SUPPLY CHAIN QUANTUM TECHNOLOGIES

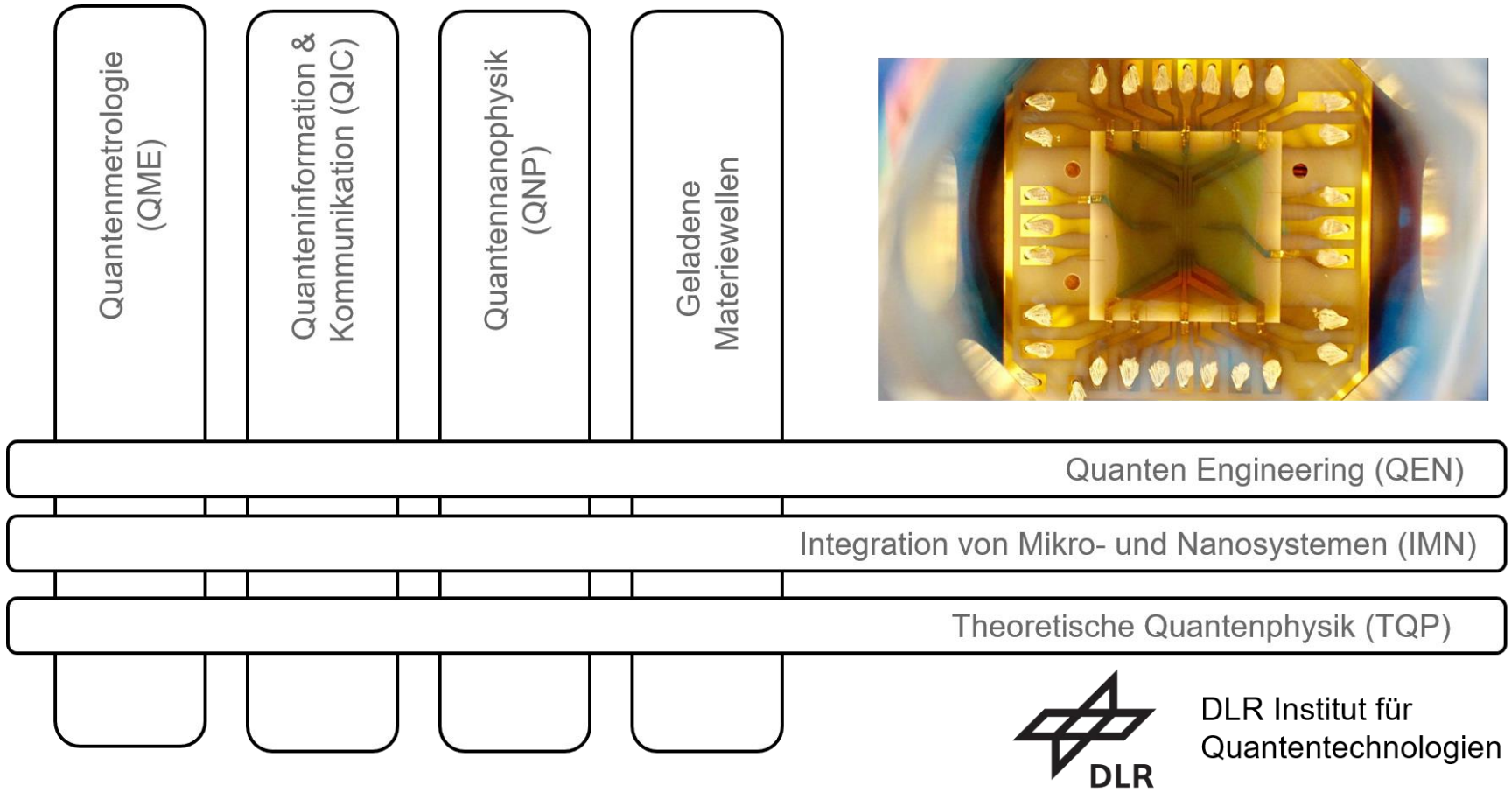
Prof. Dr. Kai Bongs

DLR Institut für Quantentechnologien, Ulm

DLR

DLR-QT, Ulm

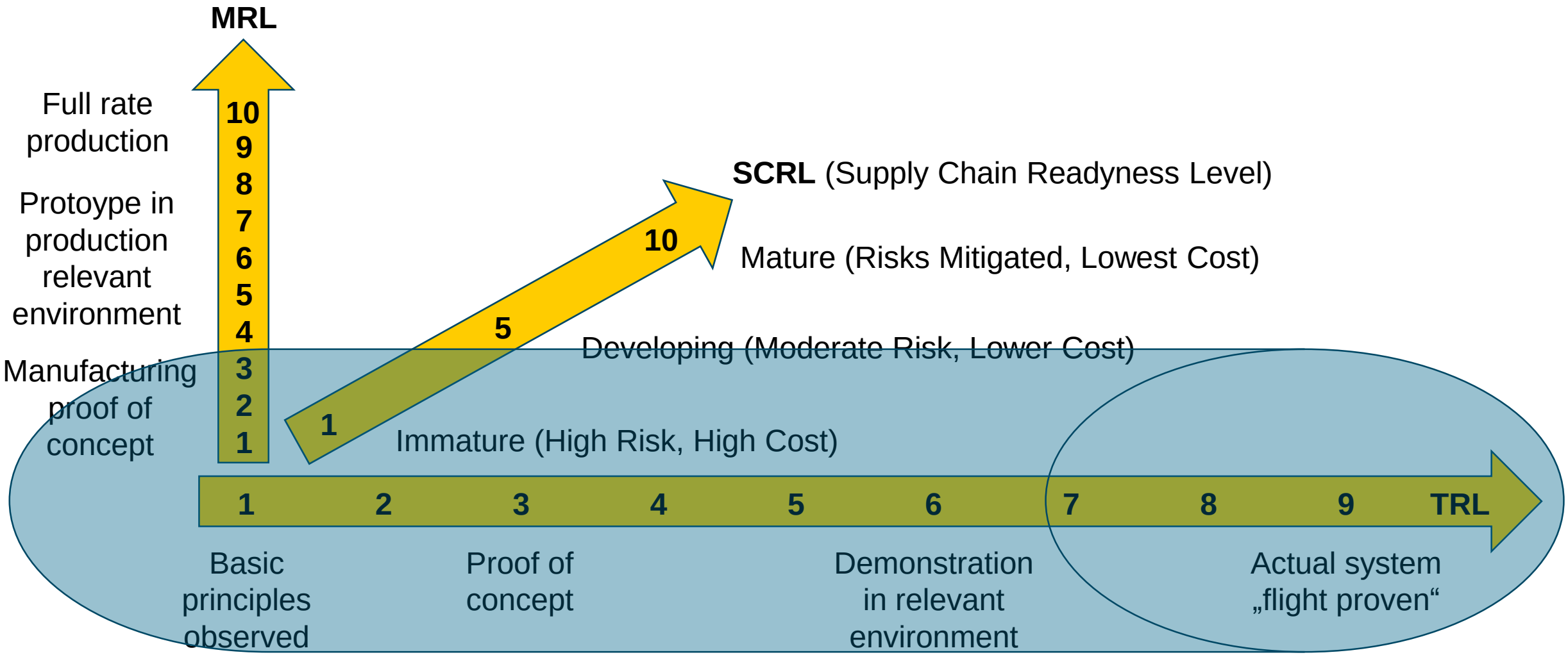
