

EIGENSCHAFTEN, ANWENDUNGEN UND ÖKONOMISCHE CHANCEN VON QUANTENSENSOREN

Webinar Bayern Innovativ

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Institutsdirektor QT

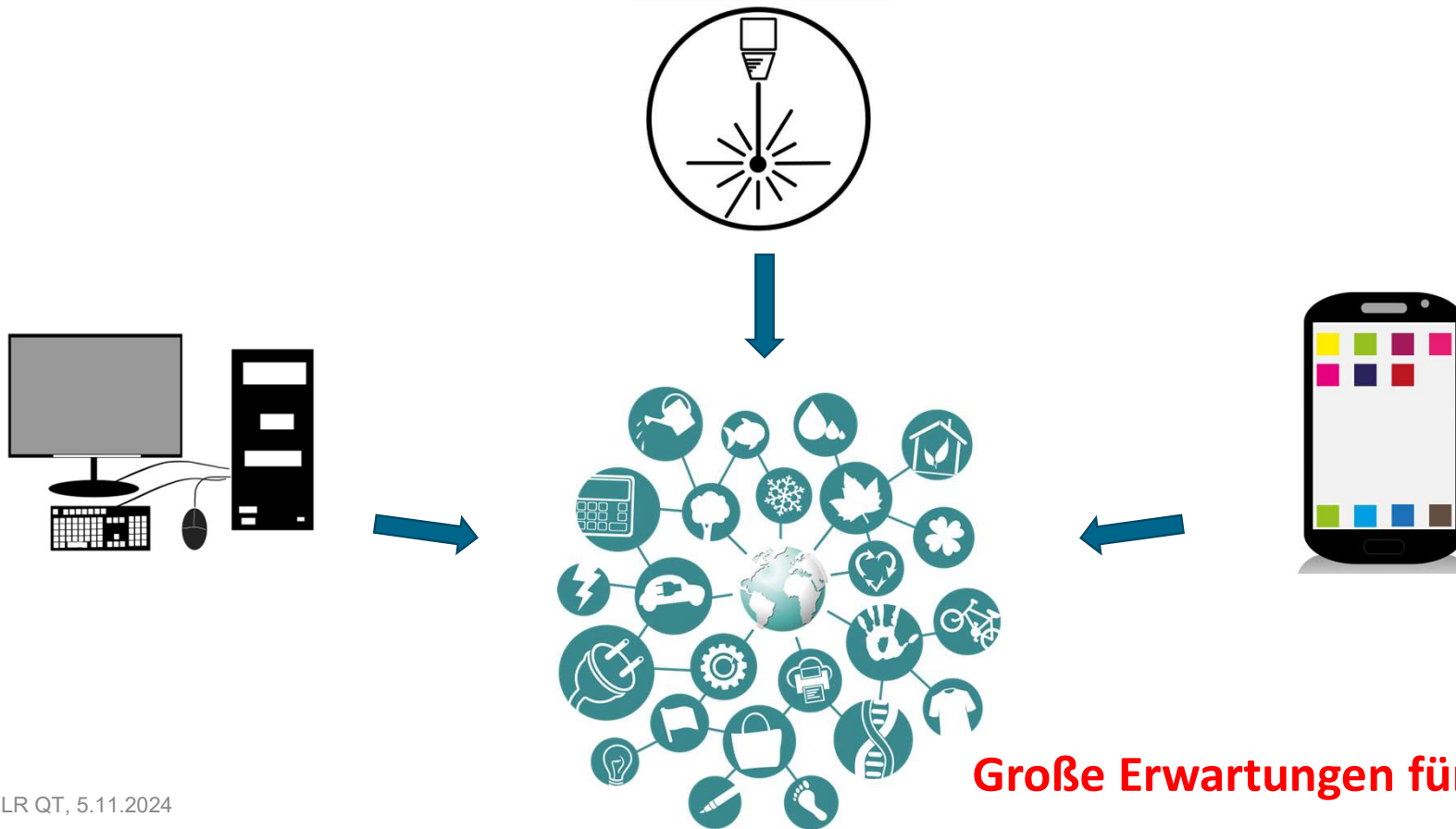
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89081 Ulm



Quantum 1.0



Technologie basierend auf dem quantenmechanischen Verständnis von Festkörpern



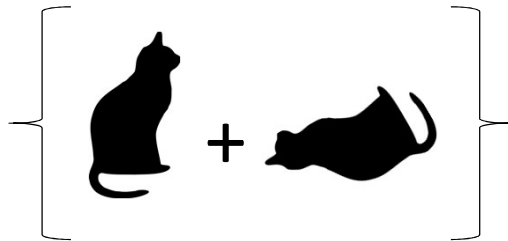
Große Erwartungen für Quantum 2.0

Quantum 2.0



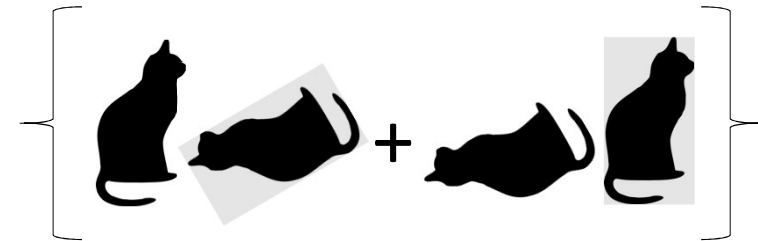
Superposition und Verschränkung

Superposition



Teilchen gleichzeitig in mehreren Zuständen
→ Schrödinger's Katze

Verschränkung



„Verschränkung über mehrere Teilchen hinweg“

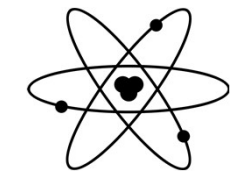
Zutaten für die Quantentechnologie



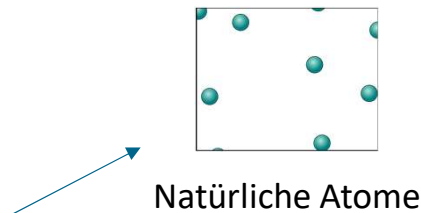
Quantenteilchen

+

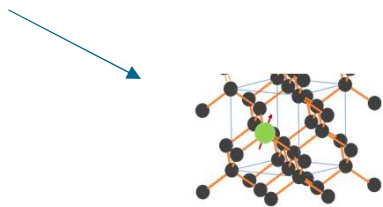
Kontrolle



Atome / Ionen



Natürliche Atome



Künstliche Atome

- NV Diamant*
- Quantenpunkte*
- Supraleitende Ringe*

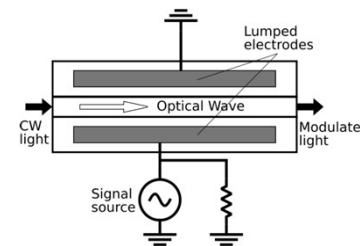
...



