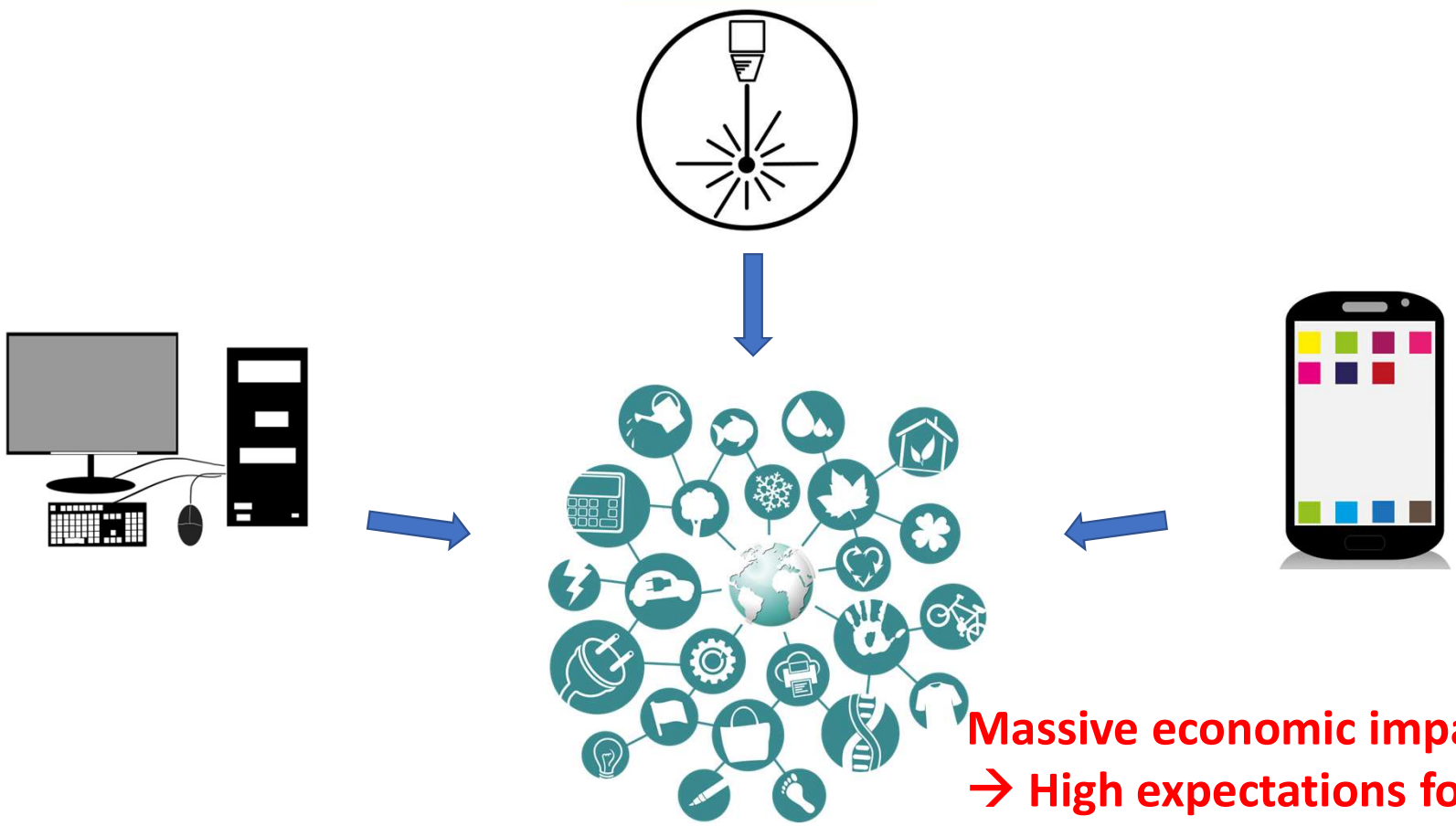
ECONOMIC OPPORTUNITIES OF QUANTUM SENSING

