Overview of Quantum Computing Efforts in Singapore

QC Benchmarks Views

Ye Jun

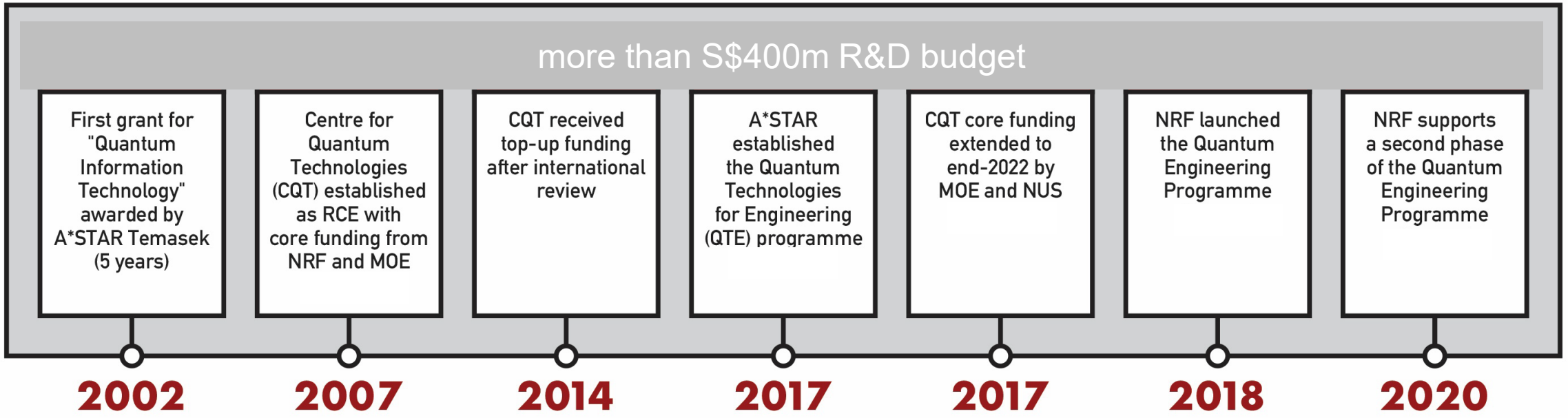
Senior Scientist/Innovation Targe Area Lead (Quantum Computing)

Institute of High Performance Computing, A*STAR, Singapore

11 May 2023

SG's steady investments over two decades

Key quantum funding initiatives in Singapore (SGD) by year

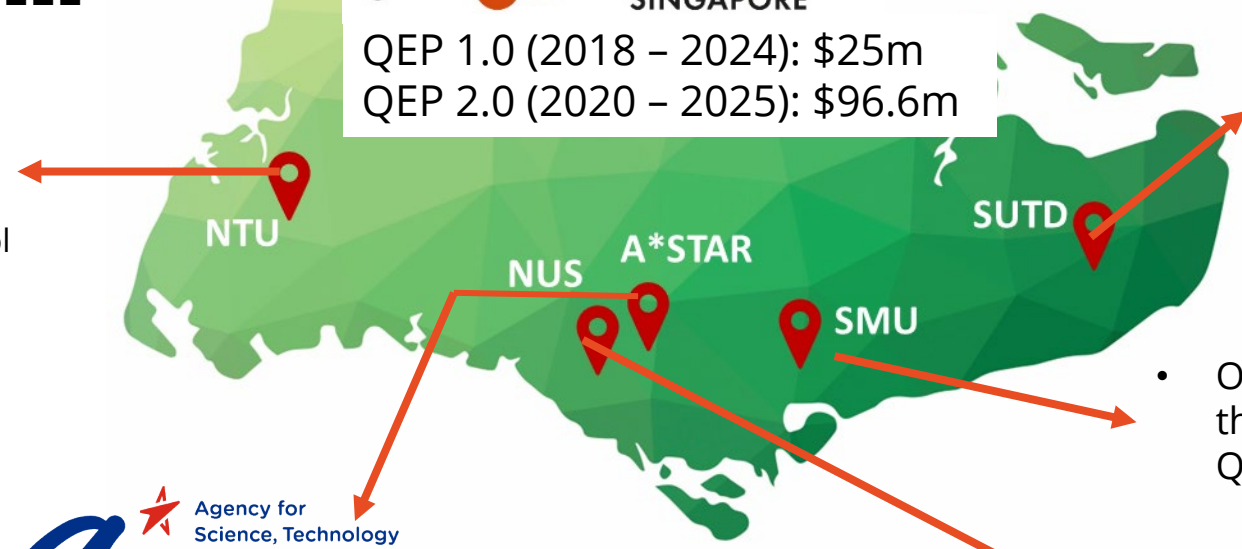


Quantum Ecosystem in Singapore with Multiple Peaks of Research Excellence

NATIONAL QUANTUM OFFICE SINGAPORE

QUANTUM ENGINEERING PROGRAMME SINGAPORE

QEP 1.0 (2018 – 2024): $25m
QEP 2.0 (2020 – 2025): $96.6m



NANYANG TECHNOLOGICAL UNIVERSITY — SPMS, EEE

- NTU houses several centres and initiatives with linkages to Quantum:
  - Nanyang Quantum Hub
  - Centre for Disruptive **Photonic Technologies** (Quantum control of light at the single- or few-photon level)
  - Quantum Science and Engineering Centre (photonic chips)

SINGAPORE UNIVERSITY OF TECHNOLOGY AND DESIGN — EPD

- Active in national programmes such as the NQSN

- Others are connected to the rest of the Quantum ecosystem through the Quantum SG initiative

NANYANG QUANTUM HUB

cqpt

Agency for Science, Technology and Research SINGAPORE — IMRE, IHPC, IME, NMC

- IMRE hosts the **National Quantum Fabless Foundry**
- A major partner of the **National Quantum Computing Hub** (through IHPC and NSCC) with major research activities in **Quantum Computing** algorithms, middleware and hardware
- QTE in IMRE drives **Quantum Sensing** tech development and **Quantum Computing** materials development
- NMC drives **Quantum Metrology** development with their Lu-based optical clock
- SERC is coordinating WOA Quantum activities with CQS leading it

NUS National University of Singapore — ECE, Physics

- Hosts the **National Quantum-Safe Network** (NQSN) and **CQT**

CQT Centre for Quantum Technologies

Governance and coordination

National Quantum Steering Committee
Co-chairs: Prof Low Teck Seng, Quek Gim Pew
Members: NRF, A*STAR, NQO, EDB, CSA, IMDA, GovTech, Temasek, CQT, NUS, NTU, DSO

National Quantum Office (NQO)
Executive Director: Ling Keok Tong
Chief I&E Officer: Rakesh Jaiswal Chief Scientific Officer: A/Prof Alexander Ling

Hosted at: Agency for Science, Technology and Research SINGAPORE

CQT
Dir: Prof José Ignacio Latorre

Centre for Quantum Technologies

QEP
Dir: A/Prof Alexander Ling

QUANTUM ENGINEERING PROGRAMME SINGAPORE

Quantum Technical Committee
Members: Prof Lam Ping Koy, Prof José Ignacio Latorre, Prof Rainer Dumke

++ other quantum ecosystem/ activities

CQT's research

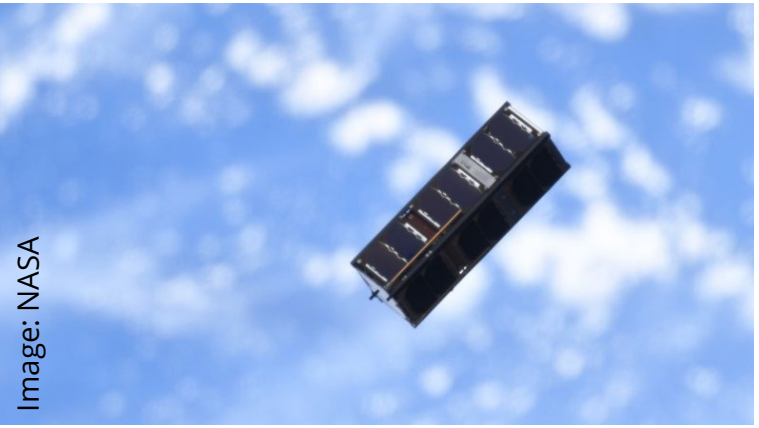
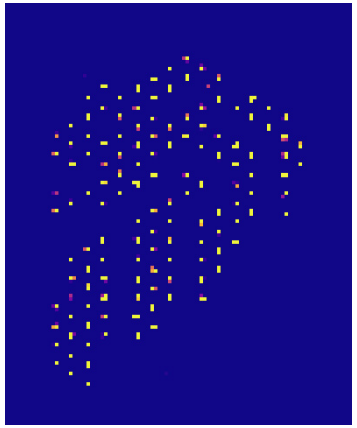
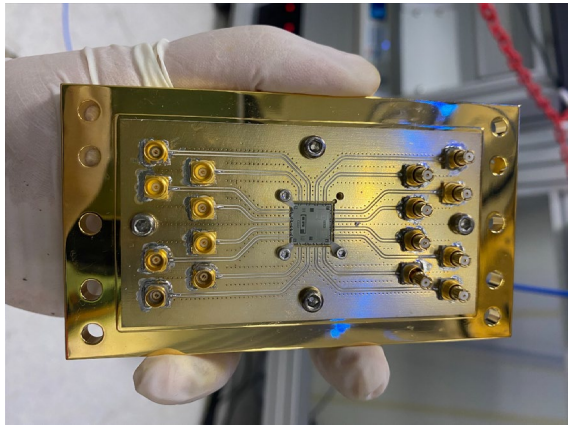
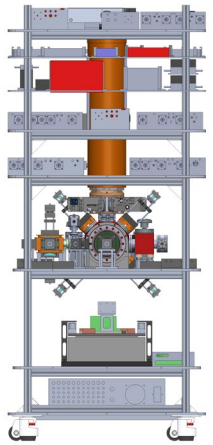
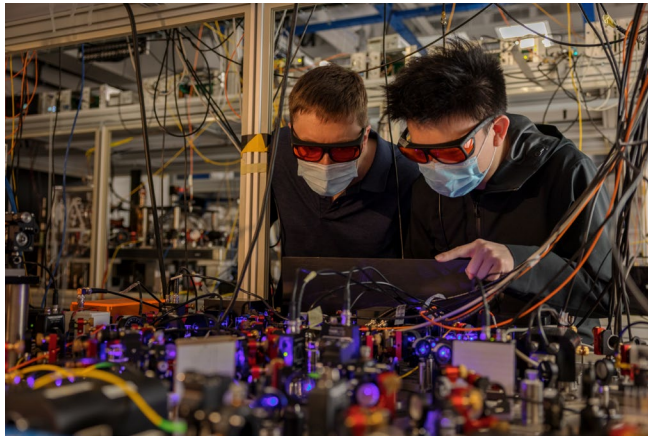


