Future of (Quantum) Computing
… and a bit on trapped ions

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- Q-Computing – special-purpose HPC accelerator
- Trapped ions – a success in Europe
- Use-cases – now and in the future
- Overcoming present challenges

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AQT

IQI

€ BEYOND FWF SFB FFG Forschung wirkt. IQI GmbH IQI

FWF A TION eQual $ IARPA

One current challenge in Austria: OpExp → 0 EUR possible?

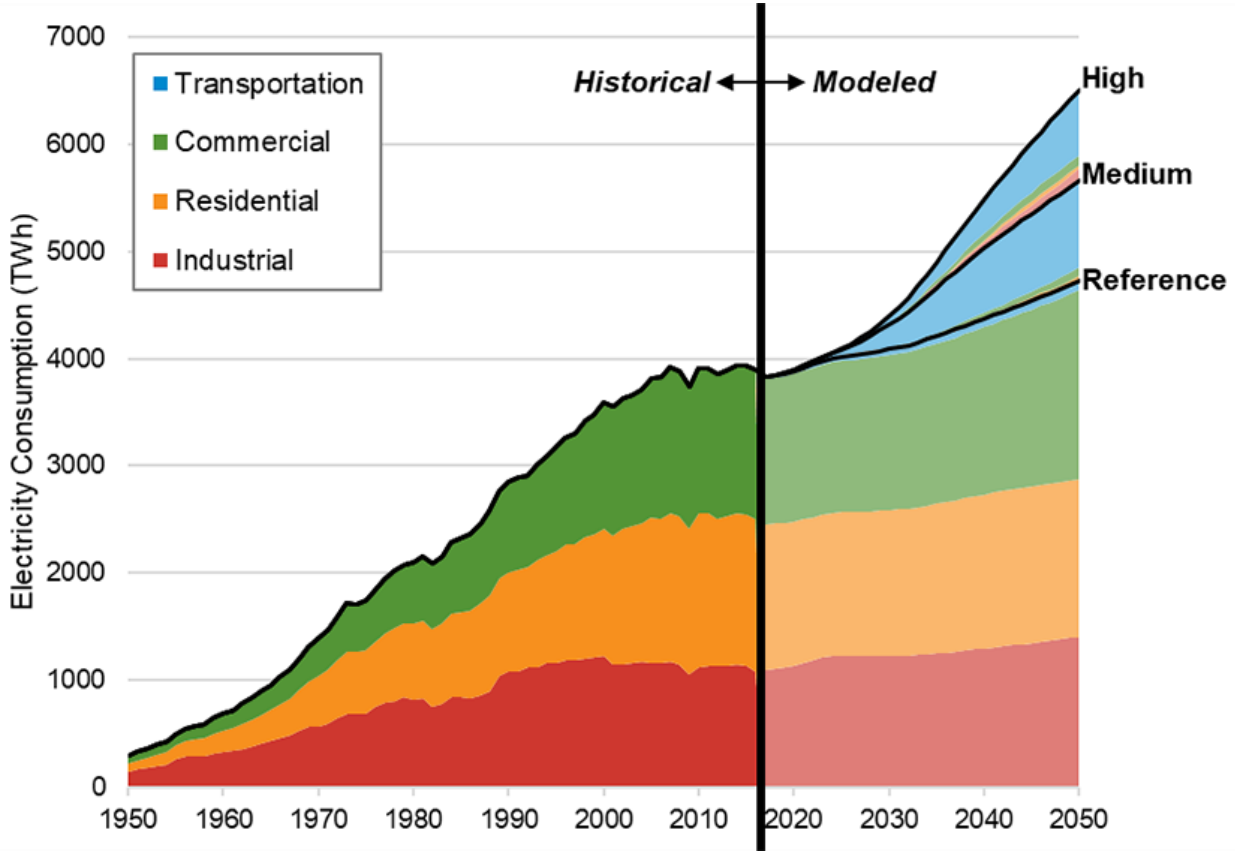
Operational Expenses at 500 kW power drain:

