COMMERCIAL APPLICATION OPPORTUNITIES AND DISRUPTIVE POTENTIAL OF QUANTUM SENSORS

Prof. Dr. Kai Bongs

DLR Institut für Quantentechnologien, Ulm

Why Quantum Sensors and Timing?

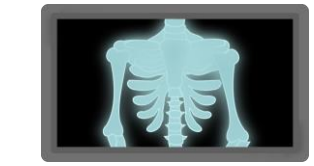
They are here NOW!!!

- Quantum Clocks define time since 1967
- Quantum Clocks underpin Satellite Navigation
- Early Quantum Magnetometers and Quantum Gravimeters are commercially available
- Quantum Sensors for acceleration, rotation, electric fields, electromagnetic fields from RF to THz,… have all been demonstrated in the laboratory to be „better“ than classical sensors

Sensors and Timing underpin more of our economy than most think!

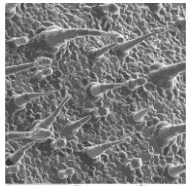
Sensors Changing the Economy

From Nobel Prize to Disruptive Business Opportunity



X-rays

Aperture synthesis in radioastronomy → SAR Radar



Electron Microscope

Giant Magnetoresistance → Hard Drives

MRI

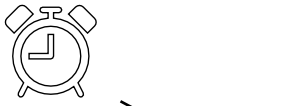
CCD

Quantum Clocks Potential to Change Business Models

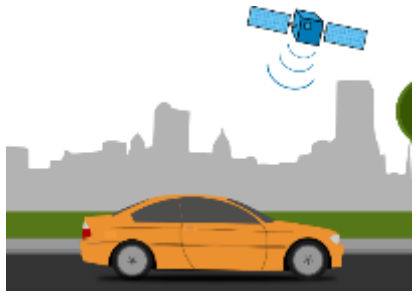
Timing Today: Centralized Model

Communication and energy networks

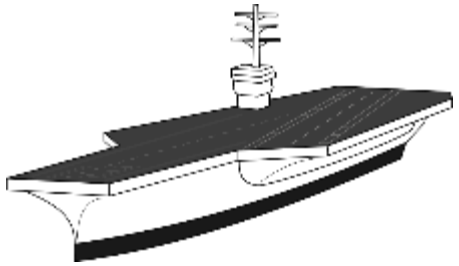
Finance



UTC mostly via GNSS



Navigation



Defence

Timing via Global Navigation Satellite Systems:

+ „Free“ to use
+ Worldwide availability
+ 30 ns within UTC

→ Widespread use in industry and critical national infrastructure

- Can be easily spammed or spoofed
- Is not available everyehere (e.g. underwater)
- Risk to critical infrastructure in case of conflict
- Potential limits to communication

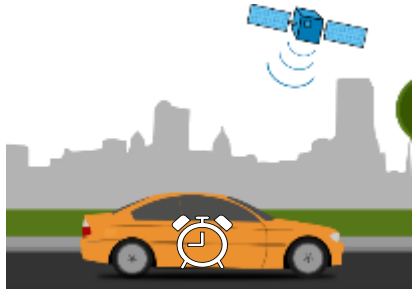
Quantum Clocks Potential to Change Business Models

Timing Future: „Edge“ Model

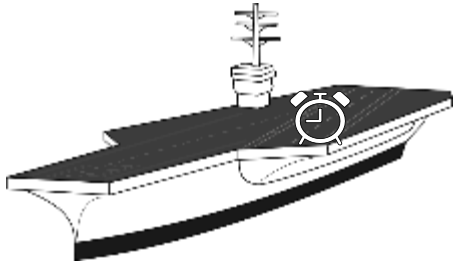
Communication and energy networks

Finance

Local timing with synchronization



Navigation



Defence

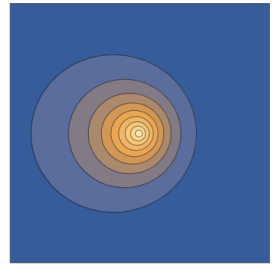
Quantum „Edge“ Timing:

+ Resilience
+ Network architectures with higher bandwidth and better energy efficiency
+ Architectures for safe autonomous vehicles
+ Improved air and space surveillance

- Not „free“ to use
- Will need 10-15 years of development to reach full potential

How do Quantum Clocks Work?

A quantum clock replaces the manmade frequency reference in a classical clock (e.g. a pendulum) with an atom

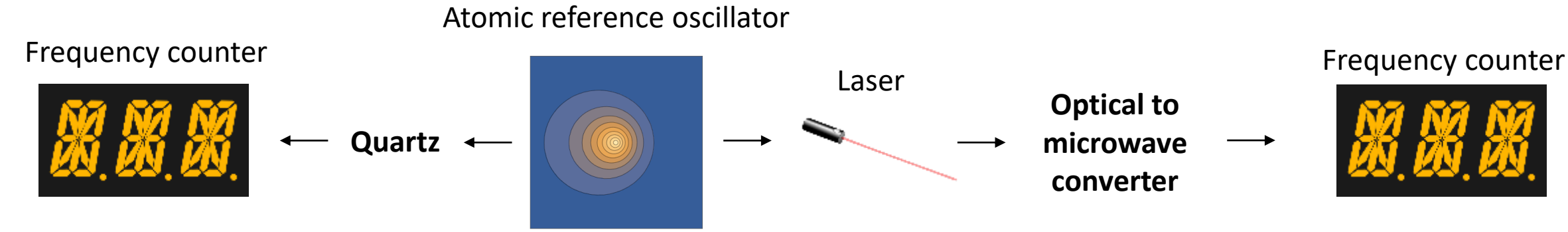


Always made the same by nature
Precision governed by the laws of physics

Microwave (old) and Optical (new) Quantum Clocks

A quantum clock replaces the manmade frequency reference in a classical clock (e.g. a pendulum) with an atom

