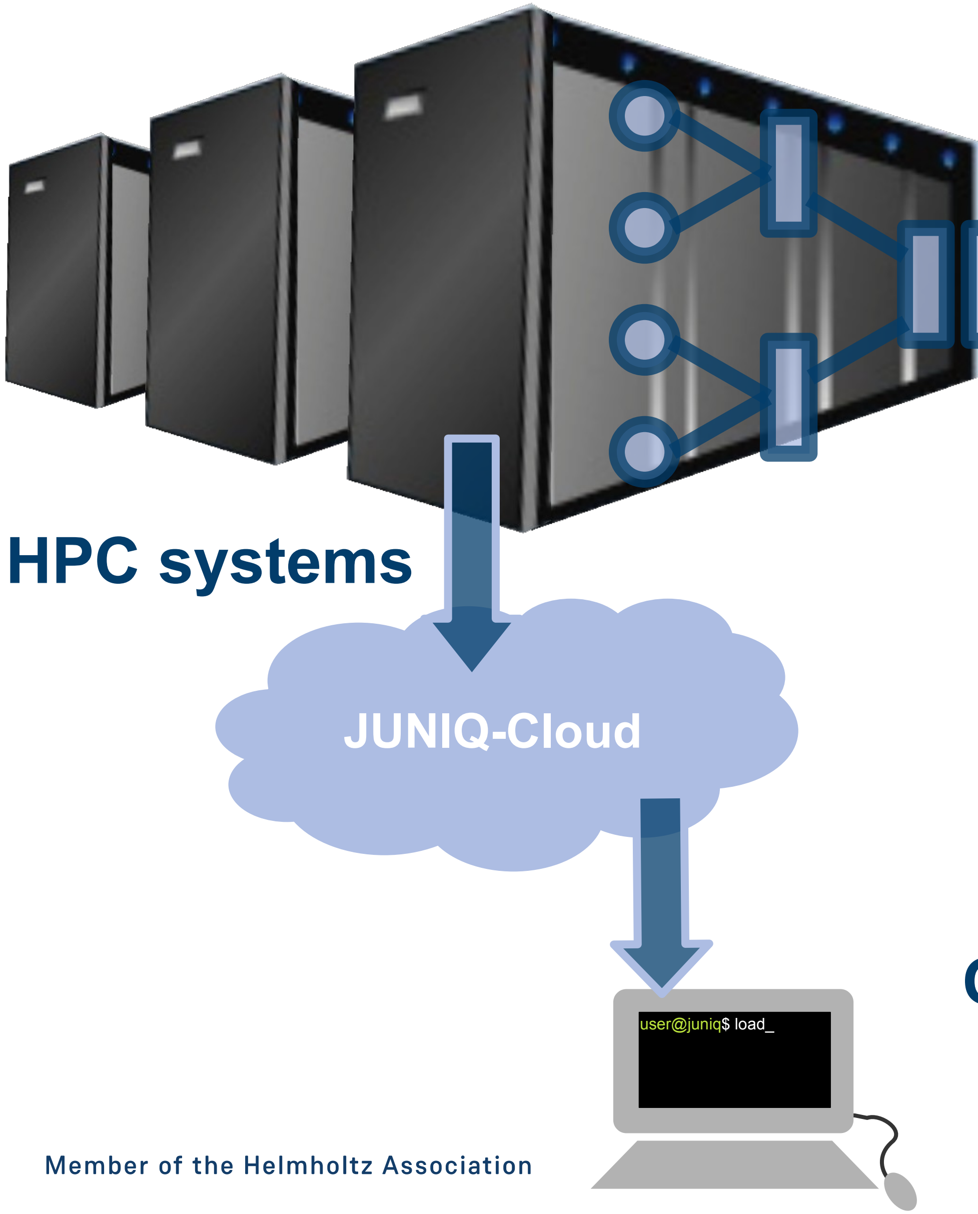
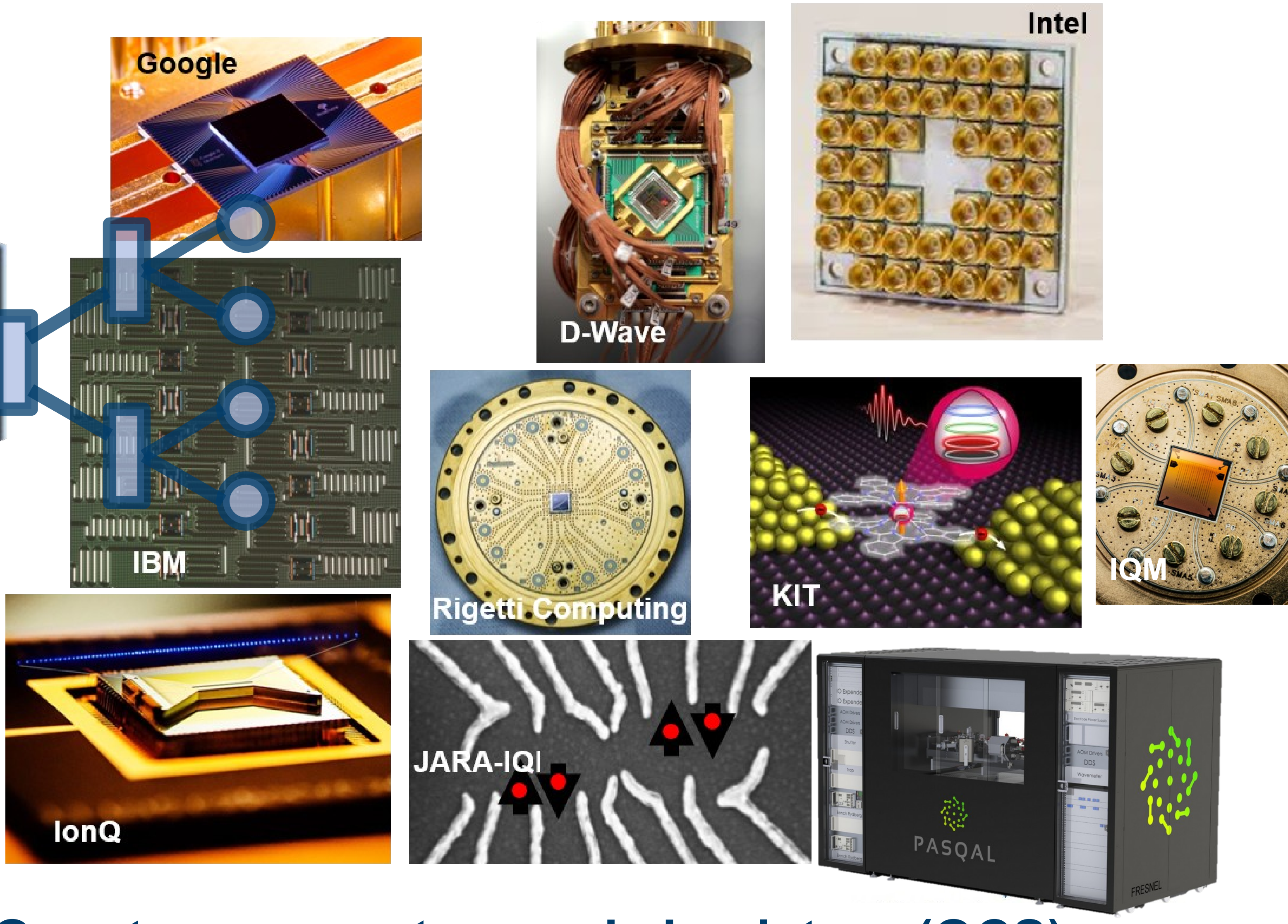
QUANTUM COMPUTING AT JSC

