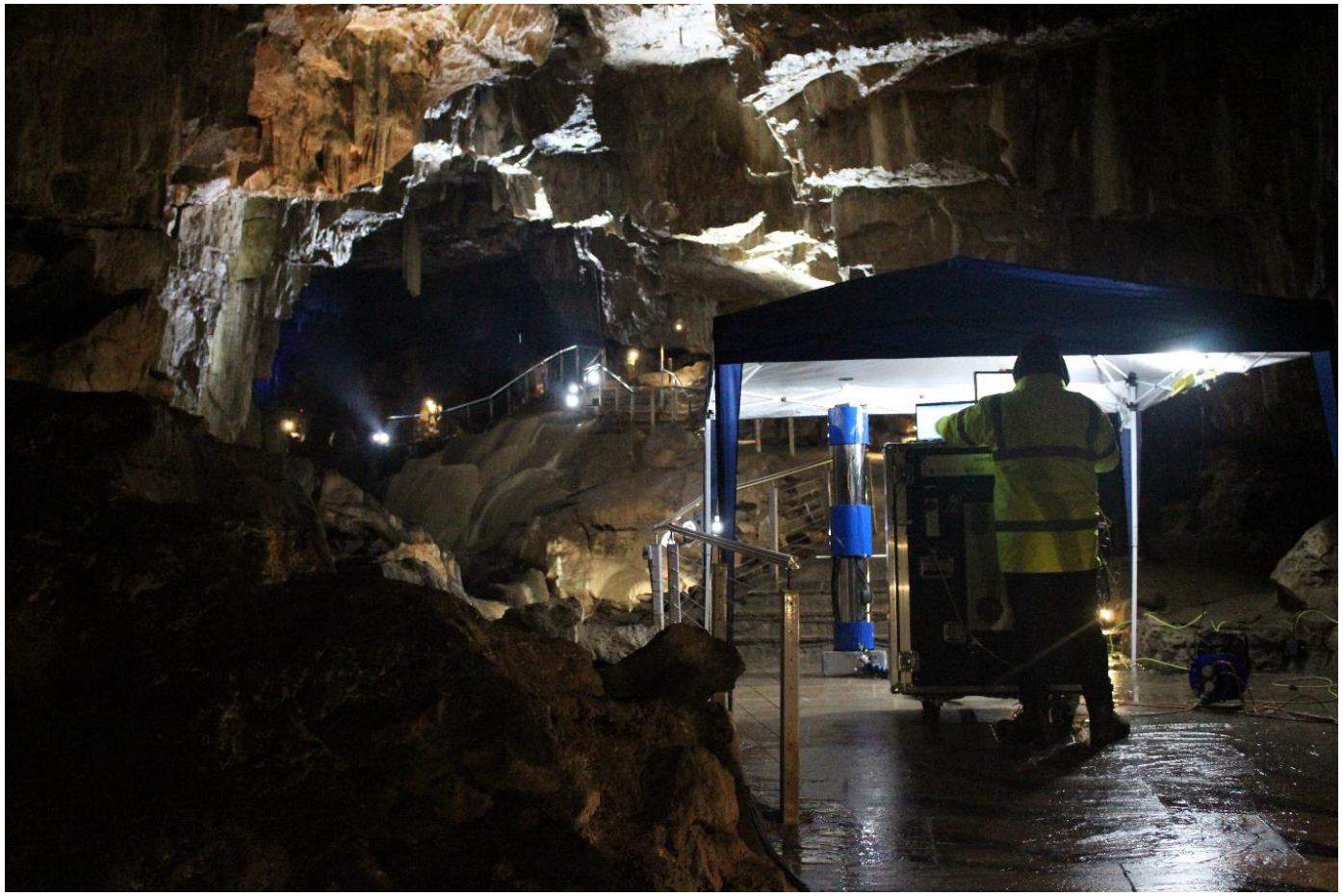




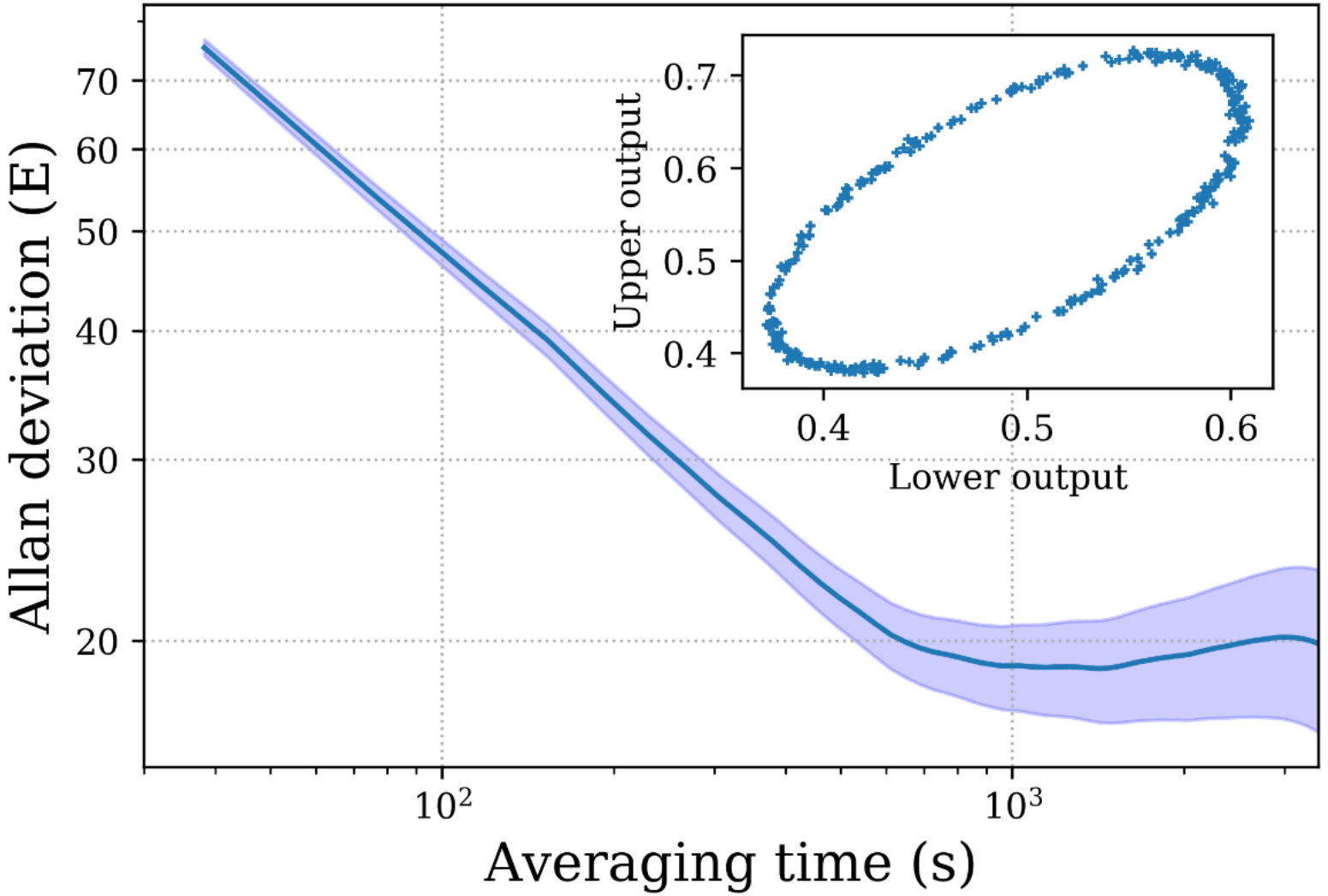
Stray*, B. *et al.* Quantum sensing for gravity cartography. *Nature* **602,** 590–594 (2022); patent granted