Photonen



Laser- oder RF Pulse



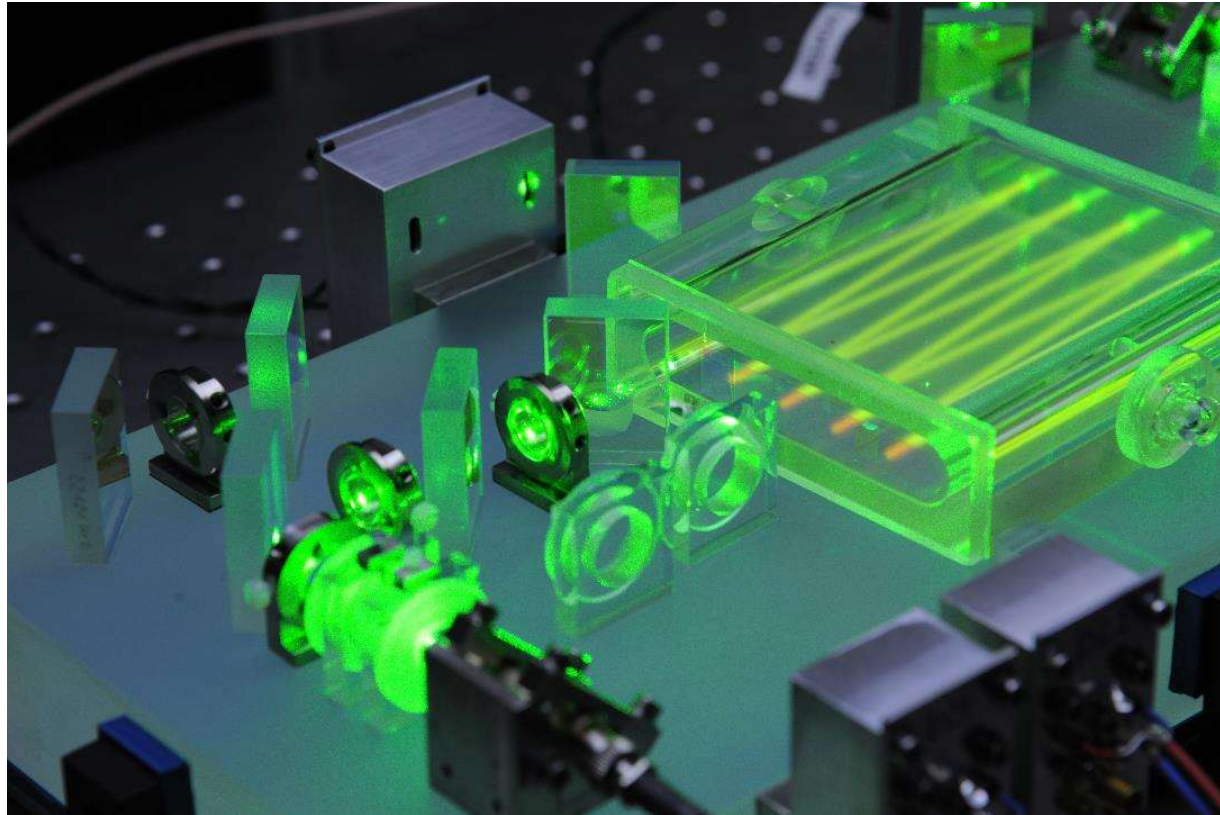
Nichtlineare Kristalle
Photonische Systeme

- Elektronik
- Software
- Abschirmung
- Verpackung
- Nutzerschnittstelle

...

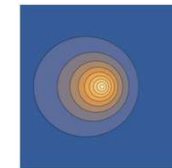
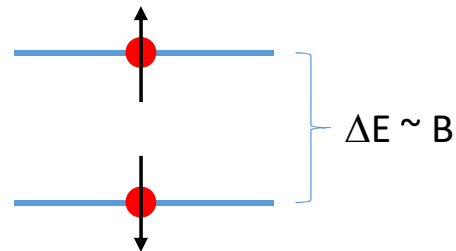
This is how it looks like

DLR Iodine clock

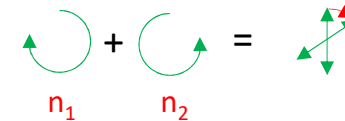
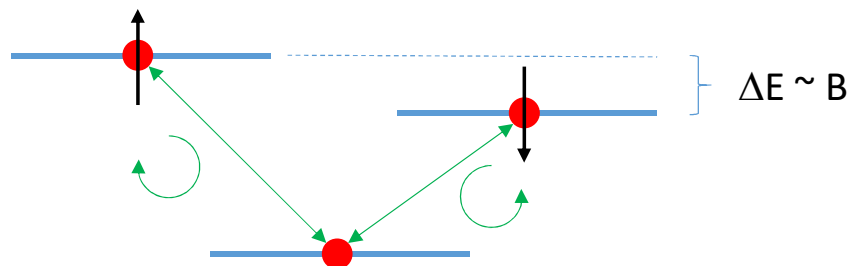


