QUANTUM COMPUTING @ JSC

Overview of Devices, Applications, and Live-Coding

2025 I DR. DENNIS WILLSCH


Quantum Computer
Superconducting qubits
Quantum Computer
Semiconducting qubits
Quantum Computer
Trapped-ion qubits
Supercomputer @JSC
QC & QA Emulators
Quantum Simulator
Neutral-atom qubits
Quantum Annealer
Superconducting qubits
IQM
PASQAL
FRESNEL
advantage

Quantum Computing Technologies

Provision strategy

HELMHOLTZ
RESEARCH FOR GRAND CHALLENGES

HELMHOLTZ
QUANTUM

Quantum Annealer

Analog quantum computer with superconducting qubits

Hosting since 2021

Quantum Simulator

Analog / digital quantum computer with neutral-atom qubits

Hosting since 2025

Quantum Computer

Digital quantum computer with trapped-ion qubits, semiconducting qubits, and superconducting qubits

Hosting and cloud-access since 2024 - 2026

D-Wave The Quantum Computing Company **Advantage**

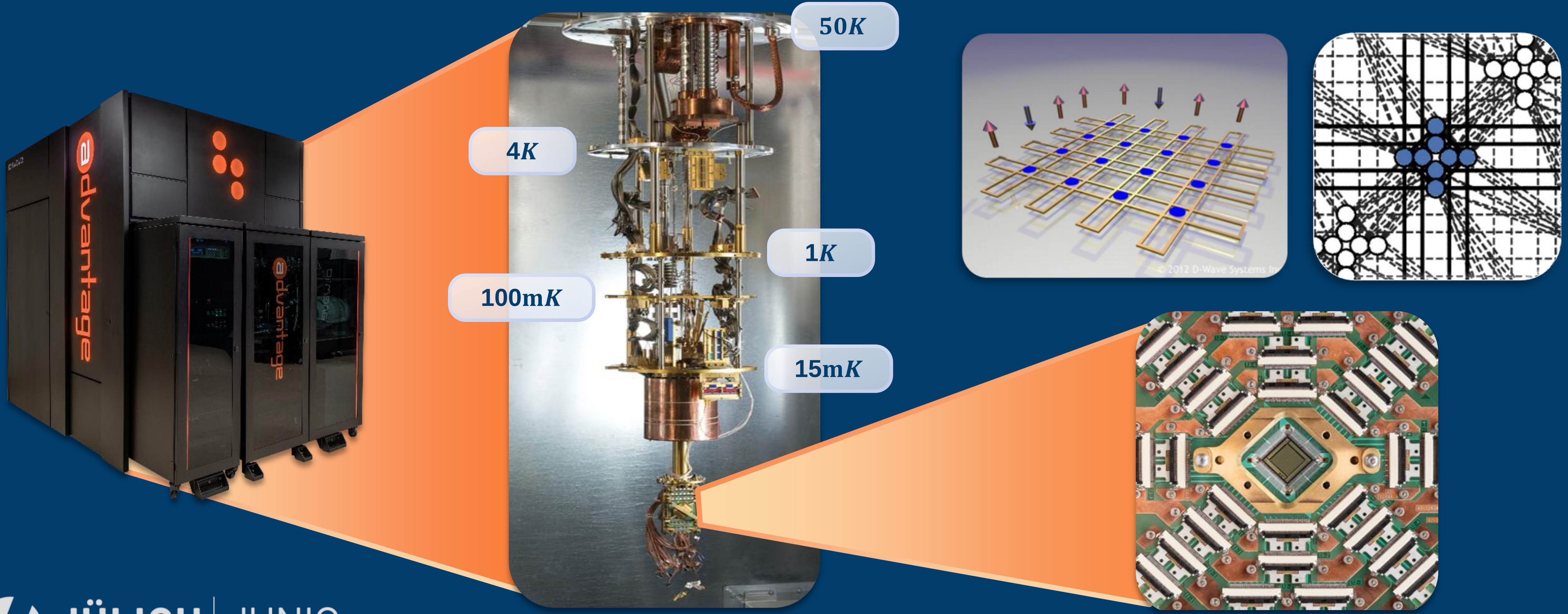
