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Trapped ions quantum computing
- challenges and perspectives

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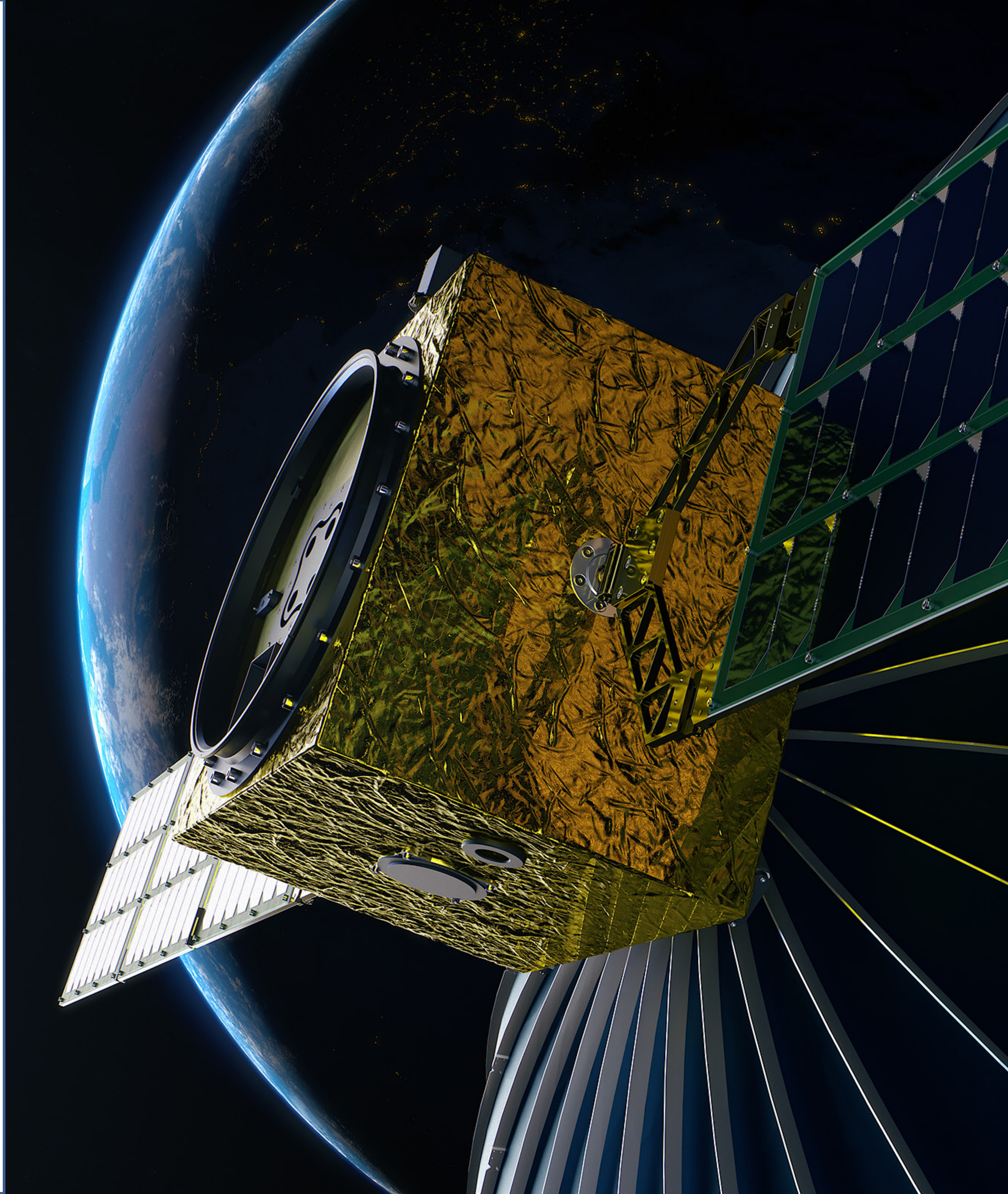
Creotech Instruments S.A.

Established in 2012
Headquarters in Piaseczno, Poland
~180 employees
82% R&D

Member

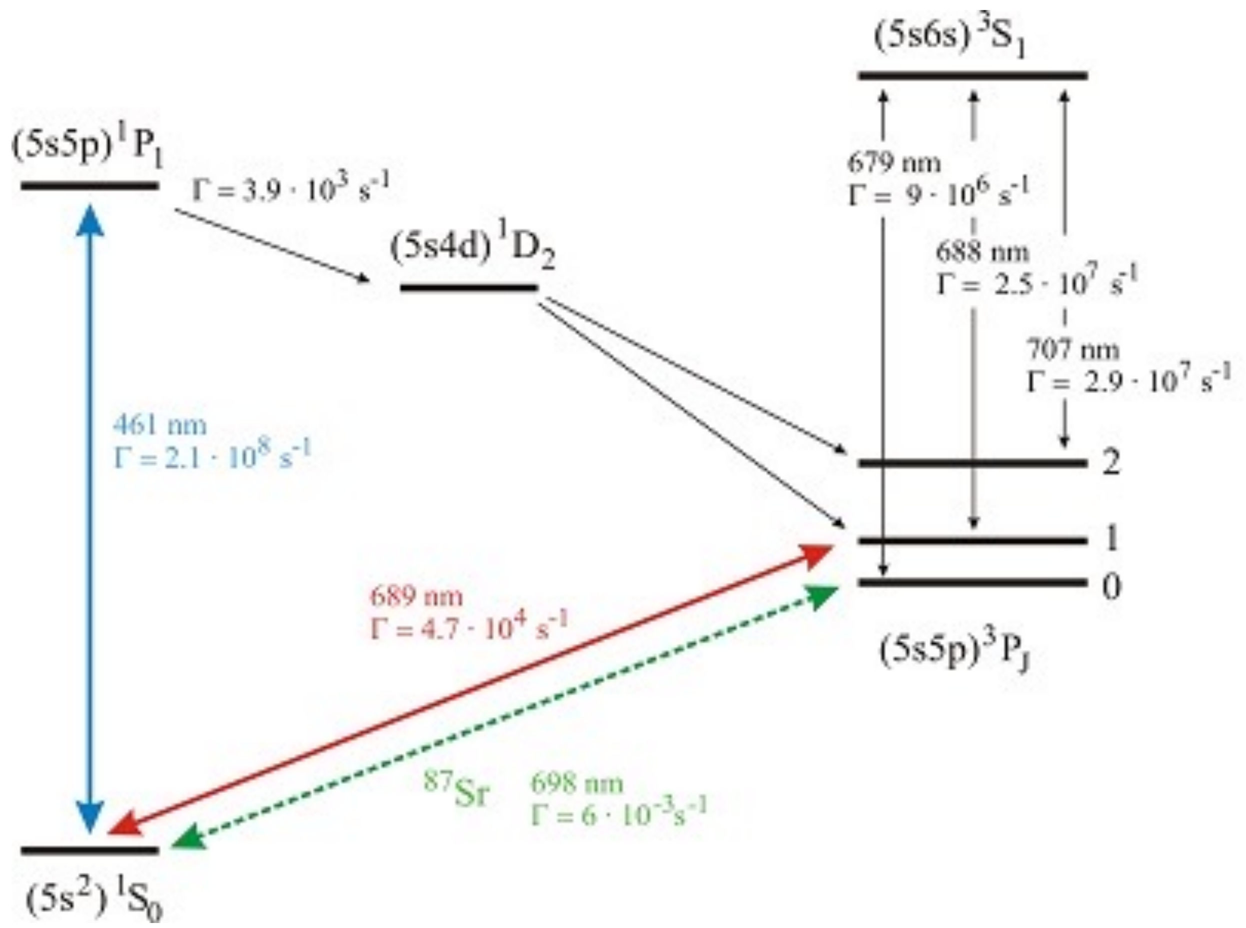
- Certified (automotive, medical, Space) manufacturing services
- Systems for Space, satellites
- Cameras, drones, EO
- Hardware and systems for Big Science facilities
- Control systems for Quantum Technologies
- R&D, electronics engineering consultancy services

