Quantum Sensing, Computing and Communication: Game Changing Technology

Lodewijk Arntzen

26 mei 2024


let's change
YOU. US. THE WORLD.

Overview

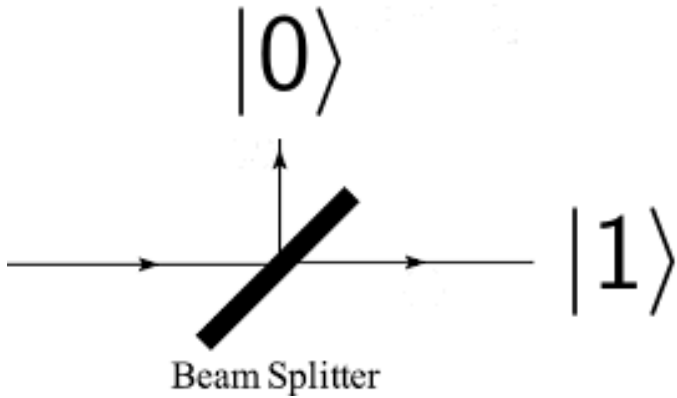
1. 100 Years of Quantum Science and Technology Revolution
2. Quantum Crash Course
3. Quantum Delta NL
4. Applications in Computing, Communication and Sensing
5. Position of UAS in Quantum Ecosystem

100 Years Quantum Science Revolution

1. 1925 Schrödinger and Heisenberg
2. 1935 Einstein, Podolsky, Rosen
3. 1935 Verschränkung (Entanglement)
4. 1935 Von Neumann, Mathematische Grundlagen der Quantenmechanik
5. 1936 The Logic of Quantum Mechanics, Birkhoff, Von Neumann
6. 1964 John Bell, Inequilities, Is Nature Local?
7. 1982 Feynmann: Simulating Physics with Computers
8. 2017 Landsman: (New) Mathematical Foundation of Quantum Mechanics
9. 2022 Nobel Prize, Aspect, Clauser and Zeilinger
10. 2025: Celabration of 100 Years Quantum Science

Quantum Crash Course

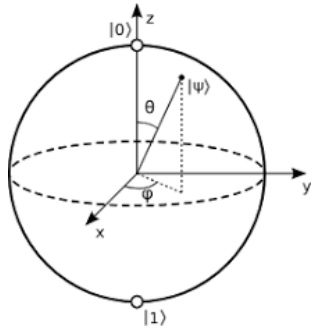
Quantum Crash Course



Quantum Crash Course

- Superposition
- Entanglement
- Measurement Problem

Quantum Crash Course



A quantum state ψ in a superposition is written as

$$|\psi\rangle = c_0 |0\rangle + c_1 |1\rangle \tag{1}$$

and for the complex numbers we require

$$|c_0|^2 + |c_1|^2 = 1. \tag{2}$$

Quantum Crash Course

The quantum state of two qubits is written as

$$|\psi\rangle = \frac{1}{2}\left(c_0\,|0,0\rangle + c_1\,|0,1\rangle + c_2\,|1,0\rangle + c_3\,|1,1\rangle\right) \tag{3}$$

which implies that this is a superposition of $2^2 = 4$ states. So a two-qubit quantum computer can already store four complex numbers.

Quantum Crash Course

The state of 4 qubits can now be written as

$$|\psi\rangle = \frac{1}{4}\left(c_0\,|0,0,0,0\rangle + c_1\,|0,0,0,1\rangle + c_2\,|0,0,1,0\rangle + c_3\,|0,0,1,1\rangle \ldots c_{15}\,|1,1,1,1\rangle\right) \tag{4}$$

this is a superposition with $2^4 = 16$ states simultaniously.

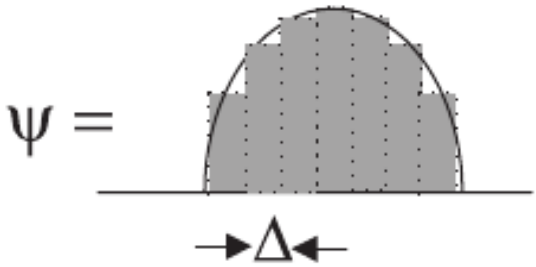
- A four-qubit quantum system can store 16 complex numbers
- Generalizing, we conclude that an N-qubit quantum system can store 2^N numbers
- How many numbers can a 256 qubit system store?