Quantum Magnetometers

Superposition of energy levels depending on external magnetic field



Oscillation frequency depends on magnetic field



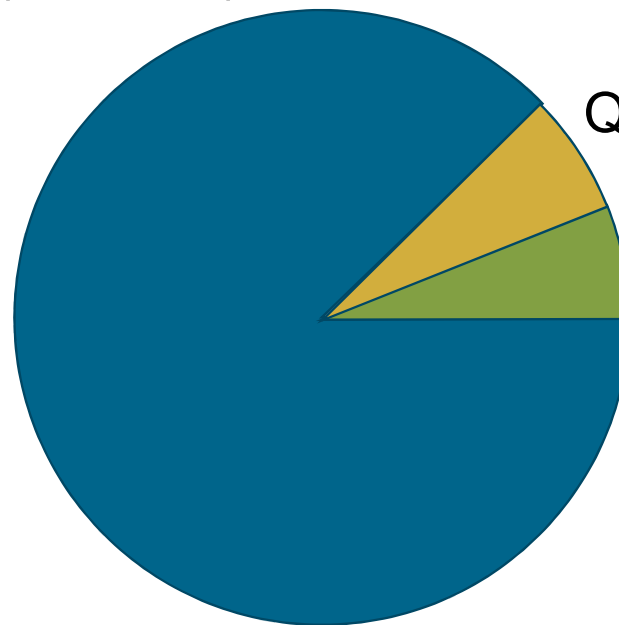
Rotation of polarization

Quantum Technology Applications and Markets



Market estimates in 2040 (source: McKinsey Quantum Technology Monitor, 2023)

Quantum Computing (\$9-\$93B)



Quantum Communications (\$1-\$7B)

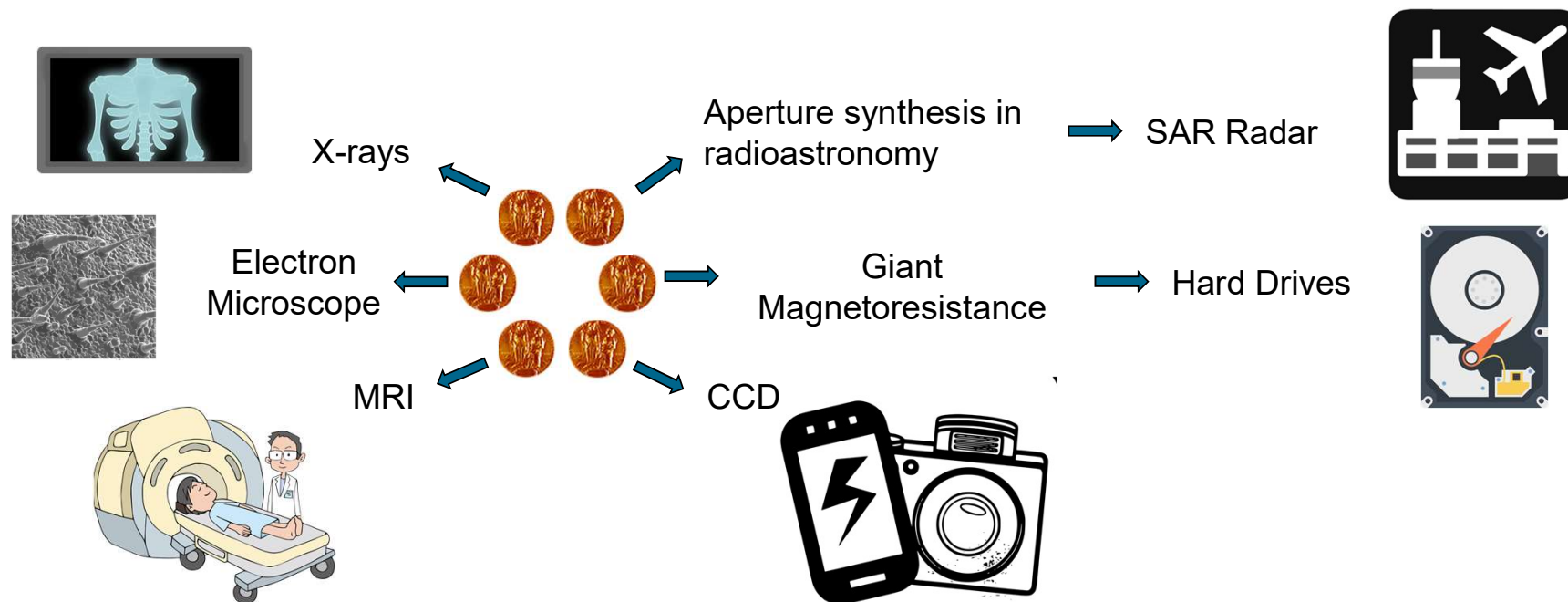
Quantum Sensing (\$1-\$6B)

Overall economic impact much larger (e.g. estimate for QC in 2035: \$620B-\$1270B)