www.creotech.pl



Atoms, ions and quantum technologies

„Oldest” quantum technologies - atomic clocks



- Strontium optical atomic clock uncertainty: 1 s over 15 billion years
- 430 trillion “ticks” per s

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Source: PTB

Trapped ions quantum computing

Qubits: quantum states of ions in RF (Paul) traps

Advantages:

- Long coherence time (~100s)
- High gate fidelity
- High connectivity
- Leveraging an existing advanced technology base from the development of atomic clocks and mass spectrometers

Problems:

- Relatively long gate and readout times (microseconds)

Commercially available quantum computers

- IonQ (USA), 23 qubits
- Quantinuum (Honeywell + Cambridge Quantum, USA+UK), 20 qubits
- AQT (Austria), 20 qubits

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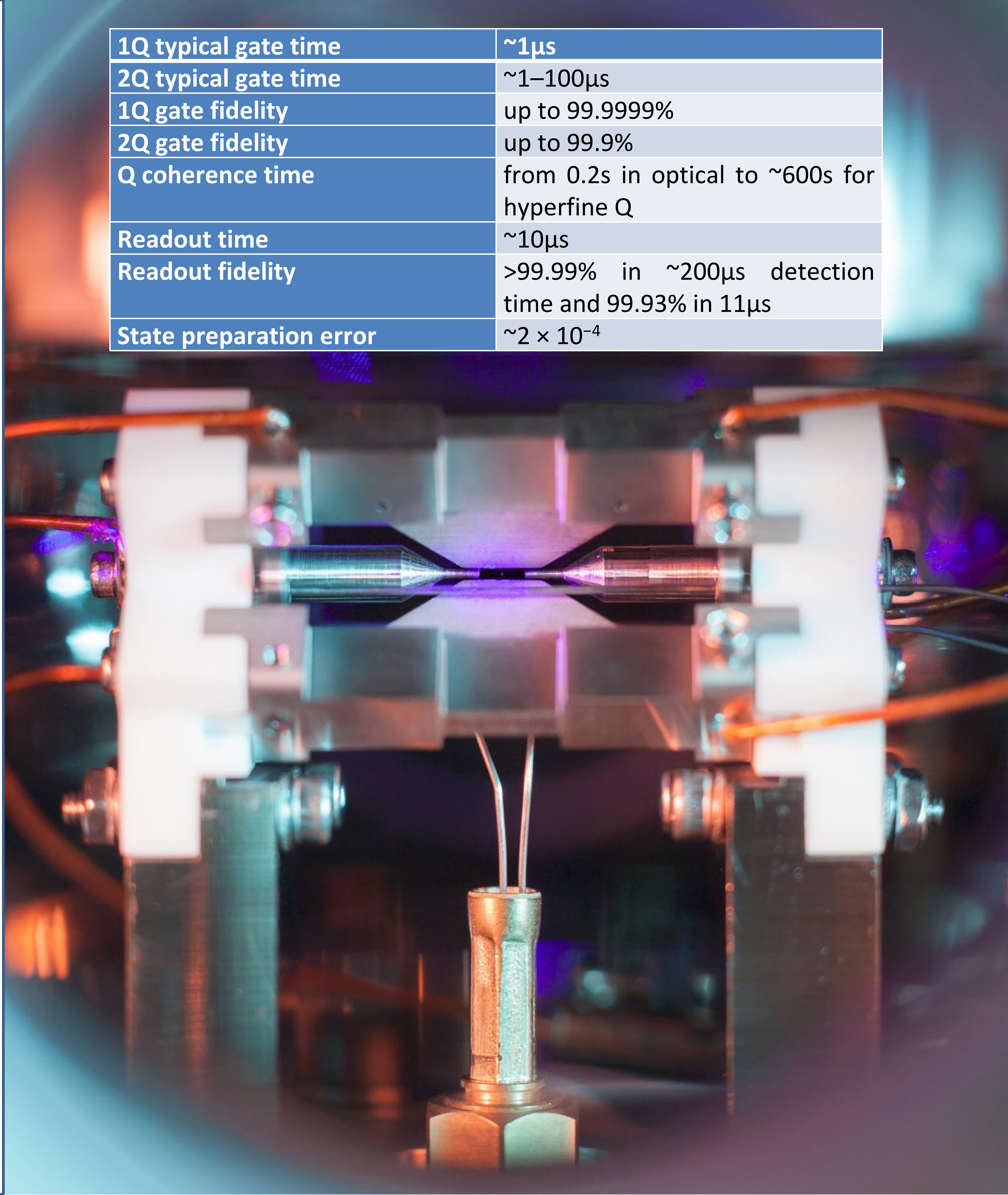
Source: University of Oxford