Quantum Crash Course

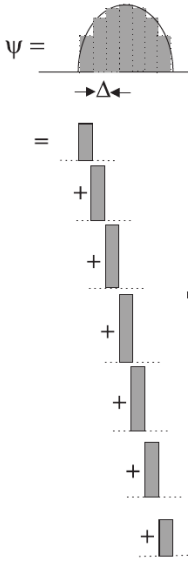
A system of two (or more) qubits can be found in an entangled state. This means that the state of qubit (1) depends on the other qubit (2)

$$|\psi(1,2)\rangle = \frac{1}{\sqrt{2}}\left(|0_1,1_2\rangle + |1_1,0_2\rangle\right). \tag{5}$$

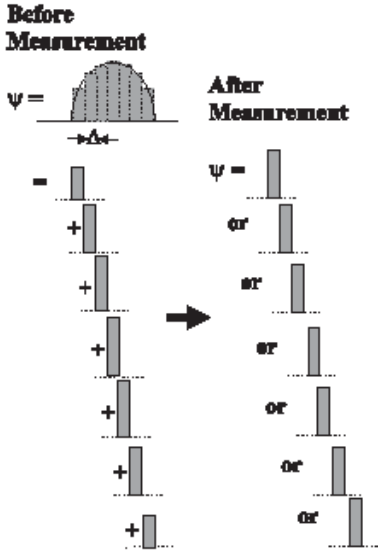
Quantum Crash Course



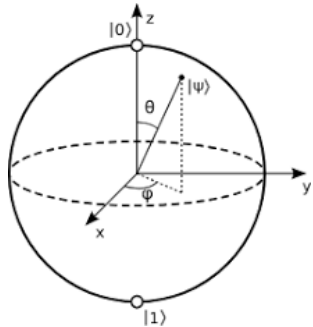
Quantum Crash Course



Quantum Crash Course



Quantum Crash Course



Recall, a quantum state ψ in a superposition is written as

$$|\psi\rangle = c_0 |0\rangle + c_1 |1\rangle \tag{6}$$

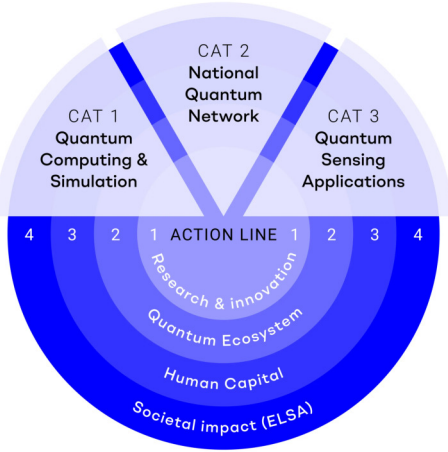
after measurement, the result simply can only be, $|0\rangle$ or $|1\rangle$.

Quantum Crash Course

Many different Qubit hardware approaches are possible, specialized and suitable depending on the application

- Superconducting Qubits
- Spin Qubits
- Topological Qubits
- Atoms in an Optical Tweezer
- Trapped Ions
- Photons (suitable for exchanging quantum information)

Quantum Delta NL



CAT 1 Quantum Computing and Simulation

Imagine a shell game using four cups and one pea.

- Question: Is it possible to find the pea in one try, with certainty every time?