Field trials

- Assessed performance and robustness in a range of trials



Performance in field environments

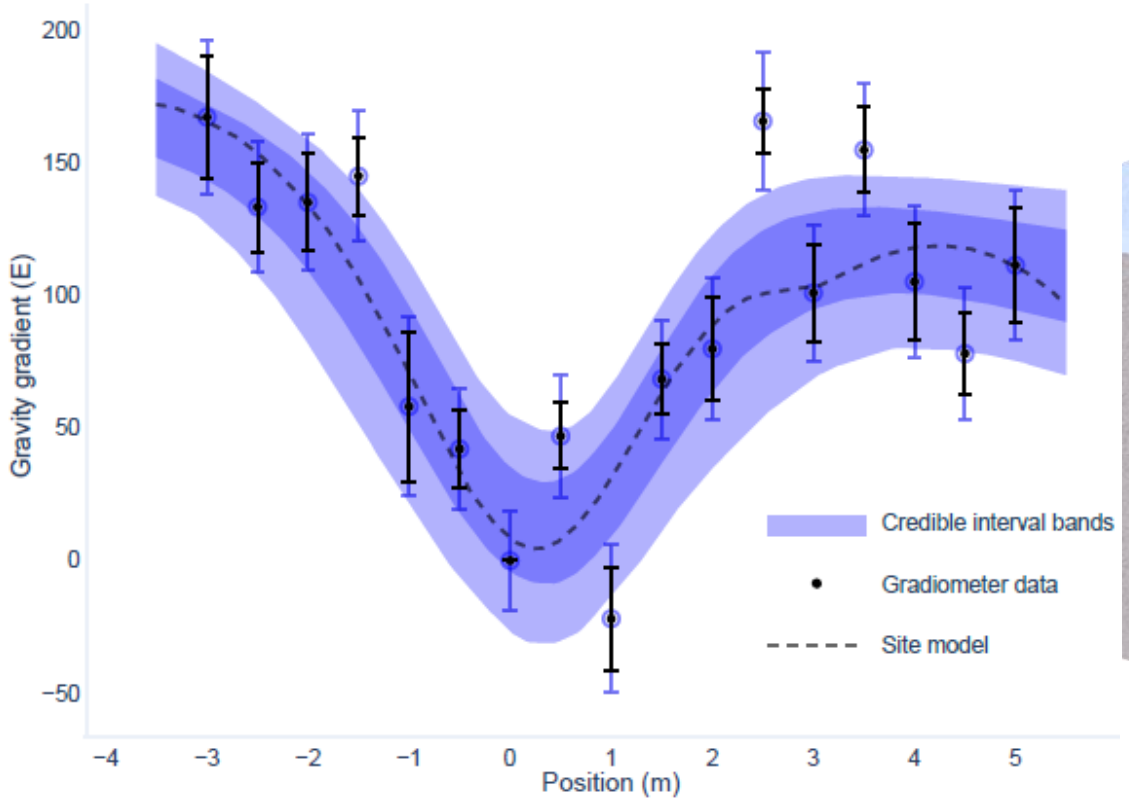


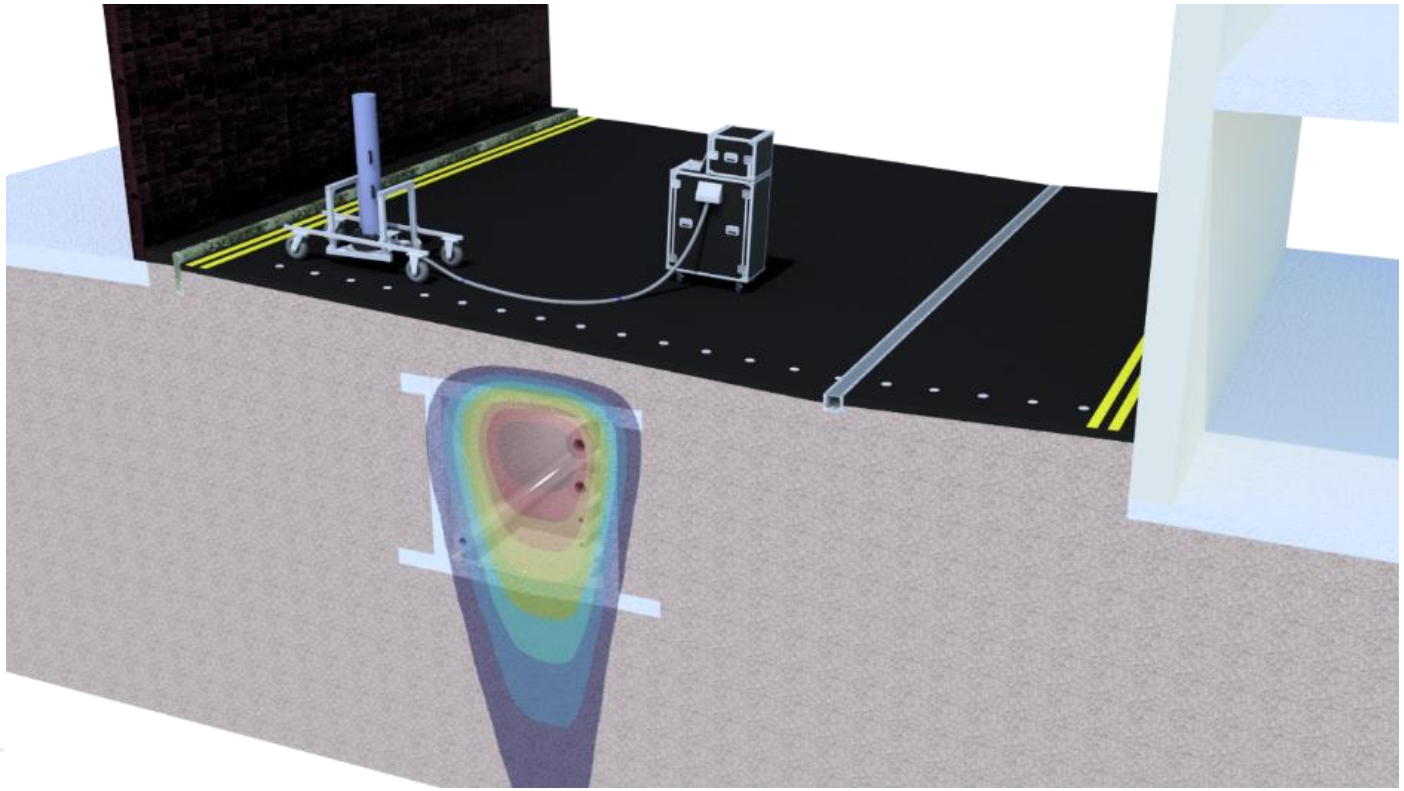
20 E is approximately the gradient due to a person near the sensor