Prof. Dr. Kai Bongs

DLR Institut für Quantentechnologien, Ulm

Quantum 1.0

Technology based on quantum mechanical understanding of condensed matter

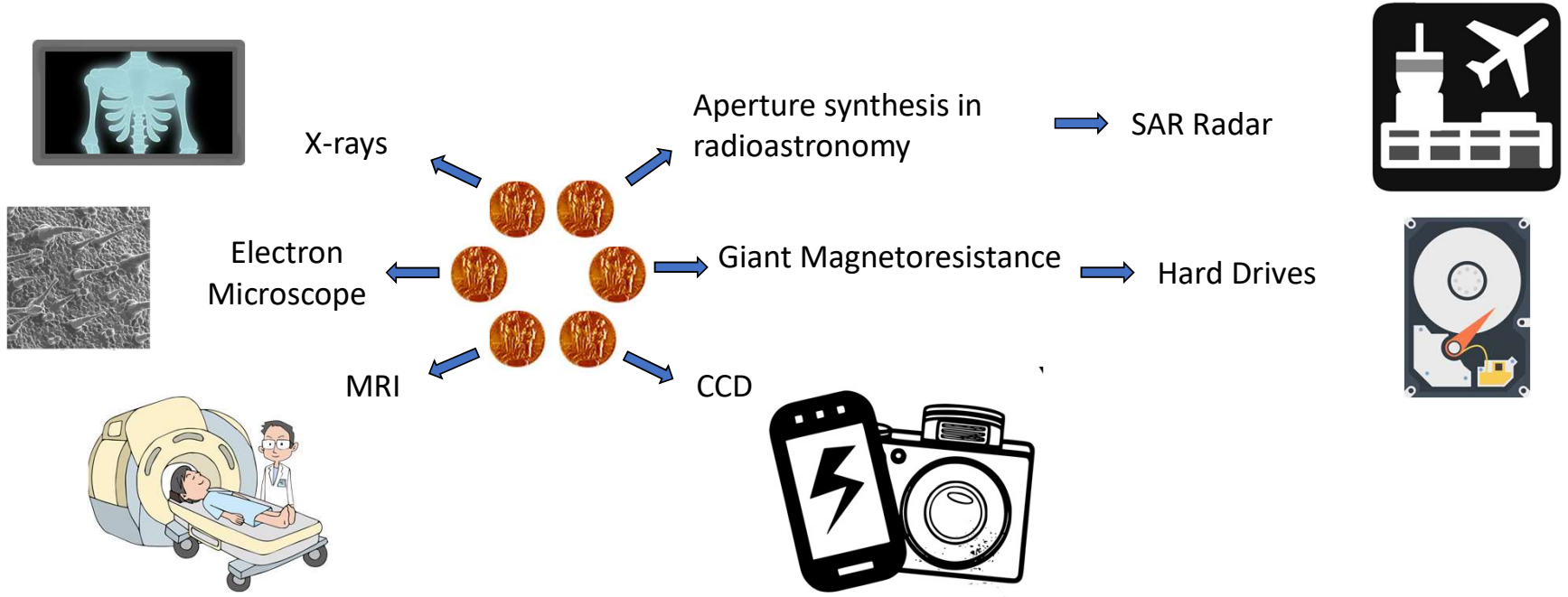


Massive economic impact!!!
→ High expectations for Quantum 2.0

Disruptive consequences of new sensors

Sensors and clocks are enabling system capabilities with large economic impact

- Historic examples based on sensor-related Nobel Prizes



Sensor utility needs systems thinking!

Why Quantum Sensors and Timing?