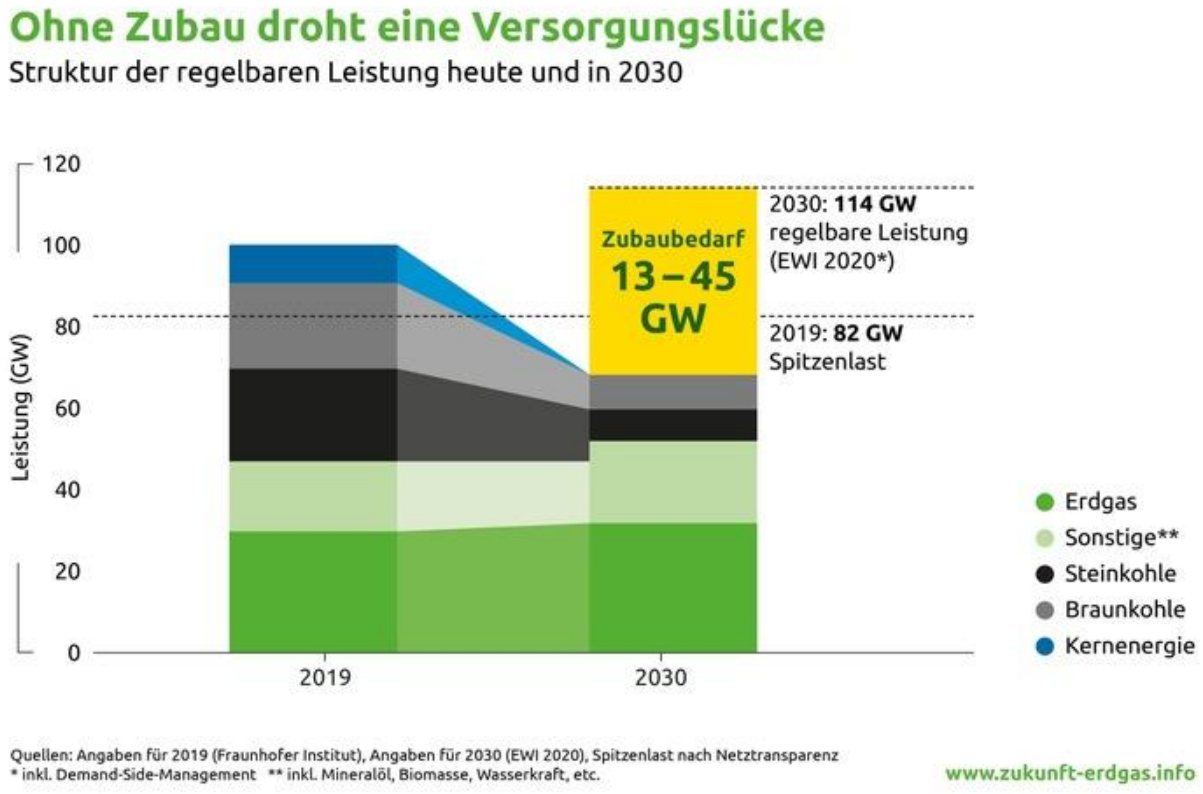
- 50% of current cost increase not covered by commitments from Ministry
- either switch off devices (despite contracts)
- or run into debt (despite legal framework)

Reduce operational costs

- Use heat-load to heat house …
- but house was never meant to be ‘data-center’,
  so the water can’t be used for the heating infrastructure
- Send hot water to district heating, but water too cold for local district
- Could send to different pipe, but company requires 10+ years commitment to invest in pipes
- Ministry doesn’t want to commit on that time-scale

Power: demand & supply indicate > OpExp





US: estimated 40% increase in coming 30 years

Germany: estimated 10% increase in 10 years while reducing power production by 30%

NREL: Electrification Futures Study: Scenarios of Electric Technology Adoption and Power Consumption for the United States (2018)

Do more, with less – special purpose solutions

Quantum Algorithm Zoo

This is a comprehensive catalog of quantum algorithms. If you notice any errors or omissions, please email me at spj.jordan@gmail.com. (Alternatively, you may submit a pull request to the repository on github.) Although I cannot guarantee a prompt response, your help is appreciated and will be acknowledged.

Algebraic and Number Theoretic Algorithms

arXiv > quant-ph > arXiv:1411.4028

Quantum Physics

[Submitted on 14 Nov 2014]

A Quantum Approximate Optimization Algorithm

Edward Farhi, Jeffrey Goldstone, Sam Gutmann

We introduce a quantum algorithm that produces approximate solutions for combinatorial opti approximation improves as p is increased. The quantum circuit that implements the algorithm optimum is sought. The depth of the circuit grows linearly with p times (at worst) the number c efficient classical preprocessing. If p grows with the input size a different strategy is proposed on 2-regular and 3-regular graphs for fixed p. For p = 1, on 3-regular graphs the quantum algc

arXiv > quant-ph > arXiv:2308.06572

Quantum Physics

[Submitted on 12 Aug 2023 (v1), last revised 17 Aug 2023 (this version, v2)]

An Efficient Quantum Factoring Algorithm

Oded Regev

We show that n-bit integers can be factorized by independently running a quant The correctness of the algorithm relies on a number-theoretic heuristic assumpt the algorithm can lead to improved physical implementations in practice.

arXiv > quant-ph > arXiv:1403.1539

Quantum Physics

[Submitted on 6 Mar 2014 (v1), last revised 23 Mar 2014 (this version, v2)]

Improving Quantum Algorithms for Quantum Chemistry

M. B. Hastings, D. Wecker, B. Bauer, M. Troyer

We present several improvements to the standard Trotter-Suzuki based algorithms used in the simulatic Wigner transformations are implemented to reduce their cost from linear or logarithmic in the number of Then, we demonstrate how many operations can be parallelized, leading to a further linear decrease in number of qubits required. Thirdly, we modify the term order in the Trotter-Suzuki decomposition, signifi modifies the Hamiltonian to reduce errors introduced by the non-zero Trotter-Suzuki timestep. All of the given for realistic molecules.