Divisions



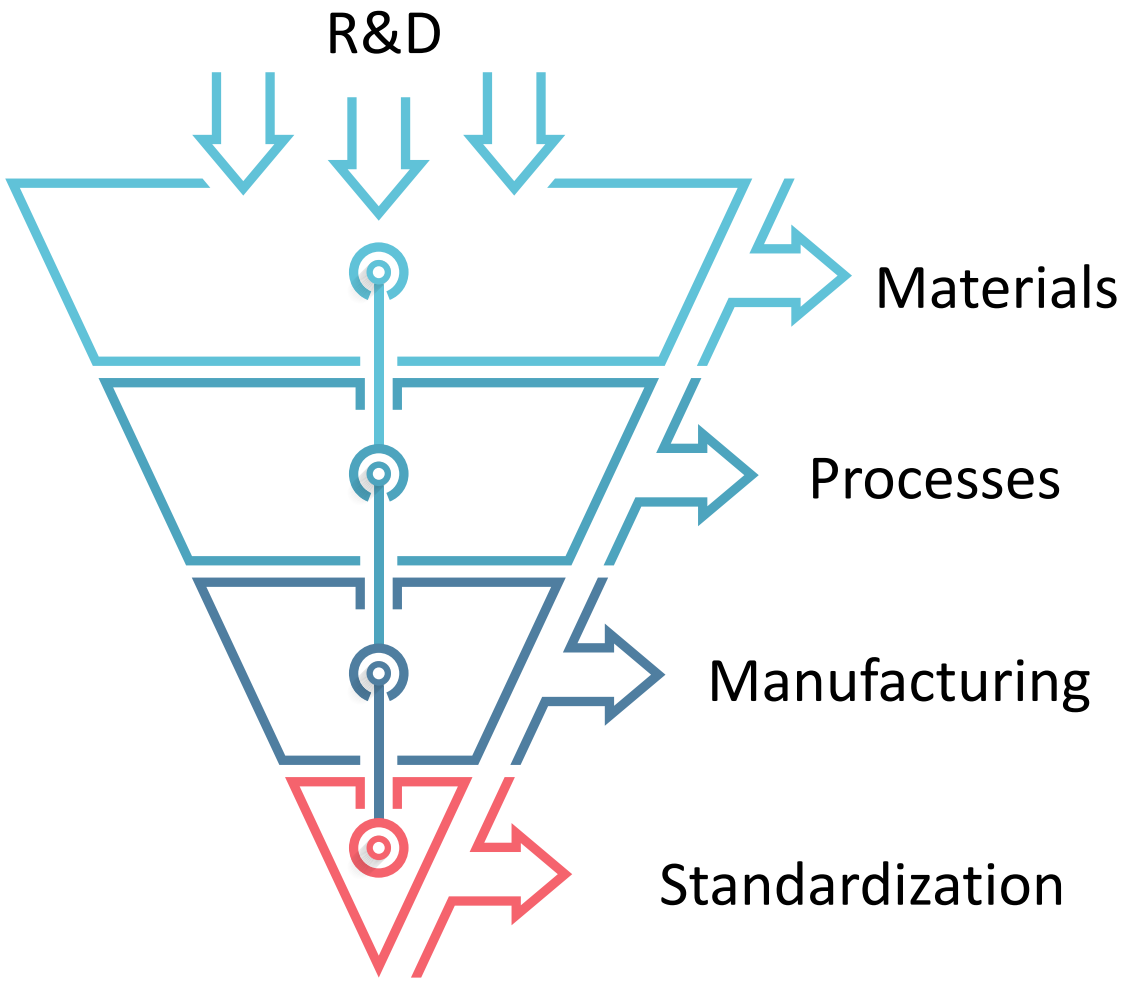
DLR Institut für Quantentechnologien

Quantum Technologies – Supporting Commercialisation

How to support the Supply Chain?