Image: NASA









Quantum Communication & Security

- Quantum communication via satellite and fibre (QKD)
- Post-quantum cryptography
- Quantum internet
- Two spin-offs
- National Quantum-Safe Network

Quantum Computation & Simulation

- Platforms: superconducting qubits, trapped ions, atom arrays, cavities, photonic chips
- Algorithms research and development
- Quantum simulation to study advanced materials
- Three startups in quantum software
- National Quantum Computing Hub

Quantum Sensing & Metrology

- Novel atomic clock design using lutetium (Lu^+)
- Gravimeter based on ultracold atoms
- Magnetic sensing with NV centers
- One start-up in quantum sensing

Advanced Instruments

- Integrated chips, field-programmable gate arrays, optical tweezer arrays
- Spin-off selling control and measurement products
- National Quantum Fabless Foundry

Basic Science

- Curiosity-driven research in areas including light-matter interactions, quantum thermodynamics and quantum correlations

Agency for Science, Technology and Research
SINGAPORE

A*STAR Quantum Innovation Centre (Q.InC)

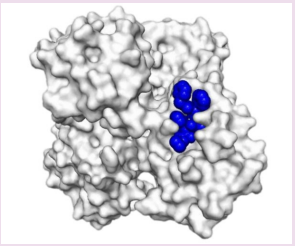
Underpinning Platforms

- **Materials**
- **Microelectronics**
- **Hardware**
- **Software Stack**

Quantum Innovation Centre
Q.InC

1) Quantum for biomedical

- Quantum sensors (medical diagnostic, ex-vivo personalized drug response)
- Quantum computing software (accelerate drug discovery process)

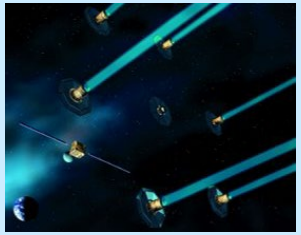


2) Quantum for security

- PNT fusion sensors
- Remote sensing

3) Quantum for space

- Quantum sensors (eg. situation awareness)
- Satellite quantum network
- Satellite quantum interferometry



4) Quantum for Infocomm Technologies

- Quantum computing software
- Quantum computing hardware

QEP research pillars and platforms

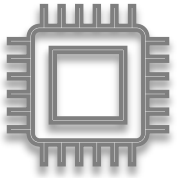
QUANTUM ENGINEERING PROGRAMME SINGAPORE

36 **R&D projects**

\+

Next effort on instrumentation & enabling technologies

Quantum Communication & Security



Quantum Computing & Processors

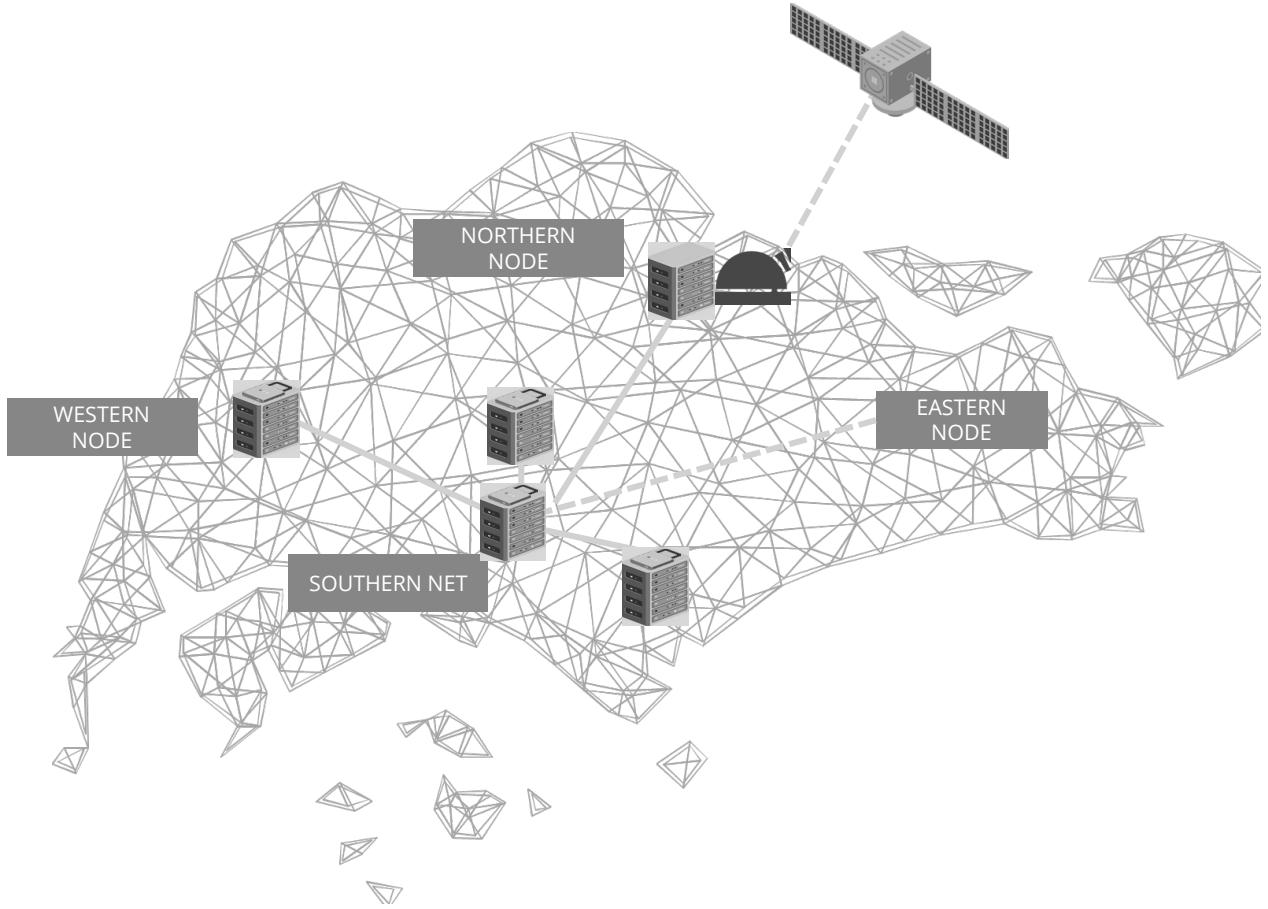
Quantum Sensors

National Quantum-Safe Network

National Quantum Computing Hub

National Quantum Fabless Foundry

NATIONAL QUANTUM-SAFE NETWORK SINGAPORE



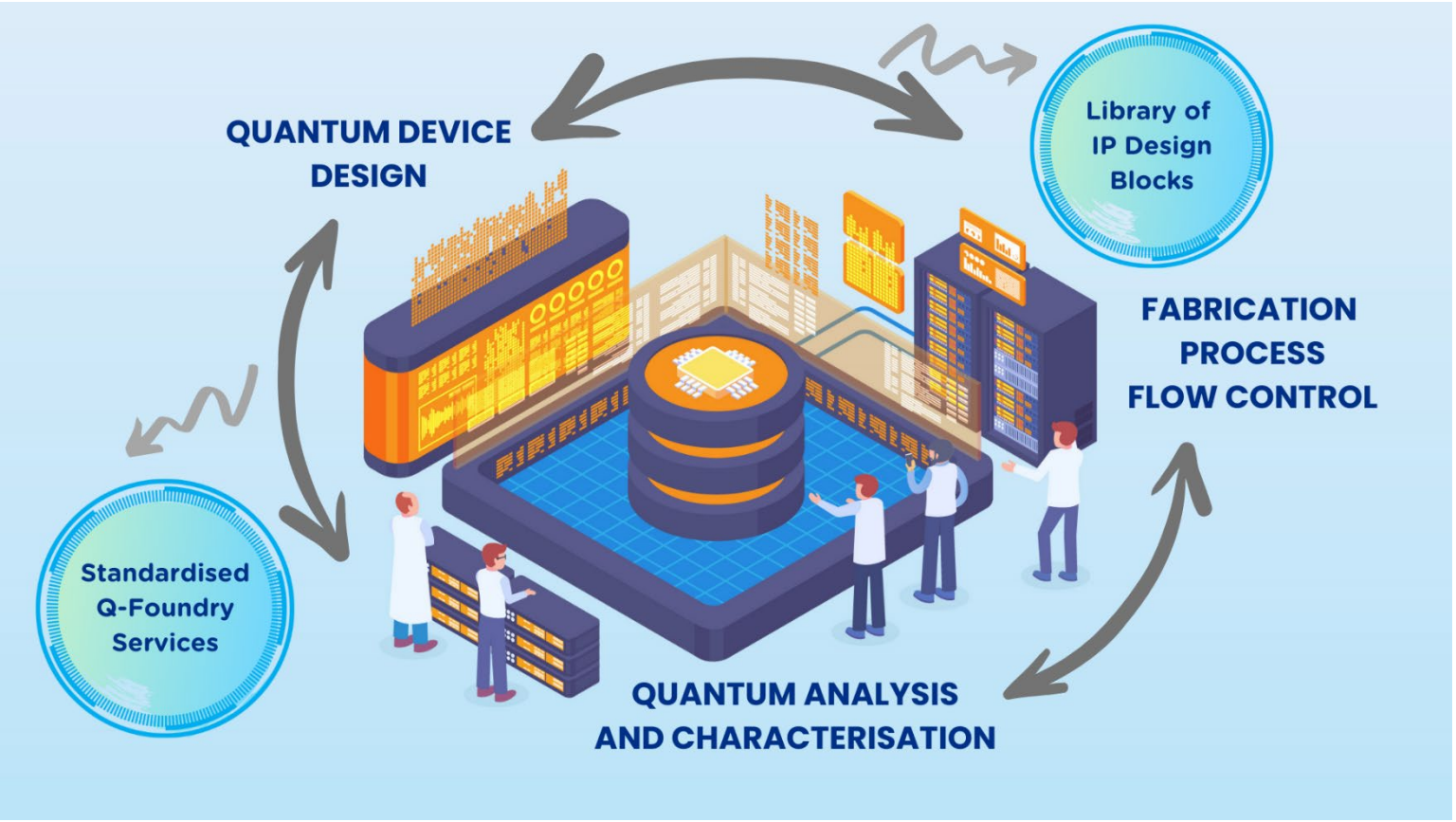
Terrestrial Metropolitan Area Network
Fibre & free-space