It is sort of like visiting a nursery school to decide which of the toddlers will become basketball stars.
Scott Aaronson, UT

Silicon

Colour Centers

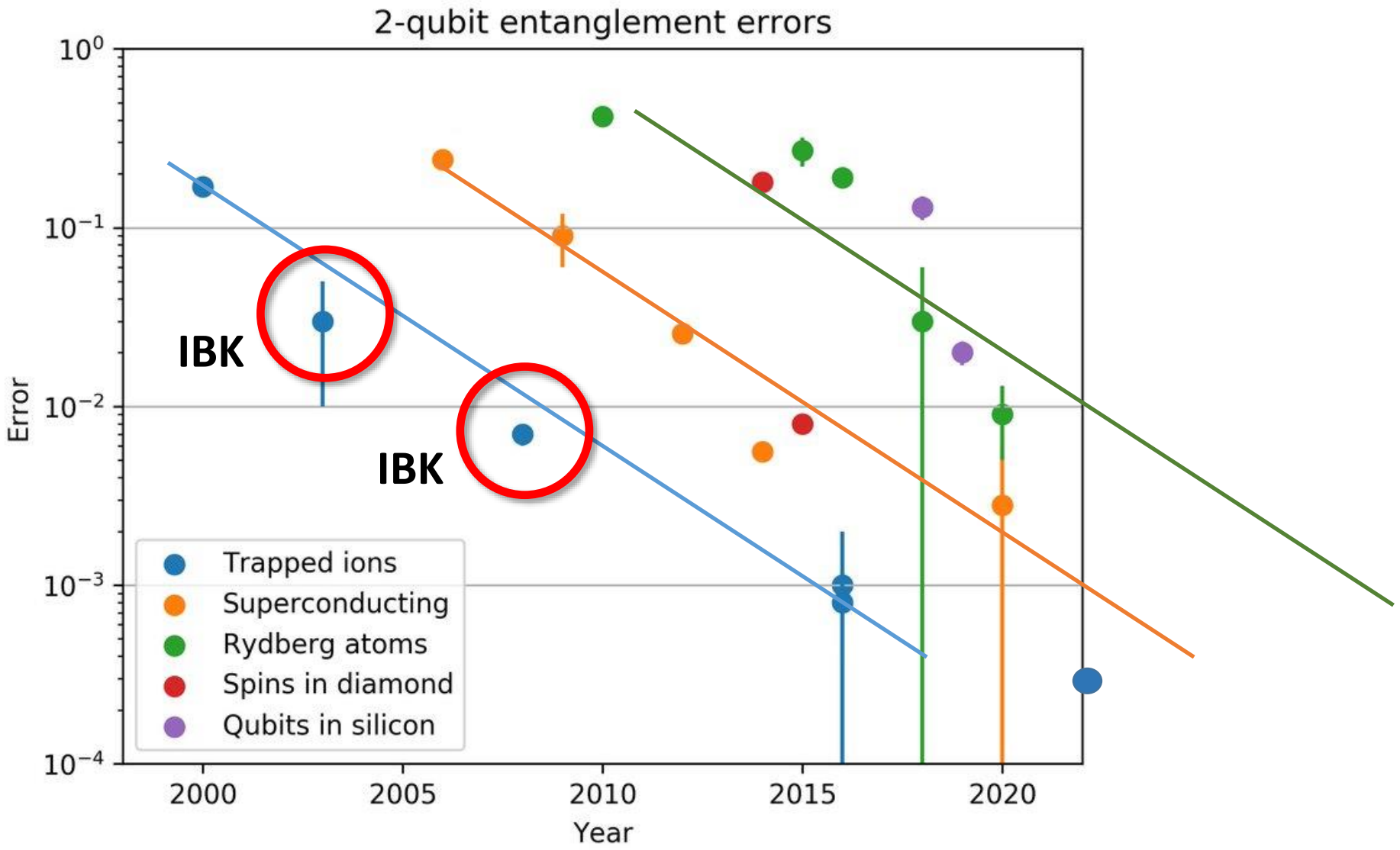
Trapped Ions

Photons