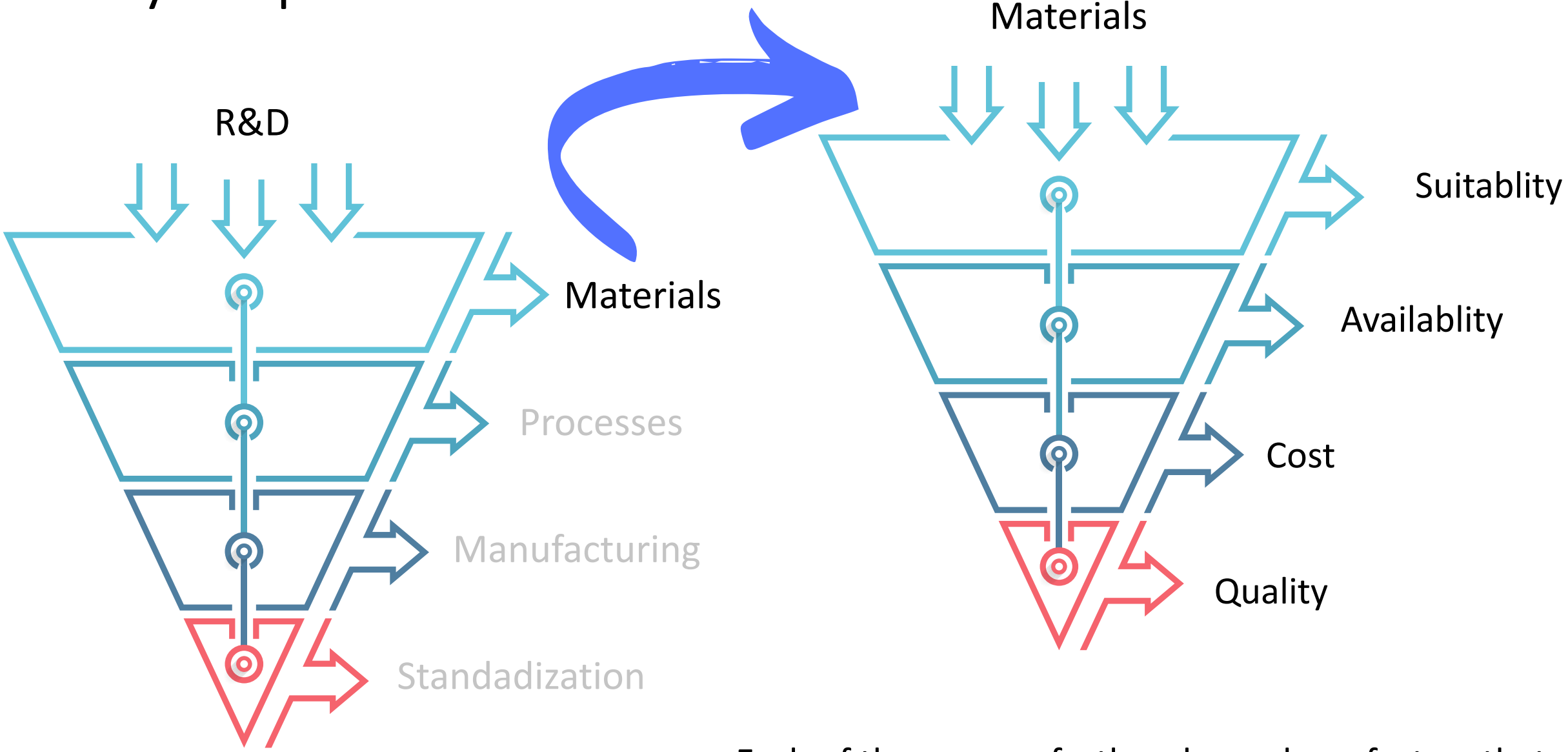
An SME view on challenges in building a supply chain



This funnel diagram shows the quick narrow-down of viable technologies that can deliver commercial quantum computers.