1 E = 10^{-9} s^{-2}

Survey to detect multi-utility tunnel

- Tunnel (2 m by 2 m) under a road between workshop and music building



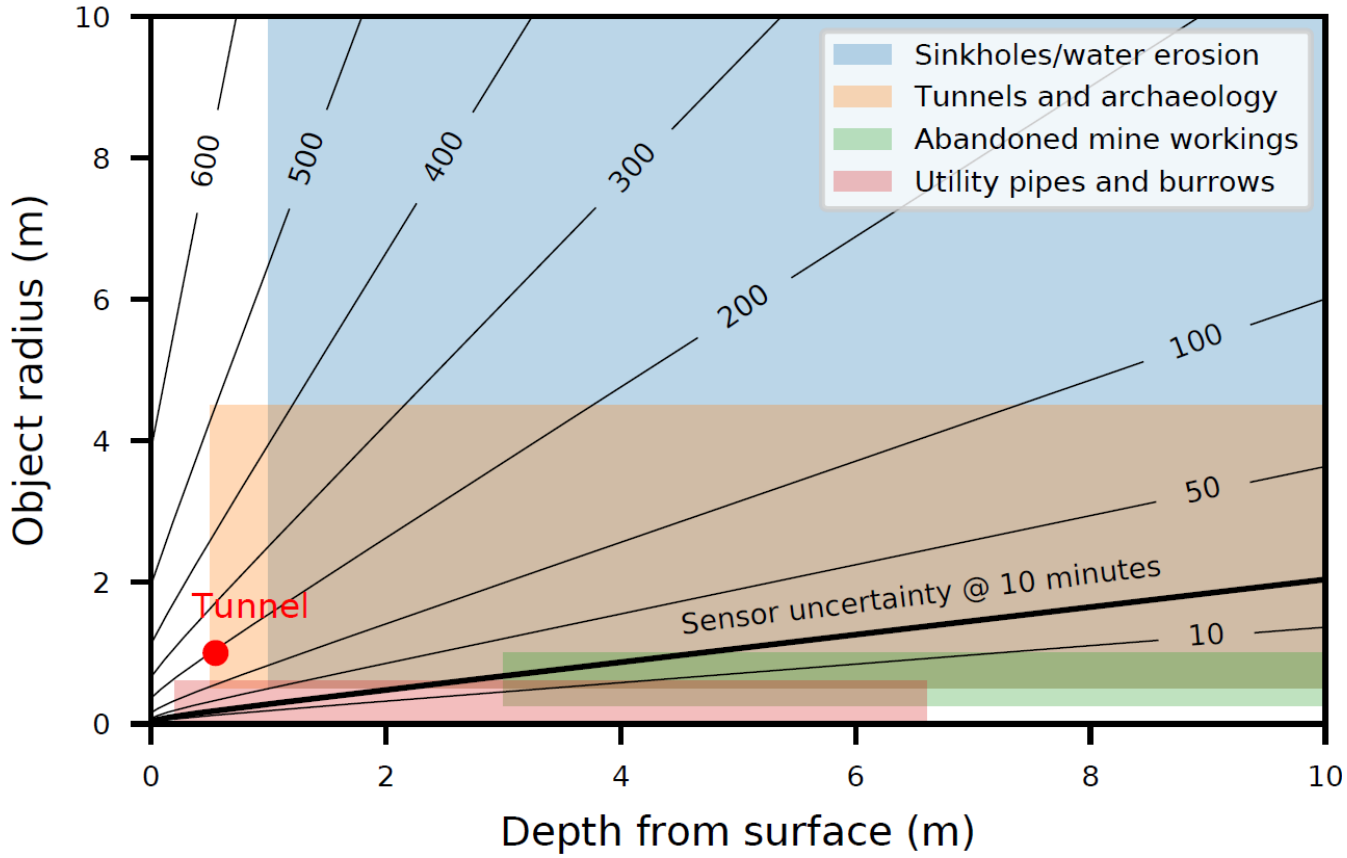


Tunnel centre localised to: ±0.19 m, horizontal; -0.59/+2.3 m, vertical

1 E = 10^{-9} s^{-2}

Comparing performance with applications

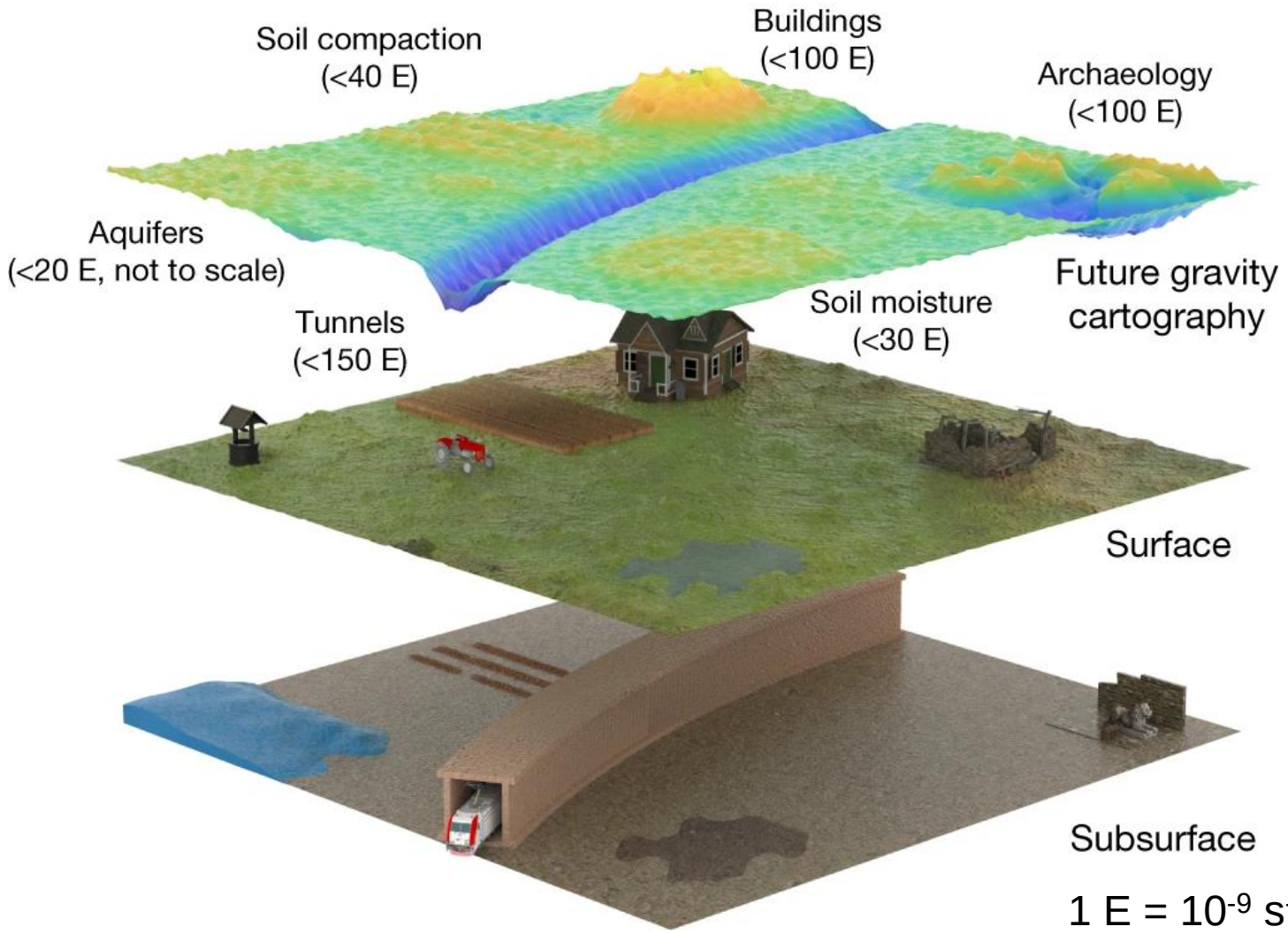