Microwave atomic clock | **Optical atomic clock**



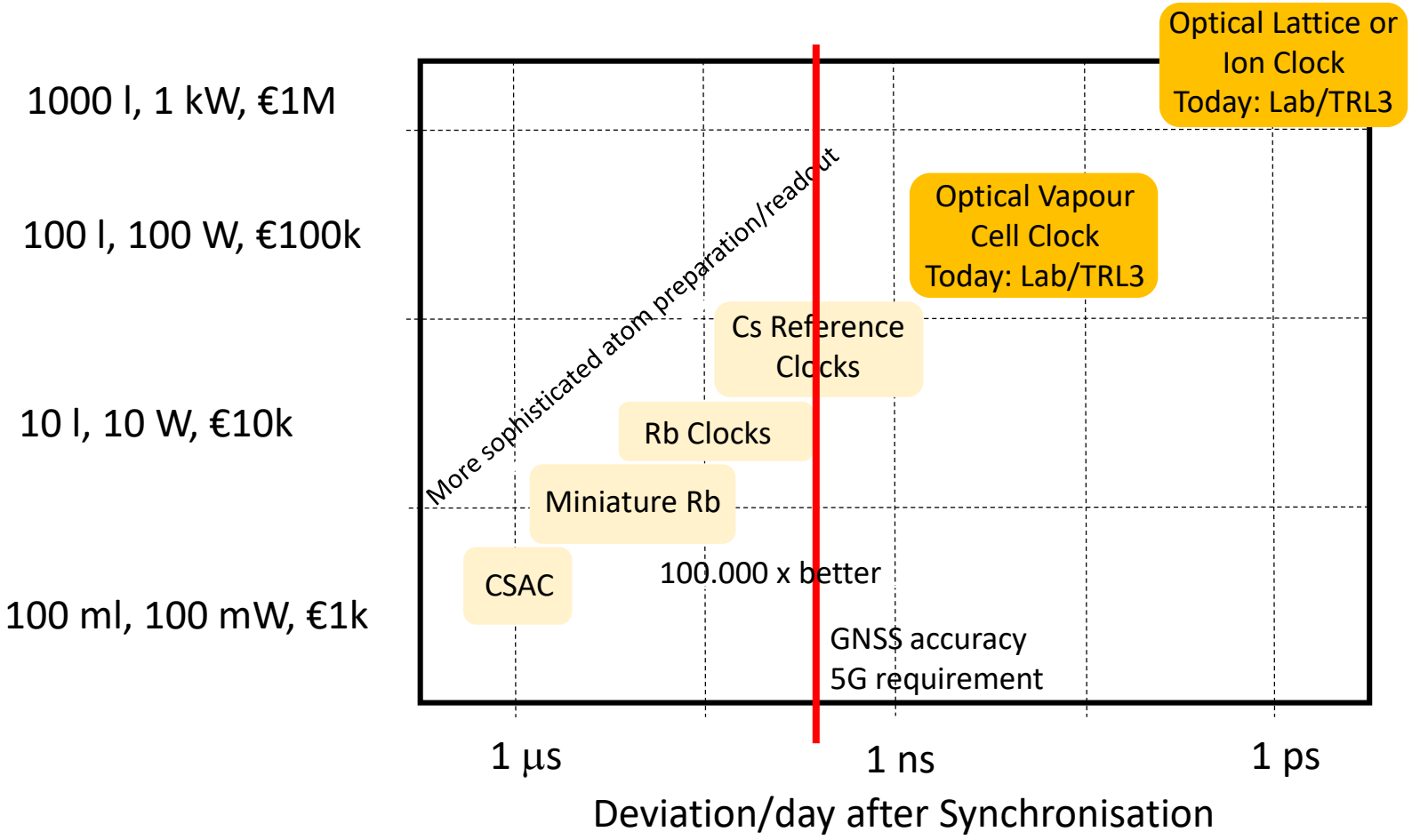
Microwave atomic transition is used to discipline a quartz oscillator

Optical atomic transition is used to discipline a laser

100.000 higher frequency
→ faster sychronization & higher precision

Why are Optical Clocks Disruptive?

So far: “linear” relationship between SWAP-C and stability



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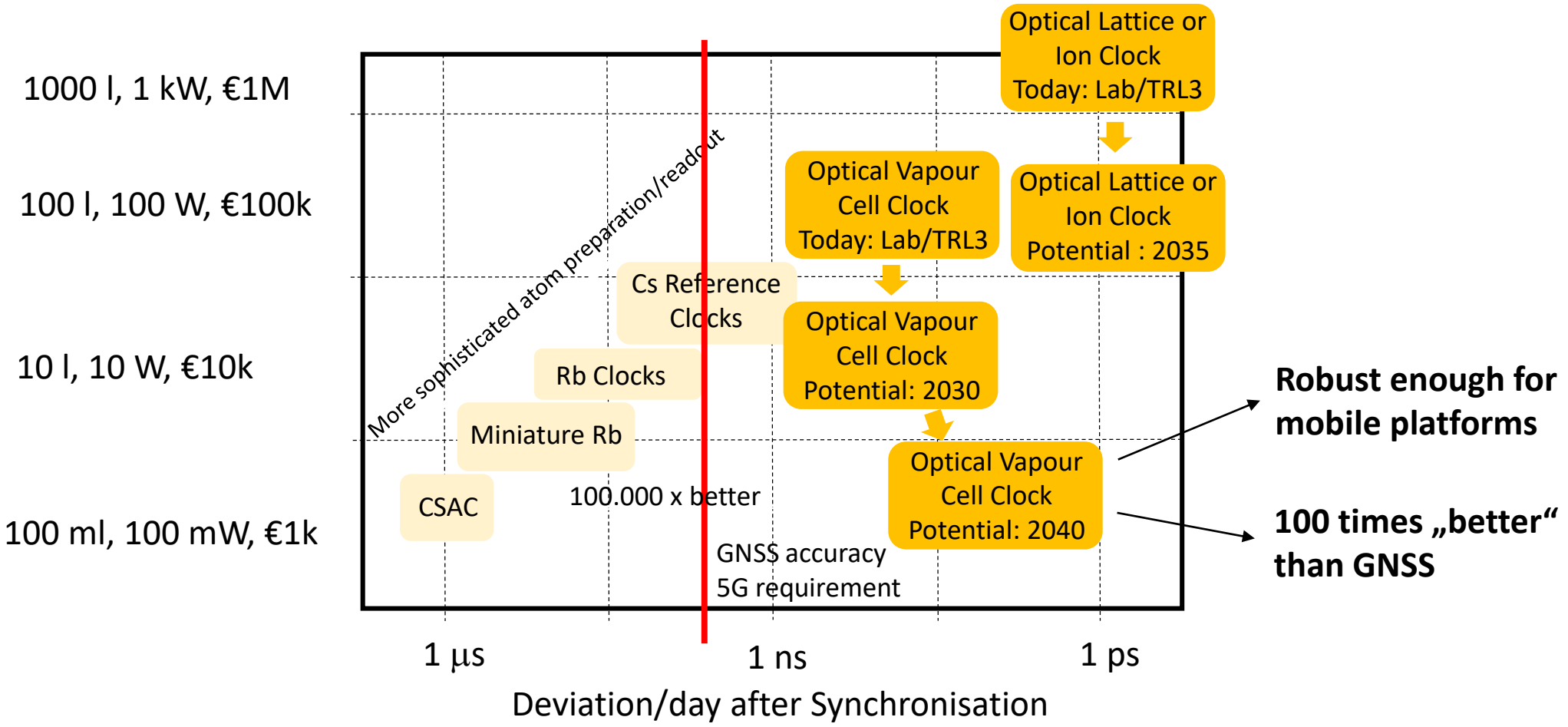