Slide courtesy of Gopi Balasubramanian, Xeedq

Why the path is narrow ?



Slide courtesy of Gopi Balasubramanian, Xeedq

Each of these areas further depends on factors that impose constraints on the usability

Sourcing for QC

Example

Microwave electronics, high-frequency components, cables, assemblies and optical elements.

main supplier USA and the current export licensing time is 60 months minimum.

Example

High frequency synthesizers, Lasers, Timing and Radio-frequency ,

main supplier USA, UK and one or two large manufacturers.

Example

Materials, modification, packaging and standardization.

multiple locations, but the quality needs to be inferred.

Slide courtesy of Gopi Balasubramanian, Xeedq

A UK view on some Quantum Computing Supply Chain Challenges

Still needed: integrated laser systems, low loss&fast optical switches/AOMs, and miniaturised vacuum systems
US dominated: FPGAs/ASICs
- For superconducting qubits, cryoelectronics is of increasing interest.
- chip fabrication for, e.g. ion traps and superconducting circuits, as well as PIC for photonics-based systems.

Dr Simon R. Plant, Deputy Director – Innovation, **National Quantum Computing Centre (NQCC)**

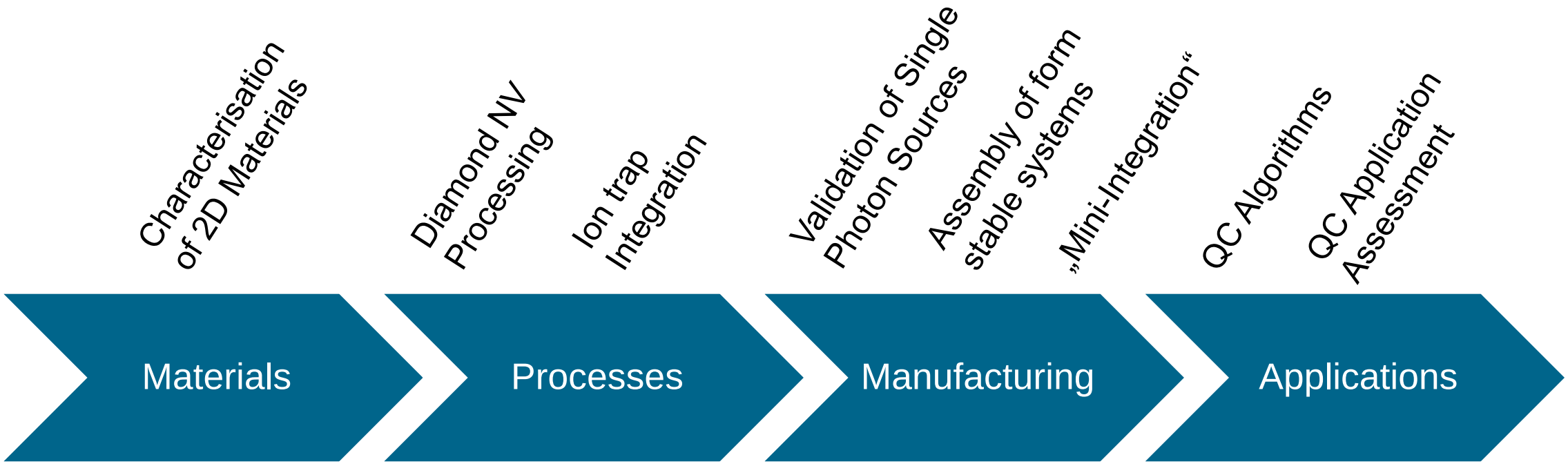
- Lithium Niobate for photonics work needs to be sourced from Taiwan at the moment.
- Ion/atom traps – UK needs an established fabrication path (US has Sandia and Lincoln Labs)
- Superconducting – The best fabs we know of are in the US, and they are also a major source of state-of-the-art superconducting amplifiers for signal recovery etc.
- Diamond – still early stage, but eventually we will need standardised facilities to build at scale
- Photonics – needs test facilities