Satellite links

Public-private collaborations
>15 companies & govt agencies

www.nqsn.sg

Led from: Centre for Quantum Technologies | NUS National University of Singapore | NANYANG TECHNOLOGICAL UNIVERSITY SINGAPORE | Fraunhofer SINGAPORE



NATIONAL QUANTUM FABLESS FOUNDRY
SINGAPORE

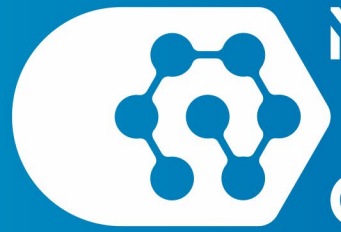
- Goals to accelerate research, develop strategic capabilities
- Technologies to develop include superconducting chips, integrated ion traps, cryo-computing and single photon detectors

www.nqff.sg

Led from:

Institute of Materials Research and Engineering
IMRE

Institute of Microelectronics
IME



NATIONAL QUANTUM COMPUTING HUB

SINGAPORE

Institute of High Performance Computing

IHPC

Centre for Quantum Technologies

SG NSCC SINGAPORE

National Supercomputing Centre

www.nqch.sg

The National Quantum Computing Hub

Hardware

- Production quantum computer
- Classical Simulator
- Cloud access

Middleware

- Full stack
- Hardware backends
- GPU backends
- Supercomputer backends

Applications

- Basic algorithms
- Applied algorithms
- Link to industry

Talent

Outreach

International Collaboration

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What quantum hardware?

Superconducting

Ion Traps

Photonics

Neutral Atoms

Solid State

NV Centers

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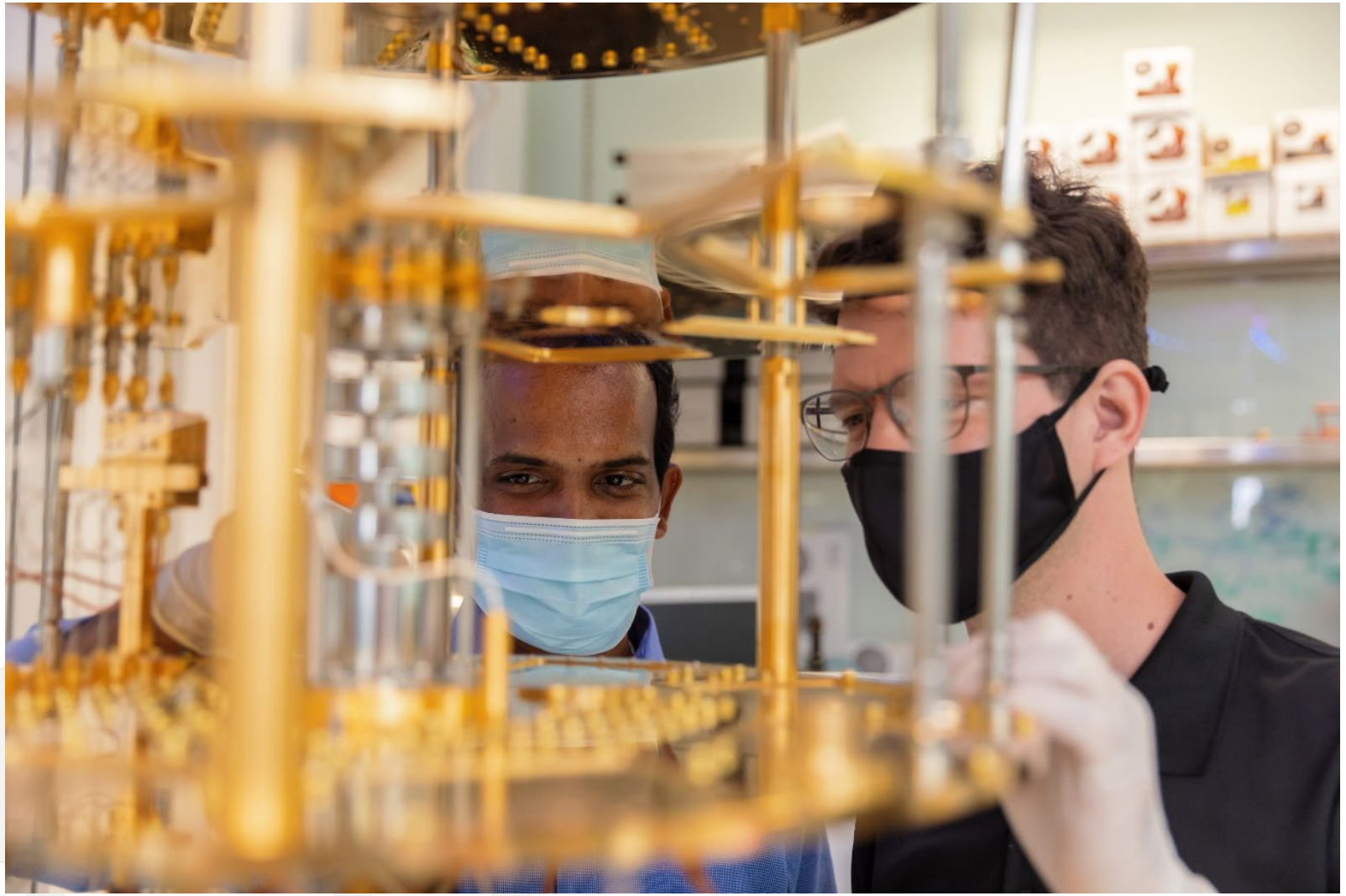

Made in SG

Superconducting quantum processor by the group of Rainer Dumke @ CQT, NTU

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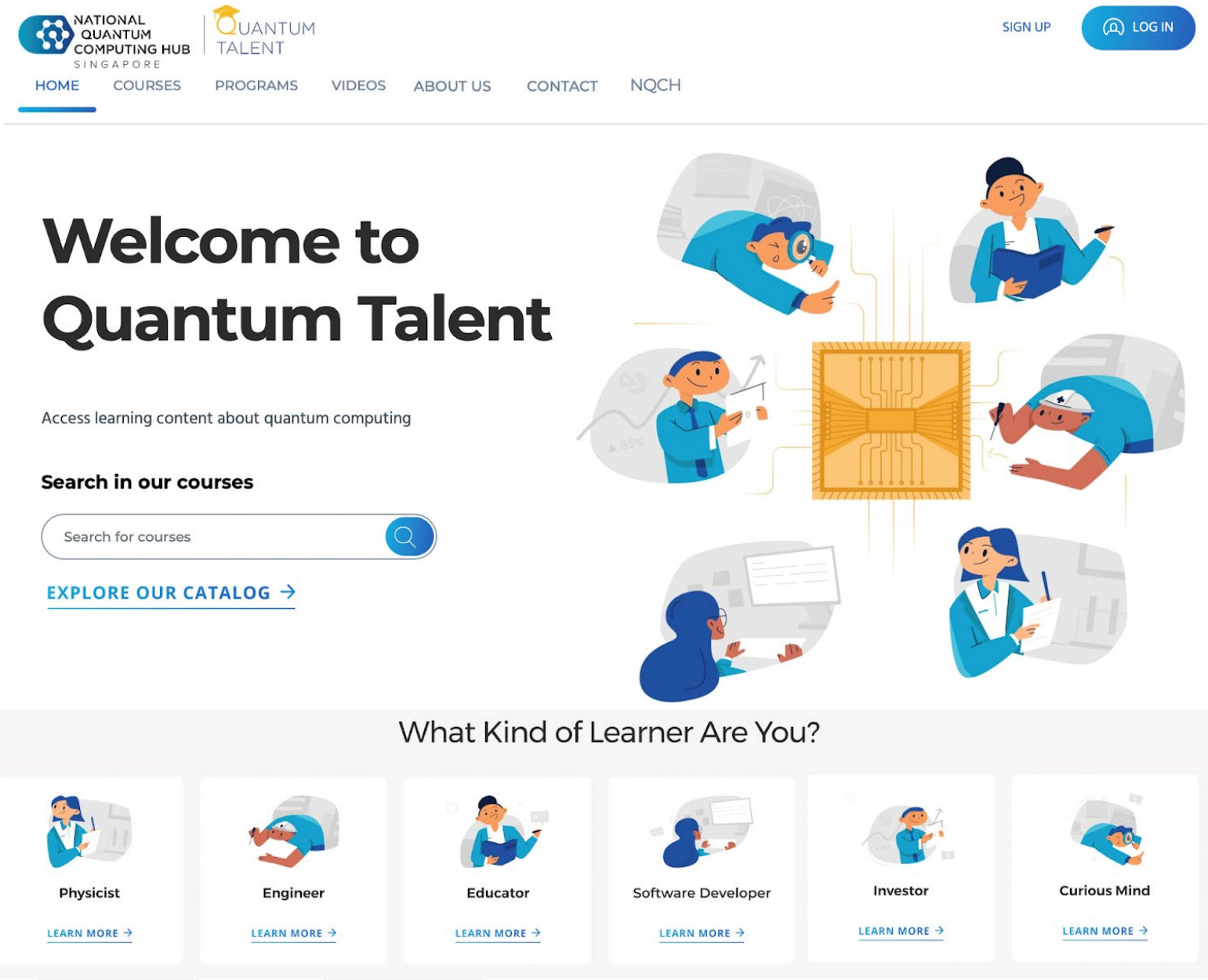
Meaningful Collaborations

e.g. MOU NQO & Finland VTT, IQM, CSC - IT Center for Science

Image Credit: VTT



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Online learning platform

- A web portal fully created by NQCH
- To provide high-quality educational materials while avoiding hype
- To build connections between talent, academic and industry
- Free for public