Cooling system

25kW power consumption

Quantum Processing Unit

5640 superconducting qubits

Pegasus topology with 40.484 couplers



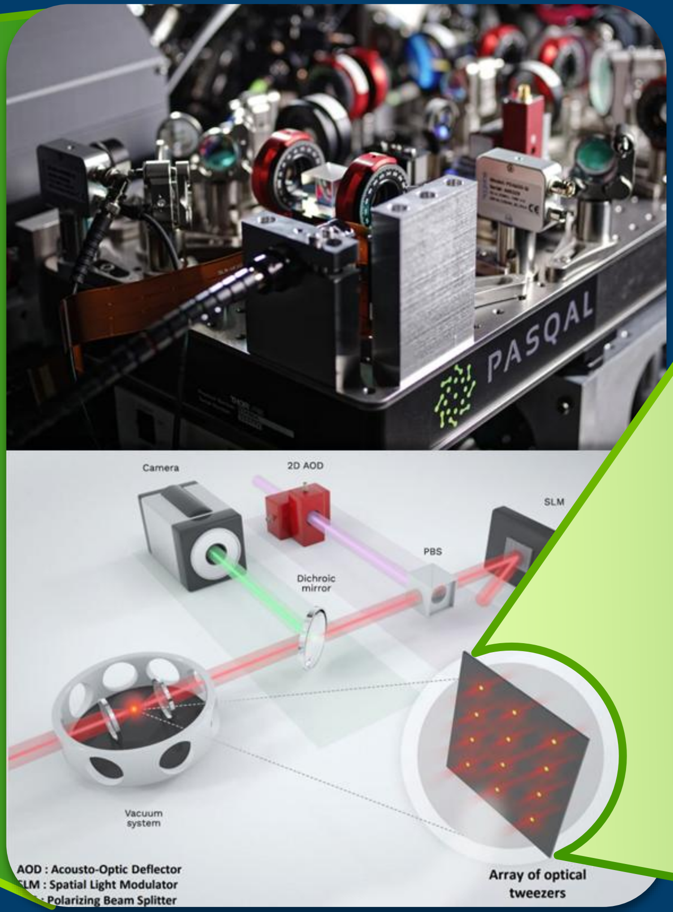
PASQAL **Fresnel**

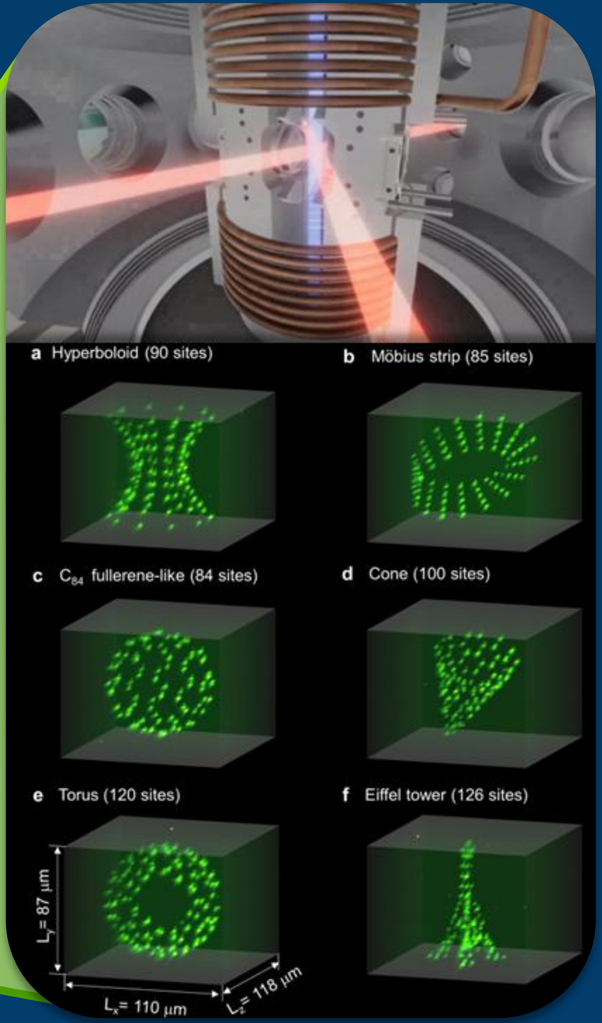
Quantum Processing Unit

<3kW power consumption

Quantum Register

100 Rydberg atoms trapped in a 3D lattice





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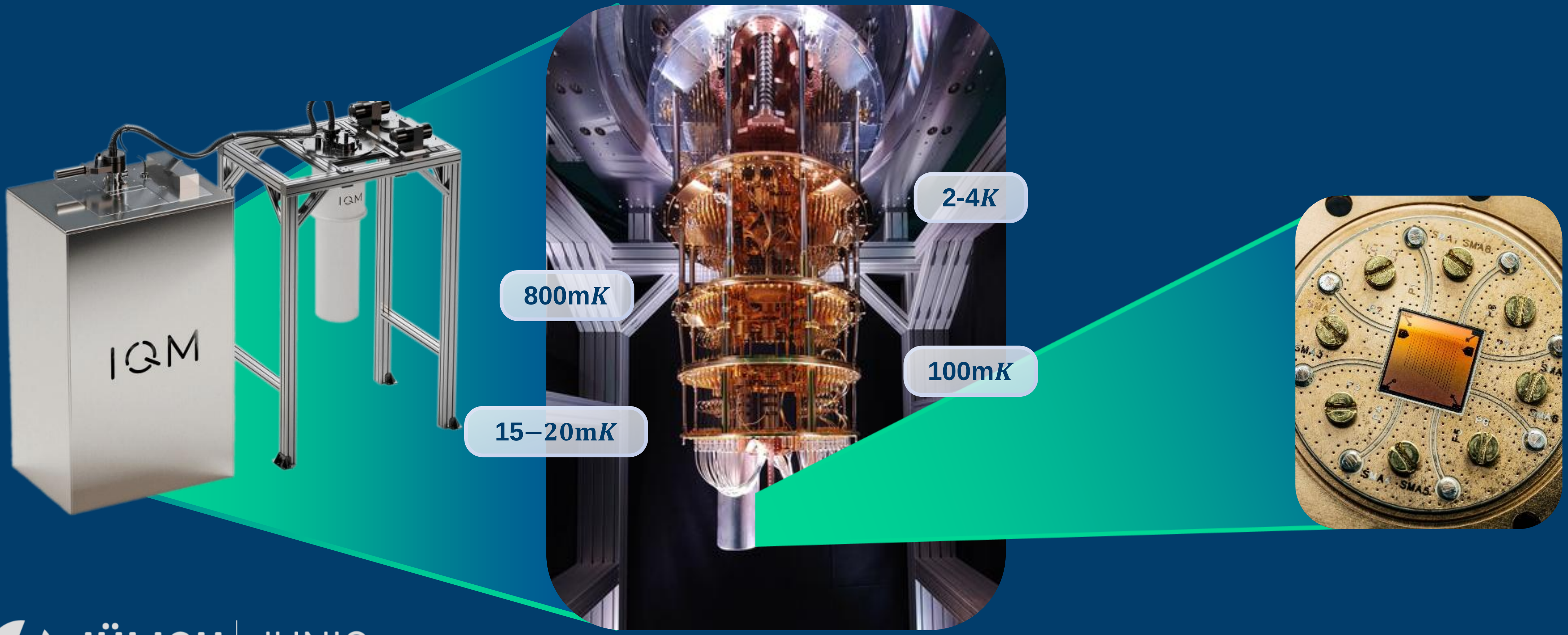
IQM **Spark**