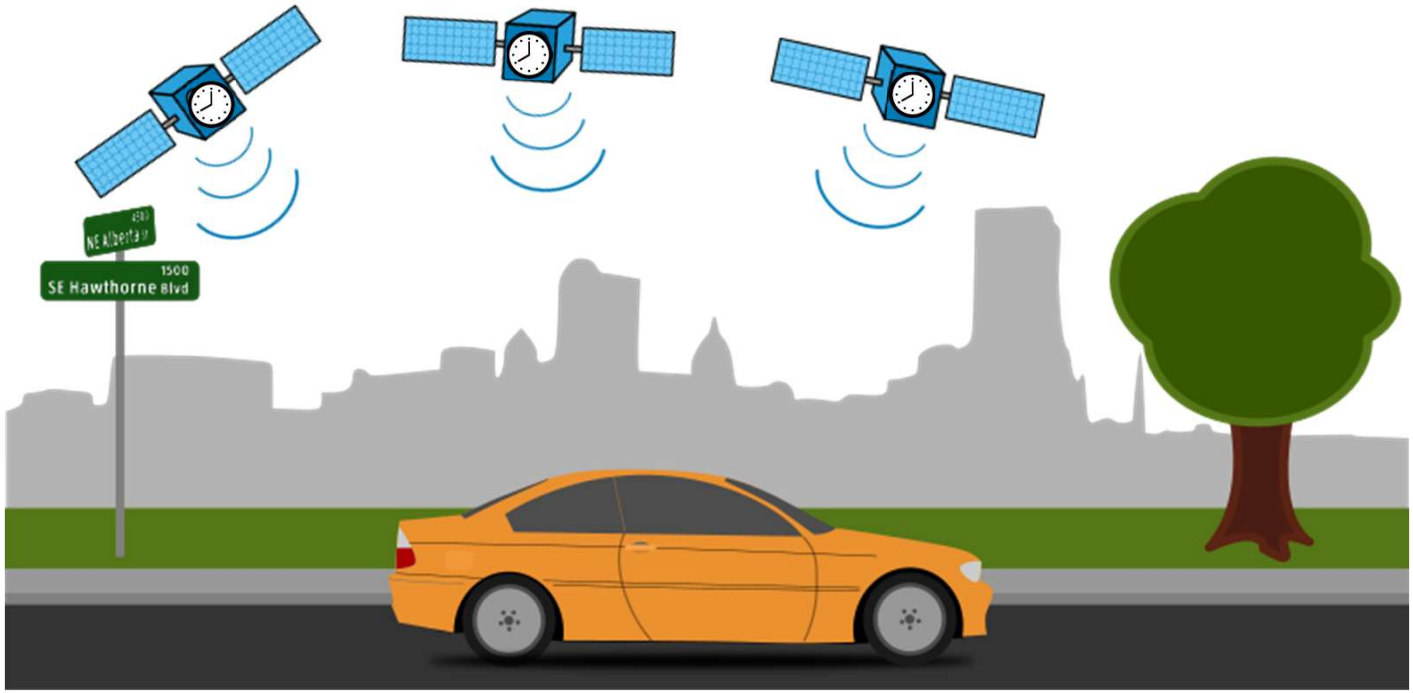
They are here NOW!!!

- 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

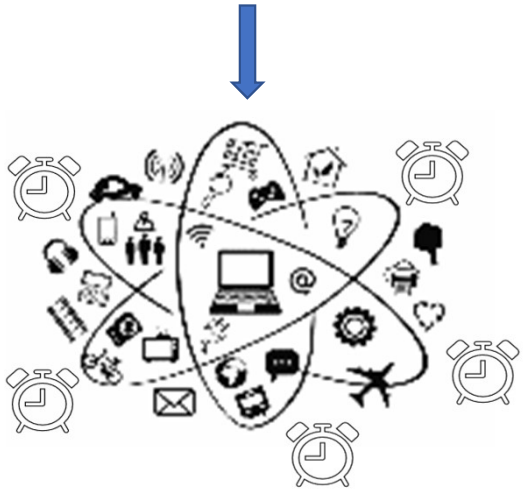
Sensors and Timing underpin more of our economy than most think!