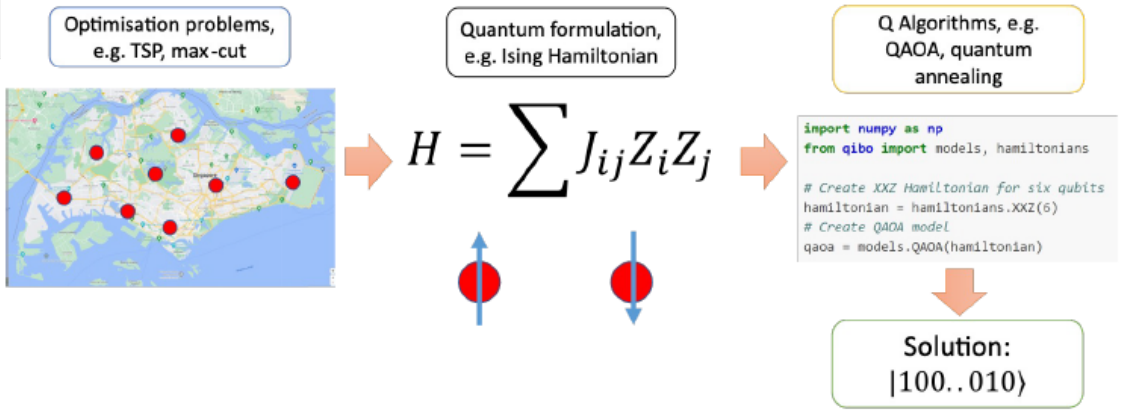
Audience

- Multi-level: Beginner → Expert
- Multi-facet: Different backgrounds

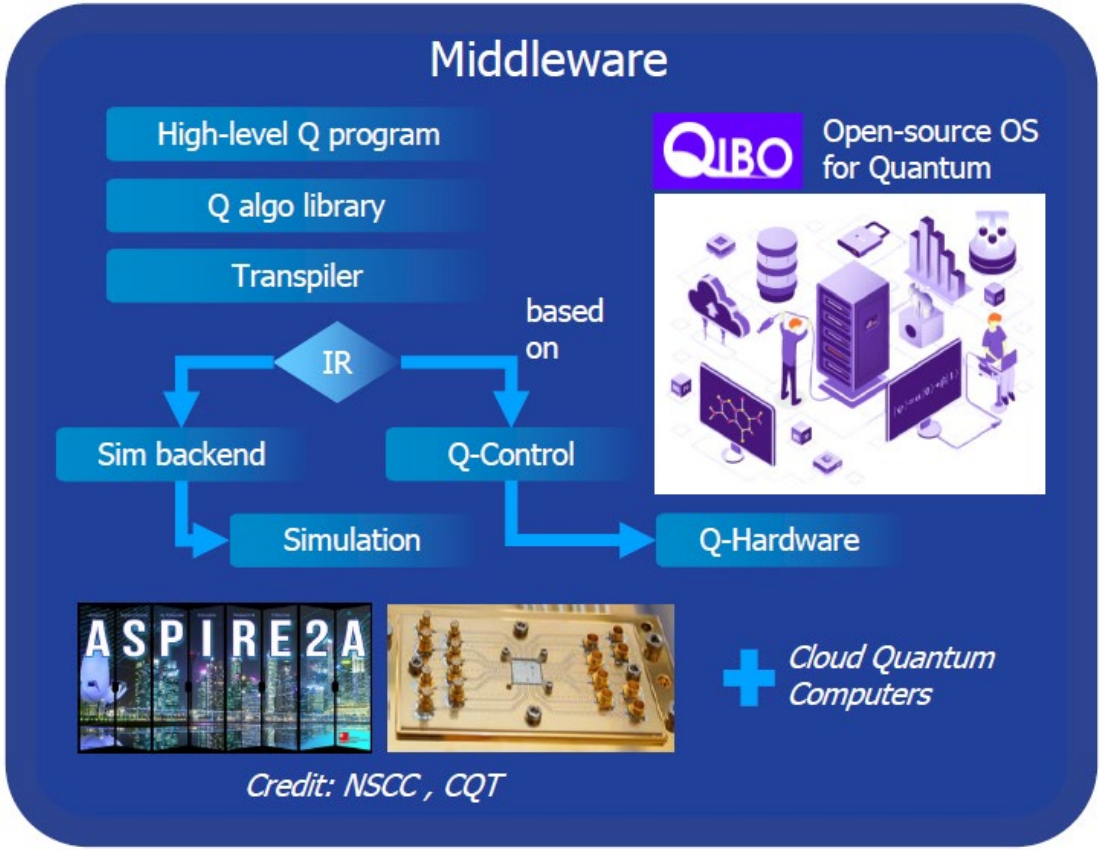
Content

- Short courses
- Stand-alone videos
- Certifiable Programs
- Blogposts and news

Quantum opensource middleware: Qibo



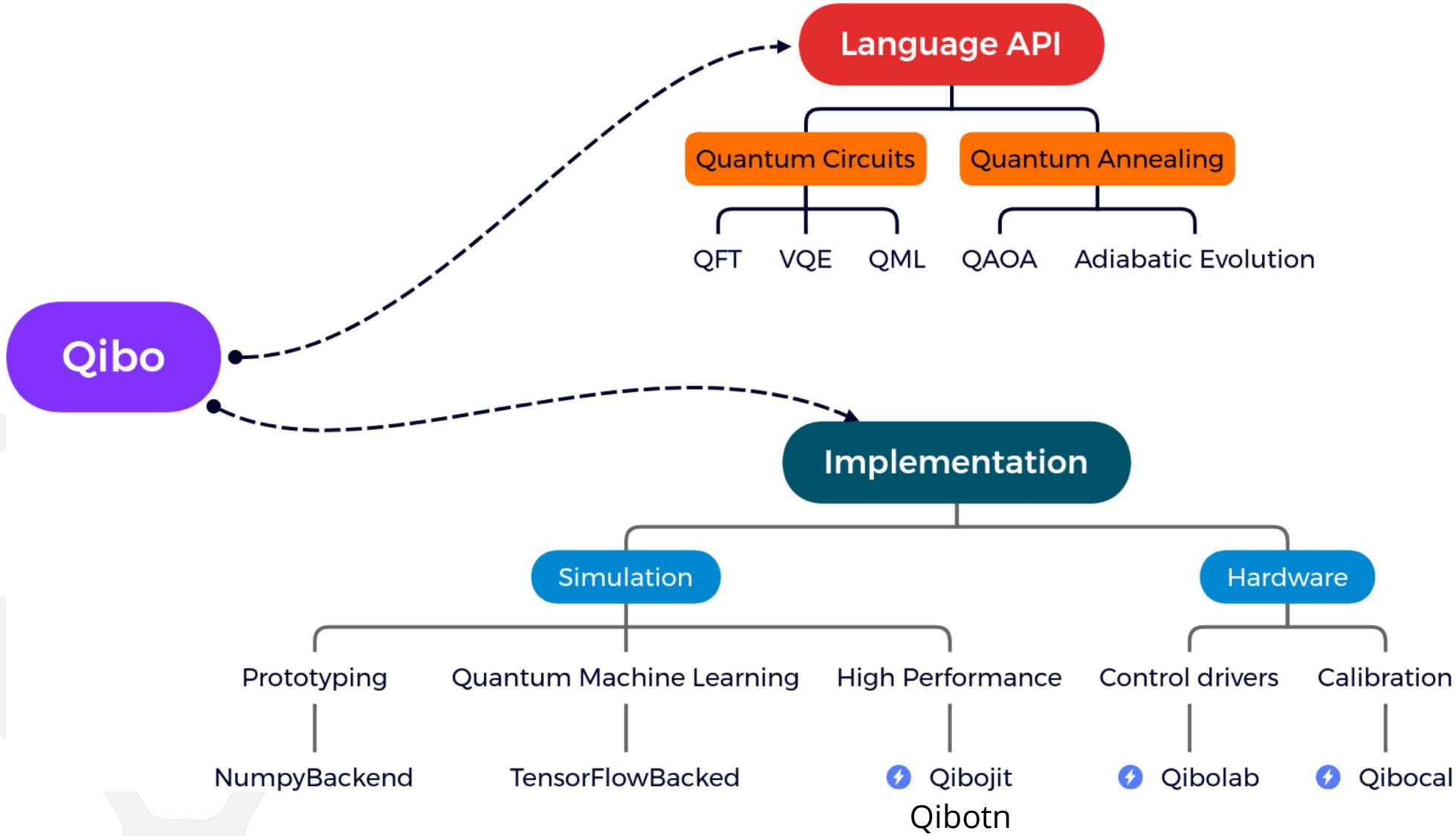
https://qibo.science/



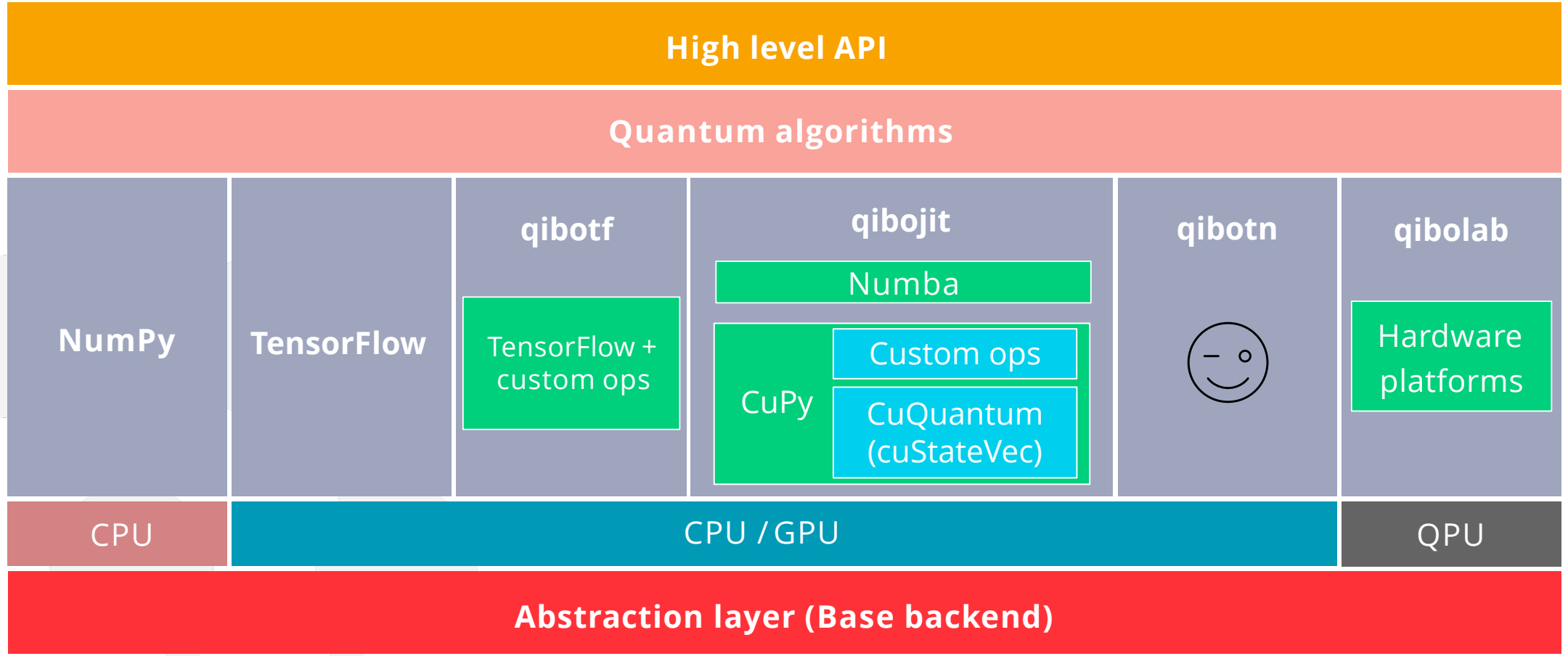
End-to-end open source platform for quantum simulation, quantum hardware control and remote access