1Q typical gate time	**~1µs**
2Q typical gate time	~1–100µs
1Q gate fidelity	up to 99.9999%
2Q gate fidelity	up to 99.9%
Q coherence time	from 0.2s in optical to ~600s for hyperfine Q
Readout time	~10µs
Readout fidelity	>99.99% in ~200µs detection time and 99.93% in 11µs
State preparation error	$\sim 2 \times 10^{-4}$

Comparison – superconducting qubits

Qubits: quantum states of nanofabricated electrical circuits

Advantages:
- 10-100ns gate and readout time
- High gate fidelity
- Compatible with standard semiconductor manufacturing technologies (CMOS foundries)

Problems:
- Chip temperature < 20 milli Kelvin
- Relatively short coherence time (~10-100µs)

Commercially available computers:
- IBM (USA), 127 qubits (Eagle), 1121 qubits planned for 2023
- Google (USA), 54 qubits (Sycamore)
- IQM (Europe), 54 planned for 2024

1Q typical gate time	~10ns
2Q typical gate time	~10ns – 100ns
1Q gate fidelity	up to ~99.9%
2Q gate fidelity	up to ~99%
Q coherence time	~50µs for capacitively shunted flux qubits and ~100µs for transmons
Readout time	~100ns
Readout fidelity	~99%

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Source: IBM Q

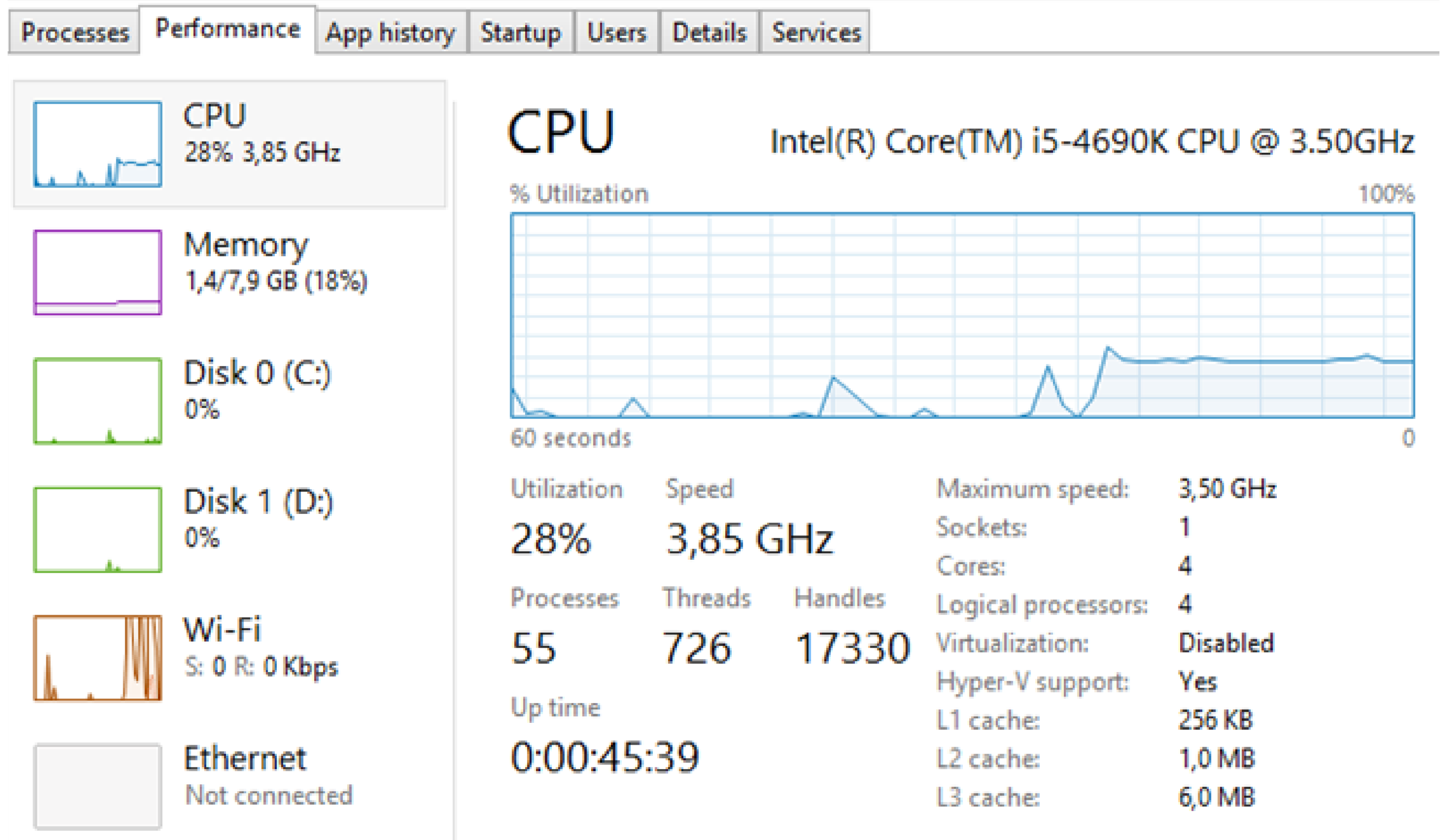
Problems of early computers

- Small number of qubits, errors

Practical applications require ~1M physical qubits

- Low coherence time and low processor ”clocking frequency”

Classical processor ~10-100 GHz
Quantum processor ~100 MHz (ions ~1 MHz)



- No “RAM” memory

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Source: U.S. Army, ENIAC

Trapped ions – building a quantum computer

Ion source and trap – where the qubits sit – Paul traps with RF and DC

- DAC and DDS signals to control the trap (DC, RF), AWG for more complex time-dependent voltage waveforms, RF or microwave magnetic fields in some trap designs

Lasers – cooling, trapping, changing and reading out the quantum state of ions

- control subsystems for laser power and frequency stabilization and laser modulation (frequency reference, optical components, EOMs, AOMs, photodiods plus control electronics – FPGA, ADC, DDS, amplifier)