Quantum 2.0 for Navigation and Time

Quantum clocks are powering current global satellite navigation systems



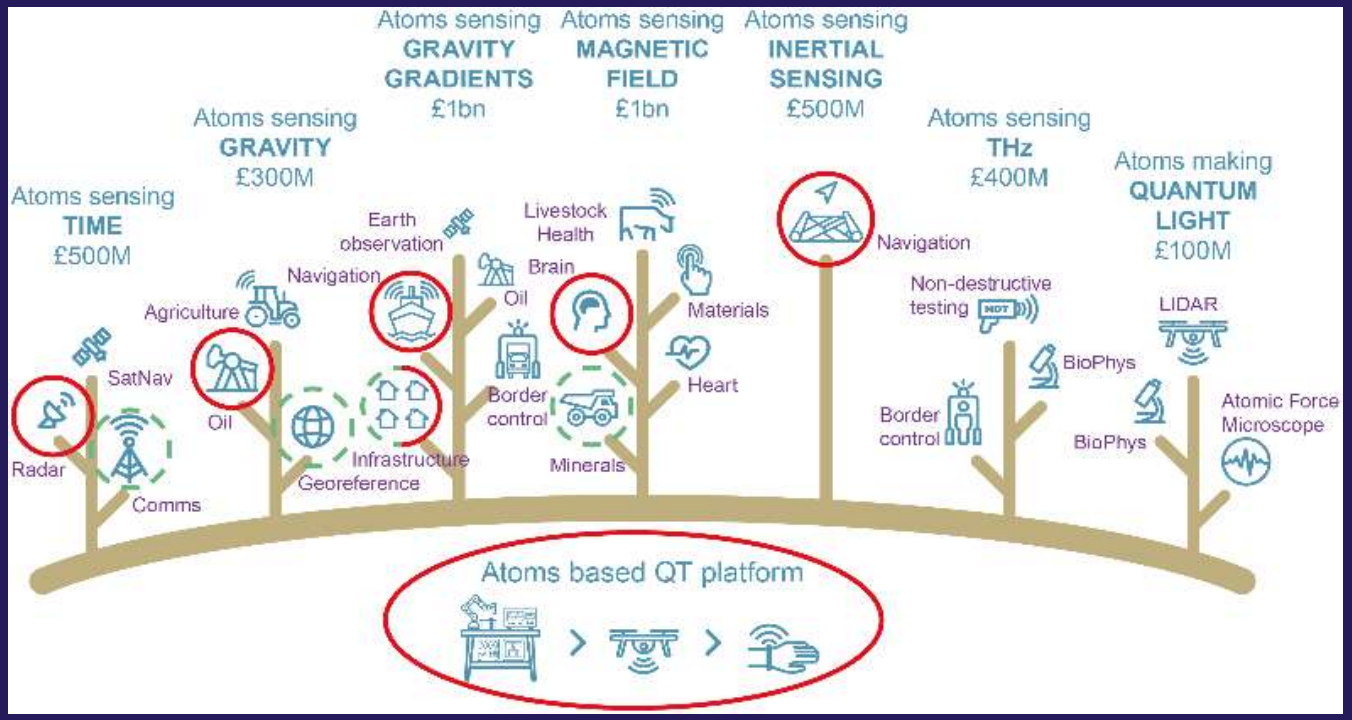
Navigation



Synchronisation

Impact: 5-10% of GDP

Roadmap to Applications



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

UK
Quantum Technology Hub
Sensors and Timing

UK NATIONAL
QUANTUM
TECHNOLOGIES
PROGRAMME

Systems Thinking for GDP-Scale Impact

Example: Healthcare Start-ups

- CERCA: Quantum Magnetoencephalography
  - Diagnostics for brain health conditions
  - E.g. Alzheimers (global economic impact: $1trn)
  - Understanding brain ageing

- NVision: Fast Diagnostics of Cancer Treatment
  - 1 week instead of 3 months → saving lifes

- Q.Ant: Control of Prostheses
  - Contactless, i.e. reliable and no rejection reactions

Roadmap for Magnetic Sensor Applications

Business Advantage through Quantum Magnetometry

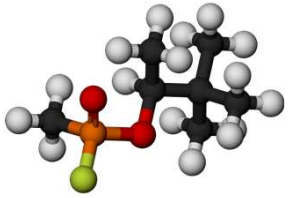
Oil and Mineral Exploration

Quantum Magnetoencephalography

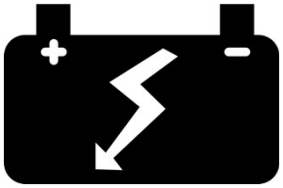
Routine Clinical Diagnostics

Gaming

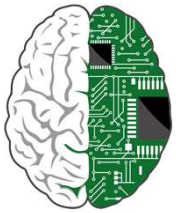
2020 2030 2040



Marker Preparation Chemical Analysis



Battery diagnostics



Brain Machine Interfaces

Gravity Sensors for Navigation

~7% GDP

Motivation: GNSS Vulnerabilities

- Reduced precision in cluttered spaces
- Does not work indoors, underwater, or underground
- Can be easily jammed or spoofed