- Current statistical uncertainty exceeds classical sensors by ~1.5-4x and performance is relevant to a range of targets



Contours in E
1 E = 10^{-9} s^{-2}

Gravity Cartography

- Removing vibration could enable rapid scanning for:
  - Road inspection
  - Rail infrastructure
  - Navigation
  - Security
  - Resource monitoring



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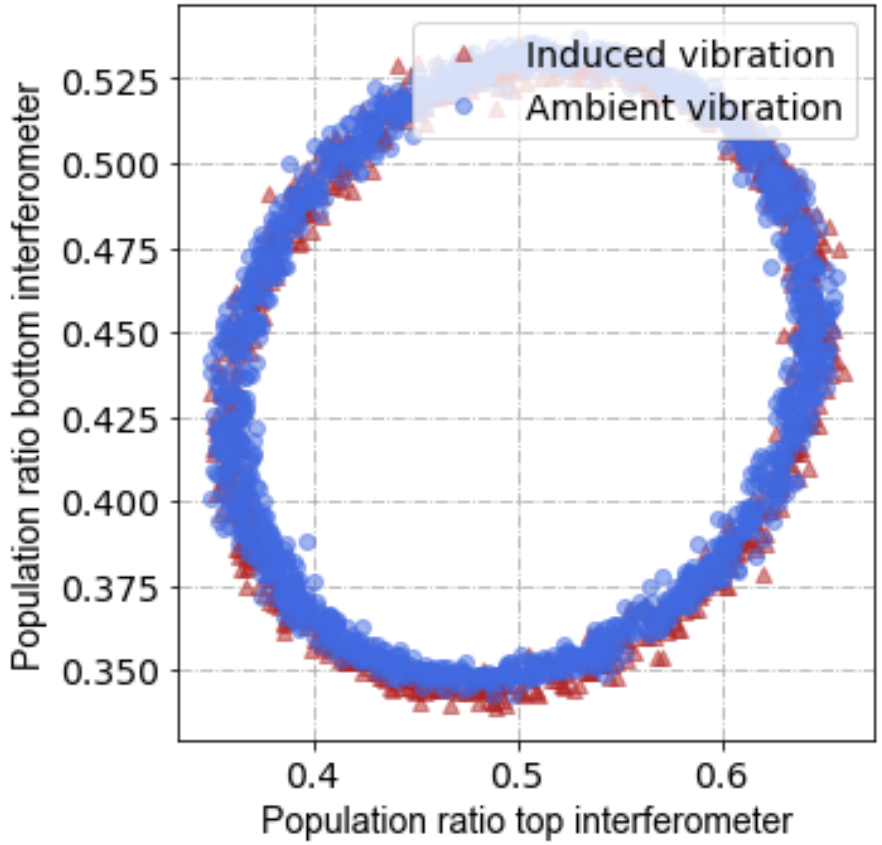
Latest field trial