Disruptive consequences of new sensors

Sensors and clocks are enabling system capabilities with large economic impact

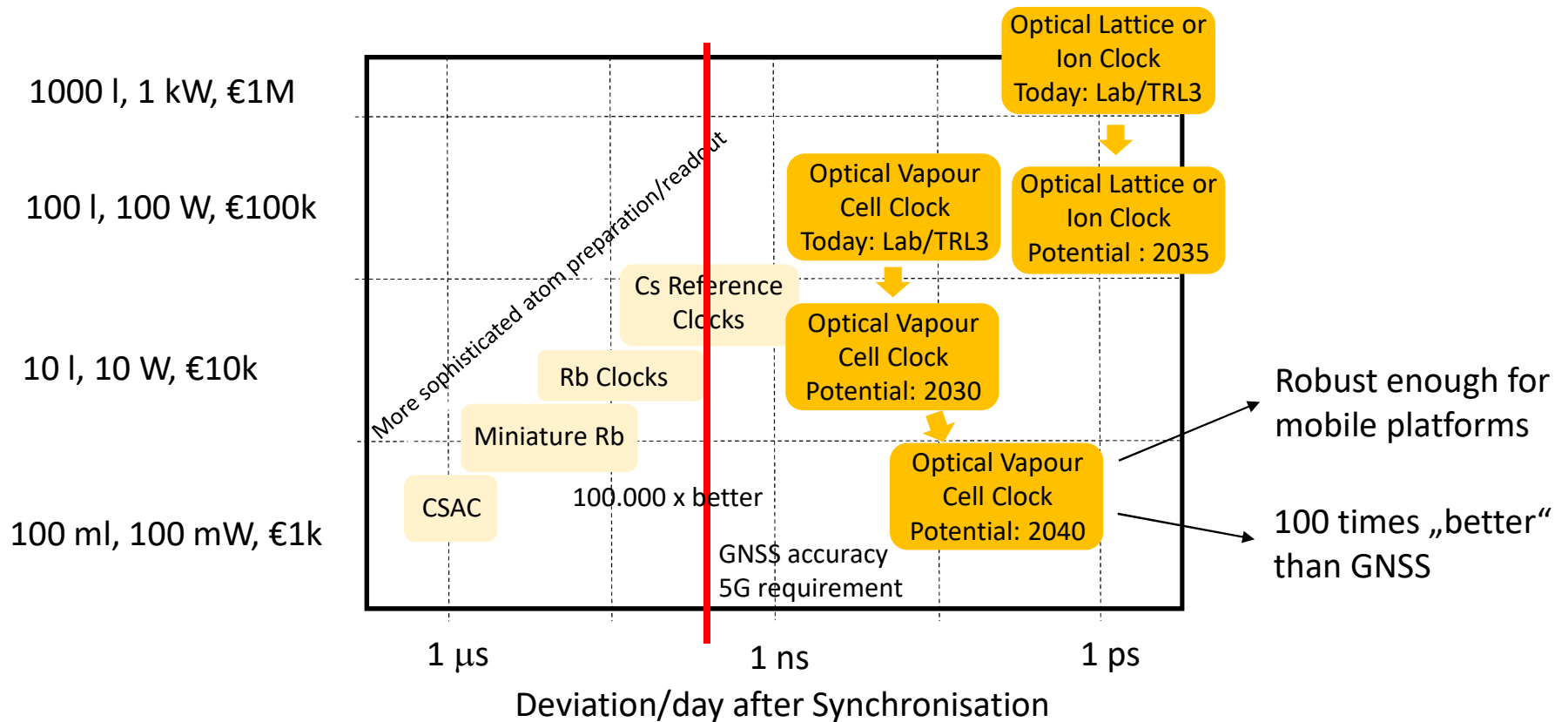
- Historic examples based on sensor-related Nobel Prizes



Sensor utility needs systems thinking!

Was macht Quantensensoren attraktiv?

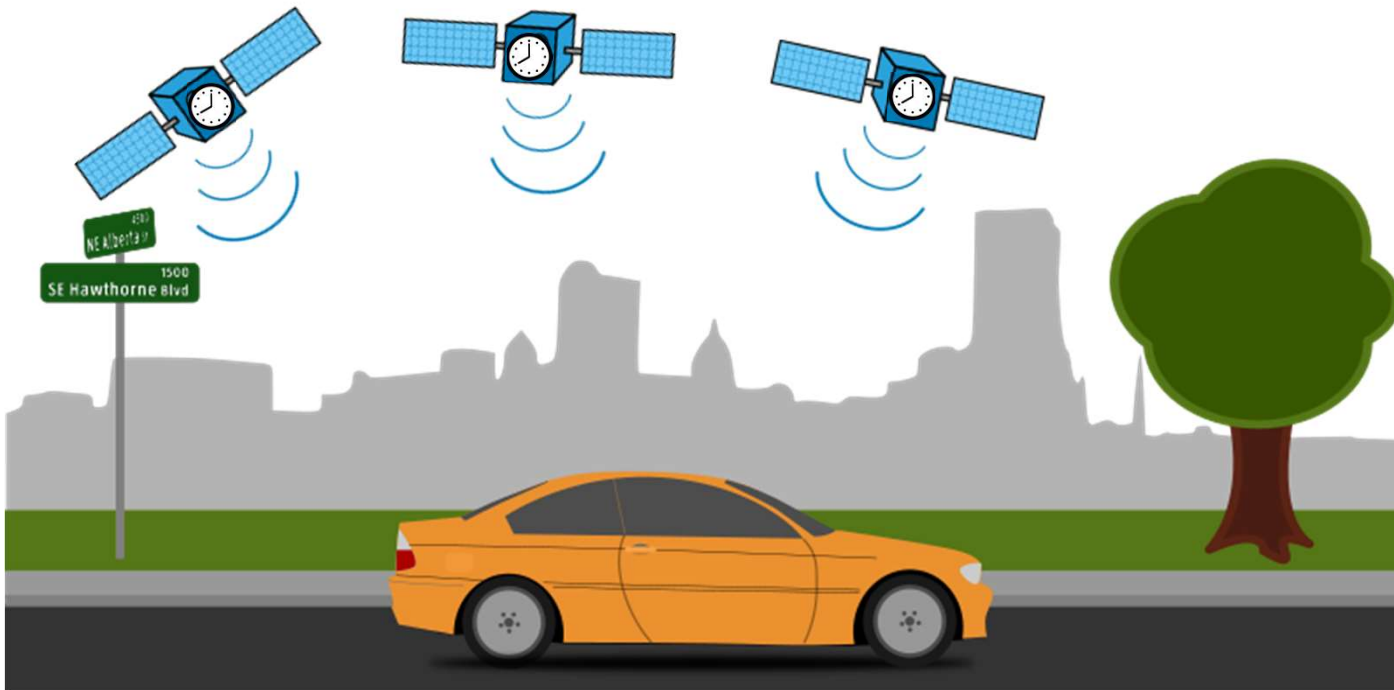
Quantenuhren – Einzigartige Eigenschaft: Ultimative Genauigkeit