Lasers plus EMCCD camera / other sensors for qubit state readout

- TTL in/out and other interfaces with the sensor

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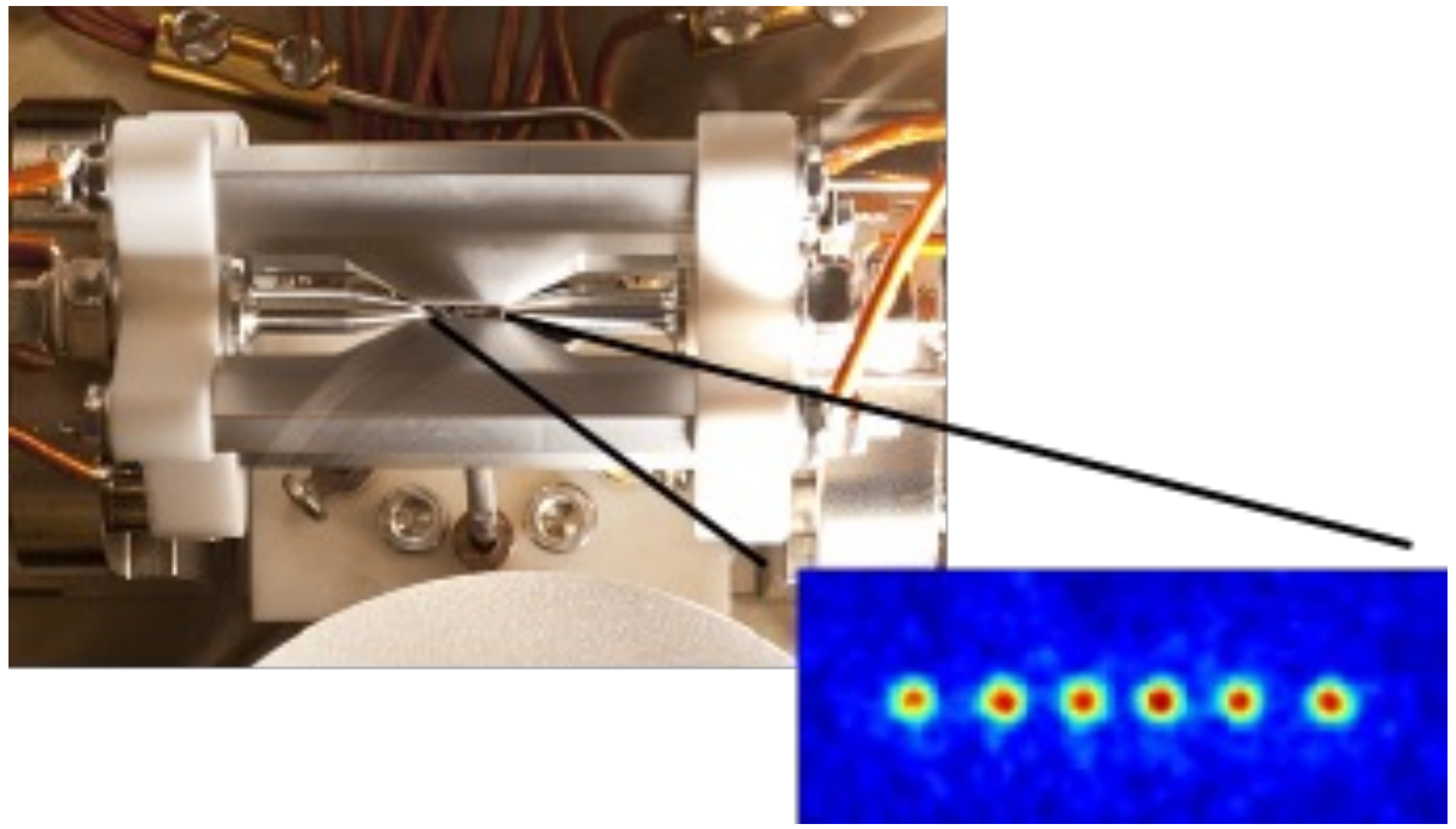
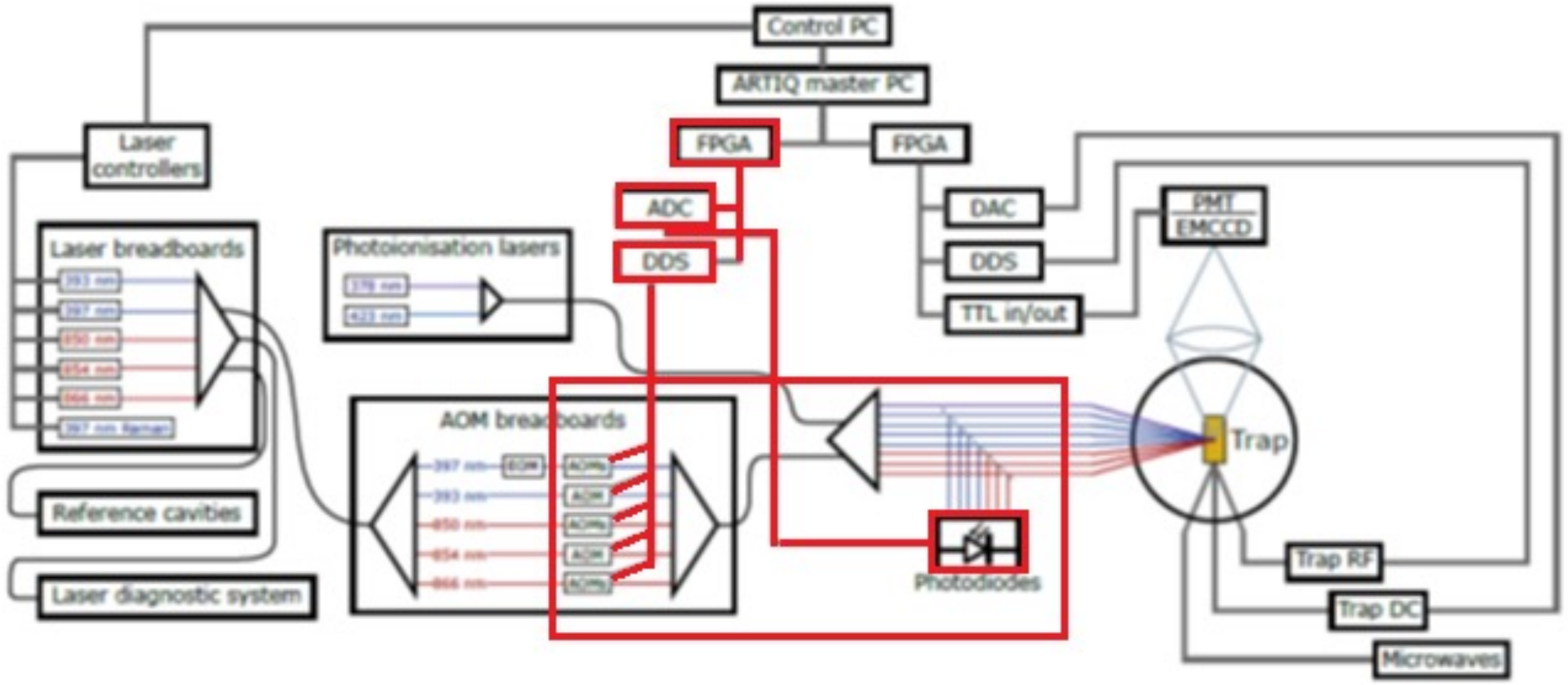