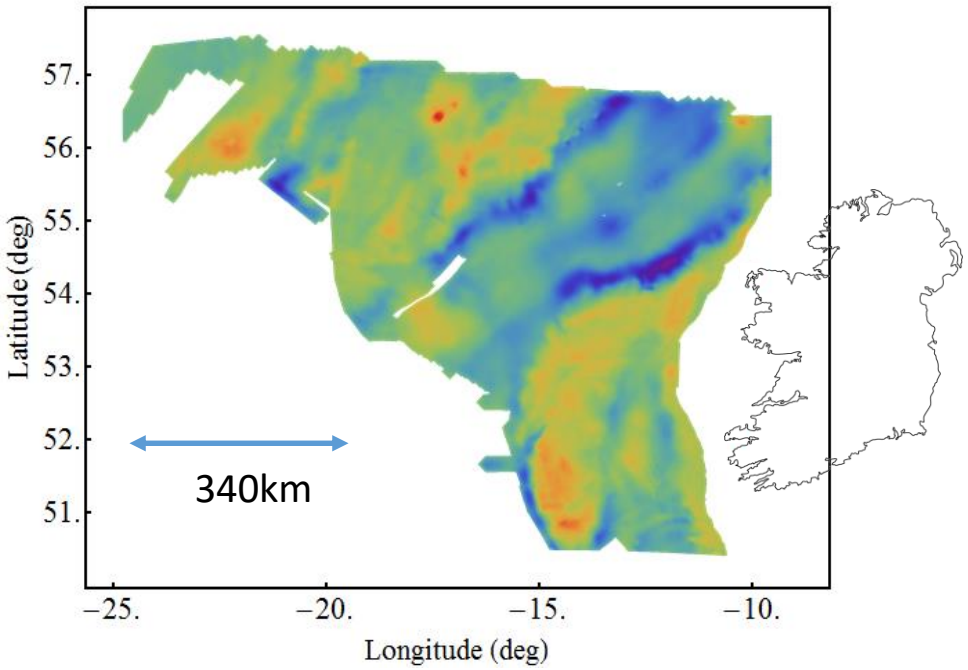
- Benchmarking in field environments: QT device operable under a range of strong applied vibration environments without issue



Next steps – alternative navigation

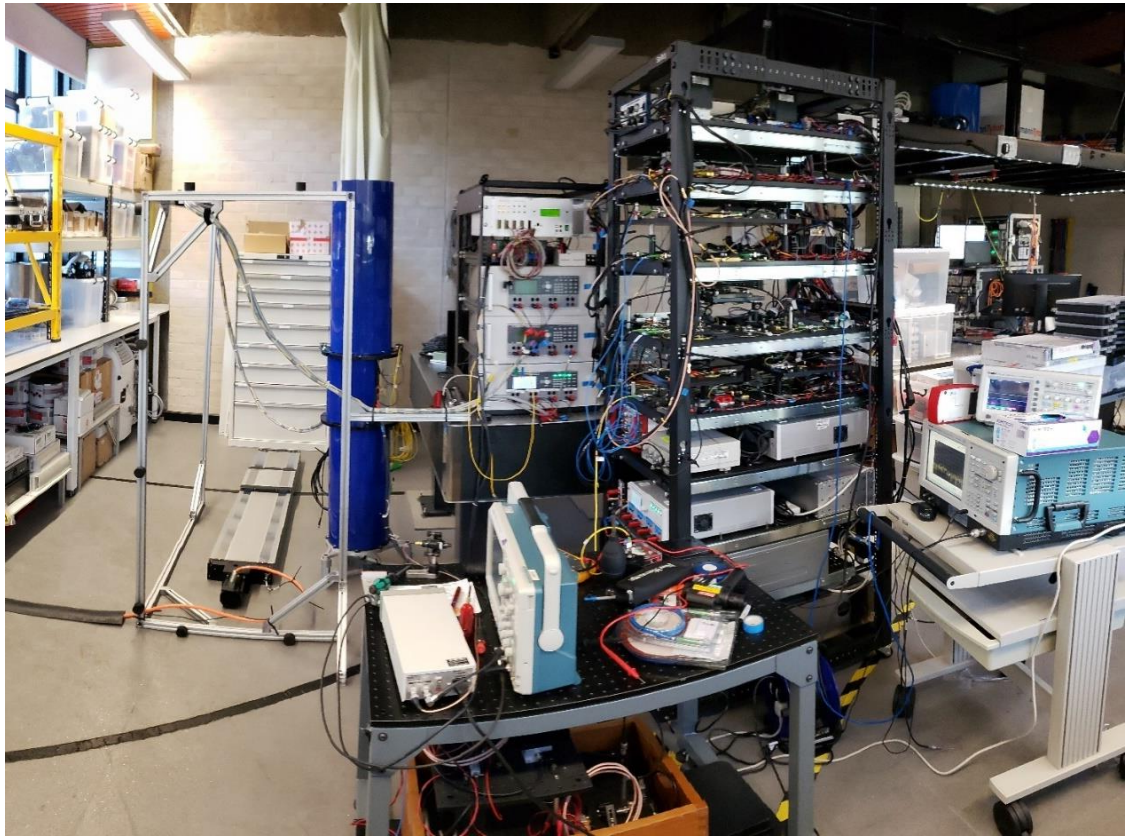
- Reference position versus changes in local gravity gradient - robust against spoofing/jamming/loss of signals, passive