JUNIQ - JÜLICH UNIFIED INFRASTRUCTURE FOR QUANTUM COMPUTING

22 MARCH 2023 I MADITA WILLSCH

JUNIQ: The Vision



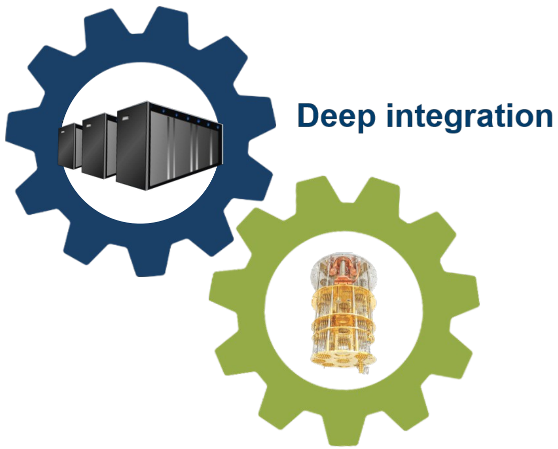


Quantum computers and simulators (QCS)

Hybrid quantum-classical computing systems

for the realization of the full potential of quantum computing

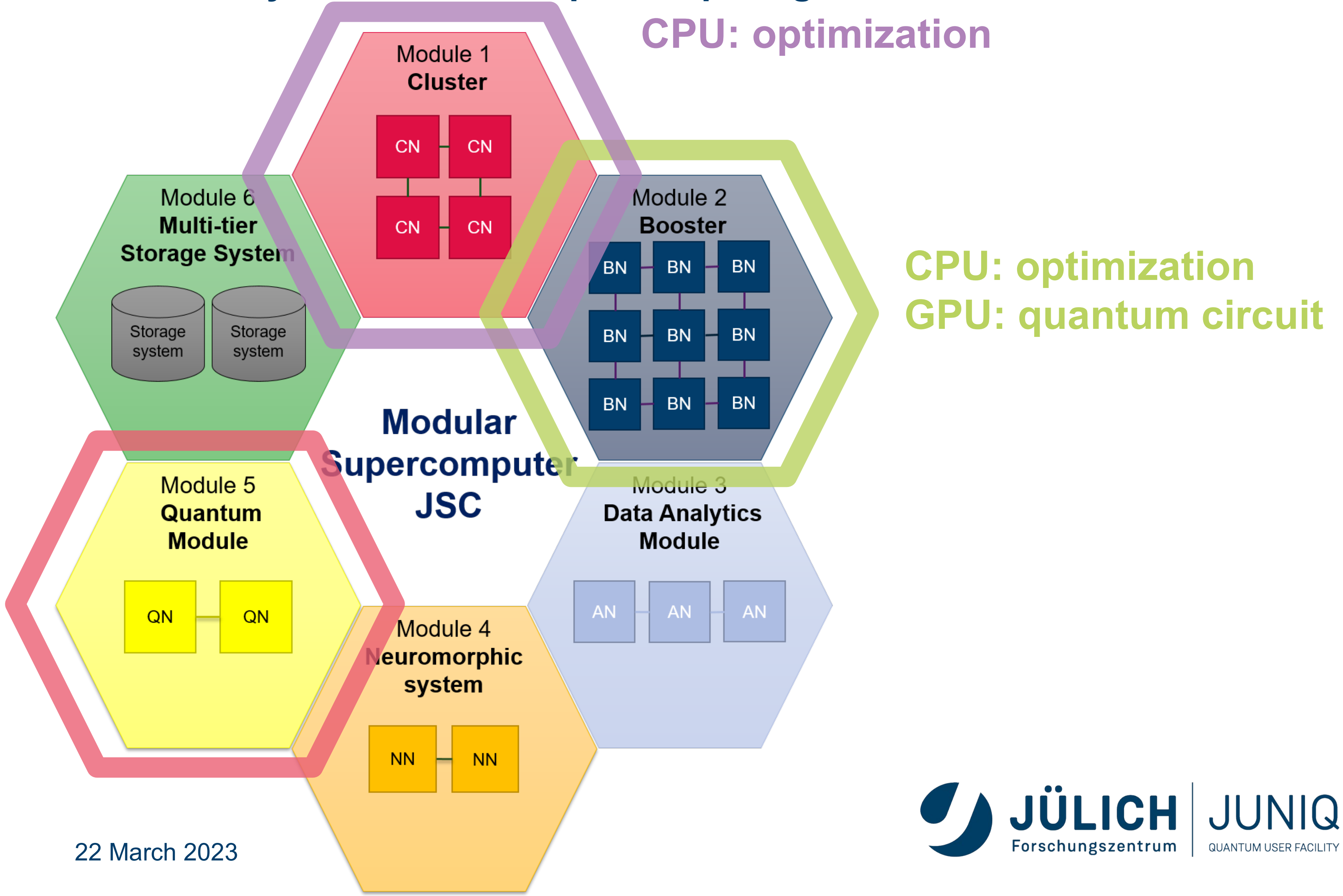
- **Hybrid quantum-classical algorithms**
  - Apply parameterized transformations to quantum system, evaluate energy expectation value → classical optimization algorithm suggests new parameters
    - Variational Quantum Eigensolver – **VQE**: quantum chemistry
    - Quantum Approximate Optimization Algorithm – **QAOA**: optimization
  - Classic workflows with potential quantum content
- **Hybrid quantum-classical hardware**