Roadmap for Optical Clock Applications

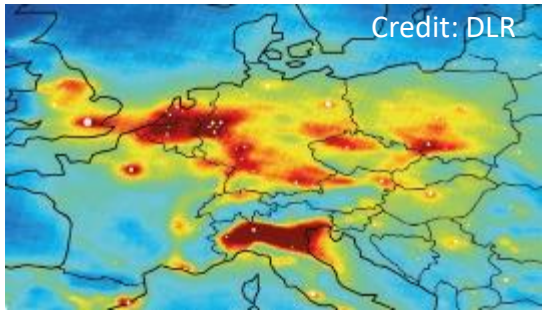
Business Advantage through Quantum Timing

Next generation GNSS

Long distance 3d imaging radar

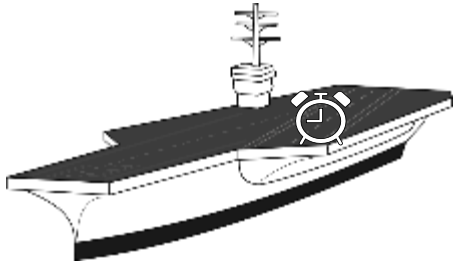
Credit: AdobeStock/J-mel

Urban airspace control



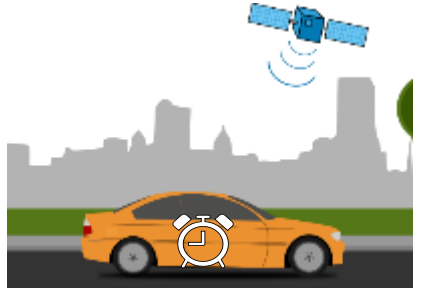
mm-level global height reference system

2030 2040 2050



GNSS resilient operation

High bandwidth communication

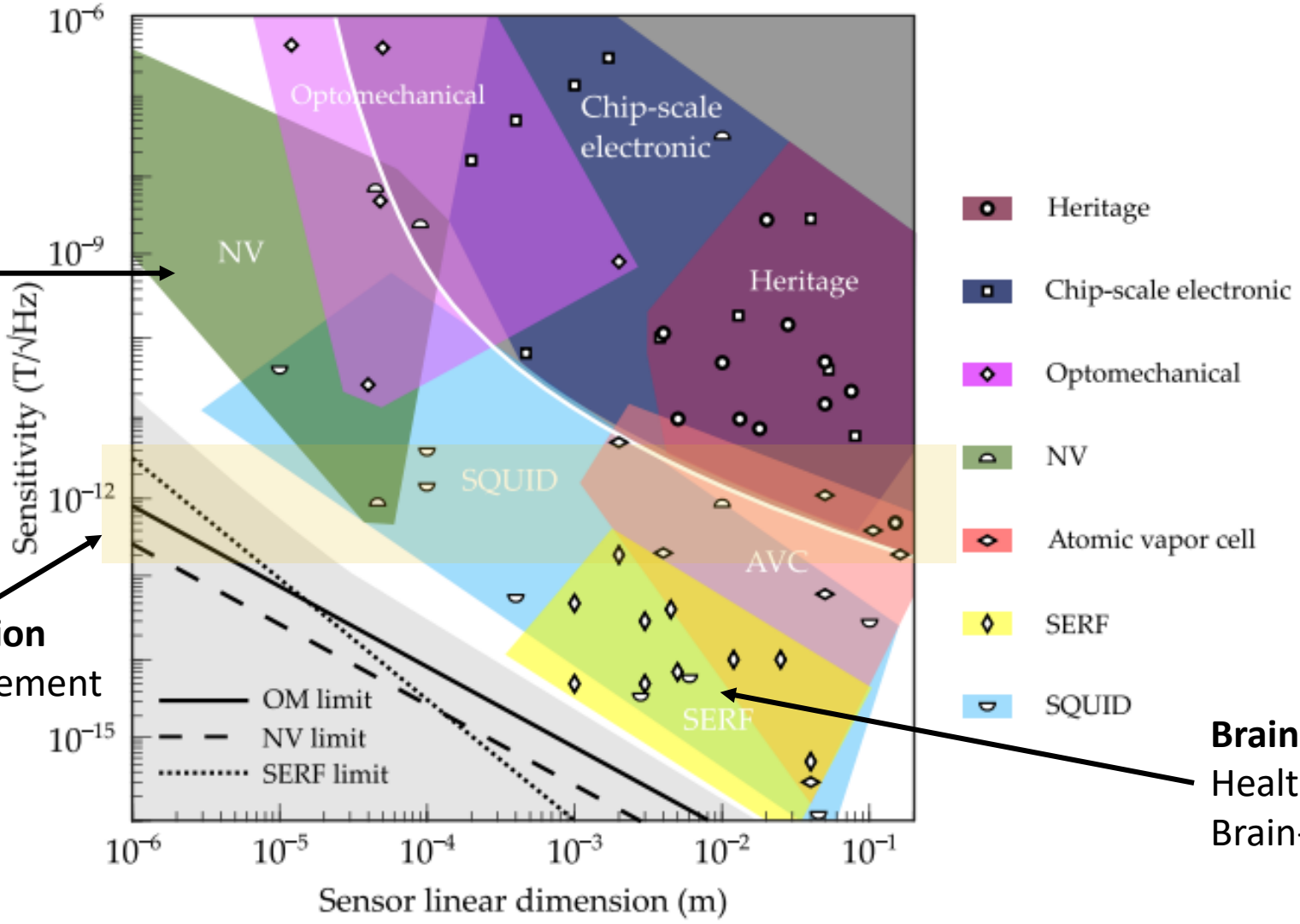


Autonomous vehicles

Magnetic Sensor Overview – Scale vs Sensitivity

Molecule detection
Biomedicine
Micosample chemical analysis

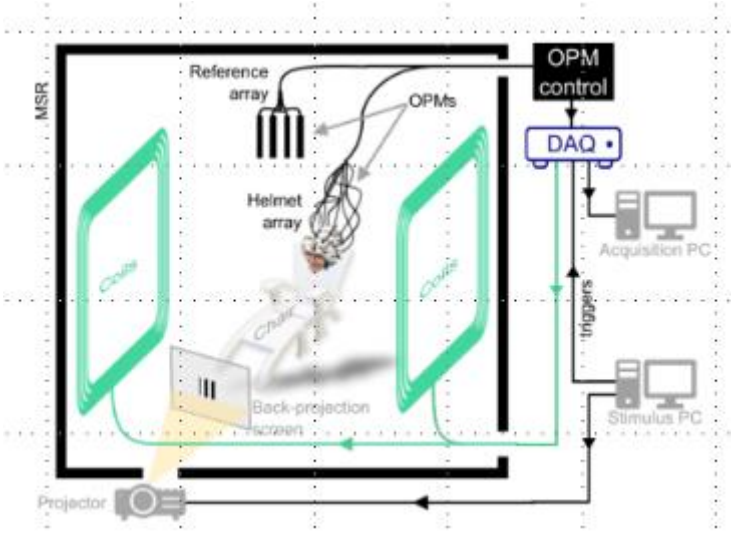
Leakage current detection
Battery lifetime enhancement
Security screening