Superconducting Circuits

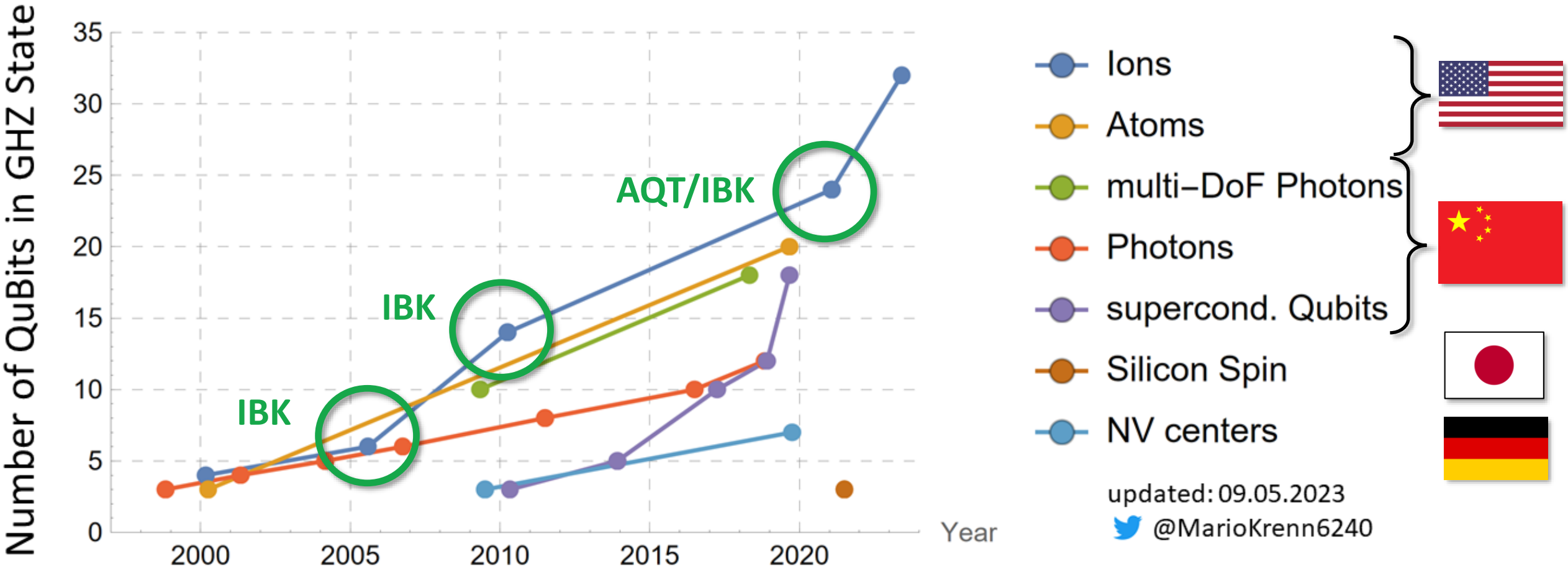
Ultracold atoms

QC Performance – Trapped Ions 5 years ahead



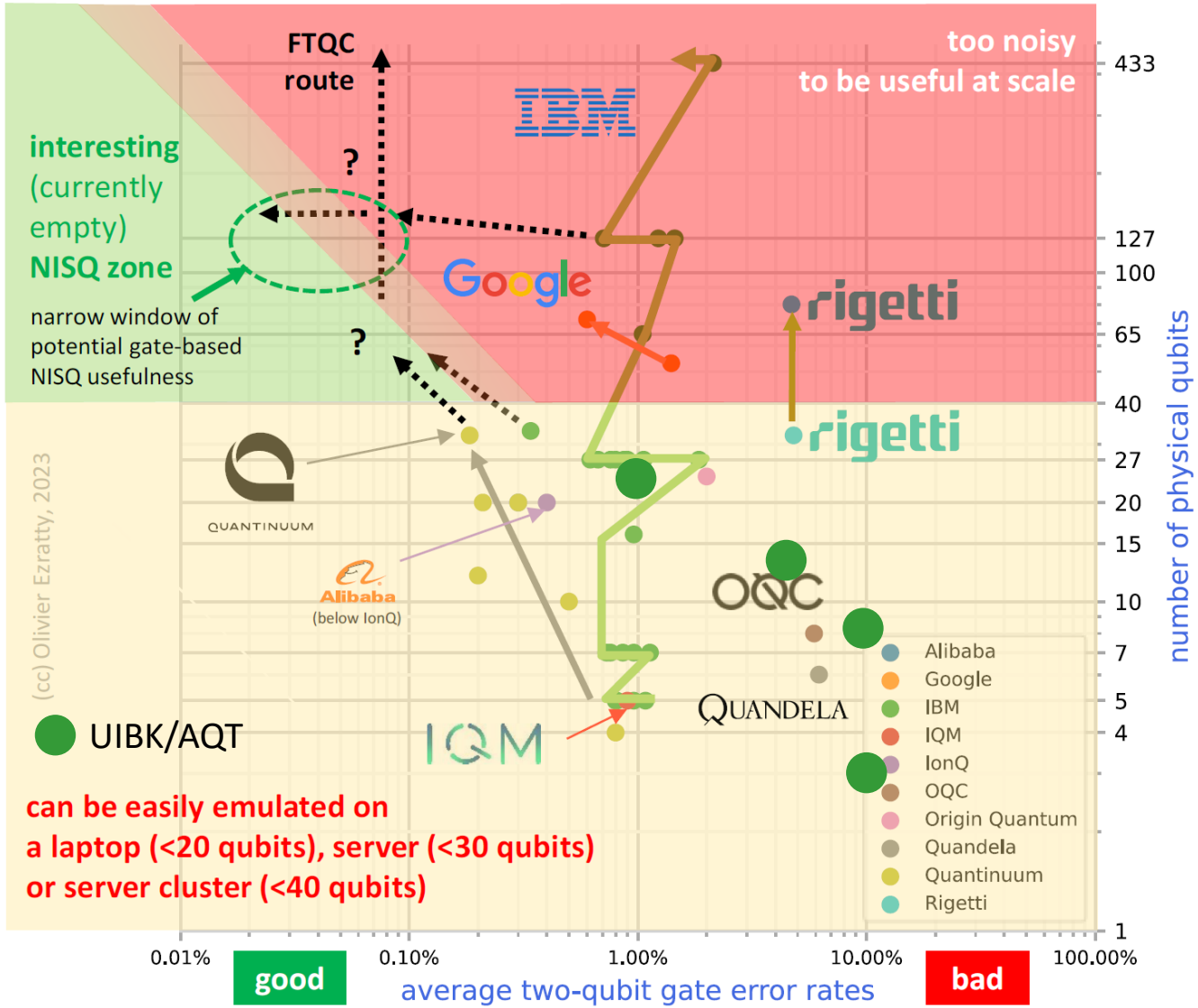
https://twitter.com/quantumpod/status/1355467206881062912