Simulated gravity gradient map over Rockall Trough

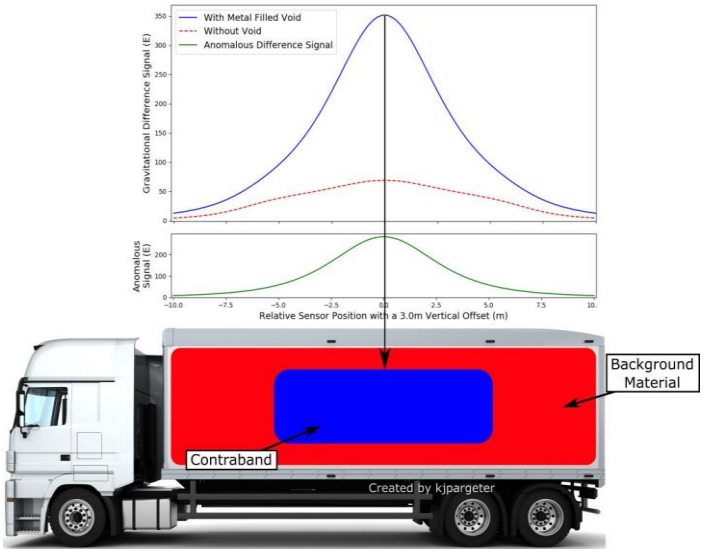


Next steps – border security

- Rapid measurement rate gradiometers for scanning at borders – reduced need to stop vehicles, improved flagging of anomalies

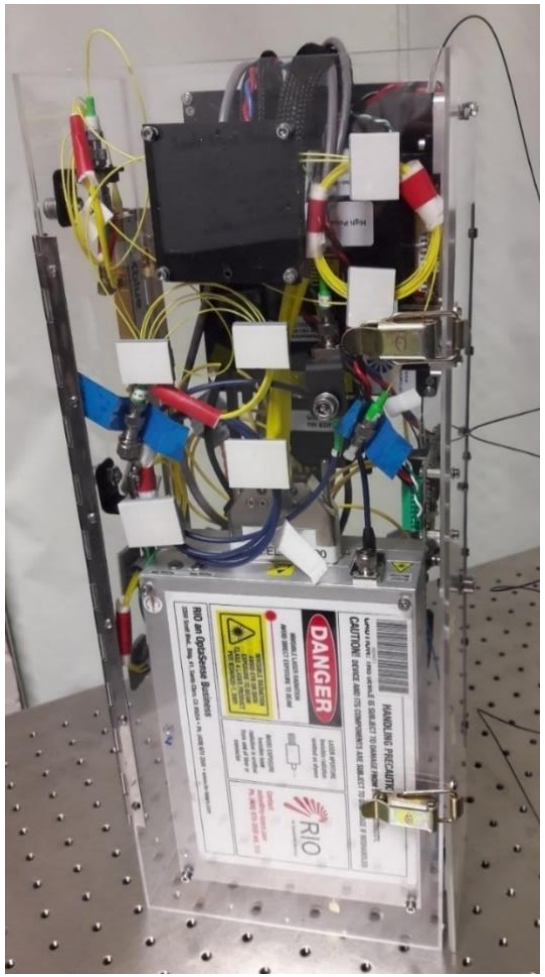


Simulations of mass anomalies inside freight



Next steps – compact sensors

- Person-portable and moving platform devices underway



Current prototype specifications:

- 100 L, 17 kg, 125 W

Exploitation (new company):