Non destructive testing



Brain signals
Healthcare
Brain-machine interfaces

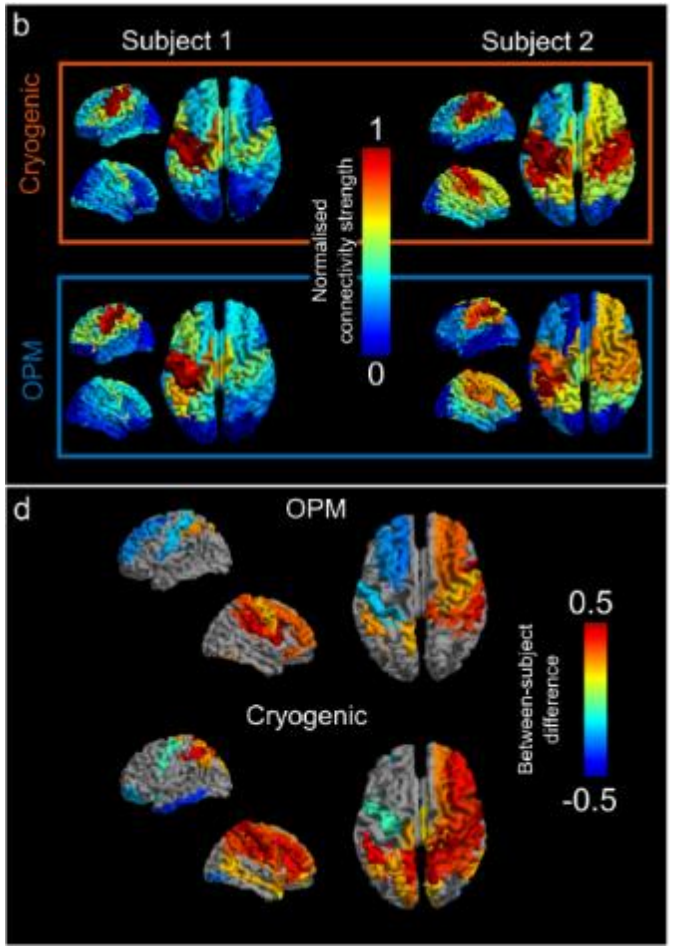
Sensors **2021**, *21*(16), 5568; https://doi.org/10.3390/s21165568

Quantum-Magnetoencephalography – Spin off from QT



Cerca:
Joint venture spin-off between Magnetic Shields and Nottingham University
Founded in 2020

First systems delivered internationally
£6M turnover in first year
>£50M requests for quotations



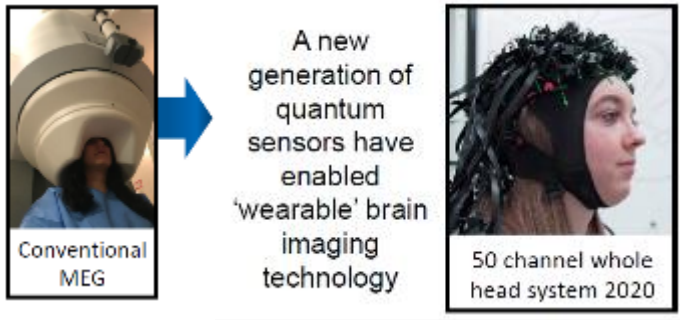
Impact Opportunities:

Epilepsy: 60M people worldwide

Dementia: 1% GDP

Schizophrenia: 1% of population

Trauma: 100.000 / year in UK



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Roadmap for Magnetic Sensor Applications