And ions lead in quantum technologies



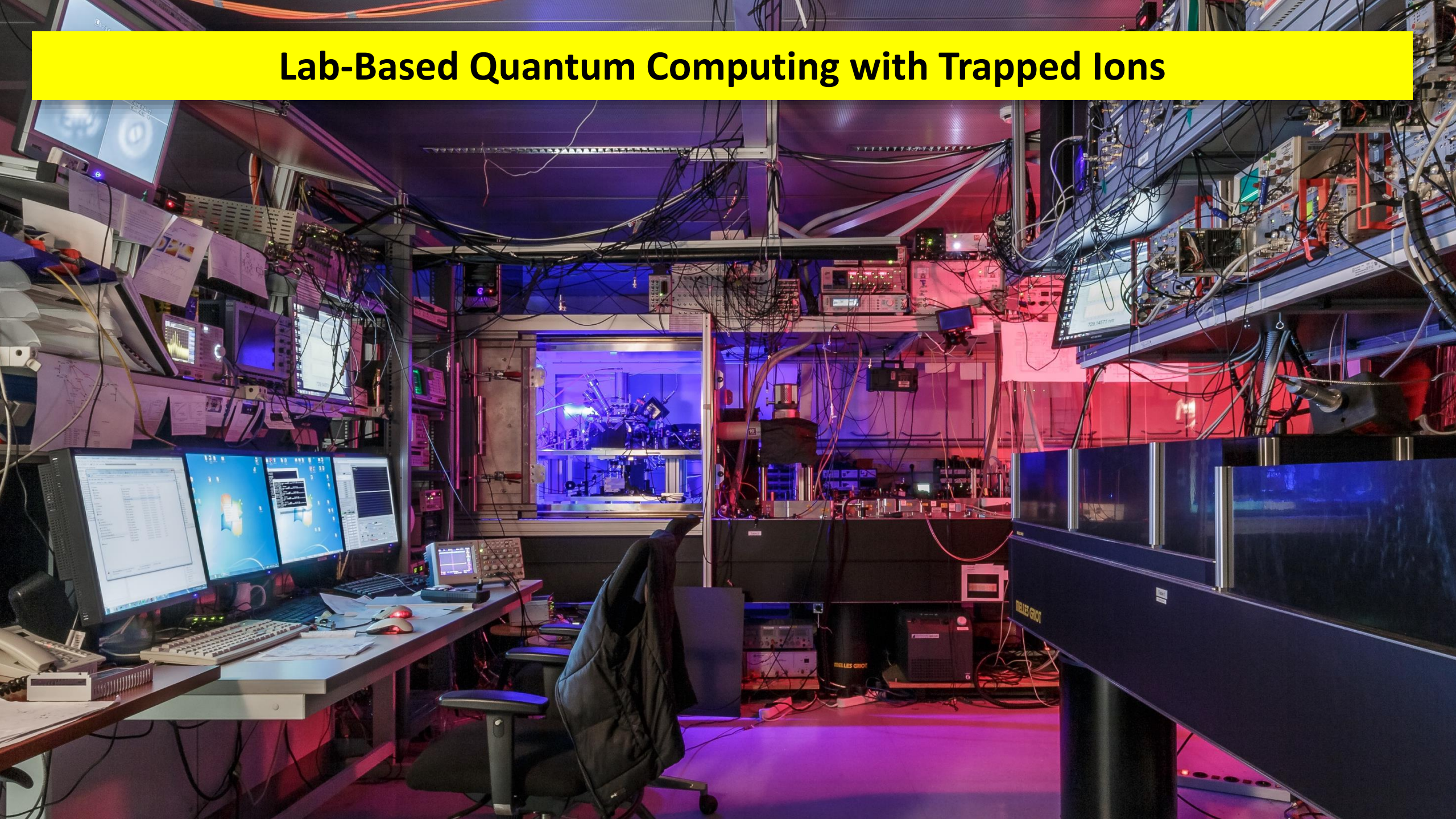
https://mariokrenn.wordpress.com/2021/01/29/reference-list-for-records-in-large-entanglement-generation-number-of-qubits-in-ghz-states/

Focusing on quality, not quantity



O. Ezratty, arXiv:2305.09518

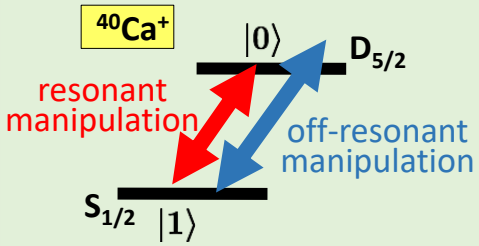
Lab-Based Quantum Computing with Trapped Ions