(think of a linux for quantum!)

Backends in Qibo



Abstractions in Qibo



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QC Benchmark is at the Heart of Our Research Focus

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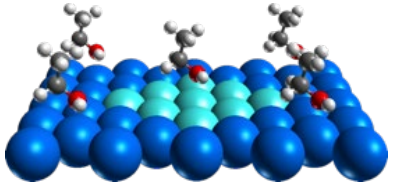
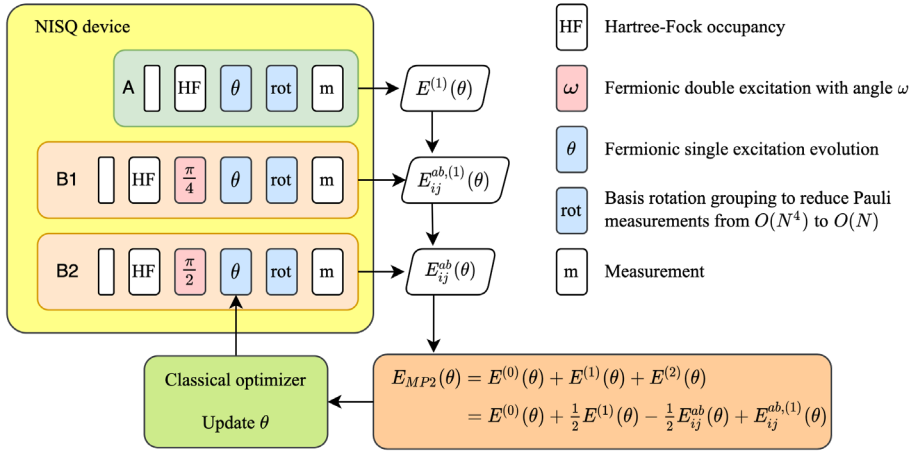
e.g., New catalyst development for efficient H_2 production

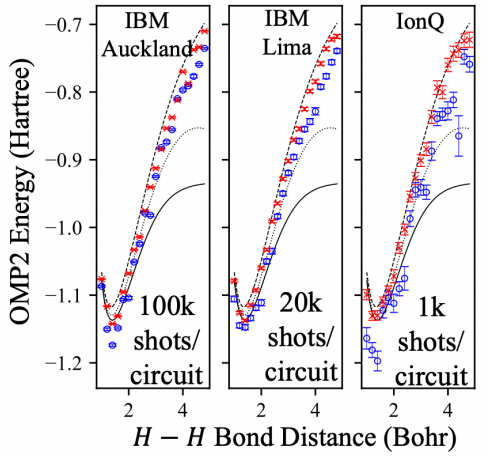





27-Qubit
IBM Auckland


5-Qubit
IBM Lima


11-Qubit
IonQ



(0-1) End user engagement

(0-2) Problem statement

(1) Mathematical formulation

Potentially Quantum easy

(2) Mapping to Quantum solvable formulations

(3-1) Quantum algorithms

(3-2) Physical models

(4) Compilation and mapping to Q hardware

(5) Benchmarking

(6) Deployment

Classically easy/feasible

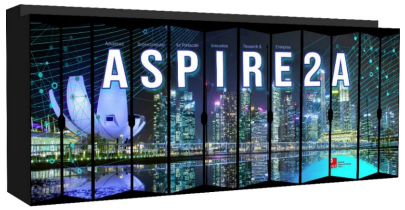
(2) Mapping to classical solutions

Full-stack hybrid platform

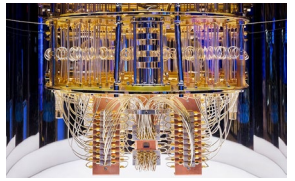
Towards Practical Quantum Advantage via Streamlined Software-Hardware Co-Design for HPC + QC Integration

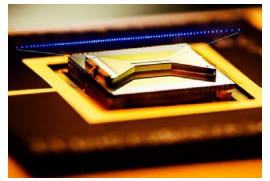
QIBO and ++

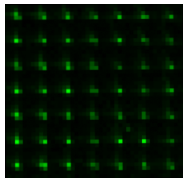
QC Benchmark



Credit: Nvidia, NSCC







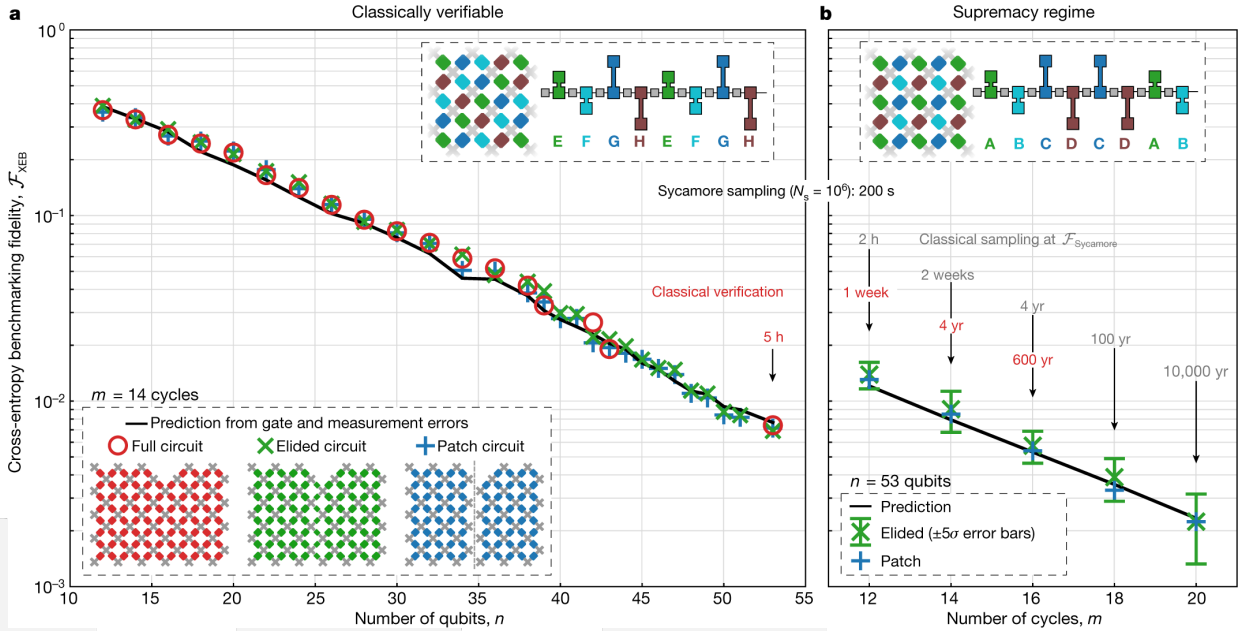
Credit: IBM, IonQ, Pasqal, DWave

Classical simulation — **Classical/Quantum Hybrid?** — **Fully Quantum**

What's the LINPACK Benchmark for such diverse systems and devices?