Cooling system

Quantum Processing Unit

5 superconducting qubits



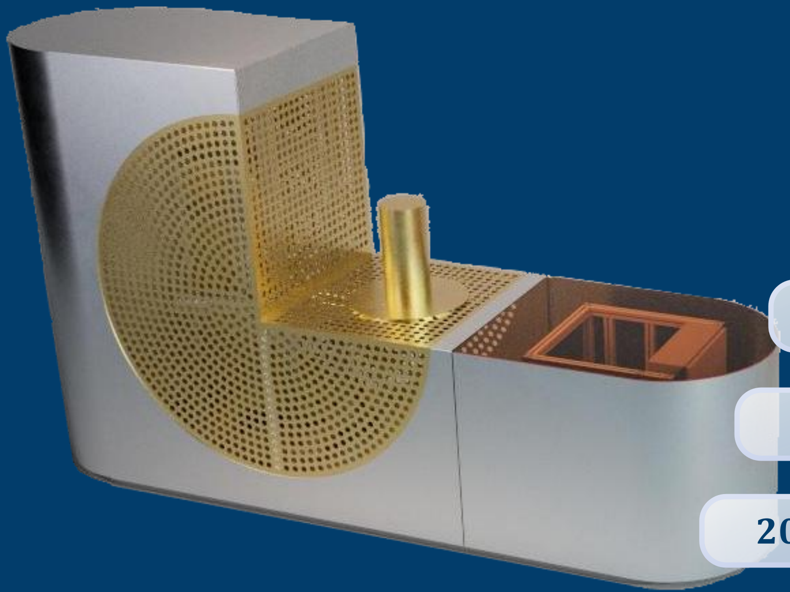
ARQUE5

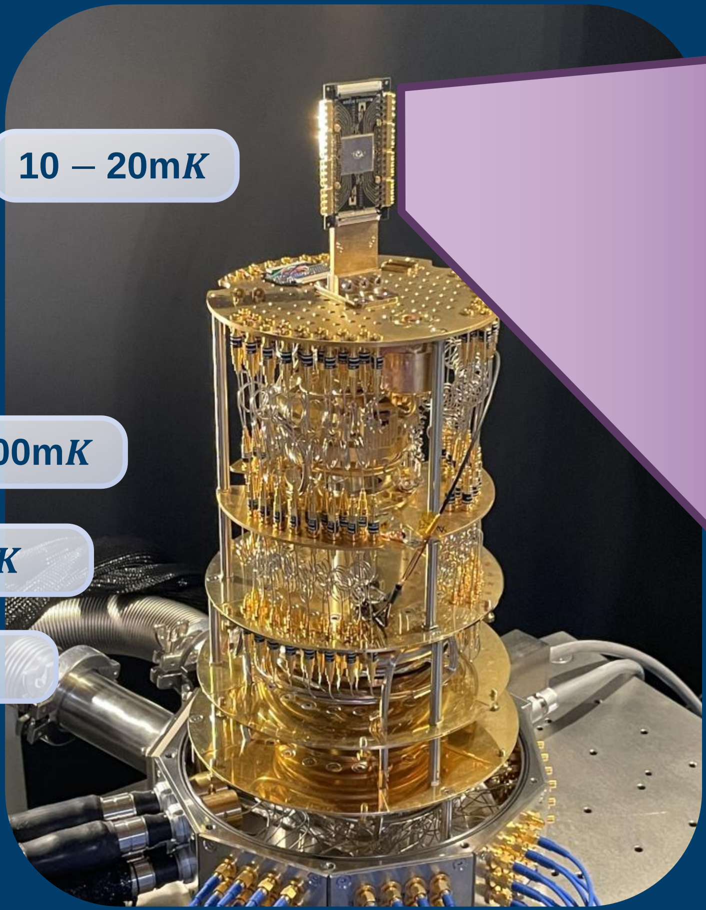
ARQUE SYSTEMS

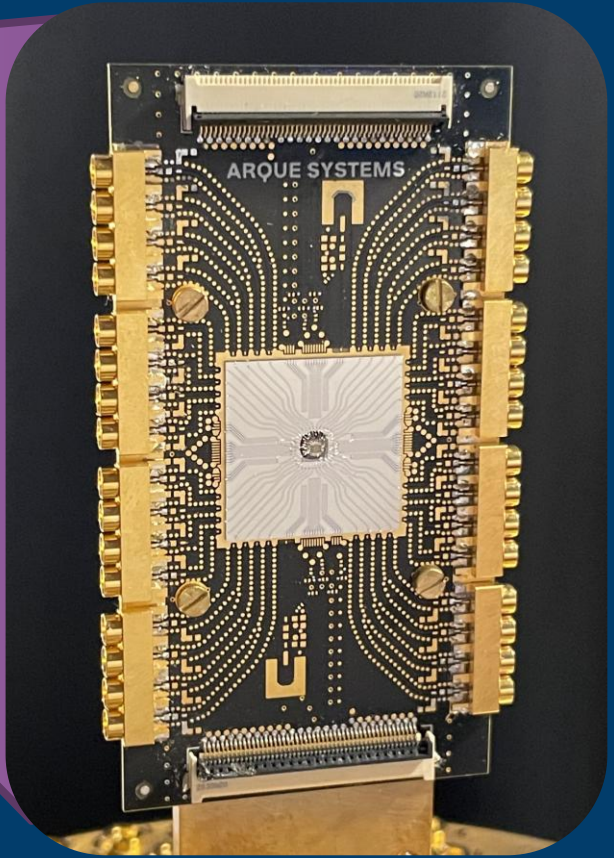