Delta-g limited

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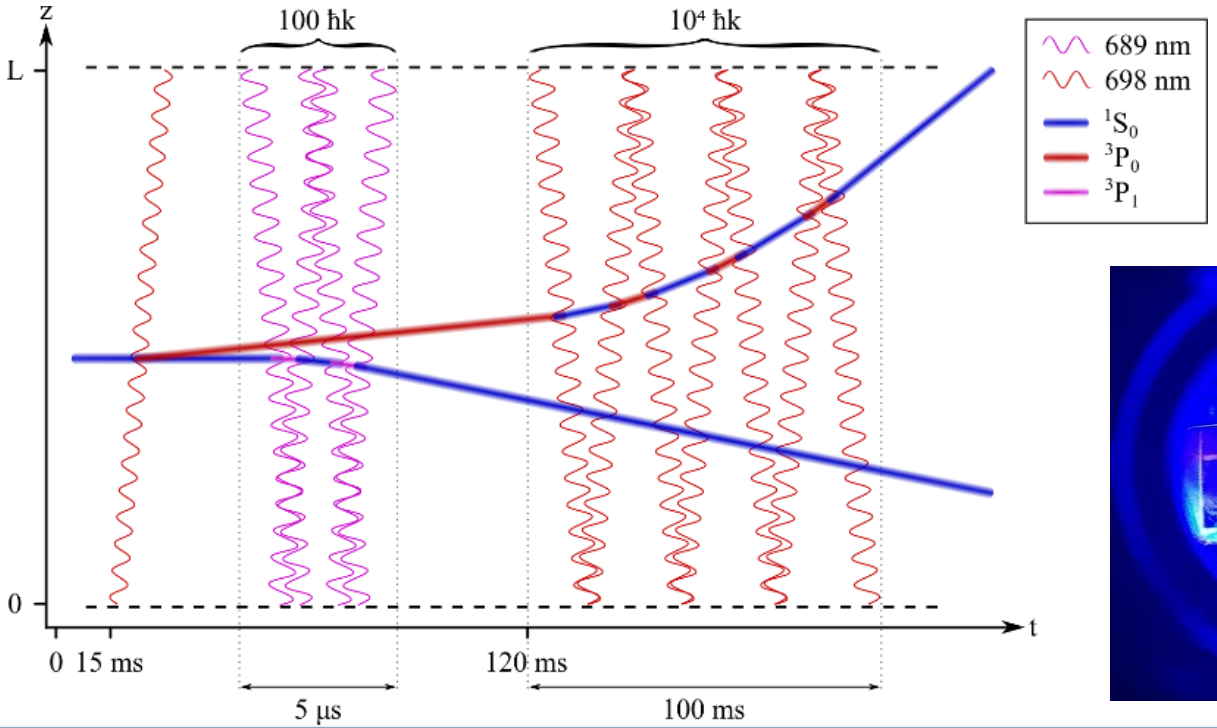
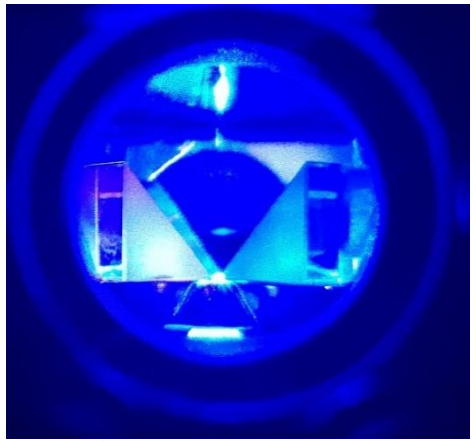
Next steps – high sensitivity

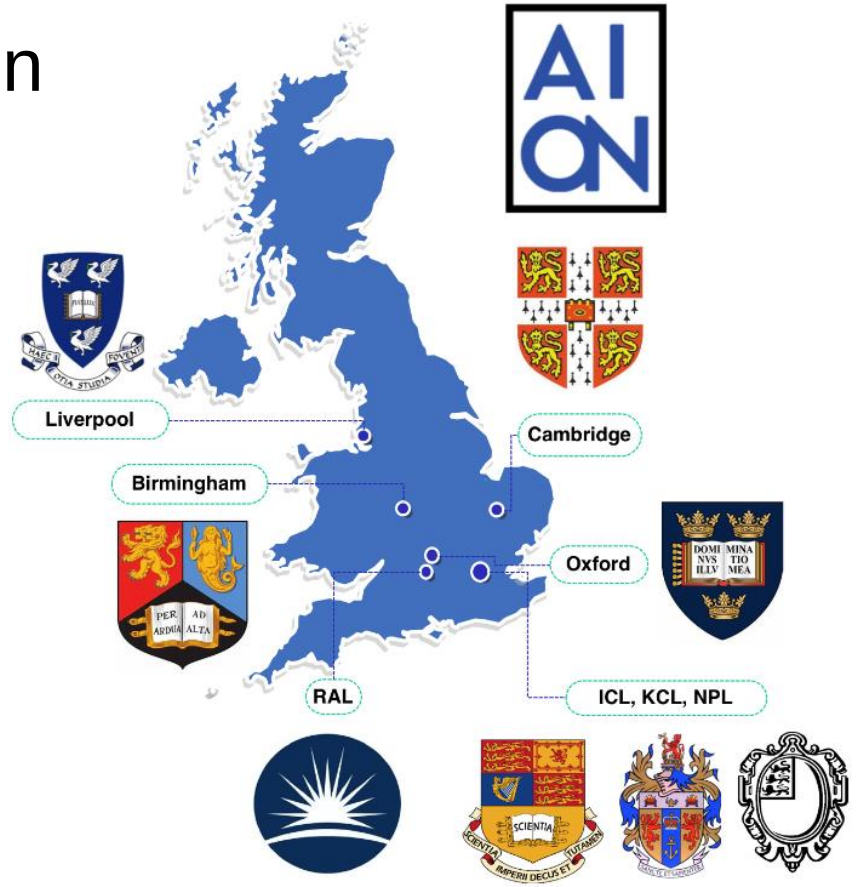
- QT for fundamental physics: AION – towards sensor for mid-band gravitational wave and dark matter investigation

UoB: Extreme momentum transfer (>$10^4\hbar k$)





Strontium atoms in a magneto-optical trap at UoB



UoB Gravity Cartography team

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School of Physics and Astronomy
School of Engineering

RSK

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Funding:

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UKRI Engineering and Physical Sciences Research Council

UKRI Innovate UK

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UoB Atom Interferometry

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Thank you for listening

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Funding:

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B.J.Stray@bham.ac.uk | M.Holynski@bham.ac.uk | PhD and research fellow positions available

Quantum sensing of gravity

- Similar to optical interferometry