Quantum 2.0 for Navigation and Time



Quantum clocks are powering current global satellite navigation systems



Navigation



Synchronisation

Impact: 5-10% of GDP

Commercial Opportunities through Quantum Clocks



Credit: ENISA

Communication



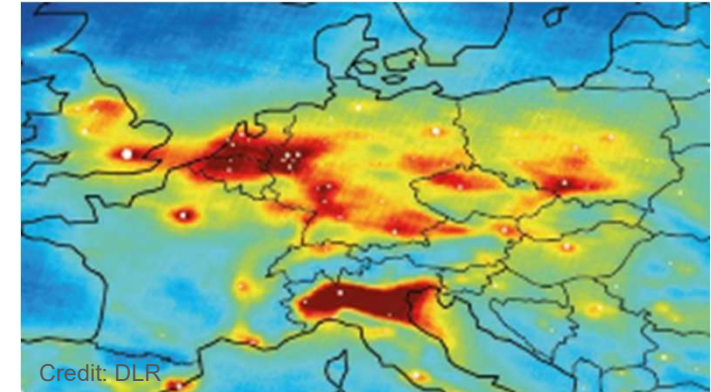
Credit: DLR

3D Radar



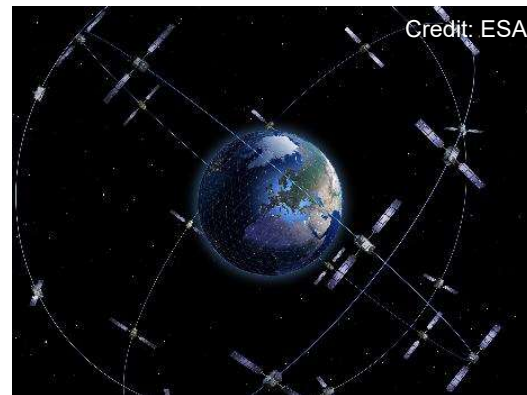
Credit: DLR

Urban Flight



Credit: DLR

Global Height Reference



Credit: ESA

Satellite Navigation

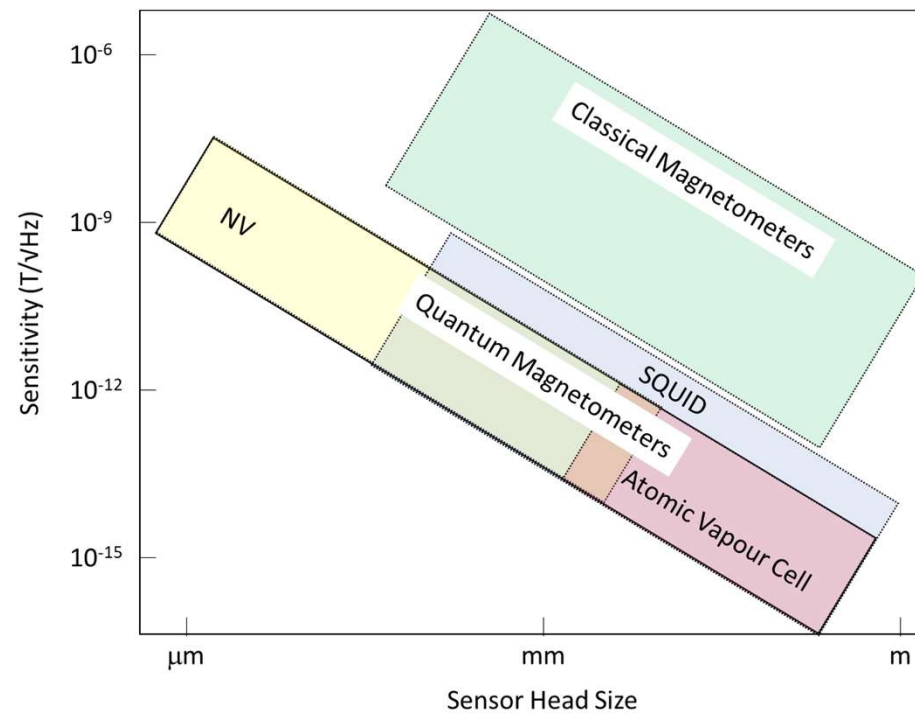


Credit: DLR

Autonomous Vehicles

Was macht Quantensensoren attraktiv?

Quantenmagnetometer – Einzigartige Eigenschaft: Hohe Empfindlichkeit bei Raumtemperatur

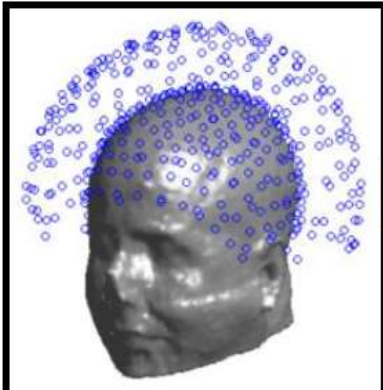




OPM-MEG development – 2015 – 2019 - Adaptation to Head Size



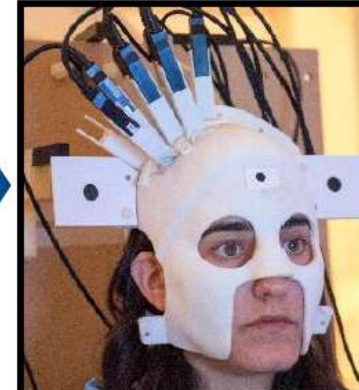
Conventional MEG



On scalp MEG simulations 2016



Single channel recording 2017



First wearable OPM array 2018



First paediatric helmet 2019

A new generation of quantum sensors have enabled 'wearable' brain imaging technology