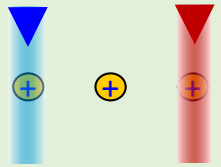
The workhorse at UIBK …

PRX Quantum 2, 020343 (2021)

Individual (and parallel) local operations



$S_z(\theta)$ $S_{x,y}(\theta)$



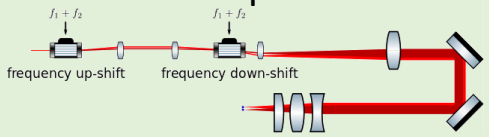
τ = 20µs
F > 99%

Control capabilities

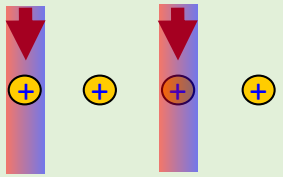
- T1 approx 1s
- T2 approx 500 ms
- Routinely work with 20+ ions
- Demonstrated 24q-GHZ state
- Supports Qiskit/Cirq/…

Local Mølmer- Sørensen entangling gate

Simultaneous addressing of multiple ions



$S^2_{x,y}(\theta)$



τ = 100µs
F ~ 99%

Automated tune-up

- Single-qubit control
- Single-setting MS up to 20 q despite full connectivity N^2 speed-up
- Tune-up to > 99% in 30 sec

QUANTUM COMPUTER

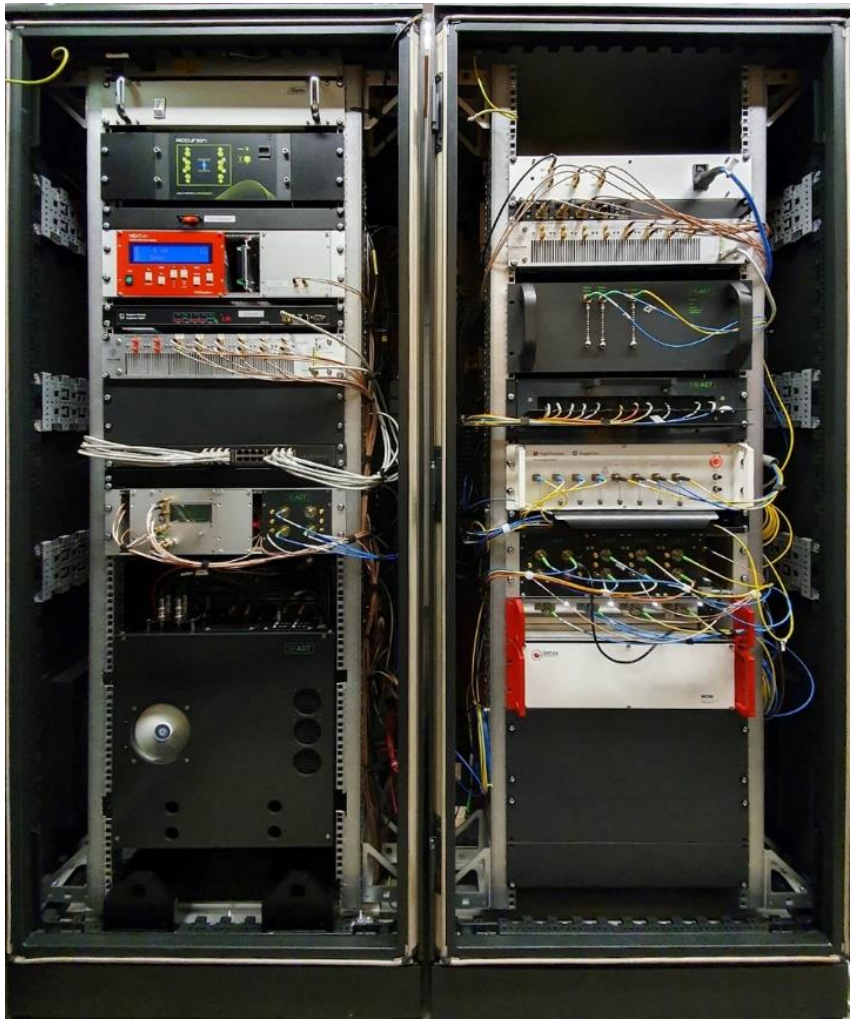
INSIDE INDUSTRY-STANDARD 19'' RACK

AQT DELIVERS:

- 50+ ion-qubits
- 24-qubit entanglement
- Shor's algorithm
- Quantum Error Correction
- Fault-tolerant performance
- Demo'd finance use-case
- Demo'd security use-case
- Demo'd chemistry use-case
- ...