GPS Jammer Store UK

Your one stop shop for GPS equipment

https://www.gpsjammerstore.uk

RESILIENT NAVIGATION and TIMING FOUNDATION

HOME BECOME A MEMBER WHO WE ARE WHAT WE DO

$5 GPS Spoofer Now Available – Hackaday.com

by Editor | Apr 24, 2018 | Blog

Blog Editor's Note: An alert member pointed us to this item just posted yesterday. Hackers have their own websites where this kind of information is readily available. We are posting it here to help inform those who worry about hackers and are trying to make policy and systems that will keep us all safer.

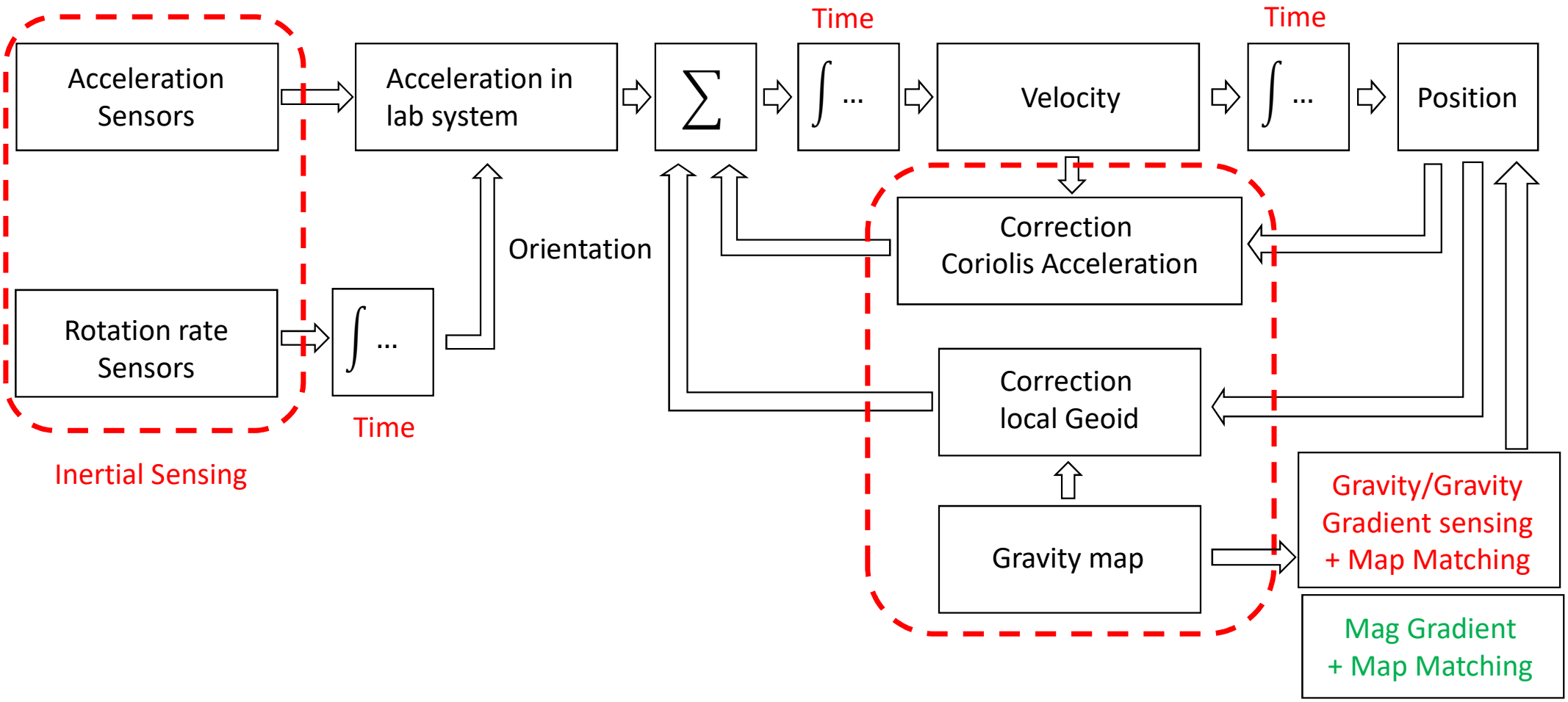
https://rntfnd.org/2018/04/24/5-gps-spoofer-now-available-hackaday-com/