Source: University of Innsbruck



Source: J. Wolf. Cryogenic, near-field quantum logic chips with passive field nulling on 43Ca+, PhD thesis, London, 2019.

Qubit control electronics

Needs:

- Low latency control (microsecond-scale response times)
- Precise time synchronization (ns scale)
- Multi-channel control, FPGA processing
- Ultra-low noise (~nV) DAC
- Laser intensity and frequency stabilization servos
- Fast ion state readout

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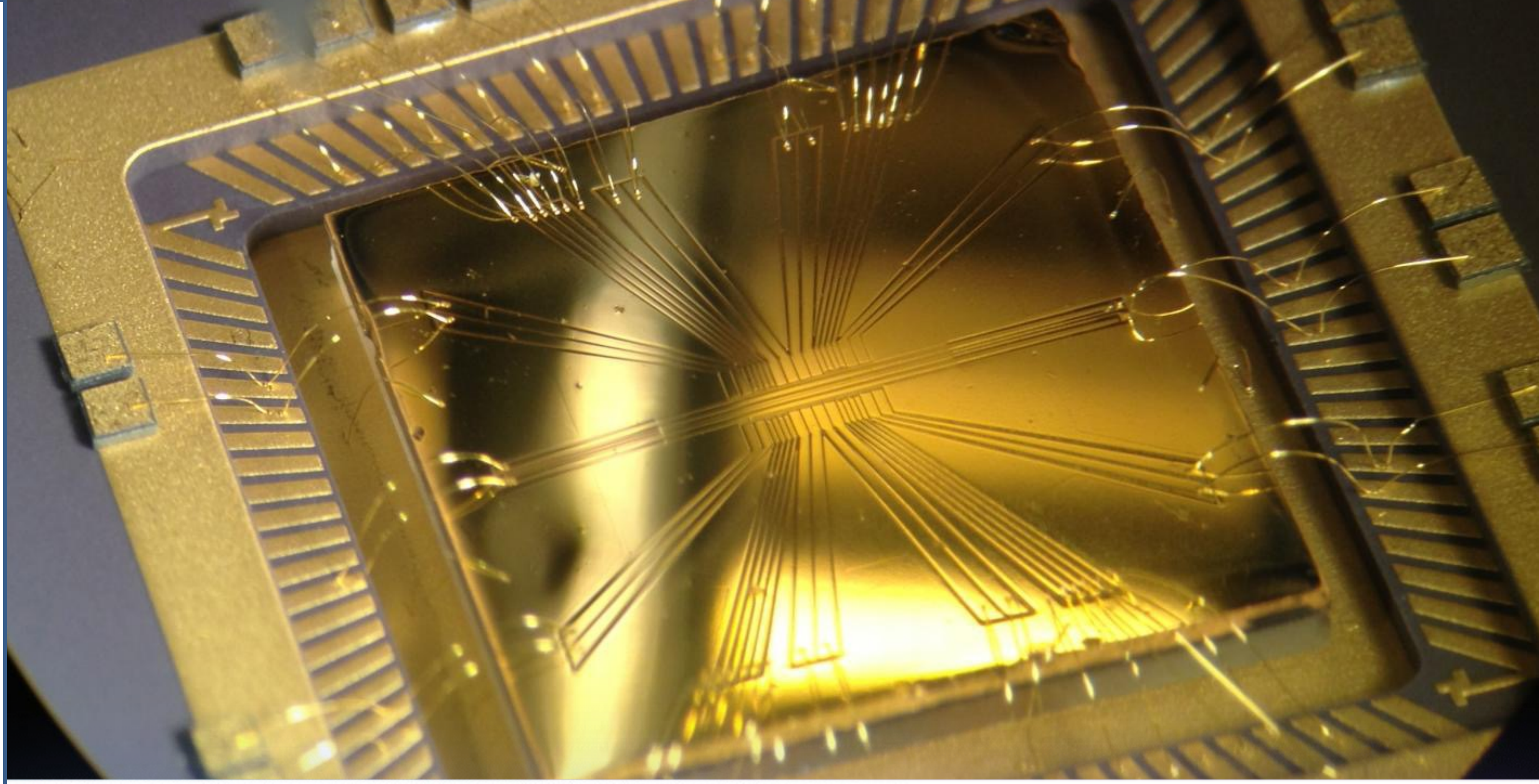
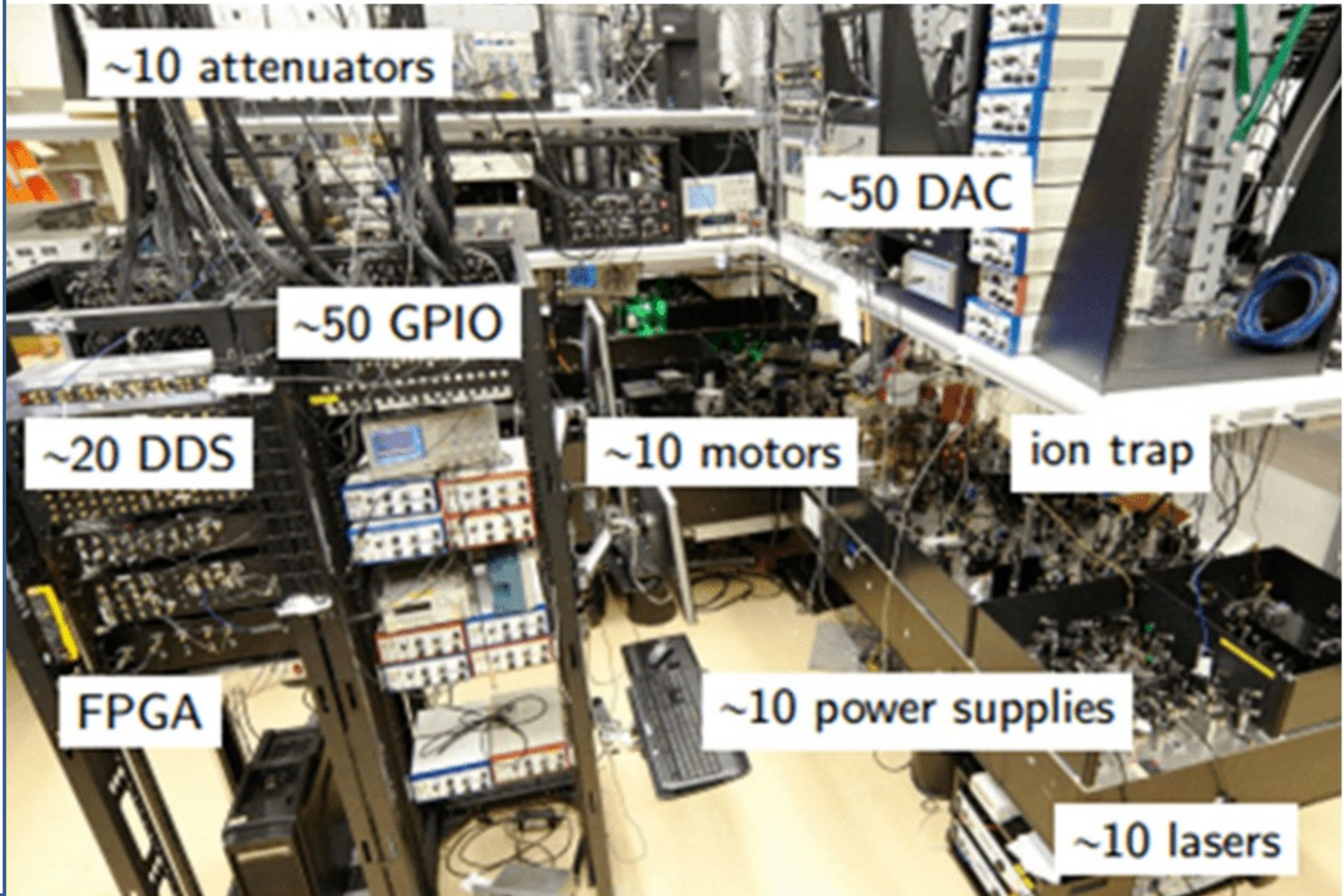
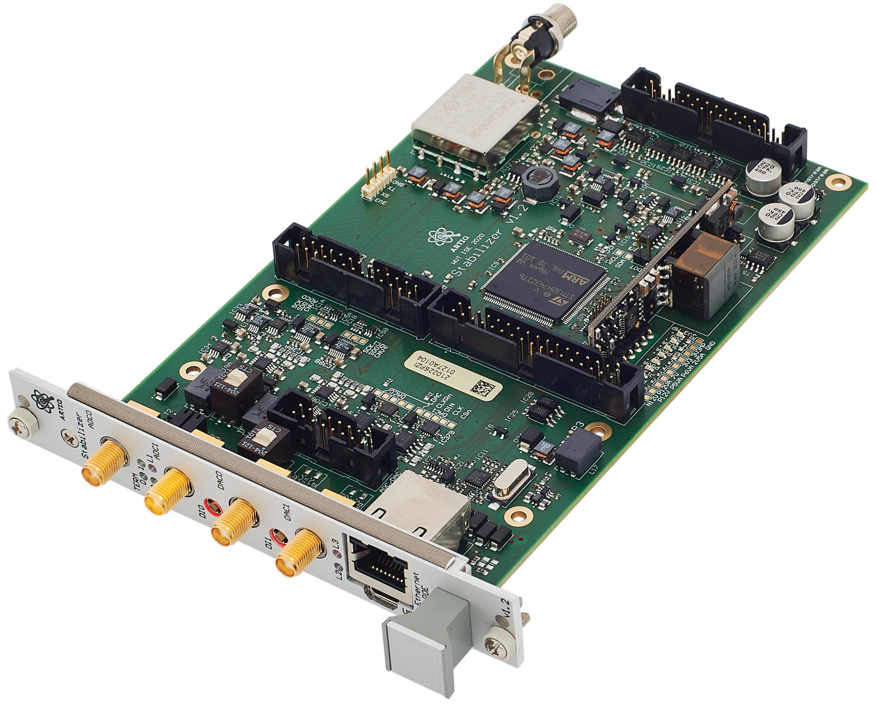
Source: University of Oxford, NIST





Sinara/ARTIQ project for Quantum Technologies

- Bottom-up initiative of the ion trap community
- Modular control and measurement hardware ecosystem, tailored to the needs of ion-trap experiments
- Compatibility with ARTIQ open software
- ~70 modules in EEM format