Dr Keith Norman

Quantum Computing & Simulation Hub

UK NATIONAL QUANTUM TECHNOLOGIES PROGRAMME

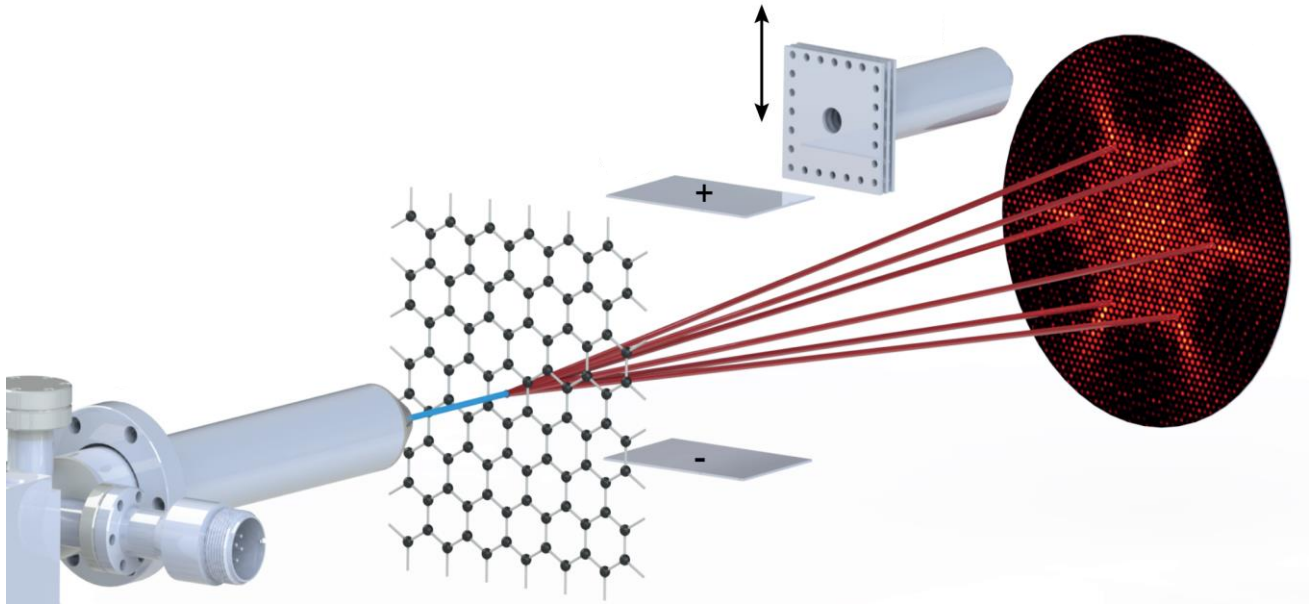
DLR-QT: Where can we help?



Materials: Characterization of 2D Materials

Aims

- Non-destructive
- Targeted introduction of defects
- Investiation and optimisation of ion beam based doping
- Thinning of 2D materials to 1 atomic layer

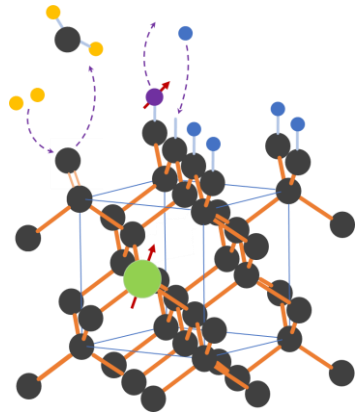


Processes: NV Surface **t**reatment at **a**tomic **r**esolution

- NV-centers must be decoupled from unintended influences by their surrounding
- A major challenge is the control over the surface

→ *The approach*: Development of surface treatments at an atomic level:

- surface cleaning & termination
- surface coating at atomic level (Atomic Layer Deposition)
- surface etching at atomic level (Atomic Layer Etching)



StarQ
Surface treatment at atomic resolution for Quantum Computing

Single crystal diamond

Diatope

Single crystal diamond with NV-centers

Advanced Quantum

Spin characterization setup in Ulm

StarQ – at QT-IMN
- Further Characterization
- Surface Treatments at atomic level
- Functional Integration
- …

QCi DLR

Clean Room facility QCI Innovation Center in Ulm

XEED The Quantum Transcendence

Quantum Computer prototype

- Project lead at QT-IMN

Dr. Markus Mohr

→ See Poster

Processes: Technology development for Ion-Trap QC (TeufiQ)

Potential work packages

- On-chip magnetic quadrupole
- Through hole ion loading
- Cryo-compatible high density probe pins

Cooperation project lead by QT-IMN for and with support by:

- Companies located at IZHH

NXP

Universal Quantum

QUDORA TECHNOLOGIES

eleQtron

- Project lead at QT-IMN

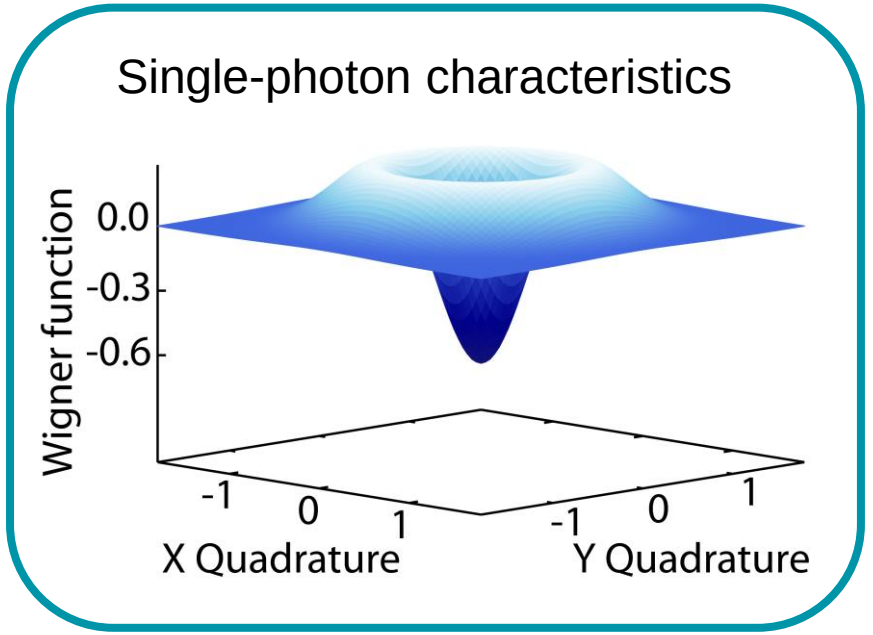
Andreas Bodschwinna

→ **See Poster**

Manufacturing: Single-photon validation

Our goals:

- Measure phase-space characteristics in the photon-number basis to *directly probe*
  - photon statistics, overlap with reference mode or complete state tomography.
- Probes all modes (vs. homodyning that measures only overlap with local oscillator).
- Does not require heavy mathematical back-transformations (vs. homodyning).

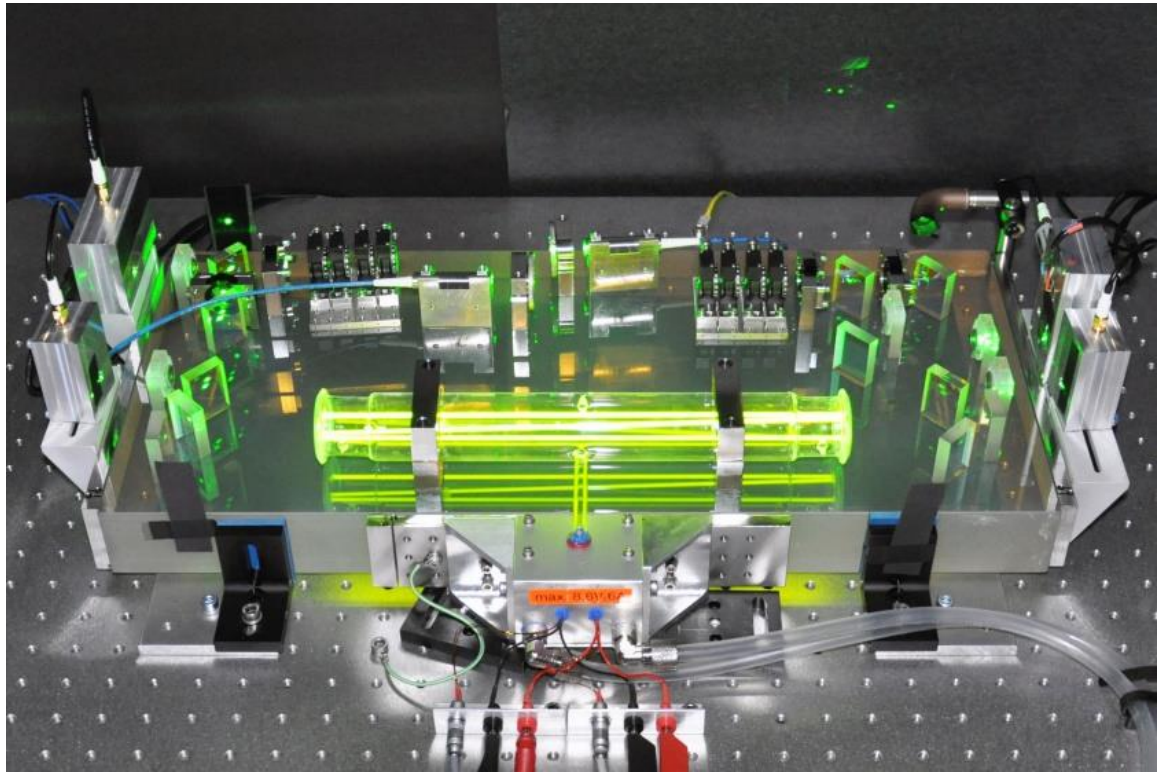


K. Banaszek and K. Wodkiewicz, Phys. Rev. Lett. 76, 4344 (1996).
S. Wallentowitz and W. Vogel, Phys. Rev. A 53, 4528 (1996).
K. Laiho et al., Phys. Rev. Lett. 105, 253603 (2010).