Collaboration: physics, materials science, electrical engineering, industry

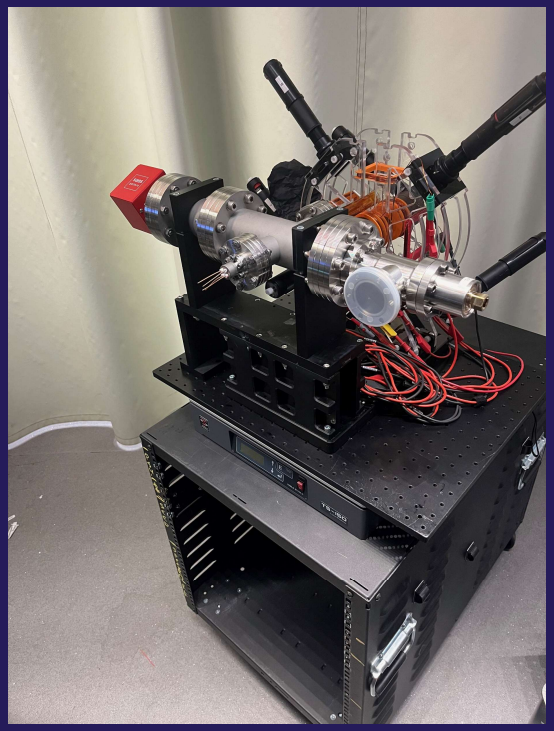
UK Quantum Technology Hub Sensors and Timing