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Oxford Physics
NQIT Networked Quantum Information Technologies
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UNIVERSITY OF MARYLAND
PTB Physikalisch-Technische Bundesanstalt Braunschweig und Berlin
Leibniz Universität Hannover
ARL
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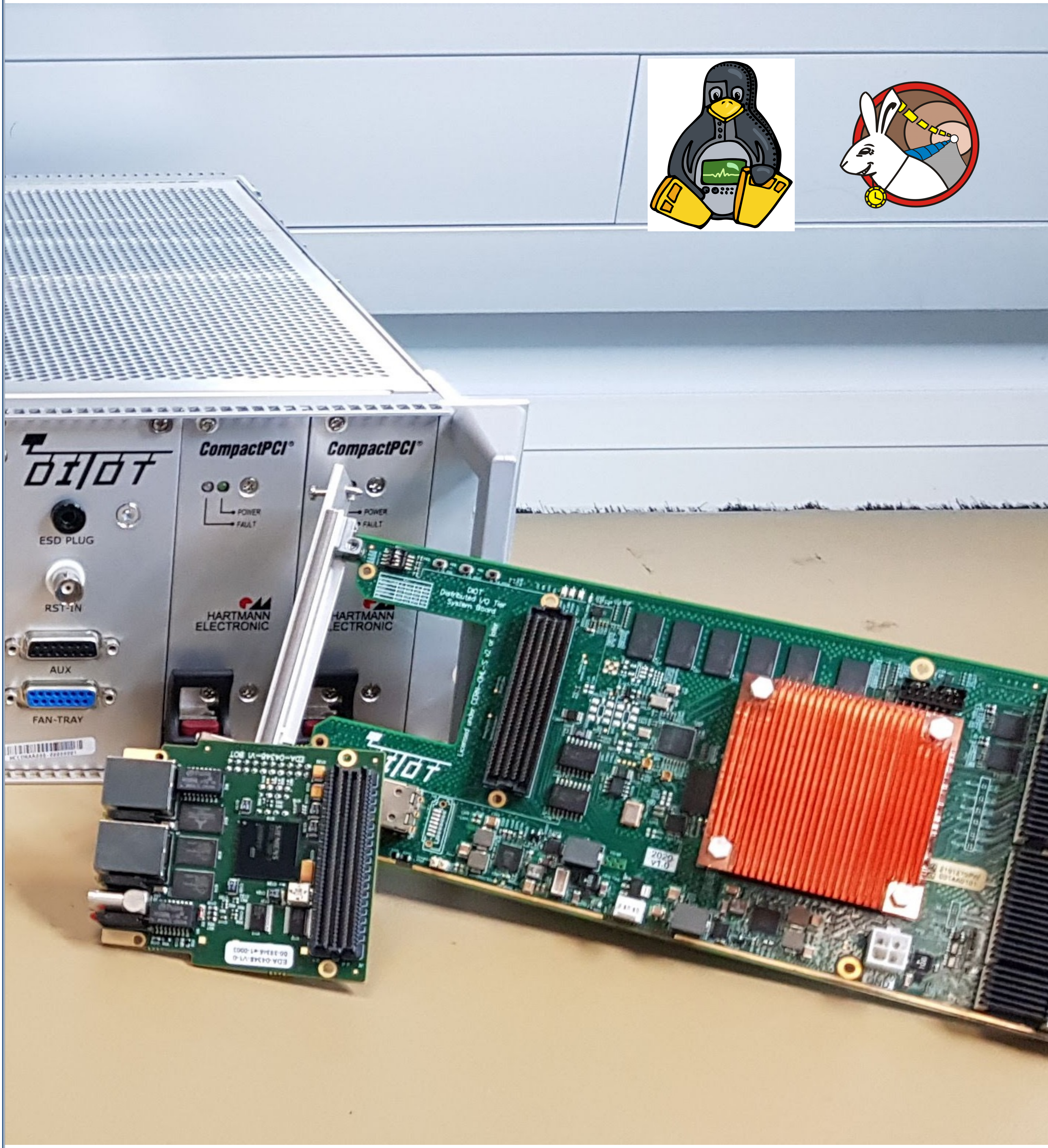
CERN connections

- CERN Open Hardware initiative
https://ohwr.org/welcome

- CERN AEgiS (Antihydrogen Experiment: Gravity, Interferometry, Spectroscopy) project – collaboration with Warsaw University of Technology on Sinara/ARTIQ

- Distributed I/O Tier (DIOT) ecosystem developed at CERN in collaboration with Creotech



Source: DIOT OHWR webpage

Qubit control challenges

- More qubits
- Better integrated control solutions
- Cryogenic UHV ASIC solutions
- Ultra-low noise and cross-talk
- Good shielding and filtering of noise
- Ultra-low latency of the control system
- Optimized qubit readout solutions
- Integration with HPC