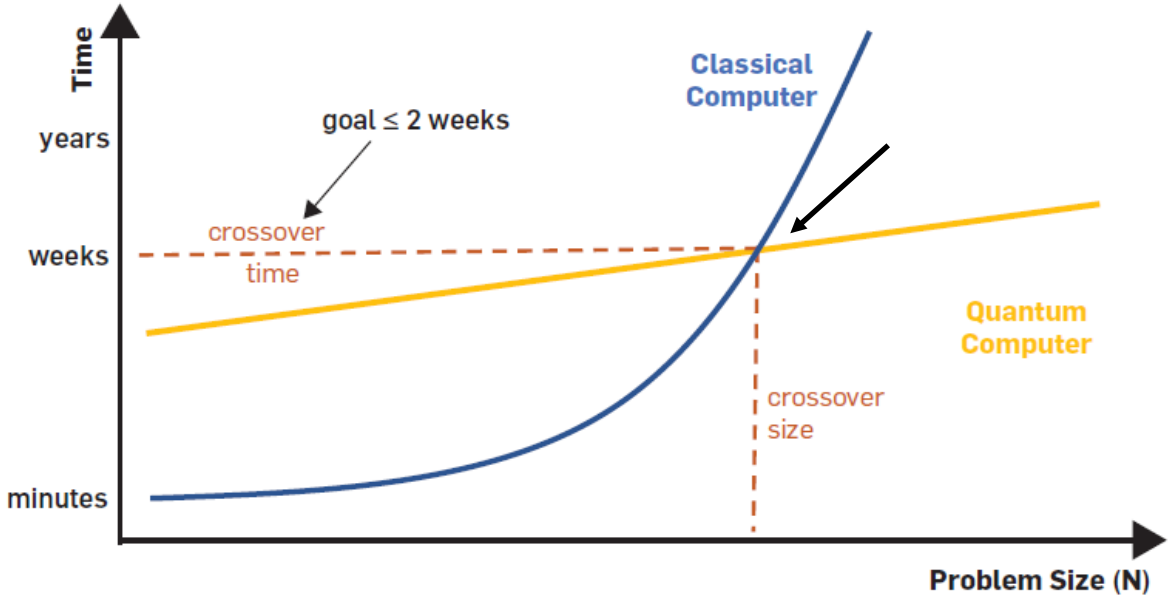
QC Benchmark

From



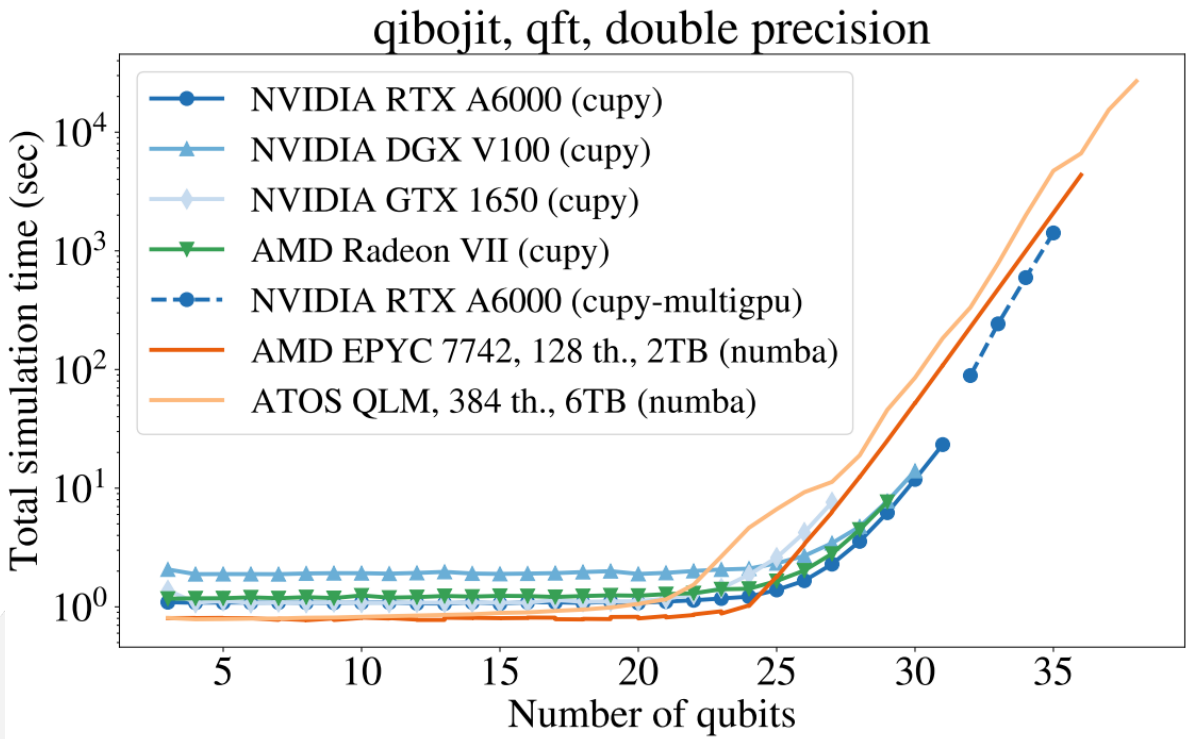
Source: [Quantum supremacy using a programmable superconducting processor | Nature]

To



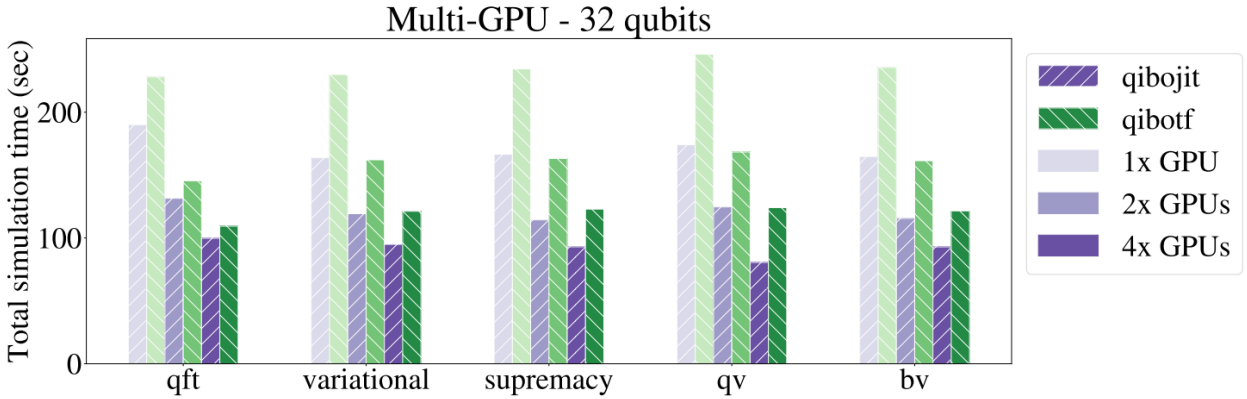
Source: [Communications of the ACM]

Benchmark of the Classical Simulators



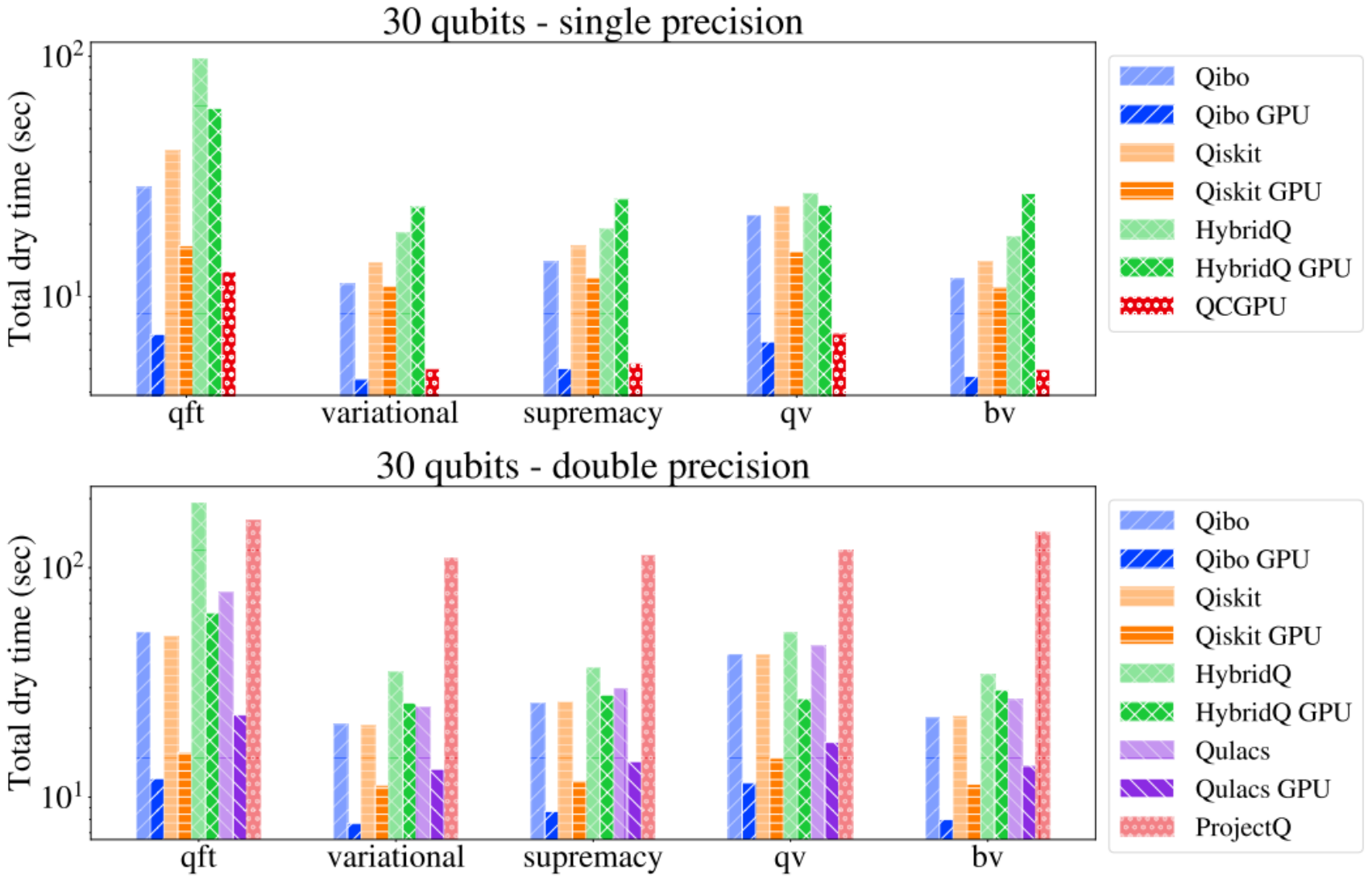
Qibojit

- Supports CPU, GPU, and multi-GPU.
- NVIDIA and AMD GPUs.
- Reduced memory footprint



Benchmark library: https://github.com/qiboteam/qibojit-benchmarks [Quantum simulation with just-in-time compilation – Quantum (quantum-journal.org)]