UK NATIONAL QUANTUM TECHNOLOGIES PROGRAMME

Schematic Setup of a Quantum Navigation System

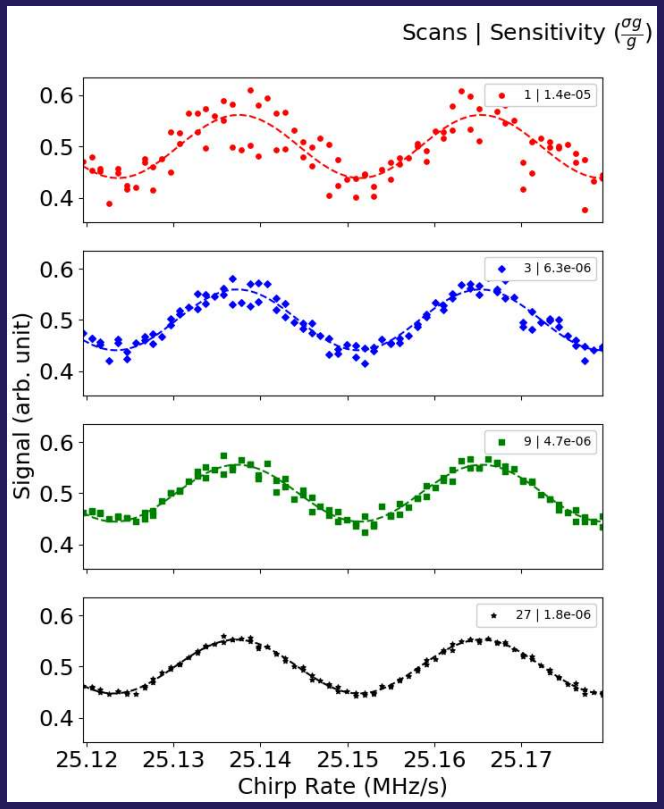


High Bandwidth Accelerometer – initiated with Toyota



Current Status

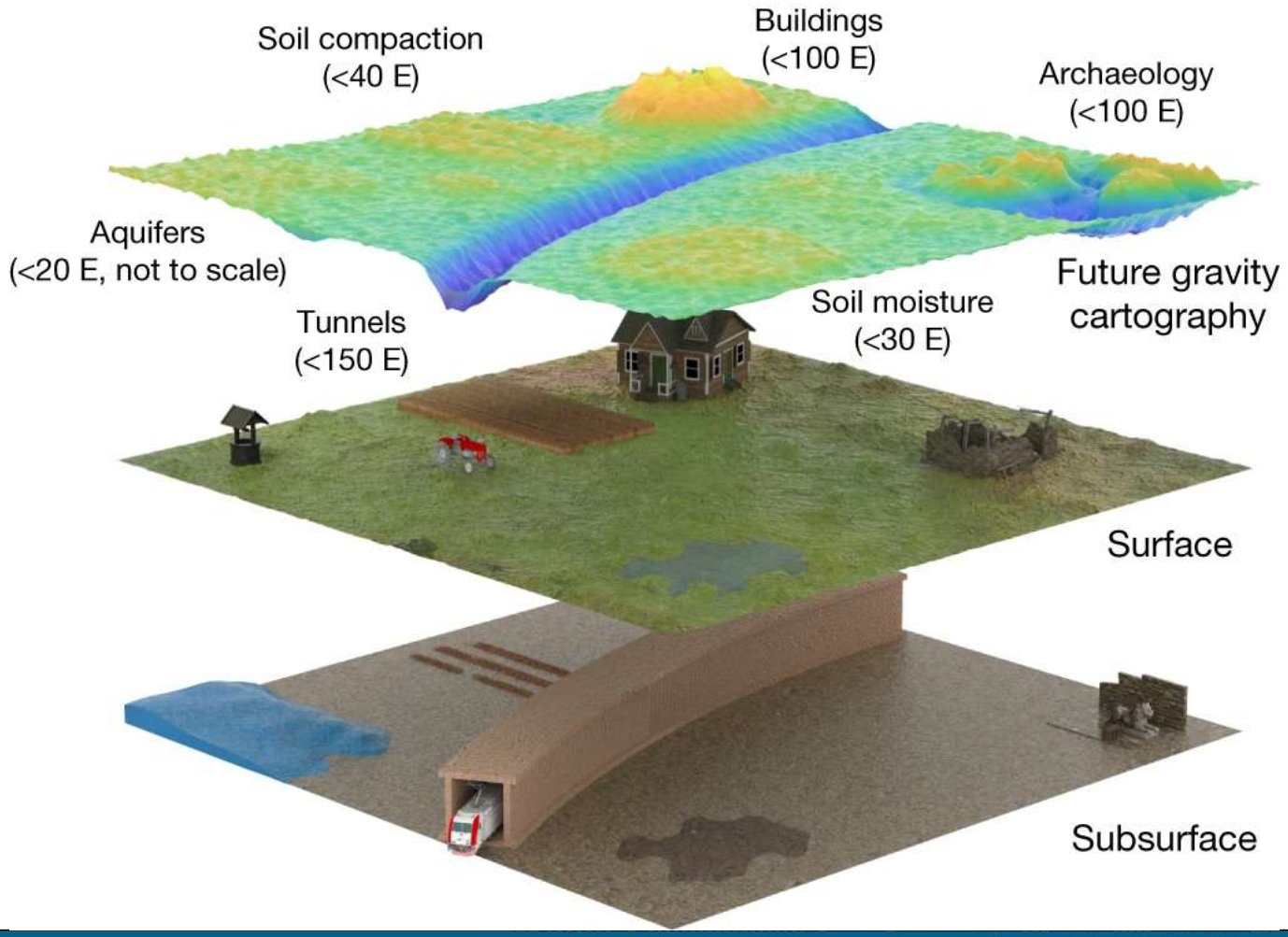
- Performance of the high-bandwidth quantum gravimeter
  - Number of cold atoms: 5×10^7
  - Temperature: 7-10 μK in 2 ms
  - Sensitivity: 1×10^{-5} g/√Hz ≅ 100 QSL (1×10^{-7} g/√Hz); about 10^{-6} g after 100 s integration.