Manufacturing: Form Stable System Assembly

Example: Optical Clock

- Based on low expansion ceramics
- Outstanding thermal stability
- High mechanical stability
- Long-term stability proven



Schuldt et al: Development of a compact optical absolute frquency reference for space with 10^{-15} instability, Appl. Optics 56, No 4 (2017).

Manufacturing: Optical Laser Metrology Systems on Space Level …

Adhesive Bonding
- Space-qualified two-component Epoxy
- Adhesive layer: few µm
- Settling time: up to hours control by heat and UV

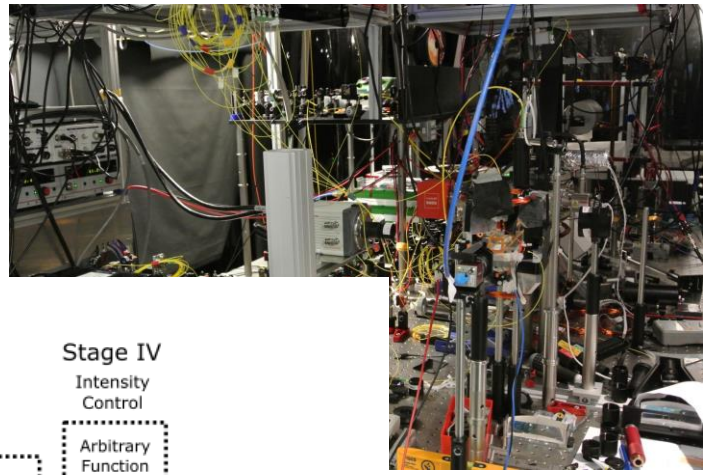
Environmental Tests (ECSS)
- Shock and Vibration tests
- TV-Tests
- Performance Tests

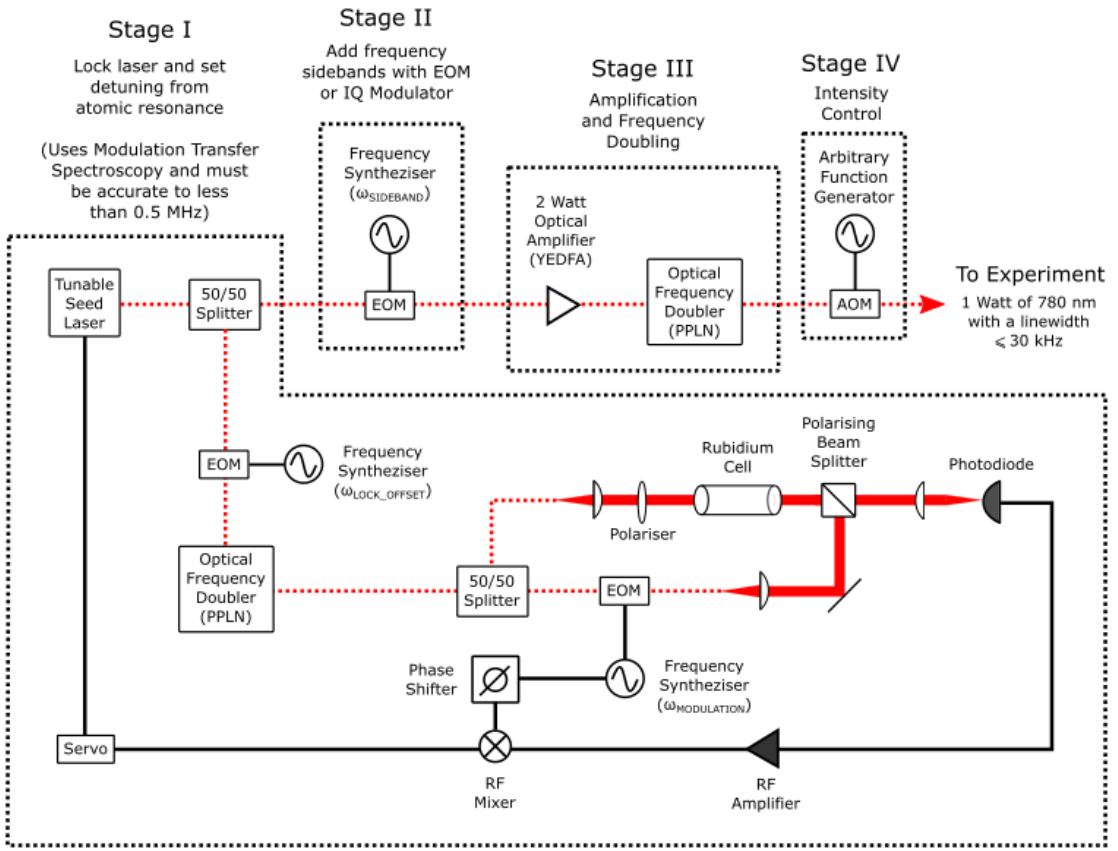
Results before/after environmental tests (ECSS):
- Displacement: <1pm at 1s
- Tilt: <1nrad at 1s

Manufacturing Challenge: Mini-Integration

Suggestions welcome

- Nanointegration of full systems needs markets of millions of items to achieve a reasonable return on investment.
- What is the middle ground between laboratory-stye setups and nanointegrated systems?