50 channel whole head system 2020



First simultaneous OPM/EEG 2019

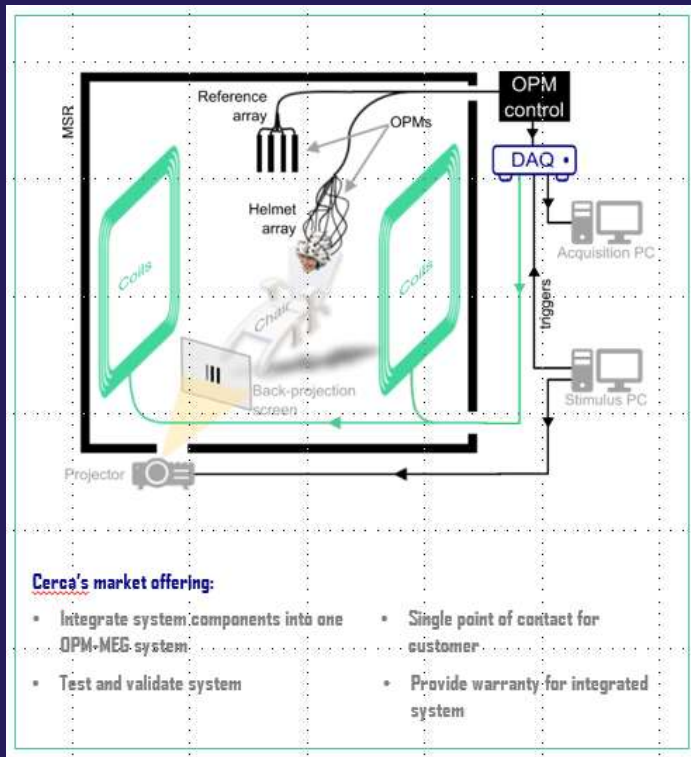


First Gen II OPM recordings 2019

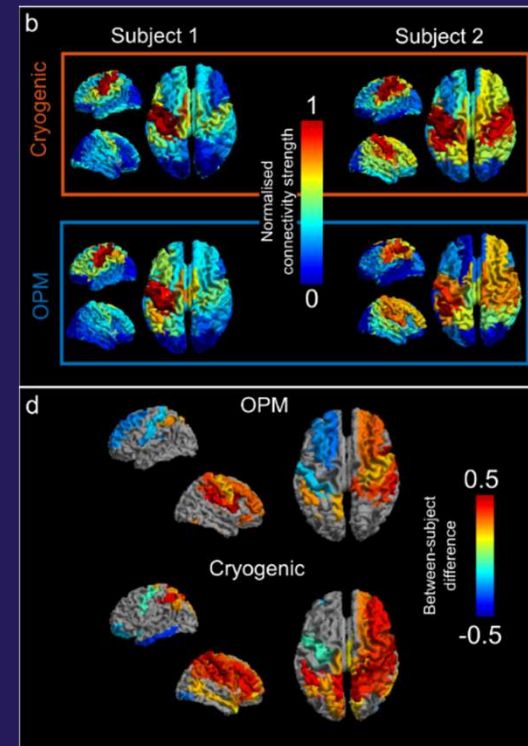


First VR-MEG recording 2019

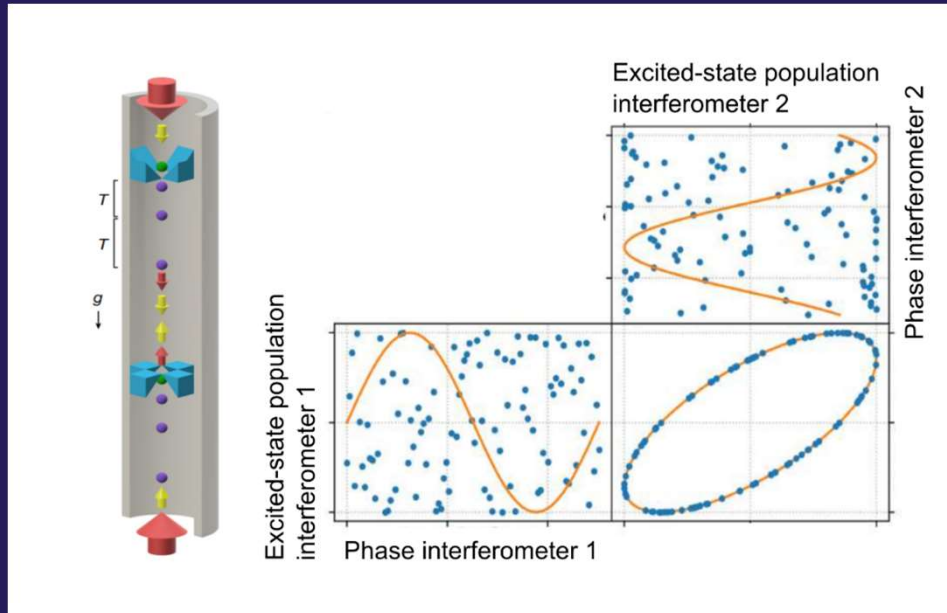
Its here NOW: Commercial Offering



Joint venture between University of Nottingham and Magnetic Shields Ltd.