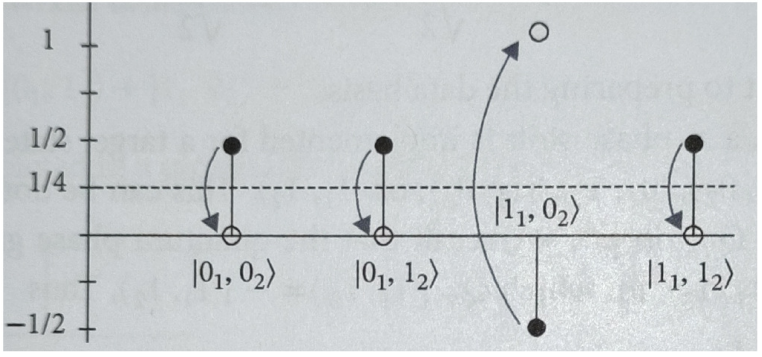
We represent our state as follows

$$|S\rangle = \frac{1}{2}\left[|0_1,0_2\rangle + |0_1,1_2\rangle + |1_1,0_2\rangle + |1_1,1_2\rangle\right] \tag{7}$$

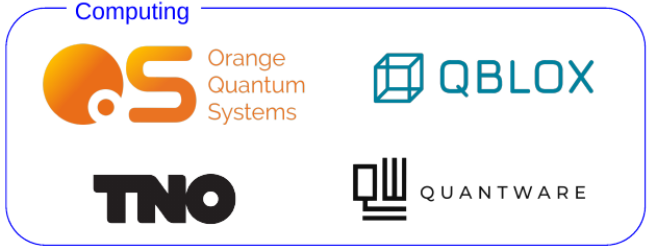
Each term represents a shell, and all amplitudes are equal to $\frac{1}{2}$. Suppose someone (without us knowing) changes the state into

$$|F\rangle = \frac{1}{2}\left[|0_1,0_2\rangle + |0_1,1_2\rangle - |1_1,0_2\rangle + |1_1,1_2\rangle\right] \tag{8}$$