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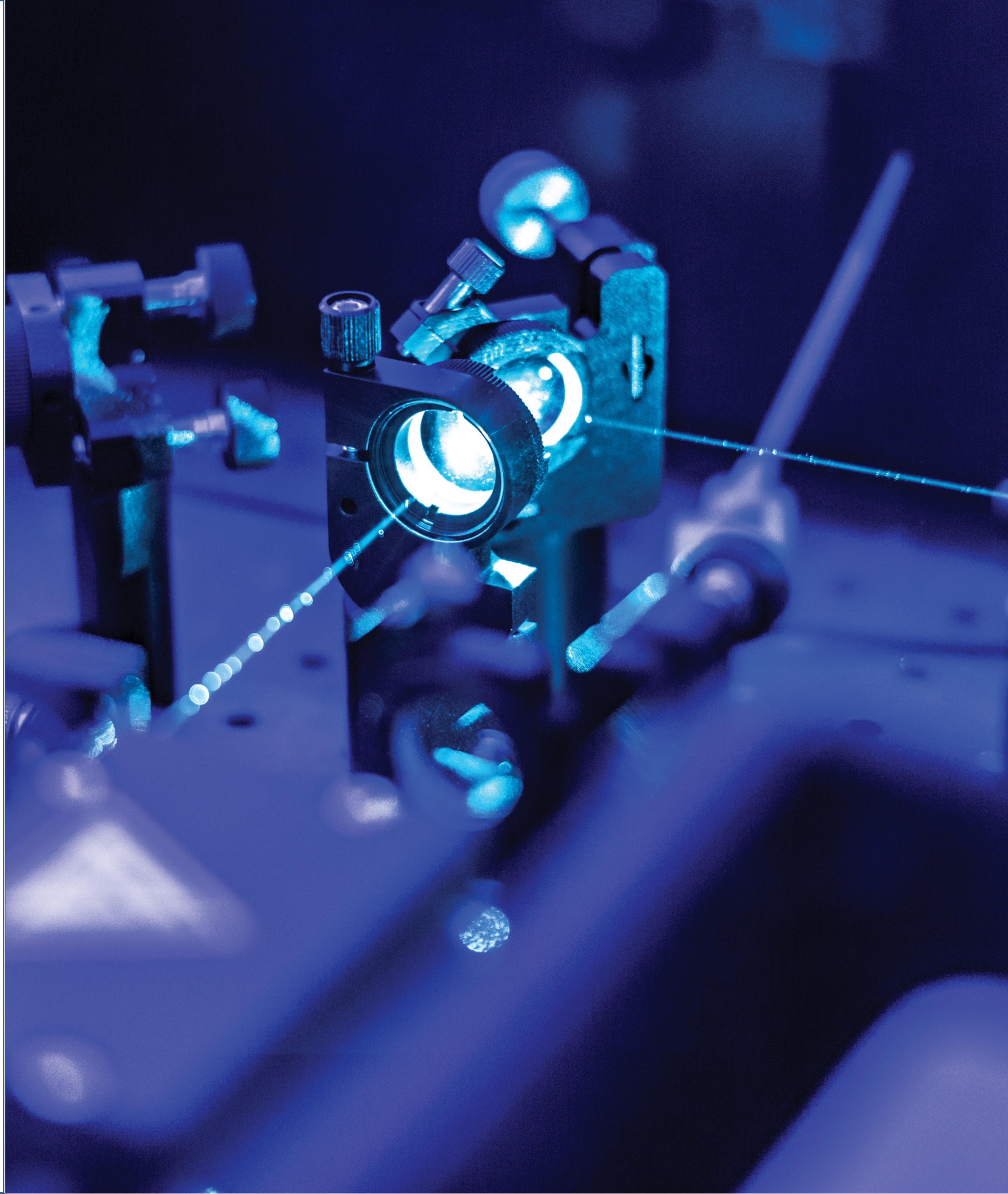
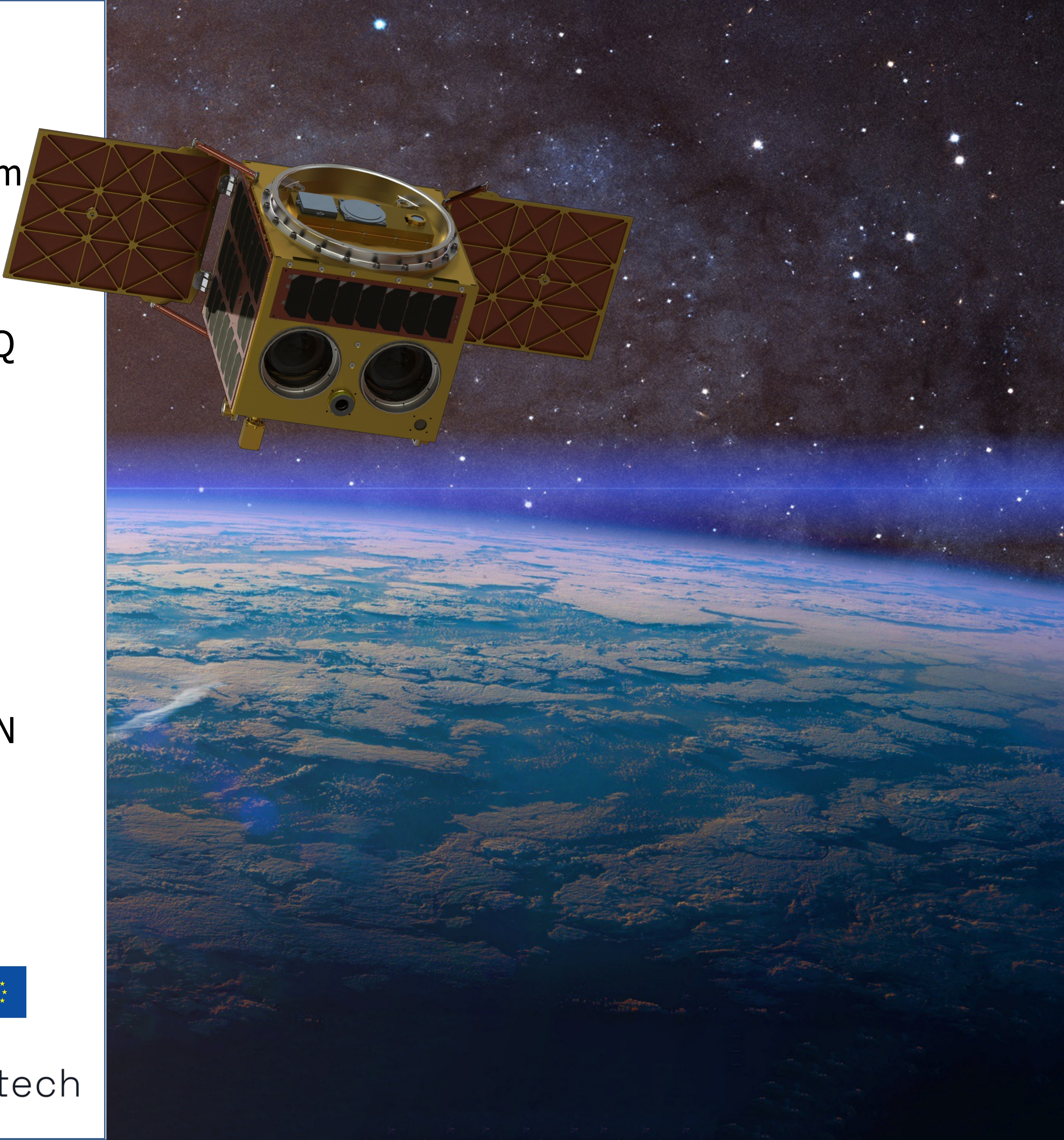


Creotech projects

- 1000 qubit quantum computer R&D project (Quantum Flagship) in a consortium led by Innsbruck U. with AQT as the commercial partner
- QuantERA project for qubit readout camera with MPQ Munich and Zagreb U.
- PL/DE bilateral project for ultra-integrated laser subsytems with Quartiq, FBH Berlin and Warsaw U.
- EuroHPC JU project for QC @HPC, led by PSNC (see talk by Piotr Rydlichowski)
- Several satellite missions, electronics design for CERN
- Always looking for interesting collaborations ☺



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