Latencies & execution times

JUNIQ in the Modular Supercomputing Architecture

A European quantum computer user facility at the Jülich Supercomputing Centre



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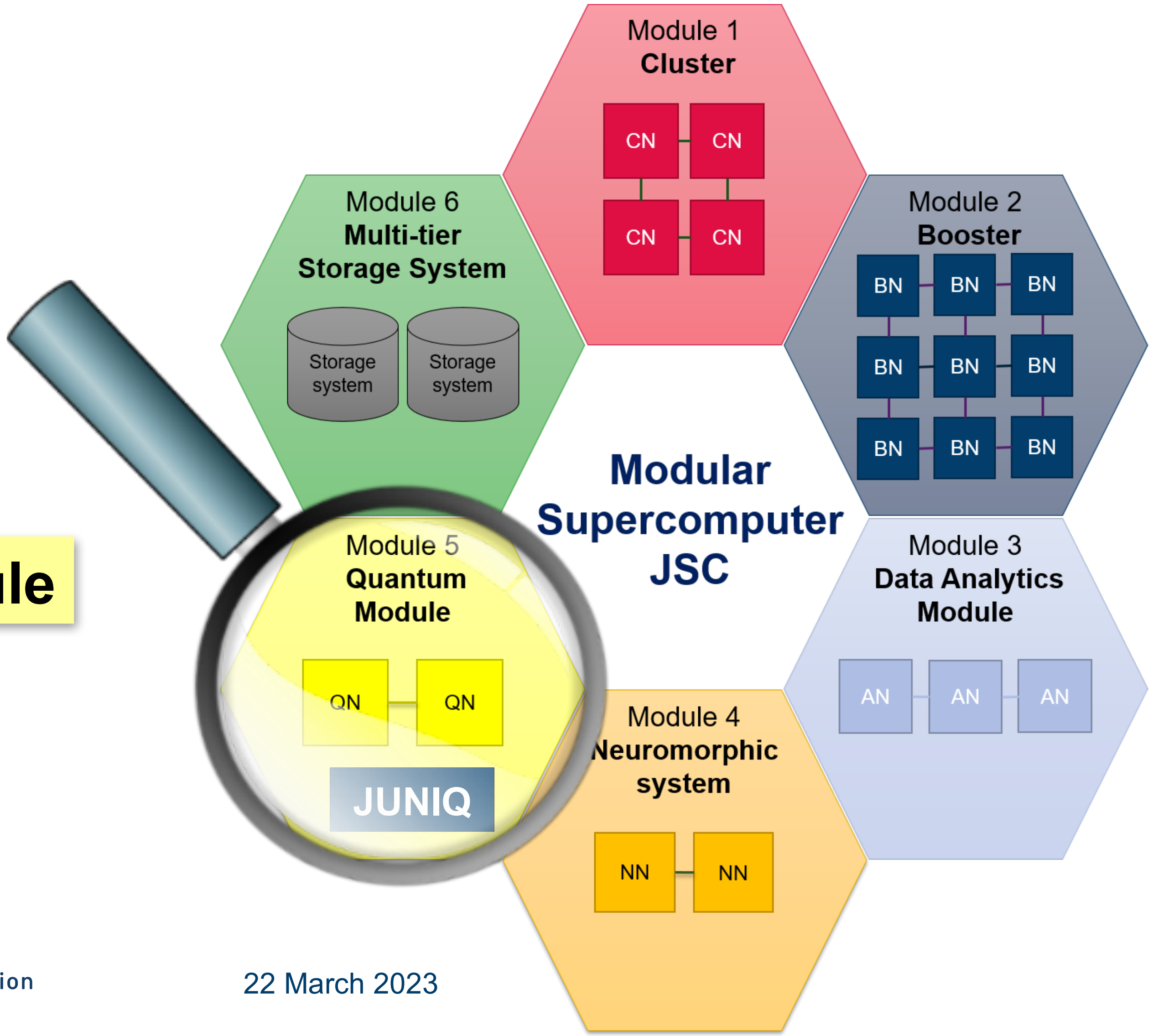