Business Advantage through Quantum Magnetometry

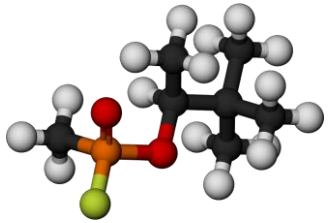
Oil and Mineral Exploration

Quantum Magnetoencephalography

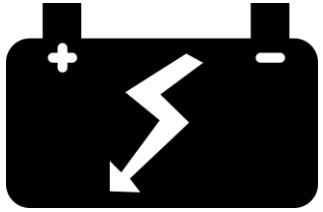
Routine Clinical Diagnostics

Gaming

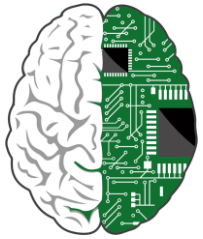
2020 2030 2040



Microsample Chemical Analysis



Battery diagnostics



Brain Machine Interfaces

Opportunities in „Mapping the Underworld“

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

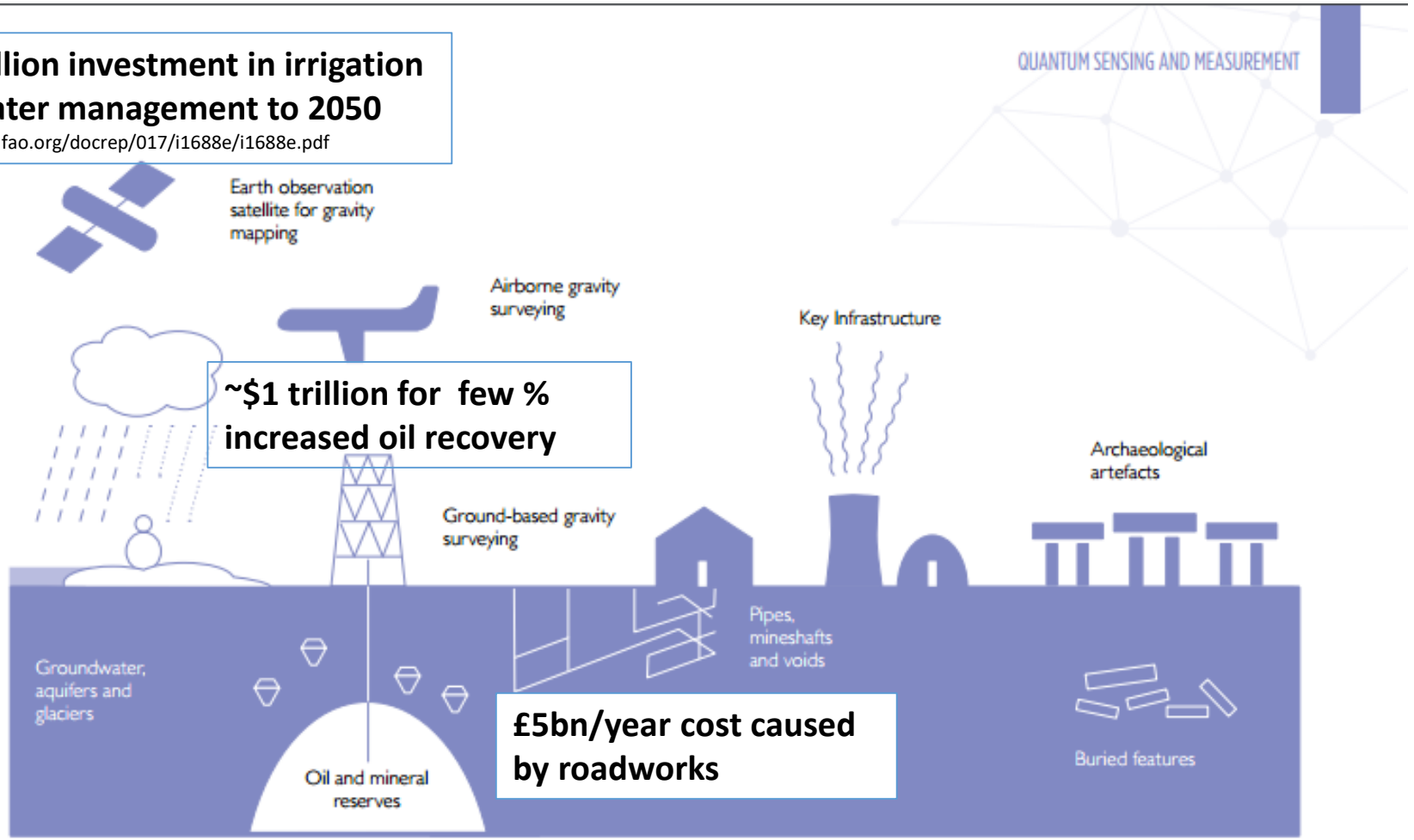
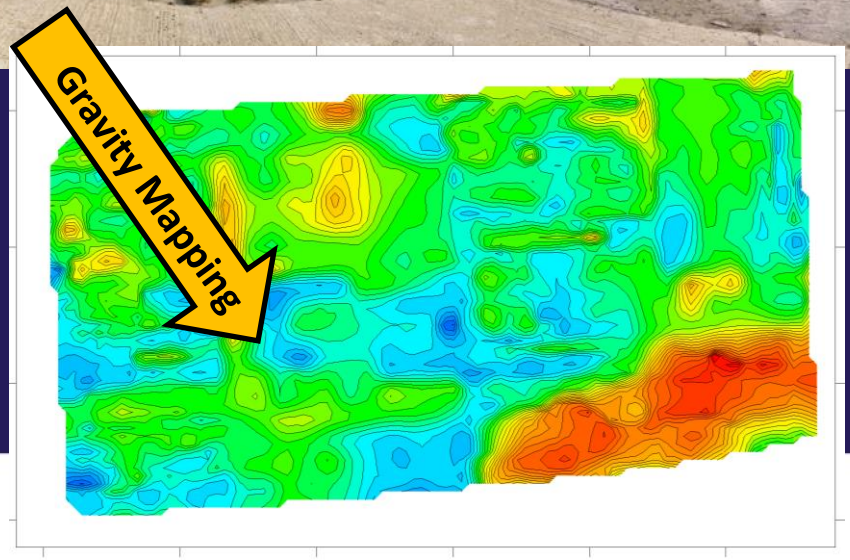


Image: Quantum Blackett Report:
https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/564946/gs-16-18-quantum-technologies-report.pdf

Microgravity Surveys and their Limitations

Example: Brown Field Site Survey



Classical microgravity sensors are sufficiently sensitive to deliver useful information!

BUT:
They take 5-10 min/measurement point

Sensor drift needs to be corrected by periodically returning to a calibration point

In this example: 1 month for 1 ha with 3 sensors and 4 persons

→ Commercial uptake hindered by cost of operation, not the sensitivity of the instrument

RSK

UNIVERSITY OF BIRMINGHAM

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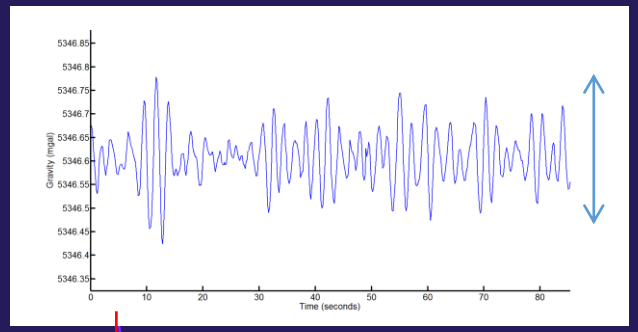
Why do Gravity Measurements take so much Time?

- Acceleration vs gravity

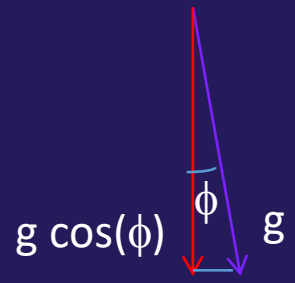


30-100 ng

Requirement to achieve 1 ng

Minutes / point

- Tilt



0.001° alignment

Better gravity sensors only provide calibration benefits, not lower measurement time/point !!!