Cooling system

Quantum Processing Unit

5 semiconducting electron-spin qubits







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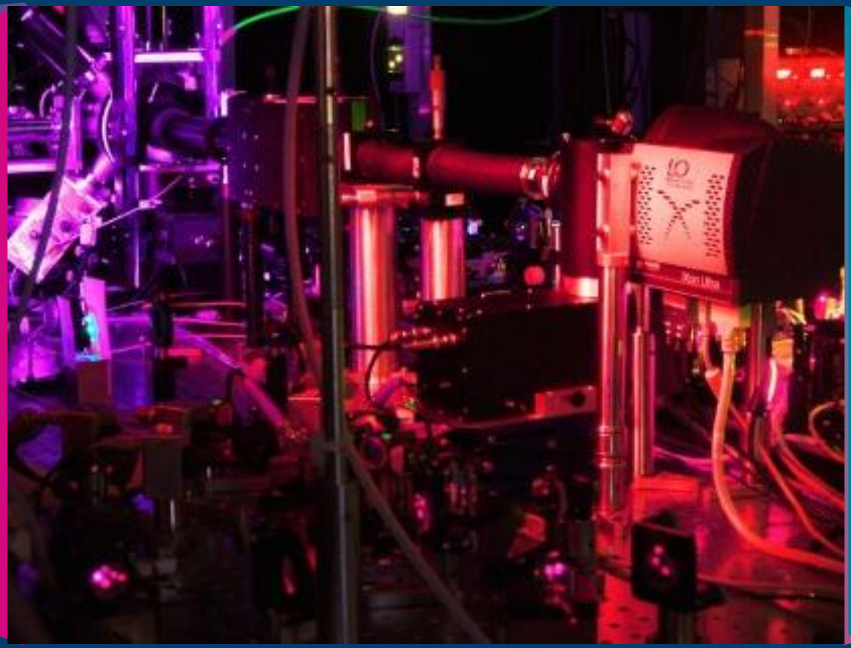
Quantum Processing Unit