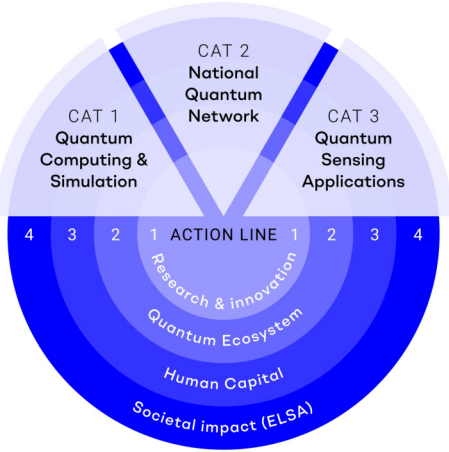
CAT 1 Quantum Computing and Simulation



CAT 1 Quantum Computing and Simulation

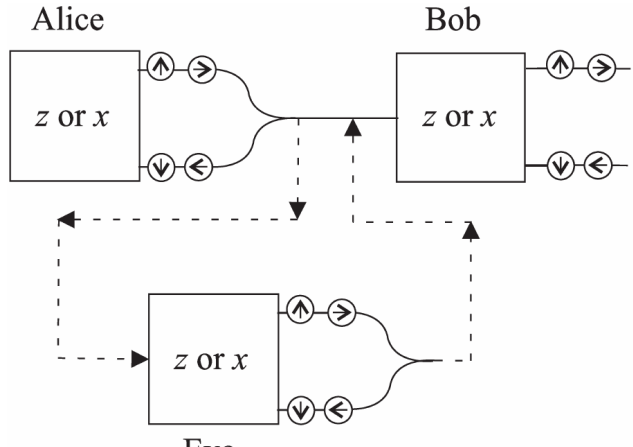


Quantum Delta NL



CAT 2 Quantum Networking

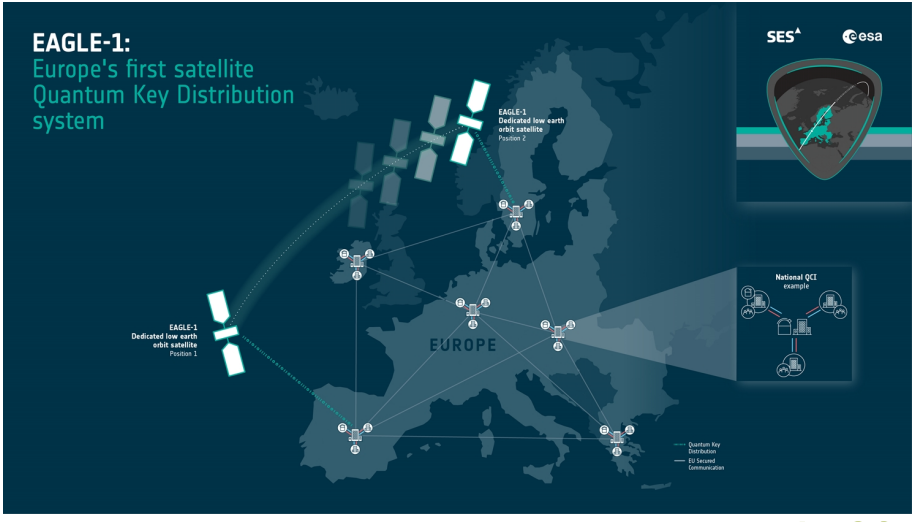
- Public Key Distribution, RSA (Classical)
- Bennet-Brassard 84 (BB-84)
- Bennet-92 Protocol



CAT 2 Quantum Networking

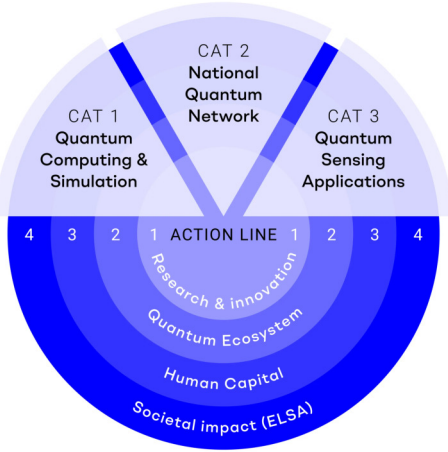
- TNO
- Airbus
- Port of Rotterdam

CAT 2 Quantum Networking



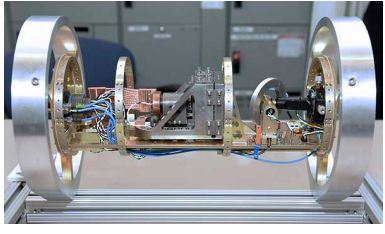
CAT 2 Quantum Networking

Quantum Delta NL

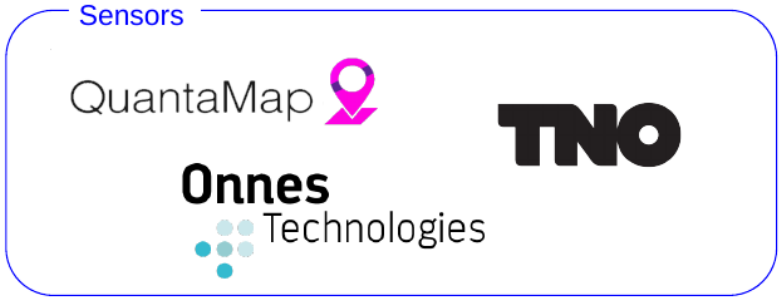


CAT 3 Quantum Sensing

- Diamond Based Testbed
- Ultracold Atoms Quantum Sensing Testbed
- Mechanical Testbed
- VSL: Improve Metrology (Timing and Frequency)
- Optical Timing and Positioning (Super GPS)
- Unjammable GPS
- Quantum Scanning Probe Microscopes (QSPM)
- Compact Magnetometers (CMAG)
- Wide Field Microscopes (WFM)