Quantum Inertial Sensors: low bias and accurate scale factor



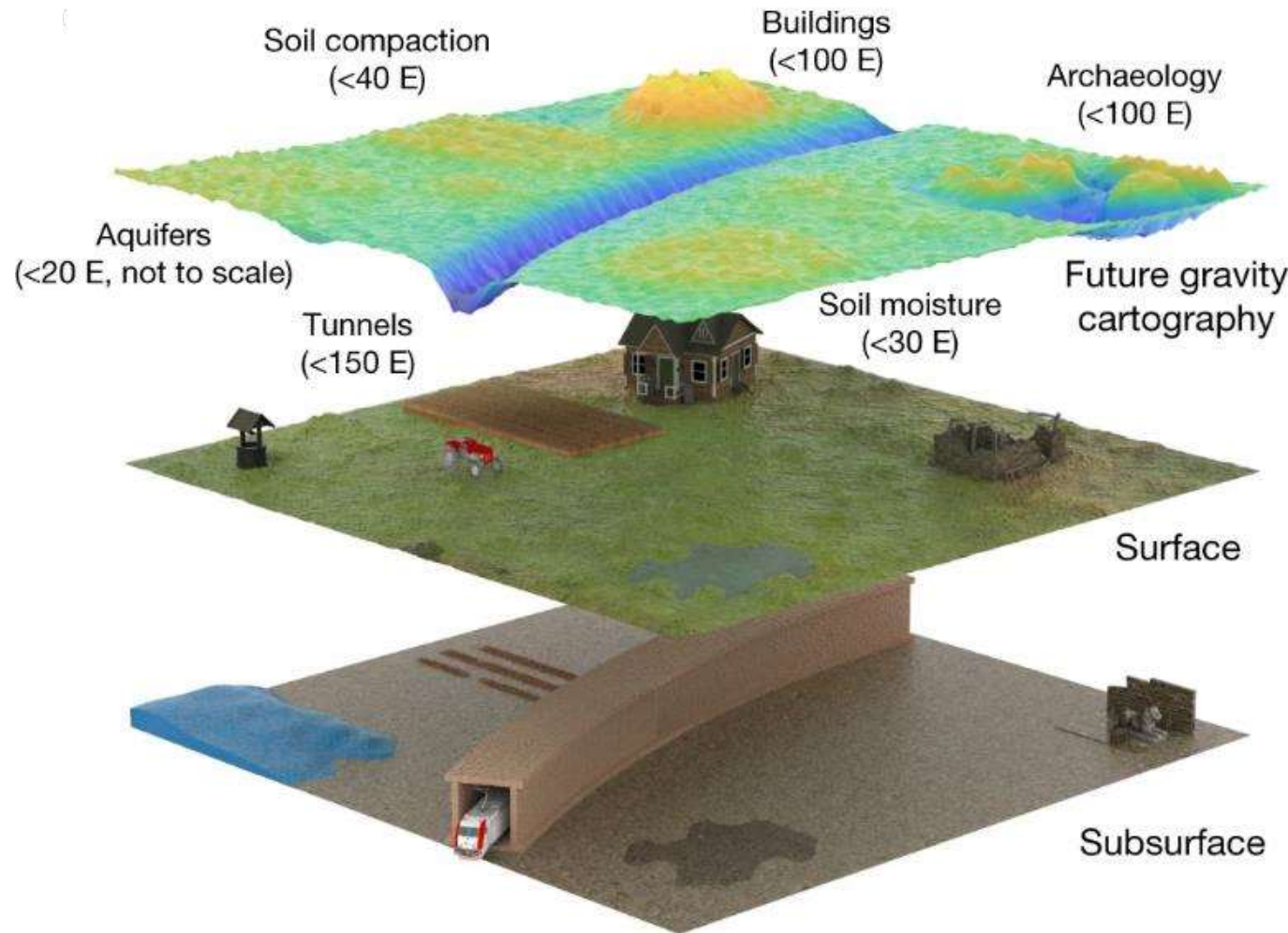
[Nature](#) volume 602, pages590–594 (2022)

Common laser beam
↓
Near-Perfect acceleration suppression and alignment in Atom Interferometry

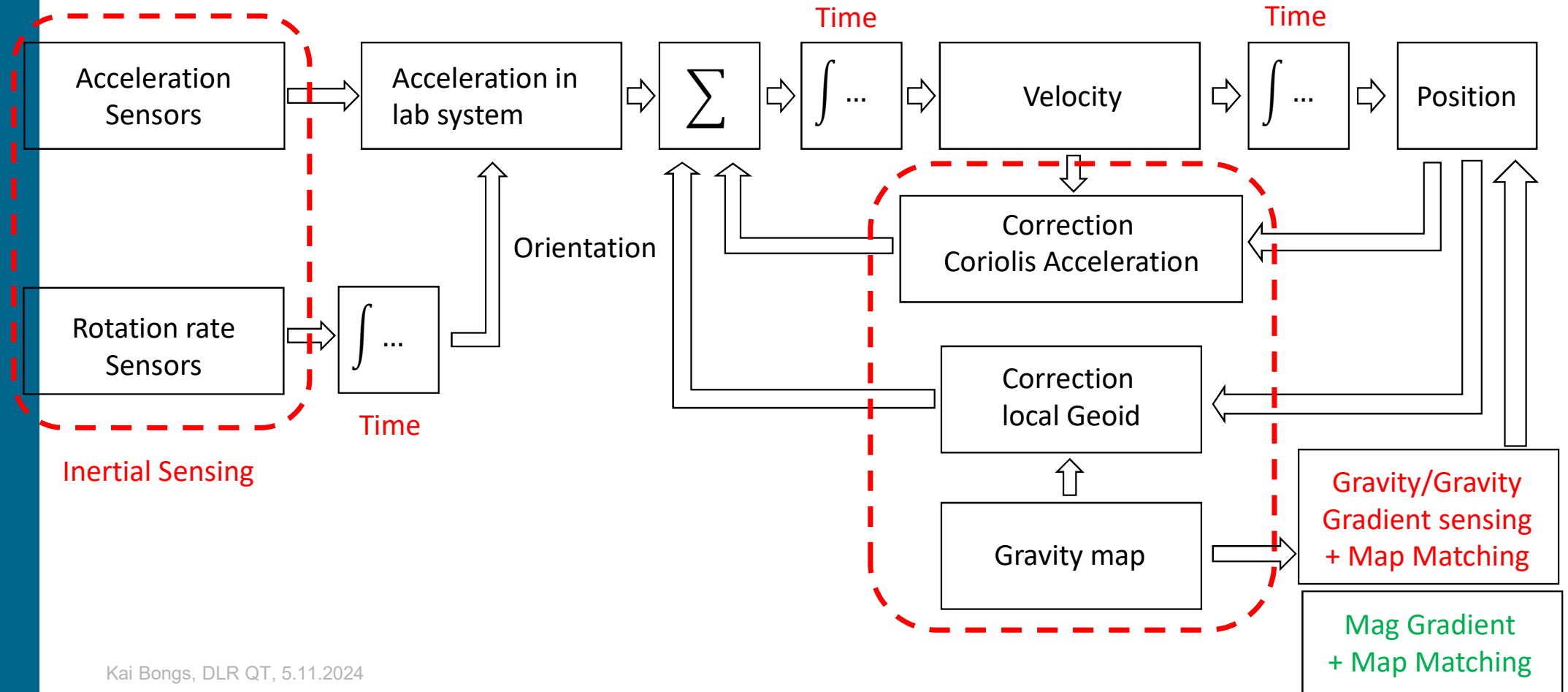


Enabling Gravity Cartography

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



Schematic Setup of a Quantum Navigation System



GNSS critical dependencies



Need for independent alternatives

64 UNTERNEHMEN & TECHNOLOGIE Satelliten

Wo bin ich?