Benchmark of the classical simulators

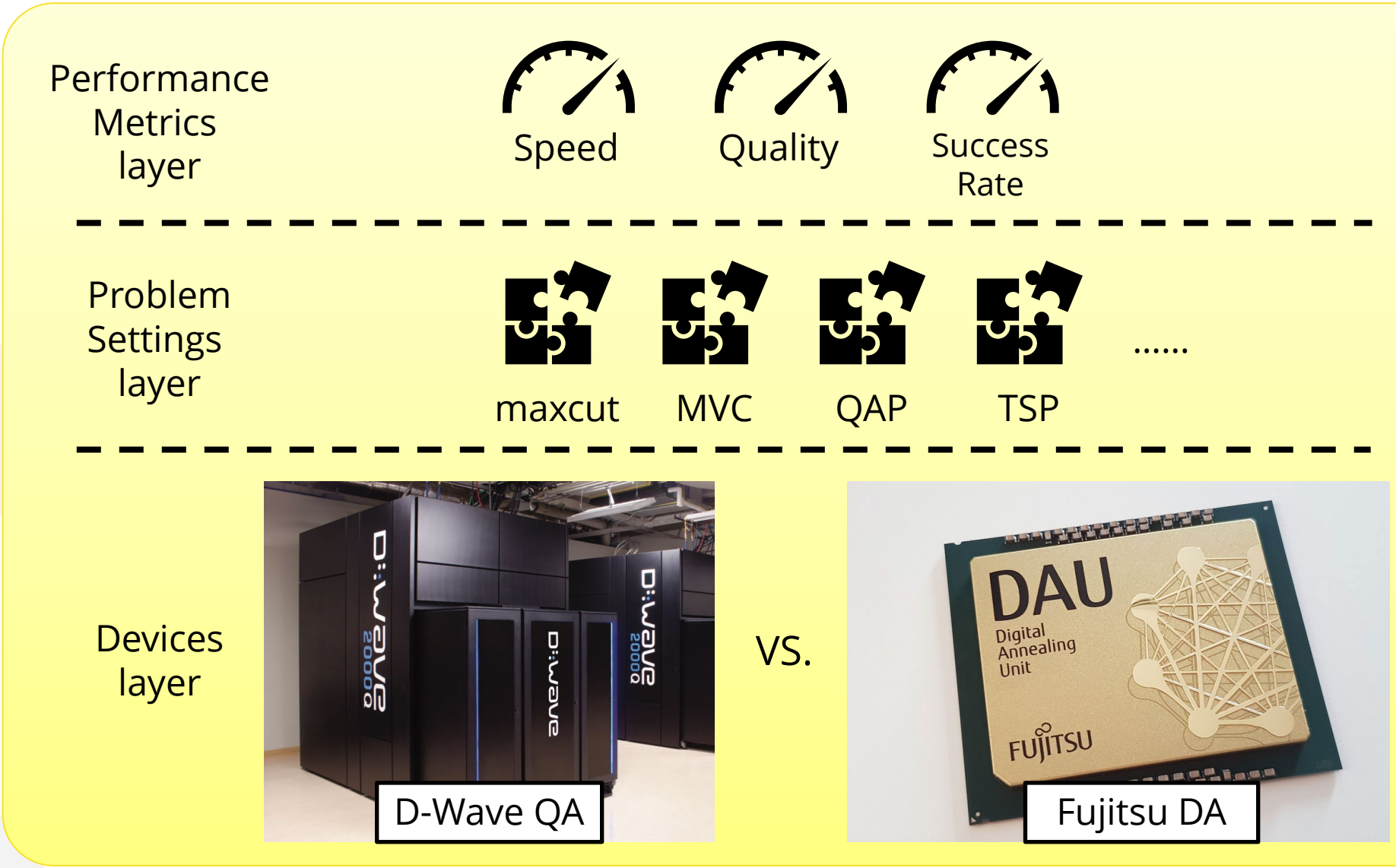


Benchmark library: https://github.com/qiboteam/qibojit-benchmarks [Quantum simulation with just-in-time compilation – Quantum (quantum-journal.org)]

Quantum and Quantum-inspired Annealing Benchmark

- Benchmark
  - Quantum Annealer (QA)
  - Digital Annealer (DA)
- Problem setting matters!
  - QA good at unconstrained problems
  - DA good at constrained problems

DOI: 10.1109/TC.2022.3219257



Quantum and Quantum-inspired Annealing Benchmark

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Objective

- Compare quantum/digital annealers
- Understand advantage and weak points
- Identify challenges and missing parts

Research Foci

- Timing/Performance v.s. problem constraint
- Timing/Performance v.s. problem size
- Timing/Performance v.s. connectivity

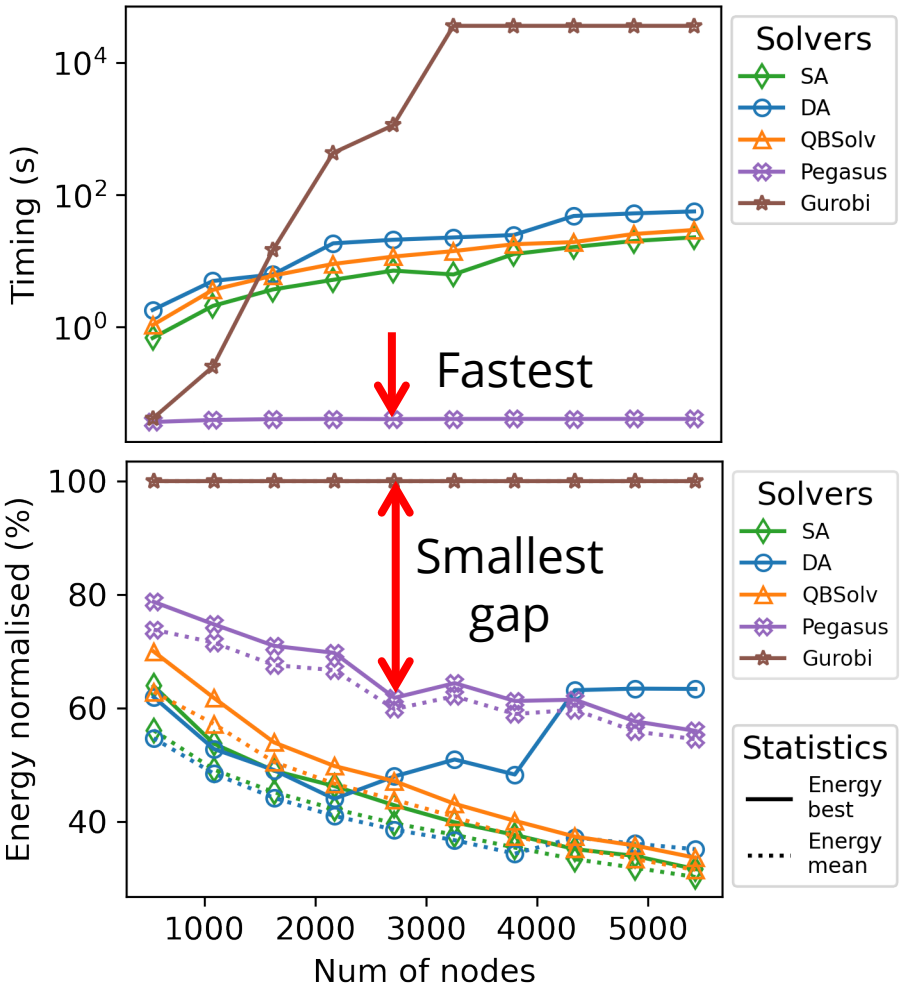
Outcomes

- Provide Guidelines on choosing appropriate annealing-based computer for an application

D-Wave Pegasus wins on the Pegasus-like max-cut problems

But the story does not end here

- **Six backends**
- **Three scientific problems**
- **Hyper-parameter exploration**
- **Synthetic/Real-world Dataset**



DOI: 10.1109/TC.2022.3219257

Quantum and Quantum-inspired Annealing Benchmark

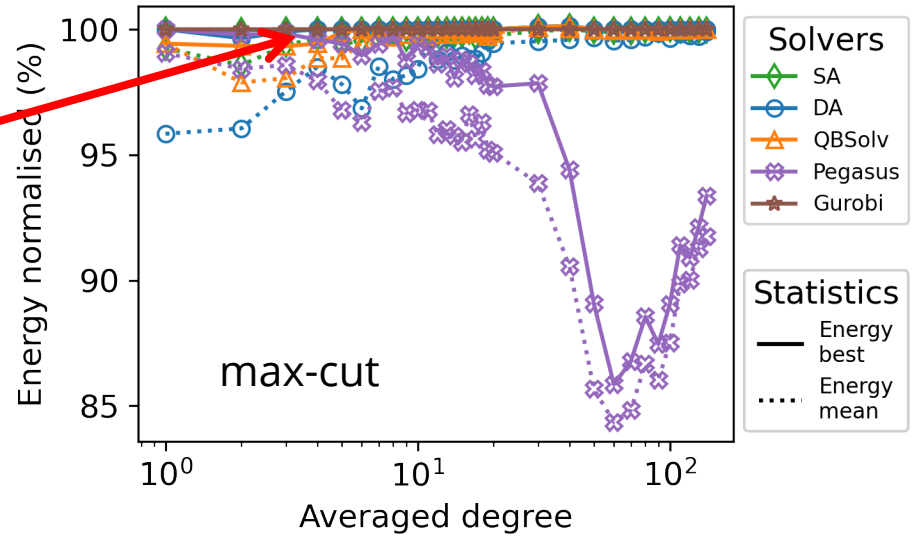
Different problem settings

+

Same graph topology

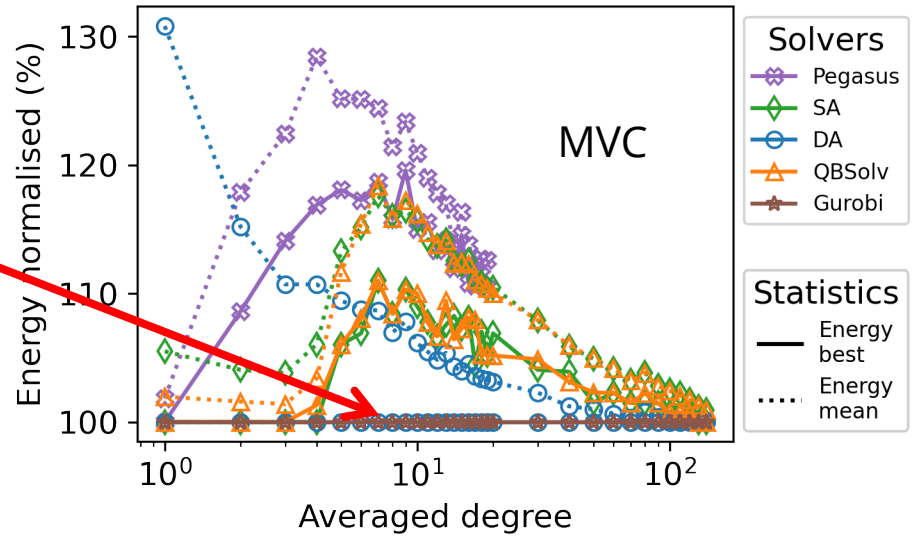
Conclusion: Problem setting matters

D-Wave Pegasus wins on sparse connectivity (Purple curves)



Up: connectivity-varied max-cut problems
Bottom : connectivity-varied MVC problems