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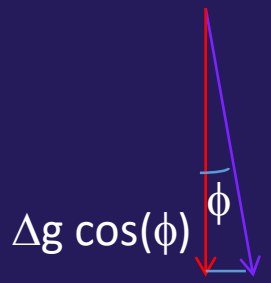
Solution: Gravity Gradiometry

- Suppression of Accelerations
- Reduced Tilt Sensitivity



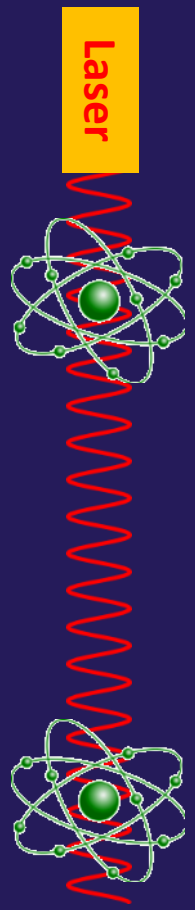
Requirement to achieve 1 ng/m

As fast as your instrument →1 s / point

3° alignment

Common laser beam

Near-Perfect acceleration suppression and alignment in Atom Interferometry



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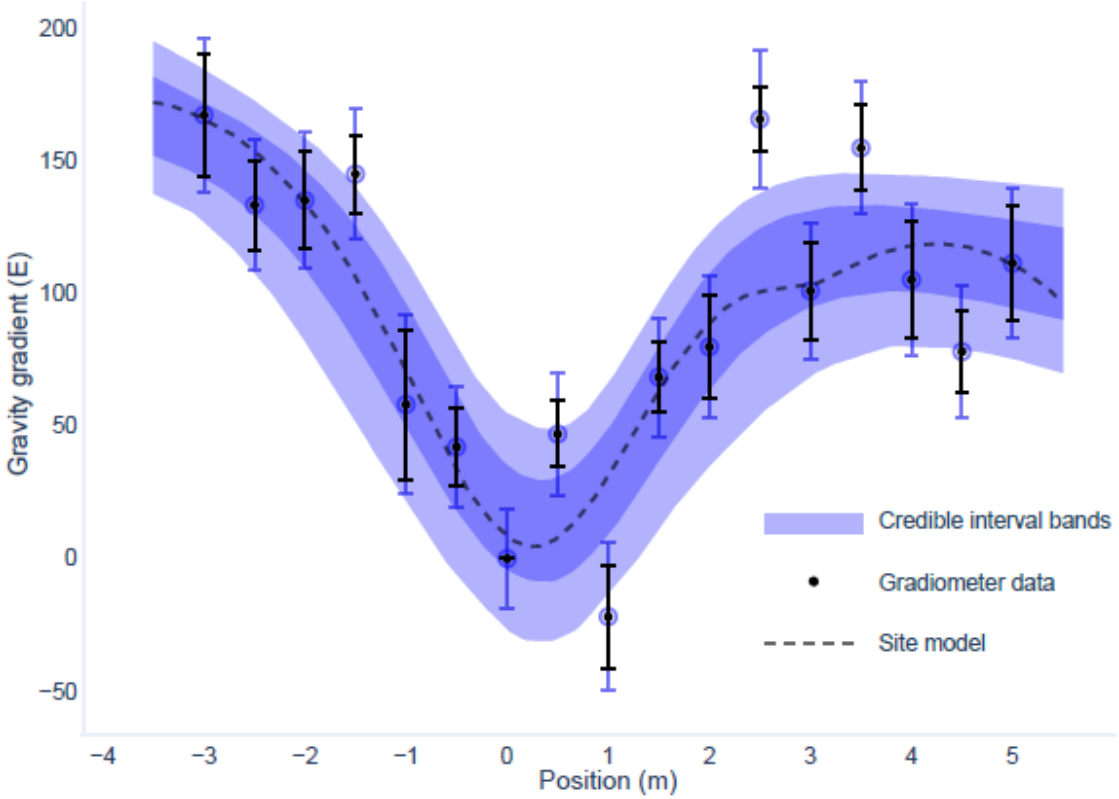
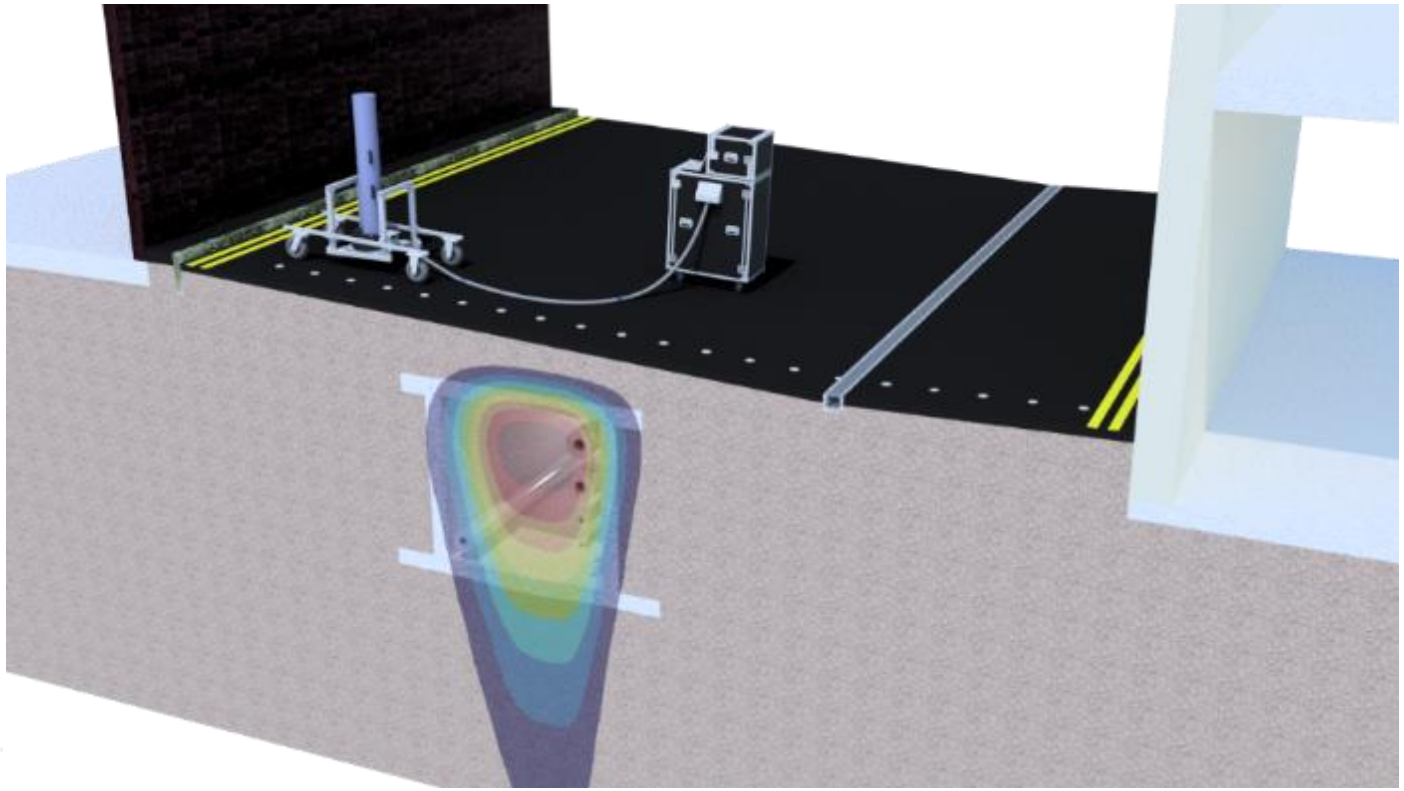
World first detection for quantum gradiometry