Satellitensysteme wie GPS steuern Wirtschaft und Verkehr. Nun werden sie großflächig gestört – und der Westen arbeitet an einer Alternative

TEXT
Thomas Kühn

Artikel gestrichelt: GPS-Signale an den Messungen
● Nichtig (0 bis 25 Prozent) Keine Daten...
● Verfügbar (25 bis 50 Prozent) ● Zu Land
● Verfügbar (50 bis 75 Prozent) ● Zu Wasser

Kai Bongs, DLR OT 5 11, 2024

UK Blackett
Report
2018

Satellite-derived Time and Position: A Study of Critical Dependencies

Government
Office for Science



FEDERAL REGISTER

The Daily Journal of the United States Government



PD Presidential Document

Strengthening National Resilience Through Responsible Use of Positioning, Navigation, and Timing Services

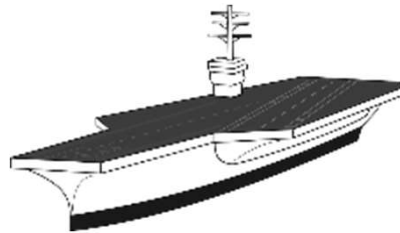
A Presidential Document by the Executive Office of the President on 02/18/2020

Wirtschaftswoche 10, 2024

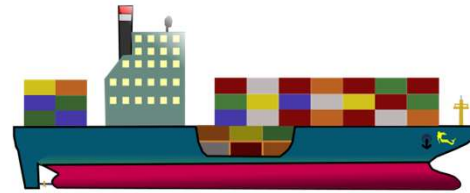
Market Roadmap for Quantum Navigation Systems



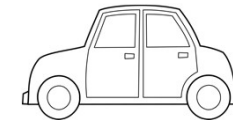
Cost and regulatory requirements as key drivers



Strategic platforms



Autonomous ships and underwater vehicles



Autonomous vehicles

2030

2040

2050

Unit cost

xM€

xxxk€

xxx€

Market volume

xxM€

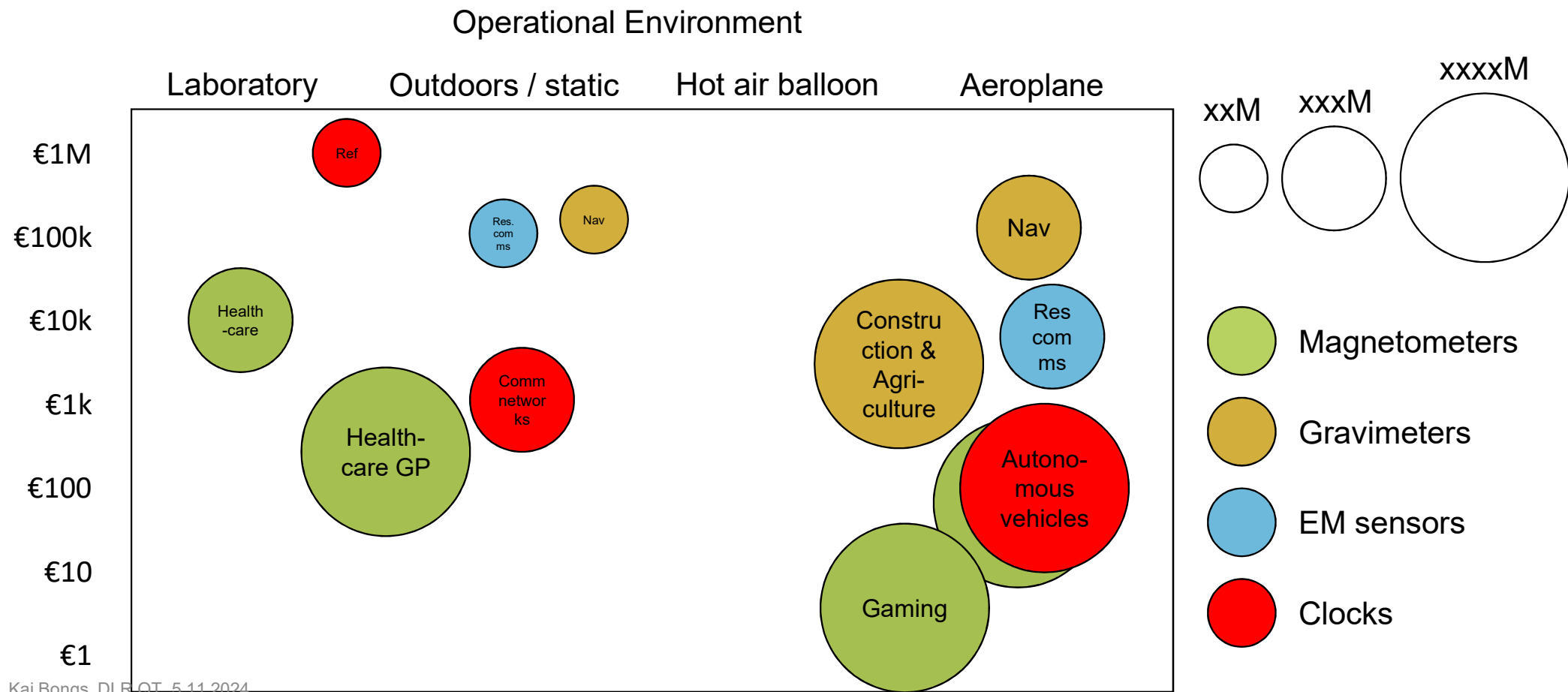
xxxM€

xxxxxM€

Potentially Accessible Quantum Sensor Markets



Key Drivers: Robustness and Cost



Thank you for listening



Questions?