Quantum Module



Plan: Seamless QC-HPC integration

Perspective:
Quantum-Classical
Hybrid Computing Models

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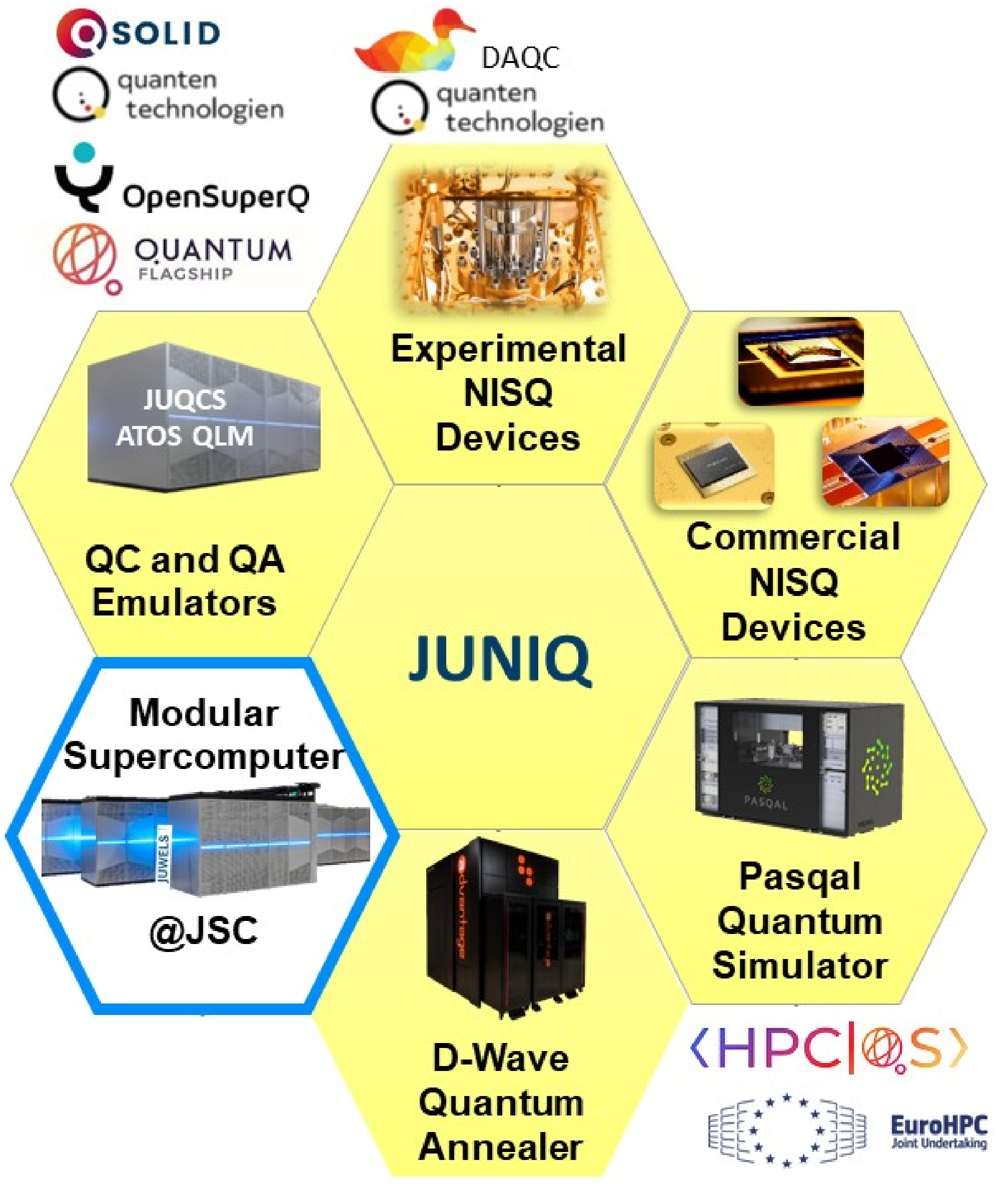