- Survey over tunnel



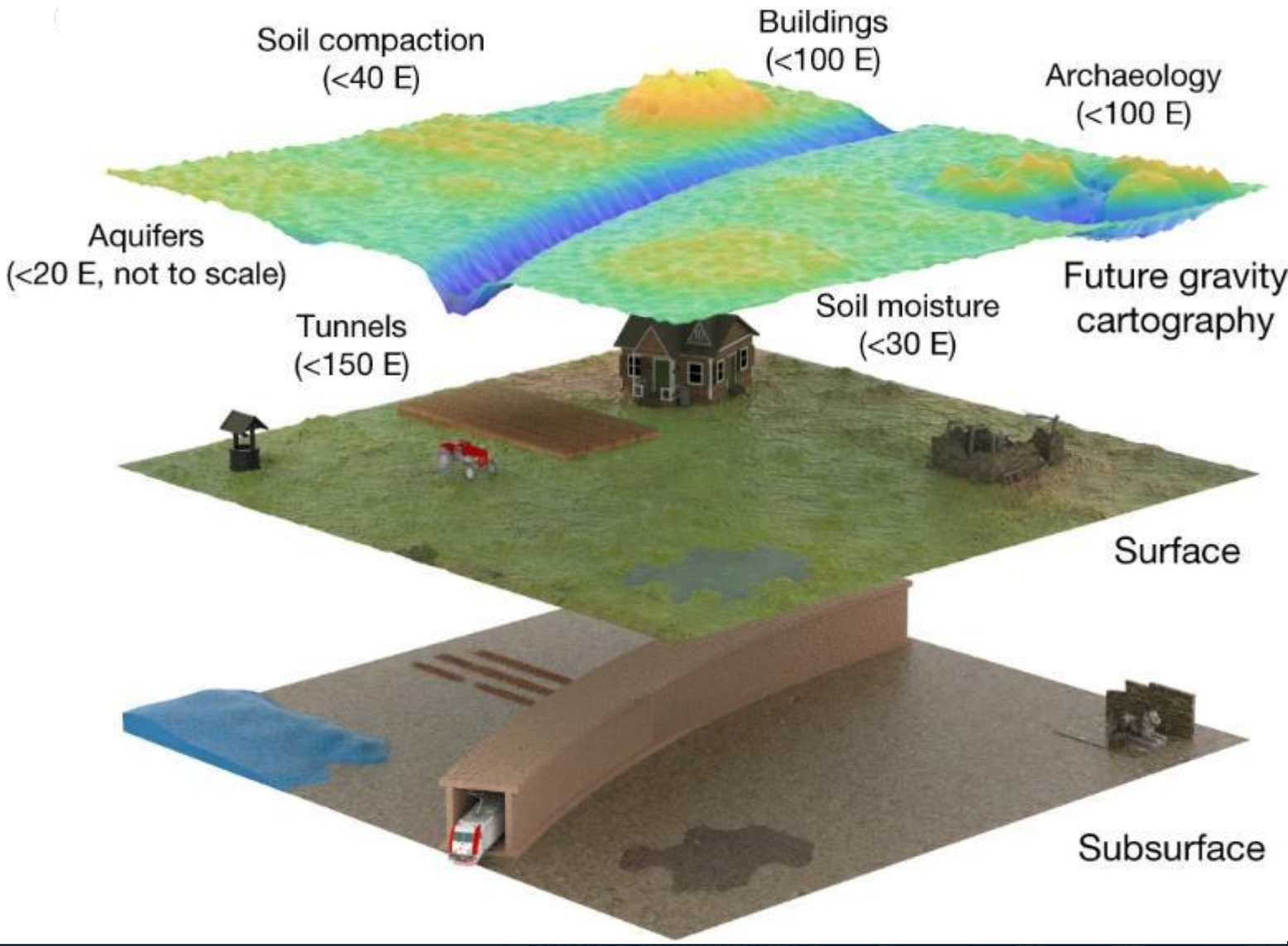


Tunnel centre localised to: ±0.19 m, horizontal; -0.59/+2.3 m, vertical

Nature **volume 602**, pages590–594 (2022)

Enabling Gravity Cartography

- Relevant to a range of applications, including:
  - Water monitoring
  - Infrastructure
  - Archaeology
  - Agriculture
  - Navigation