Linear ion trap

Quantum Register

20-30 trapped ion qubits controlled with MAGIC technology



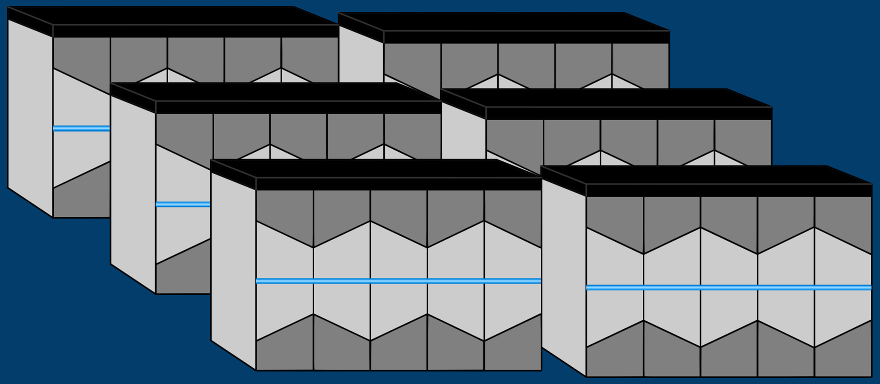
Quantum Computing Technologies

Emulation on Supercomputers

HELMHOLTZ
Spitzenforschung für große Herausforderungen.
HELMHOLTZ QUANTUM

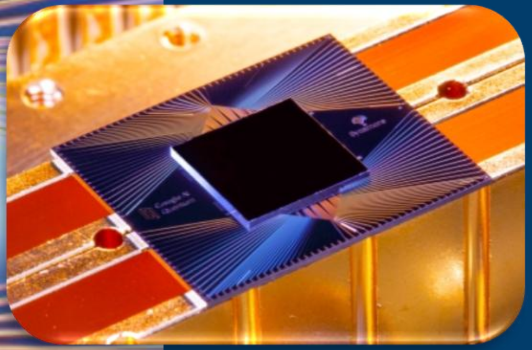
JUQCS

Jülich Universal Quantum Computer Simulator



Qubits	Memory
10 qubits	16 kiB
20 qubits	16 MiB
30 qubits	16 GiB
40 qubits	16 TiB
45 qubits	0.5 PiB

36 qubits: De Raedt et al., CPC 176, 121 (2007)
45 qubits: De Raedt et al., CPC 237, 47 (2019)
50 qubits: De Raedt et al., arXiv:2511.03359 (2025)



Benchmarking of Google's Quantum Computer Sycamore

F. Arute et al., *Quantum supremacy using a programmable superconducting processor*, Nature 574, 505-510 (2019)

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Analog Quantum Computers

A Deeper Look: What do they do?

Optimization problem type

"bias" (real number)

$$\text{Ising:} \quad \min_{s_i=\pm 1} \left(\sum_i h_i s_i + \sum_{i<j} J_{ij} s_i s_j \right)$$

problem variables (binary)

"coupler" (real number)

Why might this be interesting?

→ discrete optimization is **hard** (NP-hard)