WITH OUR SYSTEM BEING:

- Rack-mounted
- Cloud-accessible
- Data-center compatible



HOLISTIC PERFORMANCE

Evaluating the quality of our quantum computer

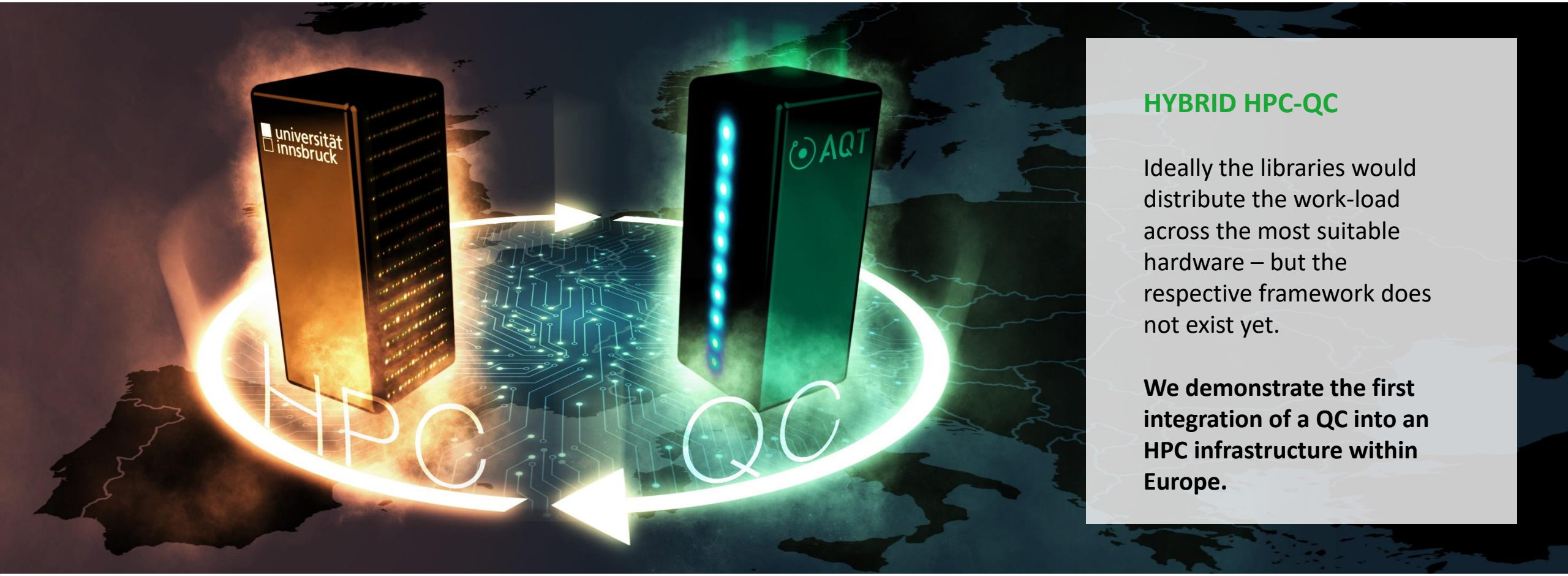
QUANTUM VOLUME

Achieving high fidelity control in continously larger registers, while maintaining versatile computations, and achieving sufficient output quality is highly challenging.

We demonstrate a quantum volume of 128, which outperforms all devices in Europe.

HETEROGENOUS HPC-QC

Demonstrating a new kind of HPC accelerator



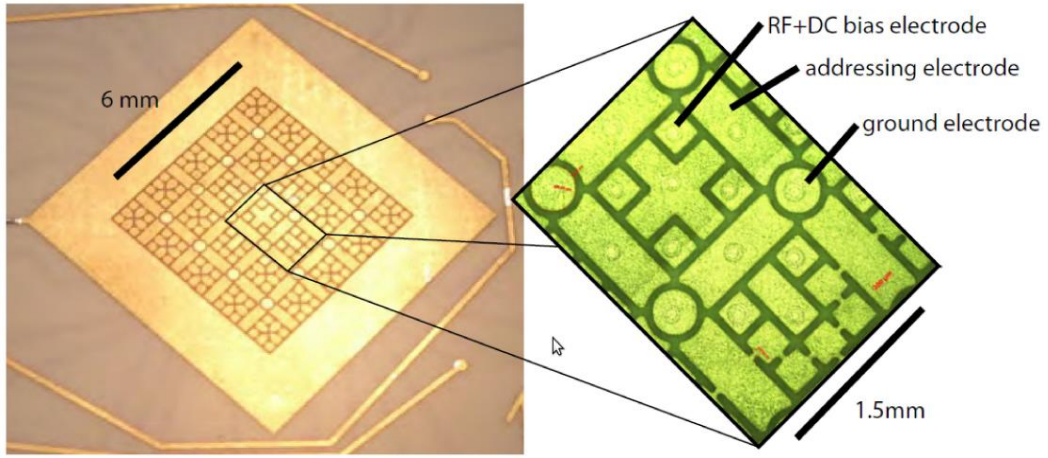
HYBRID HPC-QC

Ideally the libraries would distribute the work-load across the most suitable hardware – but the respective framework does not exist yet.

We demonstrate the first integration of a QC into an HPC infrastructure within Europe.