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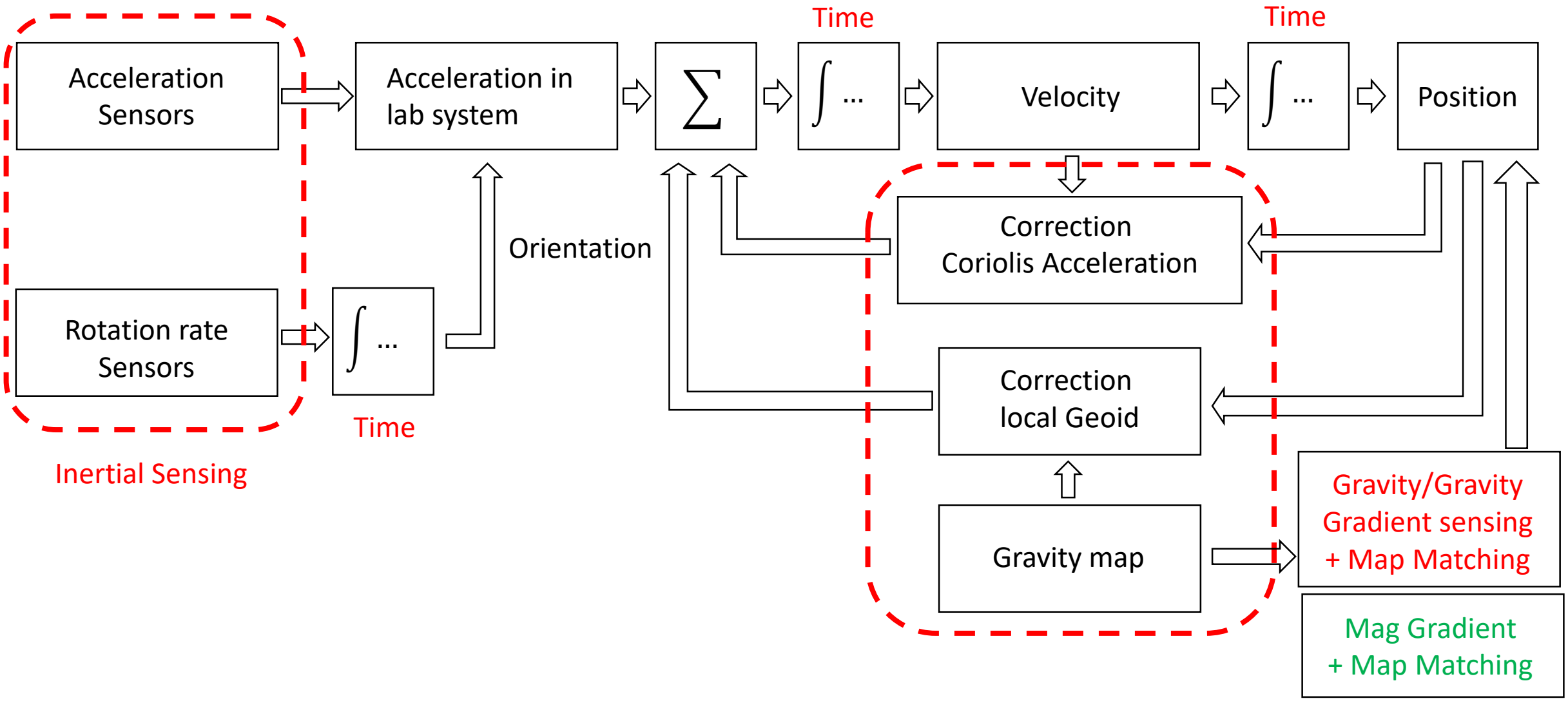
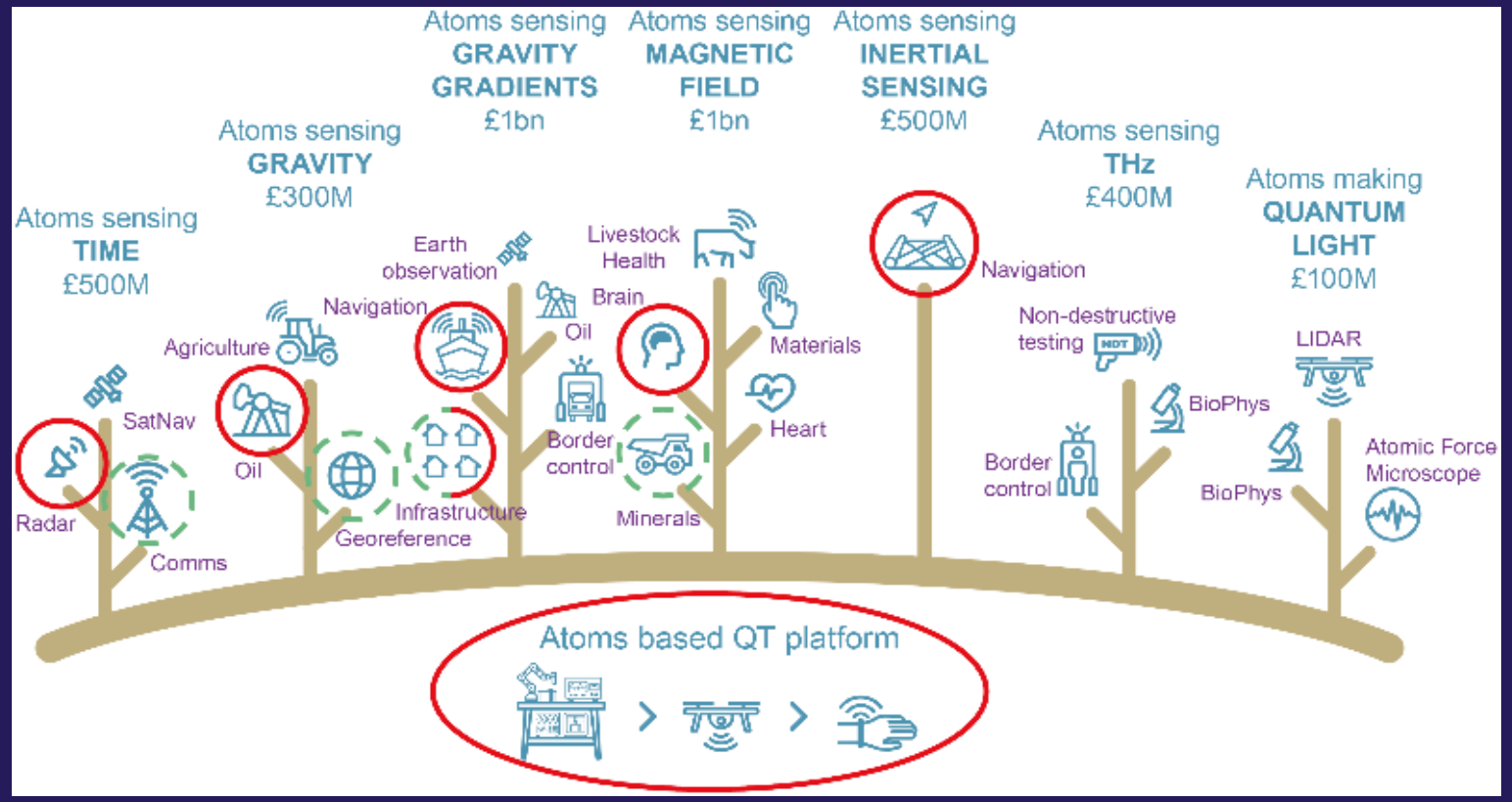
Schematic Setup of a Quantum Navigation System



Roadmap to Applications



For Atom Interferometry, see also: Nature Reviews Physics **1**, 731 (2019)

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UK National QT Hub in Sensors and Timing
Funders, Partners and Collaborators

TopGaN Quantum Technologies Ltd

EPSRC funding £59.5M, collaborative projects with over 85 companies: £150M

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If we don‘t act, others will harness the opportunity!

THANK YOU FOR LISTENING – QUESTIONS?