→ produces many solutions **simultaneously**

→ very **low** energy consumption

Analog Quantum Computers

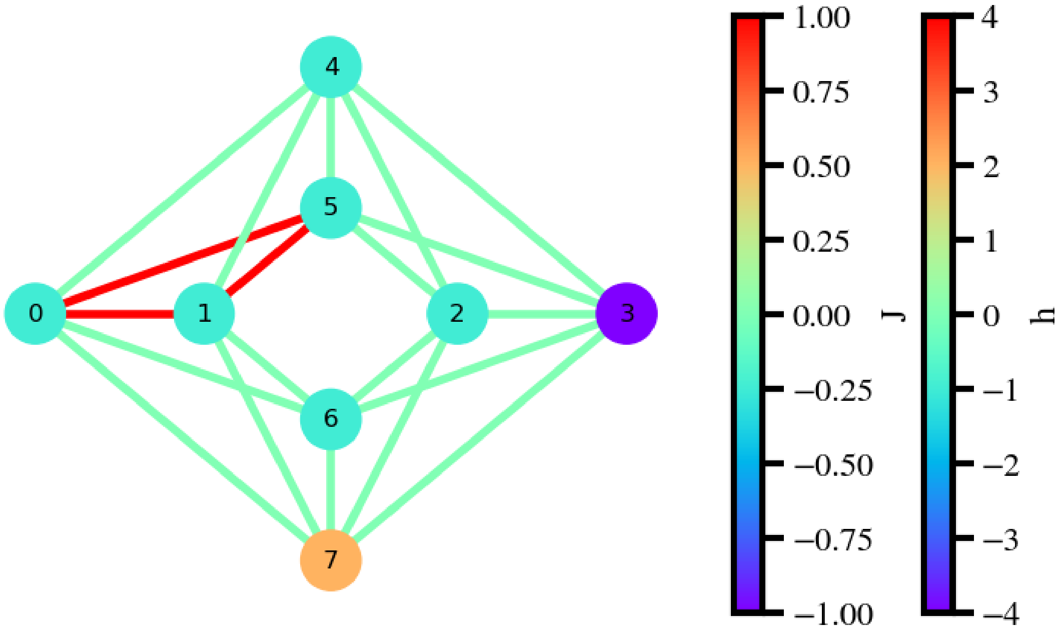
Live-Coding Example

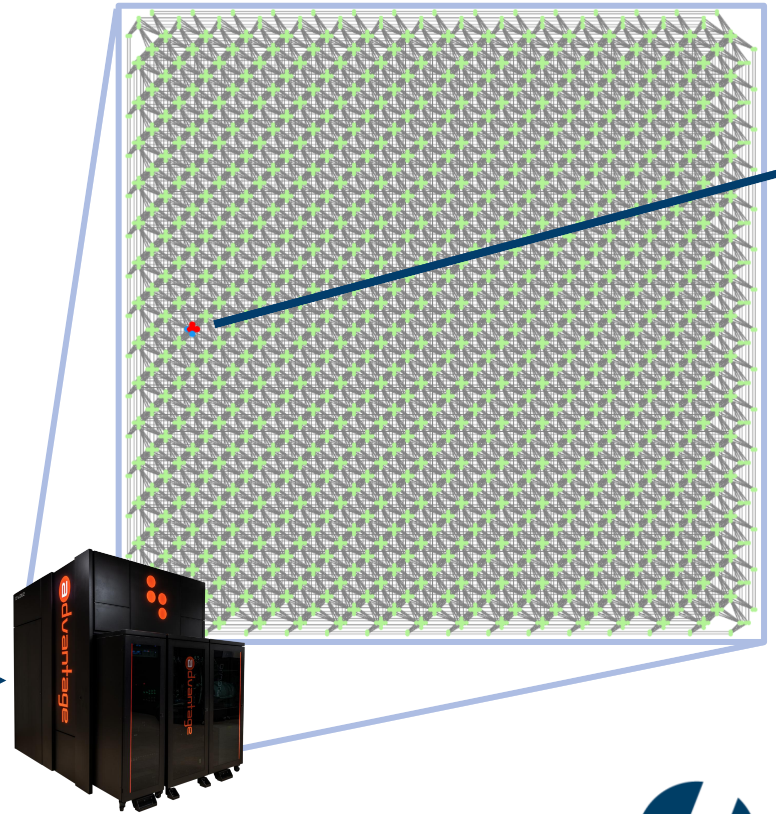
Ising:

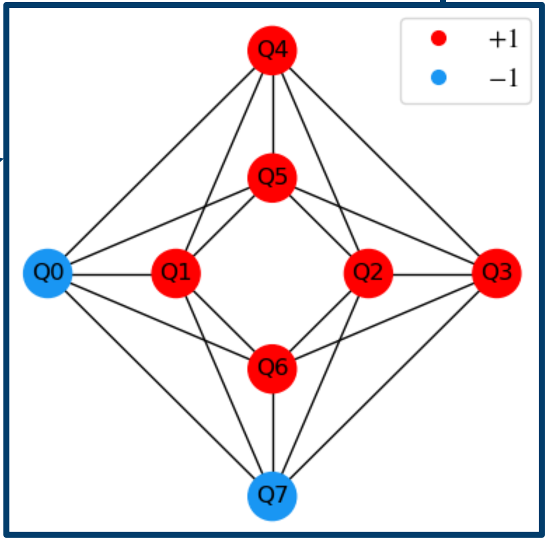
$$\min_{s_i=\pm 1}\left(\sum_{i=0}^{N-1} h_i s_i + \sum_{i<j}^{N-1} J_{ij} s_i s_j\right)$$

h_0	-1.00	h_1	-1.00	h_2	-1.00	h_3	-4.00
h_4	-1.00	h_5	-1.00	h_6	-1.00	h_7	2.00
J_{15}	1.00	J_{16}	0.00	J_{25}	0.00	J_{26}	0.00
J_{04}	0.00	J_{05}	1.00	J_{01}	1.00	J_{37}	0.00