Enabling Gravity Cartography

University of Birmingham

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



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

Towards compact sensors

- Person-portable and moving platform devices underway

CASPA

MOT on UAV

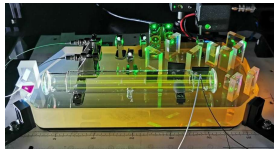
MOT in 50 m borehole

Exploitation in new start-up:

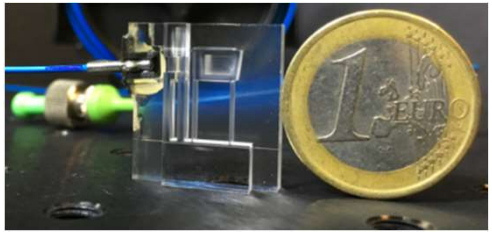
Delta g limited

Quantum Technology for Mobility

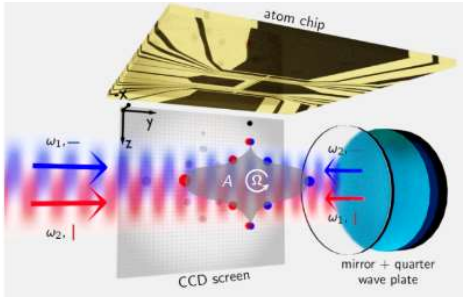
Clocks and inertial sensors (with DLR SI, KN, GK, OS)



DLR-clock to fly on ISS



Optomechanical: DLR QT



Atom interferometry: DLR SI

Future generations of Galileo

Augmenting an existing system

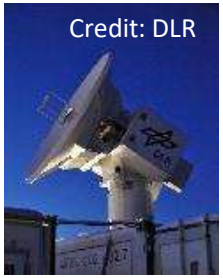
Inertial sensors

Needing systems of systems engineering

Roadmap for Optical Clock Applications

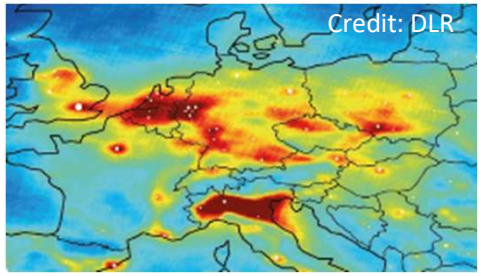
How to make the systems engineering happen?

Next generation GNSS



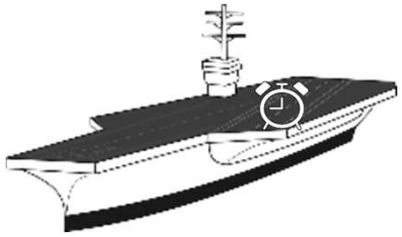
Long distance 3d imaging radar

Urban airspace control



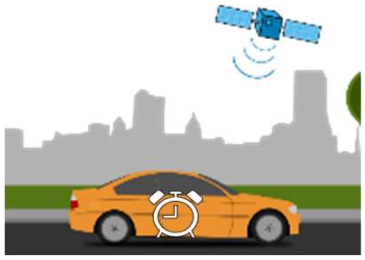
mm-level global height reference system

2030 2040 2050



GNSS resilient operation

High bandwidth communication



Autonomous vehicles

Sensor Utility Driven by System Integrators

Example: UK National Accelerator for Quantum Sensors (NAQS), led by BAES, BP and BT

- Gravity (gradients) for
  - Oil and mineral exploration (energy)
  - Map matching navigation (defence, transport)
  - Underground infrastructure (communications, water,…)
- Clocks for
  - Defence platforms (defence)
  - Seismic networks (energy)
  - Deterministic networks (communications)
- Magnetometers for
  - Exploration (energy)
  - Map matching navigation (defence)
  - Non-destructive testing (all)
- …

Benefits

- Shared development costs
- Sustainable and affordable supply chain
- Interoperability due to joint standards
- Sequential integration towards mass markets

Accelerating Sensor Utility

Key Points for Discussion

- Quantum Sensors are available and have competitive performance now
- They need market pull to prosper
- GDP-scale impact market applications are systems-driven
- Needed: Funding for systems of systems engineering aiming at application trials in relevant environments – best led by systems companies in collaboration with academia and research organisations

Institute for Quantum Technologies

Quantum technology: from Idea to Space