Quantum Computer User Facility:

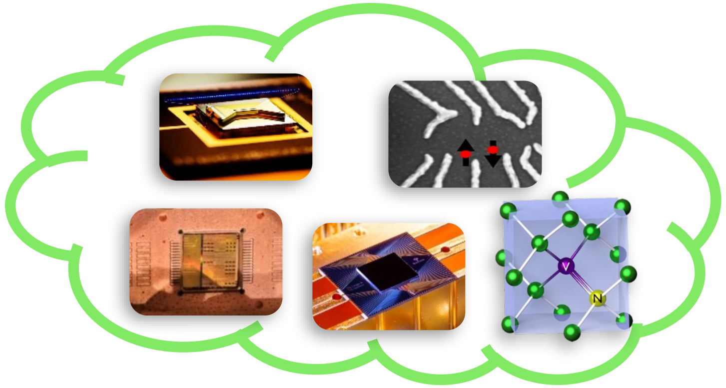
- QC user facility for science and industry
- Installation, operation and provision of QCs
- Unified portal for access to QC emulators and to QC devices at different levels of technological maturity, based on different technologies and with different functionalities (QC-PaaS)
- Development and benchmarking of algorithms and prototype applications
- Services, training and user support
- Modular quantum-HPC hybrid computing

JUNIQ Roadmap

Cloud access:
D-Wave 2000Q
(JUNIQ: BMBF, MKW-NRW)

D-Wave Advantage
(JUNIQ: BMBF, MKW-NRW)

Pasqal simulator
(⟨HPC|QS⟩: EUROHPC-JU)



IBM Q, Google, ion trap systems, NV-centers in diamond, electron spins in silicon …

2019 | 2020 | 2021 | 2022 | 2023 | 2024 | … | 2029

Emulators:
JUQCS
ATOS QLM
(JUNIQ: BMBF, MKW-NRW)

Building:
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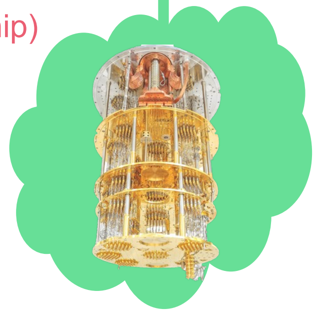
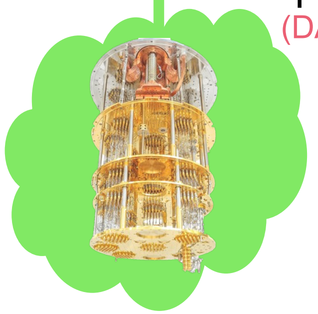
Cloud access:
NISQ computer
(Qsolid: BMBF; OpenSuperQ: Quantum Flagship)





Cloud access:
digital-analog quantum computer
(DAQC: BMBF)

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JÜLICH Forschungszentrum | JUNIQ QUANTUM USER FACILITY

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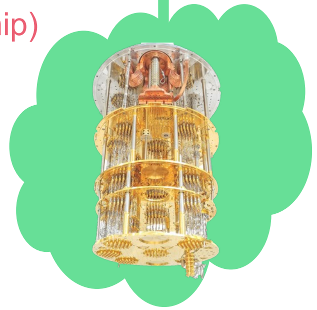