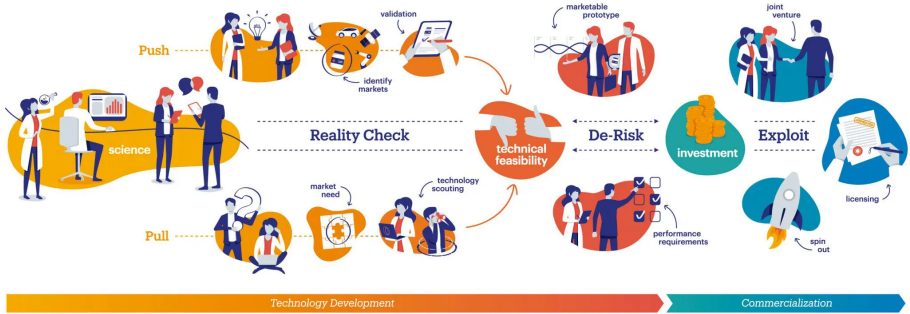


CAT 3 Quantum Sensing

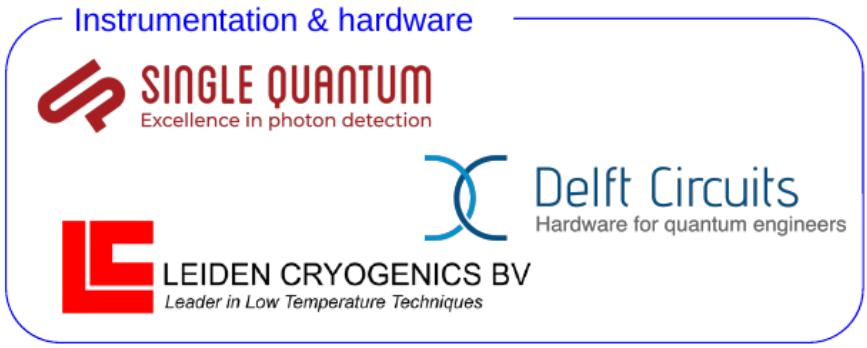


CAT 3 Quantum Sensing

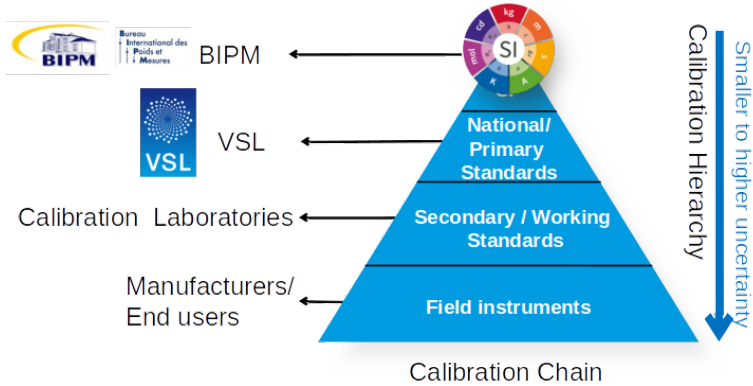
- The goal of CAT3 is to accelerate the industrialisation of quantum sensors.



Instrumentation and Hardware

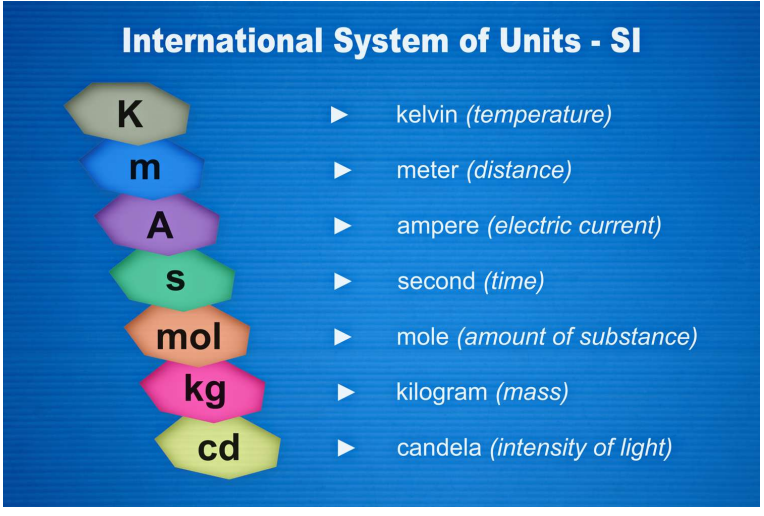


CAT 3 Quantum Sensing



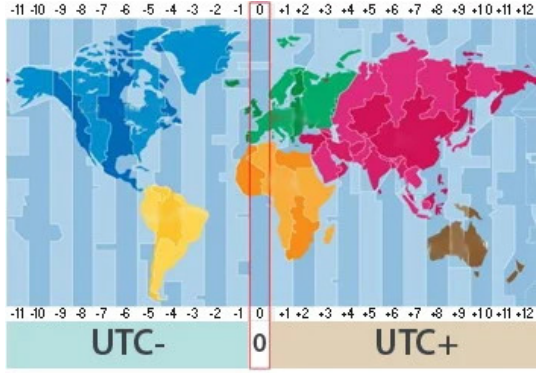
Metrological traceability requires an established calibration hierarchy