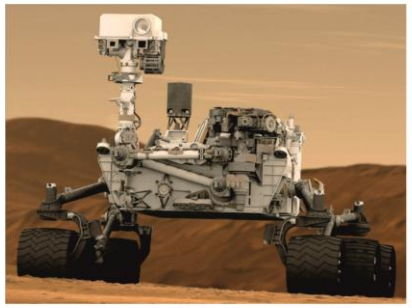




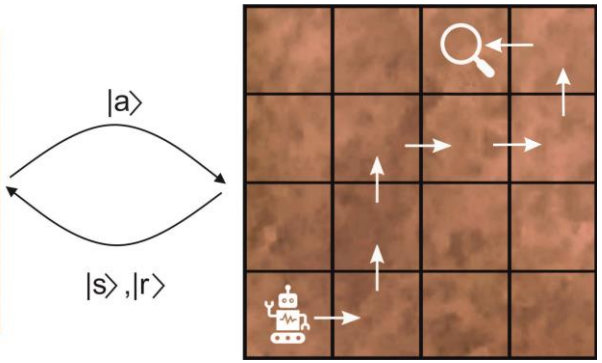
Quantum information processing in hardware-software-codesign

Quantum algorithms

e.g. quantum reinforcement learning



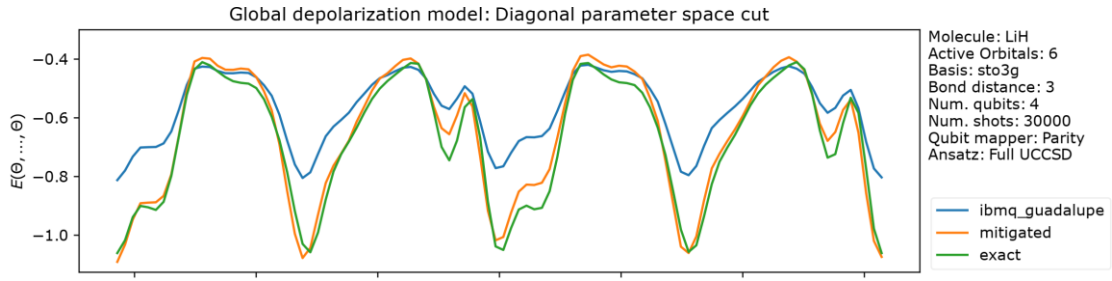
Credit: NASA/JPL-Caltech



A classical agent interacting with a problem environment can be accelerated by combining it with quantum algorithms

Implementation on NISQ Computer

e.g. transpilation/error mitigation



Quantum calculations on NISQ computer can be improved by using error models and error mitigation

Simulations and theoretical analysis of quantum systems for quantum computing

QCI-Projects:

- QLearning
- R-QIP

Contact: PD Dr. Sabine Wölk

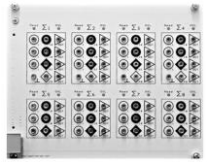
→ See Poster

Quantum simulations and applications

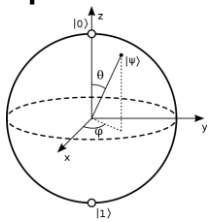
Quantum computing

- Investigate the potential of **continuous quantum systems** for **quantum computation**

Classical analog computing



Digital quantum computing



AQuRA

Industry cooperation

anabrid

Quantum applications

- Investigate the potential of **quantum computers** for **mobility applications**
- Areas of application:

Aviation

Road transport

Rail transport

Maritime transport

Intermodal transport

- Joined efforts of QT, LV, VF, TS and SE

Public tenders for industry partners

Quantum simulations

- Development and implementation of **tensor network methods** for **artificial intelligence** and efficient **quantum simulations**
- Joined efforts of QT, KI and SC

Public tenders for industry partners

QCI-Projects

- AQuRA
- QuTeNet
- QCMobility

Contact: Dr. Matthias Zimmermann

→ See Talk

We are here to help – Please talk to us

Contact Information

- 2D Material characterization – Christian.Brand@dlr.de
- Soft nanostructuring and assembly – Jakob.Buchheim@dlr.de
- Single Photon source characterization – Kaisa.Laiho@dlr.de
- Laser metrology and assembly – Claus.Braxmaier@dlr.de
- Opto-electro-mechanical assembly – Kai.Bongs@dlr.de
- Quantum Computing algorithms – Sabine.Woelk@dlr.de
- Quantum Computing applications – Matthias.Zimmermann@dlr.de
- General industry collaboration - Kai.Bongs@dlr.de

THANK YOU FOR LISTENING – QUESTIONS?

Bildquelle hier angeben