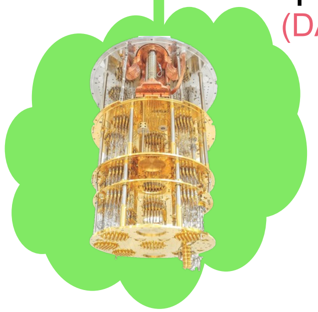

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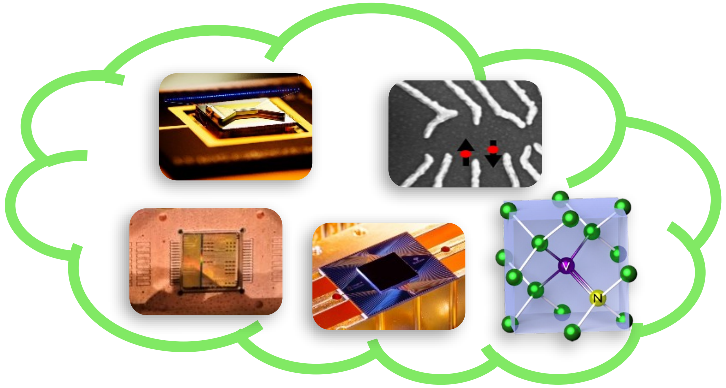

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Jülich Universal Quantum Computer Simulator – JUQCS

- **What?**
  - Emulation of gate-based quantum computers
- **How?**
  - State-vector simulation → memory requirement is 2^N
  - Gate-applications (matrix multiplication) performed by 2- or 4-component updates
  - Efficient MPI-communication scheme
  - GPU version available
- **What for?**
  - Benchmarking of real devices and quantum algorithms
  - Verification of (implementations of) quantum algorithms

JUQCS

De Raedt et al., CPC **176**, 121 (2007)

De Raedt et al., CPC **237**, 47 (2019)

Willsch et al., CPC **278**, 108411 (2022)

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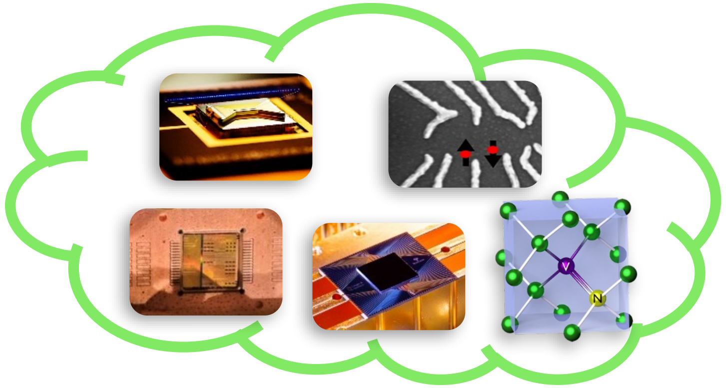

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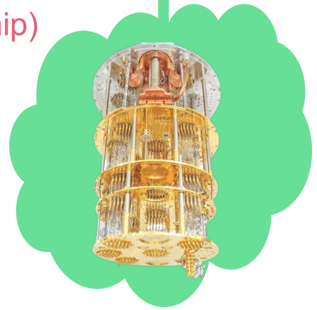

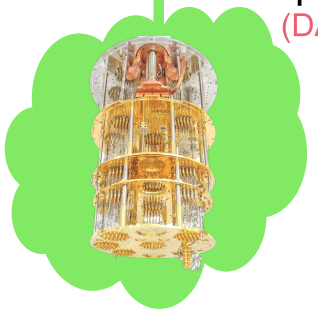

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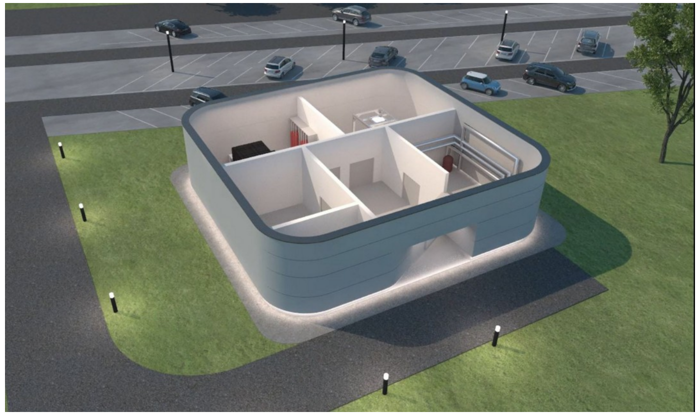
The JUNIQ Building