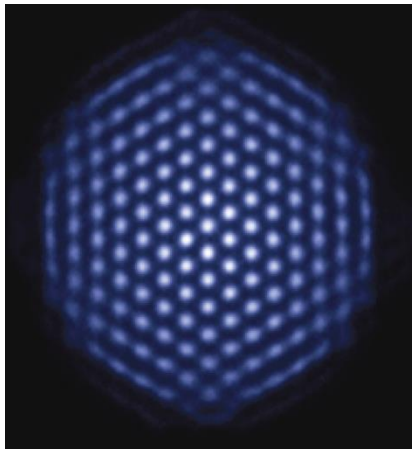
Towards FTQC in scalable 2D architectures

- 2D ion trap arrays

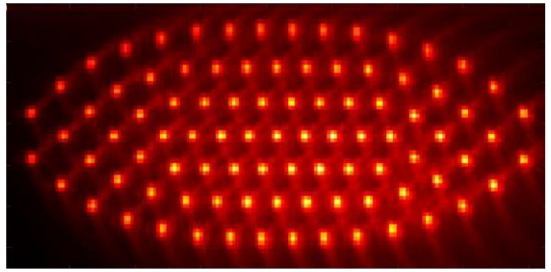


M. Kumph et al. (Blatt group)

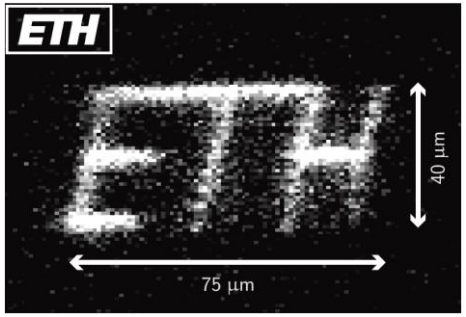
- 2D ion crystals



(Bollinger group)

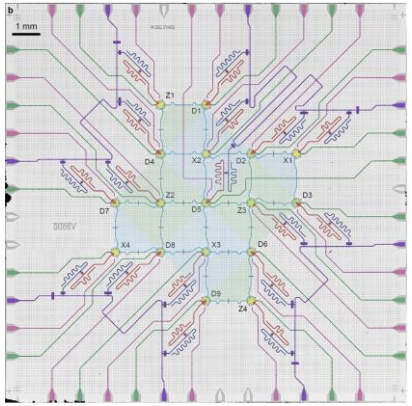


(Roos group)

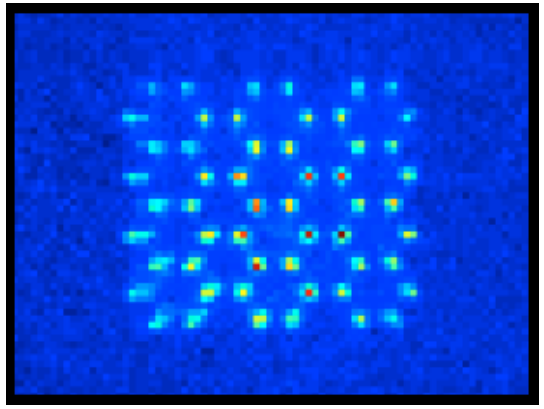


(Home group)

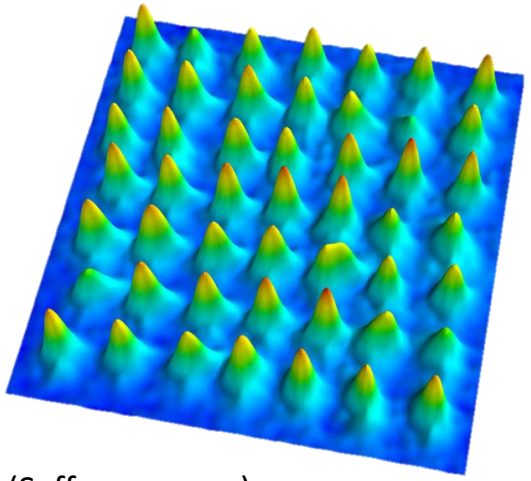
- Cold atoms in optical lattices & other AMO systems
- Solid-state platforms



(A. Wallraff)



(Browaeys group)



(Saffman group)

100+ ion-qubits w/ OpExp → 0 EUR

PV @ 5 kW

- Requires about 25 sqm surface in Tirol/Austria
- Costs for PV: about 10 kEUR @ 25 sqm
- Incl. battery for day/night operation: +5 kEUR
- Total: **about 15 kEUR**
- Amortisation: 14 years
- Self-use quota estimated at 50%

Data from pvaustria.at/pvrechner

Comparison: Dilution fridge for Superconducting

- One filling at **150 kEUR**
- He3 is non-replenishing → mag. fridge
- Power for Bluefors fridge for 1k qubits @ 91 kW

AG Quantenoptik und Spektroskopie

The international Team 2023

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Industrie Tirol

IQI GmbH

FWF bmwfw Bundesministerium für Wissenschaft, Forschung und Wirtschaft IQI $ IARPA

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The international Team 2023

European Innovation Council

FFG Promoting Innovation.

Industrie Tirol


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Research & engineering
Hiking & skiing
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