CAT 3 Quantum Sensing



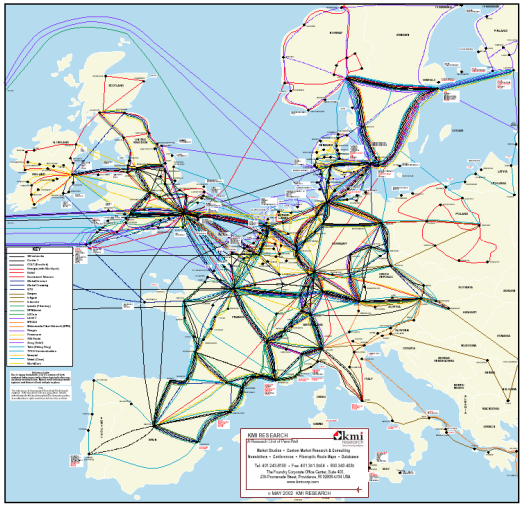
CAT 3 Quantum Sensing

- Worldwide 90 UTC Time Laboratories - using 400 Atomic Clocks



CAT 3 Quantum Sensing

- Worldwide 90 UTC Time Laboratories - using 400 Atomic Clocks

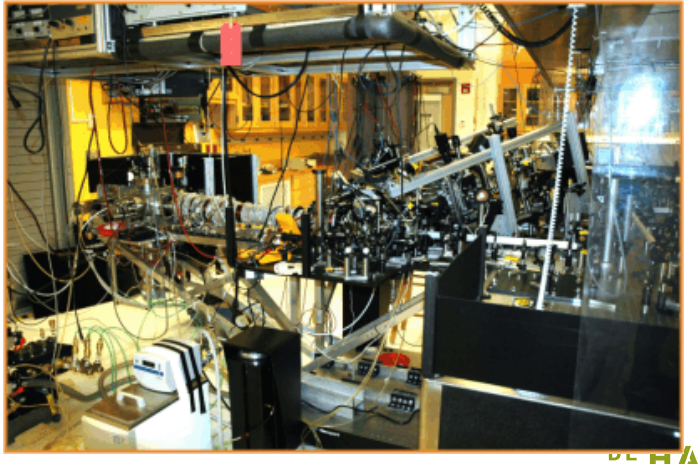


CAT 3 Quantum Sensing

- Build the best Clock in the World: Ultracold Atoms Testbed - Florian Schreck

CAT 3 Quantum Sensing

- Build the best Clock in the World: Ultracold Atoms Testbed - Florian Schreck



CAT 3 Quantum Sensing

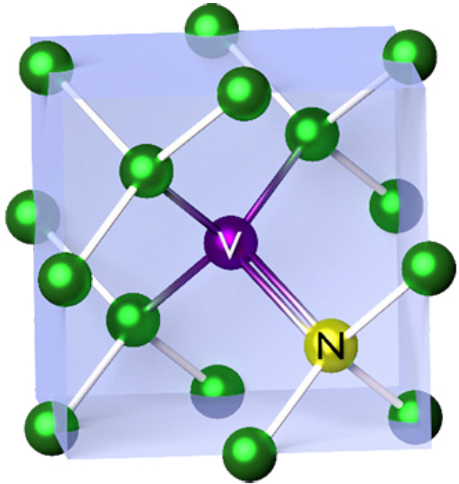
- Predict Vulcano Eruptions? Philippe Bouyer