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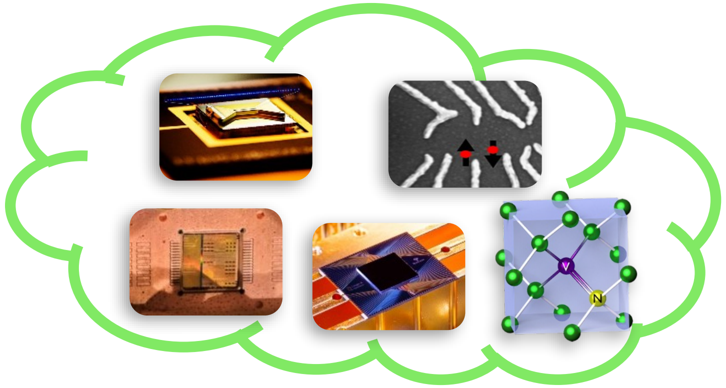

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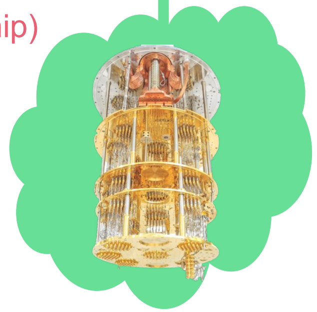

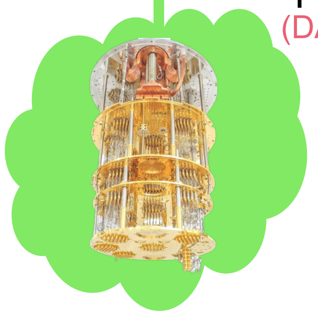

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Quantum Annealers

What do they do?

Quadratic Unconstrained Binary Optimization

"bias" (real number)

$$\text{QUBO:}\quad \min_{x_i=0,1}\left(\sum_i a_i x_i + \sum_{i<j} b_{ij} x_i x_j\right)$$

problem variables (binary)

"coupler" (real number)

Why might this be interesting?

- discrete optimization is hard (NP-hard)
- produces many solutions "simultaneously"
- low energy consumption (compared to HPC)

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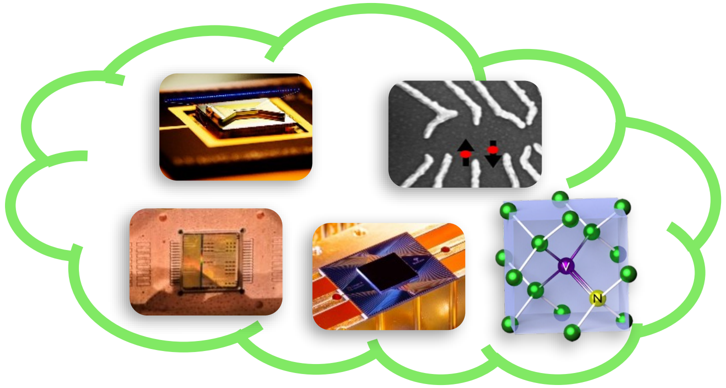

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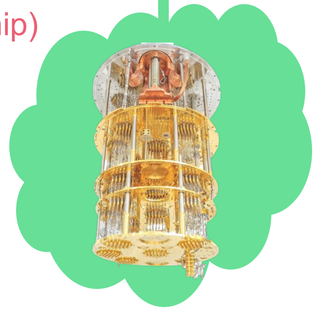