	Q0	Q1	Q2	Q3	Q4	Q5	Q6	Q7	energy	num_occurrences
0	-1	1	1	1	1	1	1	-1	-11.0	34
1	1	1	1	1	1	-1	1	-1	-11.0	39
2	1	-1	1	1	1	1	1	-1	-11.0	26
3	-1	1	1	1	1	1	-1	-1	-9.0	1





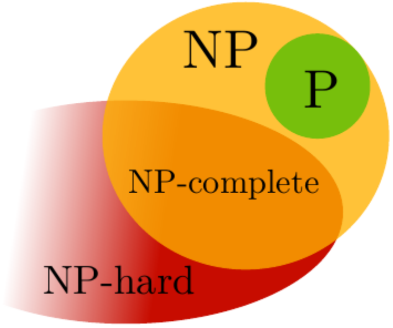


Solution on JUPSI

References and more information:
https://doi.org/10.34734/FZJ-2025-02577
https://jugit.fz-juelich.de/juniq/benchmark-suite

Analog Quantum Computers

How to Solve My Application Problem?



- **First Task:** Translate problem to Ising or QUBO
  - **Ising Problem**

$$\min_{s_i=\pm 1}\left(\sum_{i=0}^{N-1} h_i s_i + \sum_{i<j}^{N-1} J_{ij} s_i s_j\right)$$

  - **QUBO Problem**

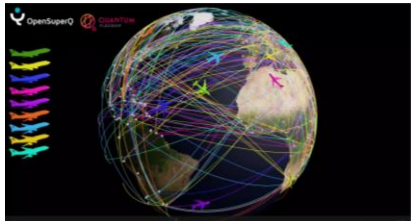
$$\min_{x_i=0,1}\left(\sum_{i\leq j}^{N-1} x_i Q_{ij} x_j\right)$$

Quadratic
Unconstrained
Binary
Optimization

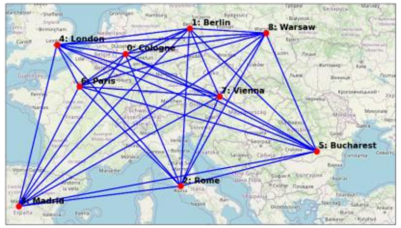
→ "NP-hard": Can in principle "solve" any problem

→ **But:** Not guaranteed to find a quantum advantage!

- Examples for which we have done this:



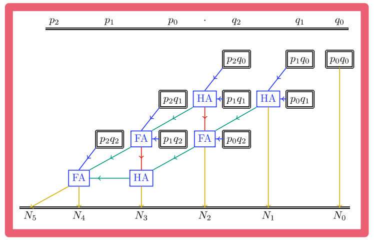
Tail Assignment



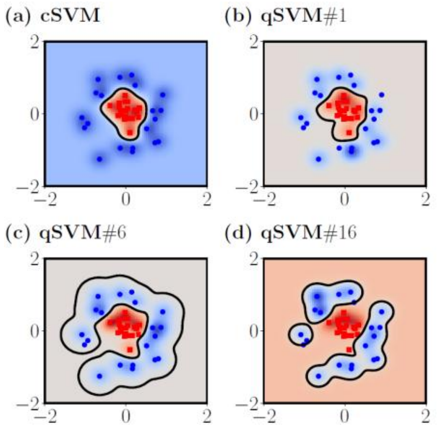
Traveling Salesman

Remote Sensing

Garden Optimization



Integer Factorization



Quantum Machine Learning

- **Available in the JUNIQ Benchmark Suite** https://jugit.fz-juelich.de/juniq/benchmark-suite