CAT 3 Quantum Sensing

- Internal Navigation at Sea

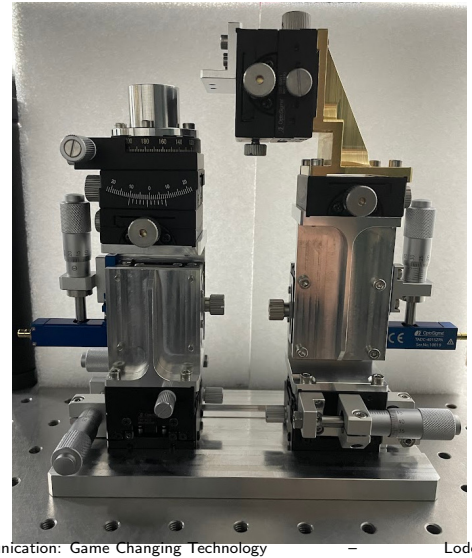
CAT 3 Quantum Sensing

- Diamond NV Centres: High Precision Magnetic Mapping



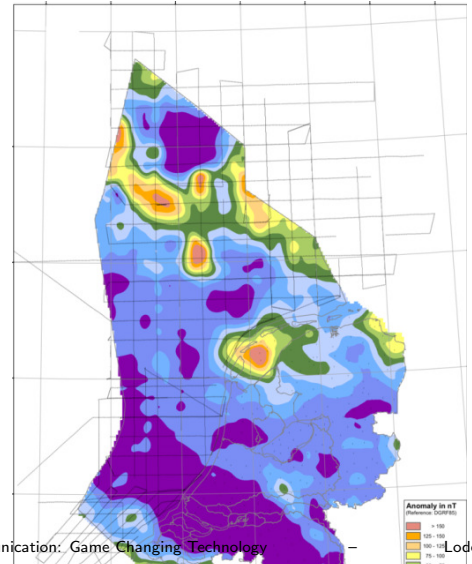
CAT 3 Quantum Sensing

- Diamond NV Centres: High Precision Magnetic Mapping



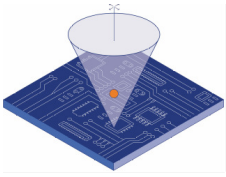
CAT 3 Quantum Sensing

- Diamond NV Centres: High Precision Magnetic Mapping

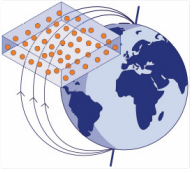


CAT 3 Quantum Sensing

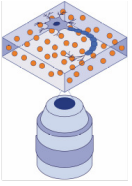
- Diamond NV Centres: High Precision Magnetic Mapping



Scanning probe microscopes (QSPM)



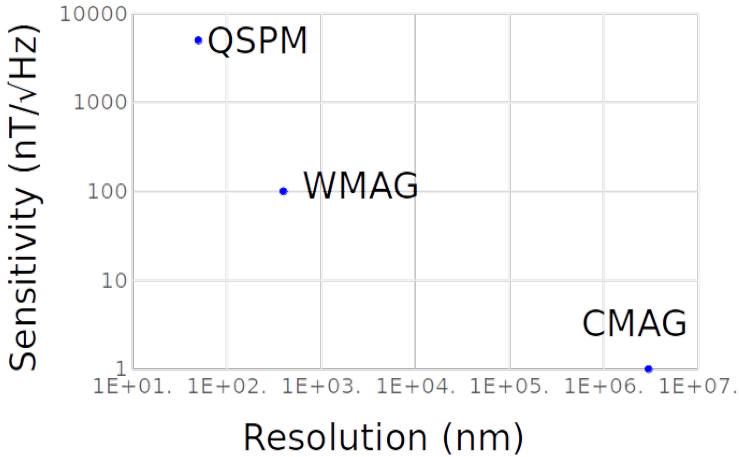
Compact magnetometers (CMAG)



Wide field microscopes (WMAG)

CAT 3 Quantum Sensing

- Diamond NV Centres: High Precision Magnetic Mapping



CAT 3 Quantum Sensing

- Set up Applied Research in Sensing, Computing and Networking
- Market Pull - Technology Push
- Close Coorporation with Start-ups and Companies
- Connecting: Talent and Learning Centres (Vocational, UAS, TU, U, Companies, Testbed Facilities,...)
- Education: Master Quantum Technology
- Photonics, Cryogenics, Cleanroom Technology