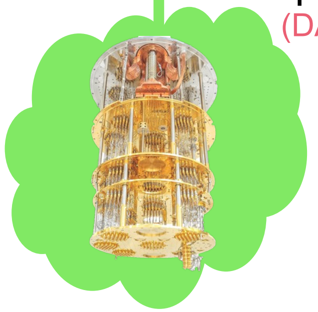

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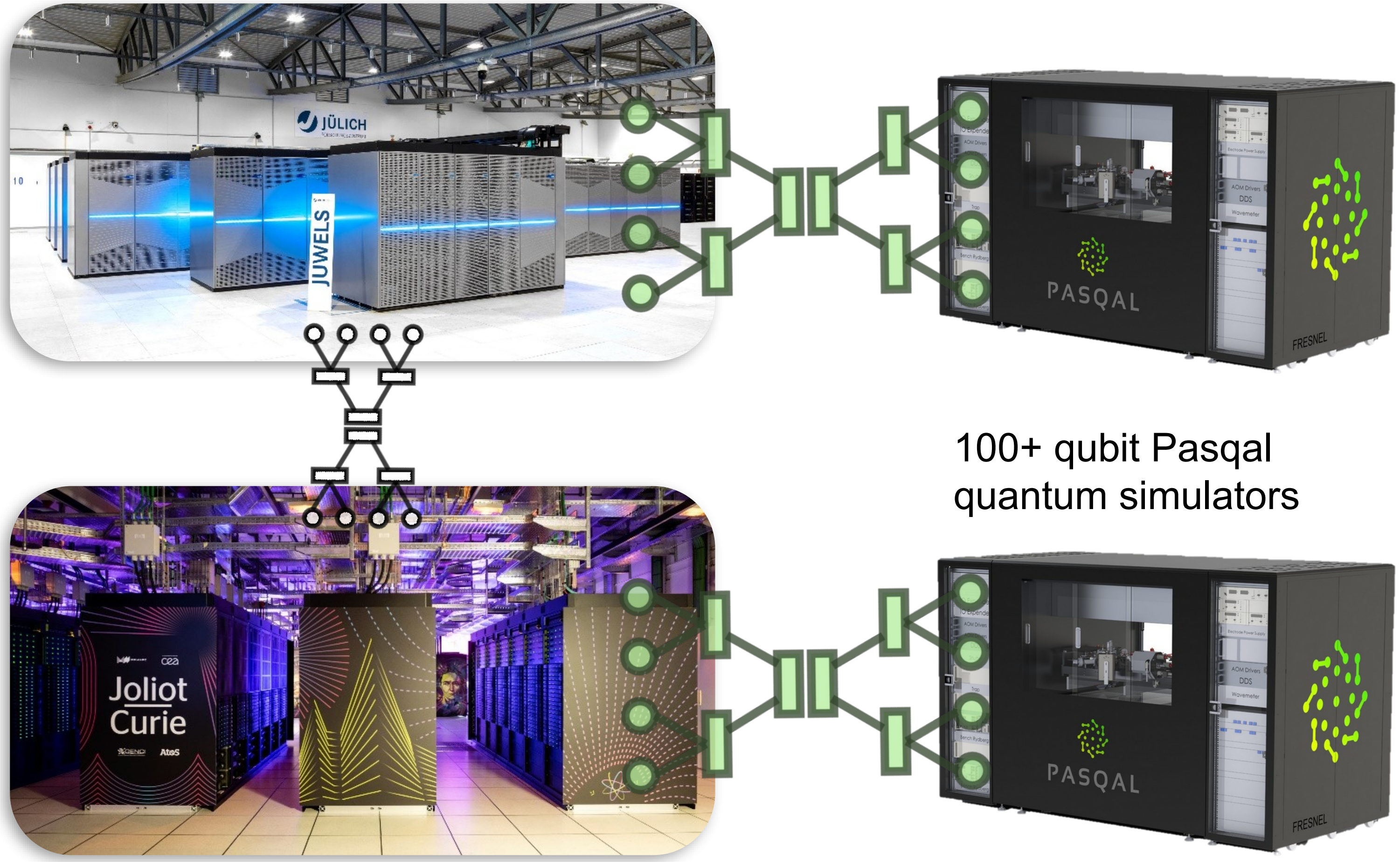
⟨HPC|QS⟩ EuroQCS

High Performance Computer and Quantum Simulator hybrid



100+ qubit Pasqal quantum simulators

EuroHPC Joint Undertaking

Support for the first hybrid HPC / Quantum Computing infrastructure in Europe

December 1, 2021 November 30, 2025

ParTec, cnrs, parityqc, FLYSIGHT, Atos, JÜLICH Forschungszentrum, cea, GENCI, ICHEC, SORBONNE UNIVERSITÉ, CentraleSupélec, CINECA, universität innsbruck, Inria, Barcelona Supercomputing Center, EURICE, Fraunhofer IAF

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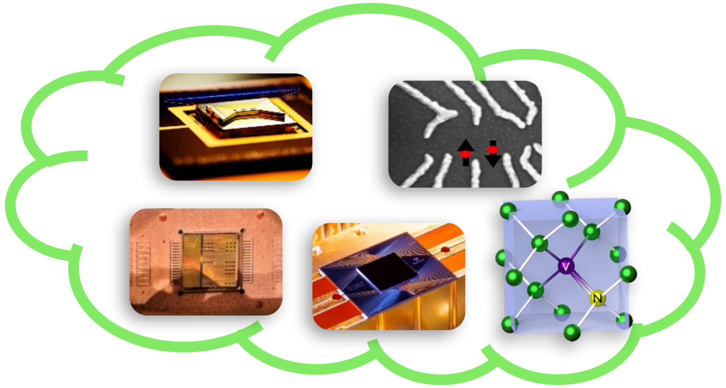

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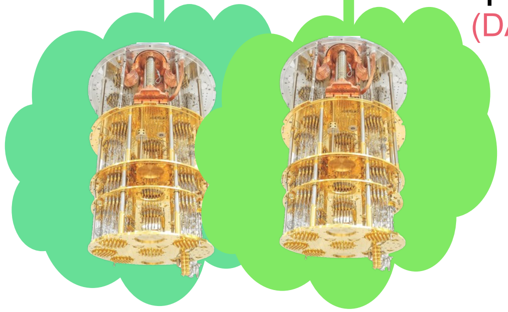

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Hybrid Usage of High Performance & Quantum Computers

High Performance Computers

Quantum Computers, Simulators & Annealers

Successful development of quantum computing applications

Hybrid Usage of High Performance & Quantum Computers

High Performance Computers

Quantum Computers, Simulators & Annealers

Thank you for your attention

Successful development of quantum computing applications

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