Fujitsu Digital Annealer wins (Blue solid line)



DOI: 10.1109/TC.2022.3219257

Cross-Device Benchmark for Quantum Chemistry

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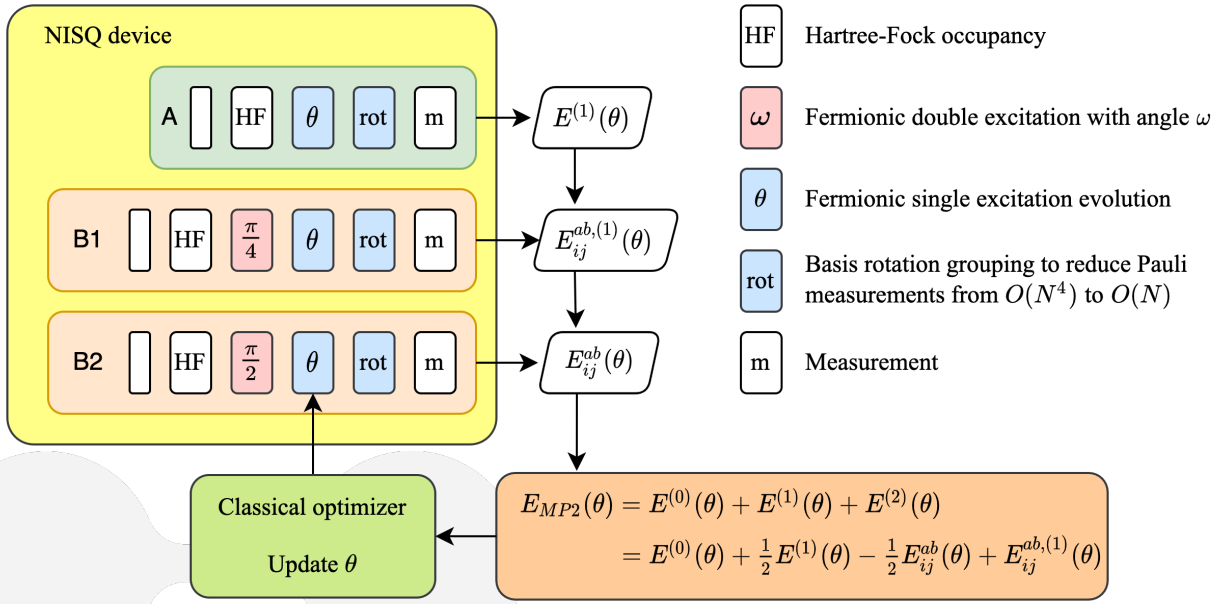
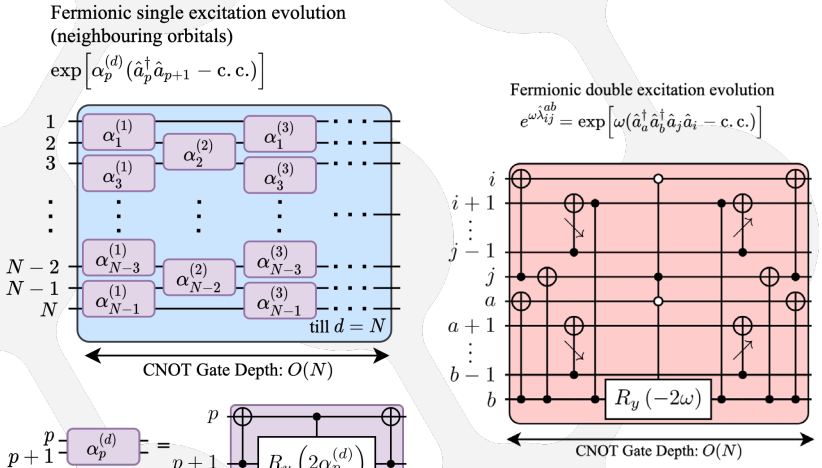
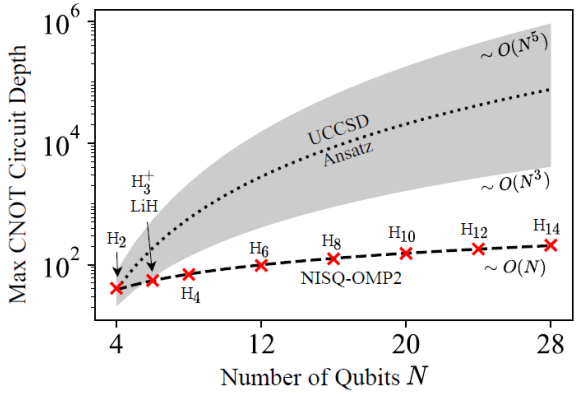
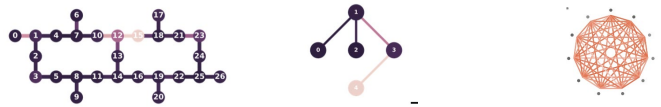






arxiv:2207.03949

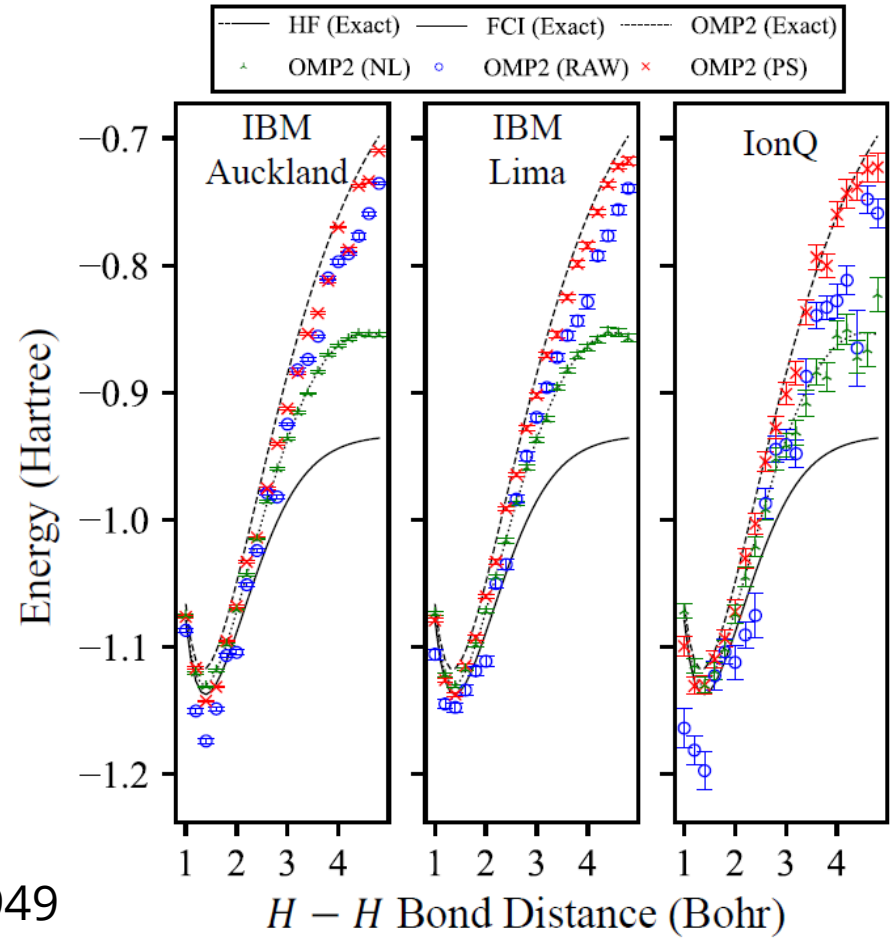
Cloud NISQ devices, H_2, OMP2/STO-3G



27-Qubit
IBM Auckland

5-Qubit
IBM Lima

11-Qubit
IonQ



New Performance Metric: Uncertainty Principle Determines The Programmability

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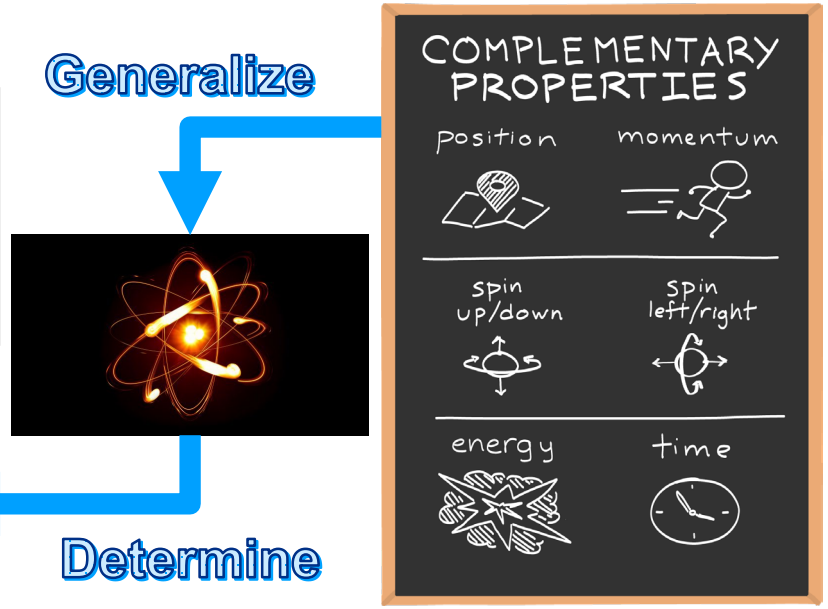
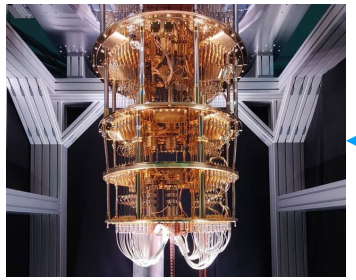
Objective

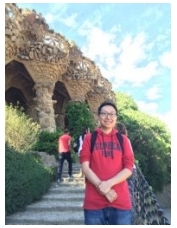
- Understanding the level of **quantum uncertainty** in the dynamics between a system and its environment.
- Evaluating the capability of a **quantum processor** to programmatically simulate a desired unitary.



Methods

- We determine the fundamental limits of the uncertainty principle of system-environment dynamics through the application of **semidefinite programming.**
- We introduce a highly versatile programming scheme for quantum processors that enables both **error tolerance** and **post-selection**.

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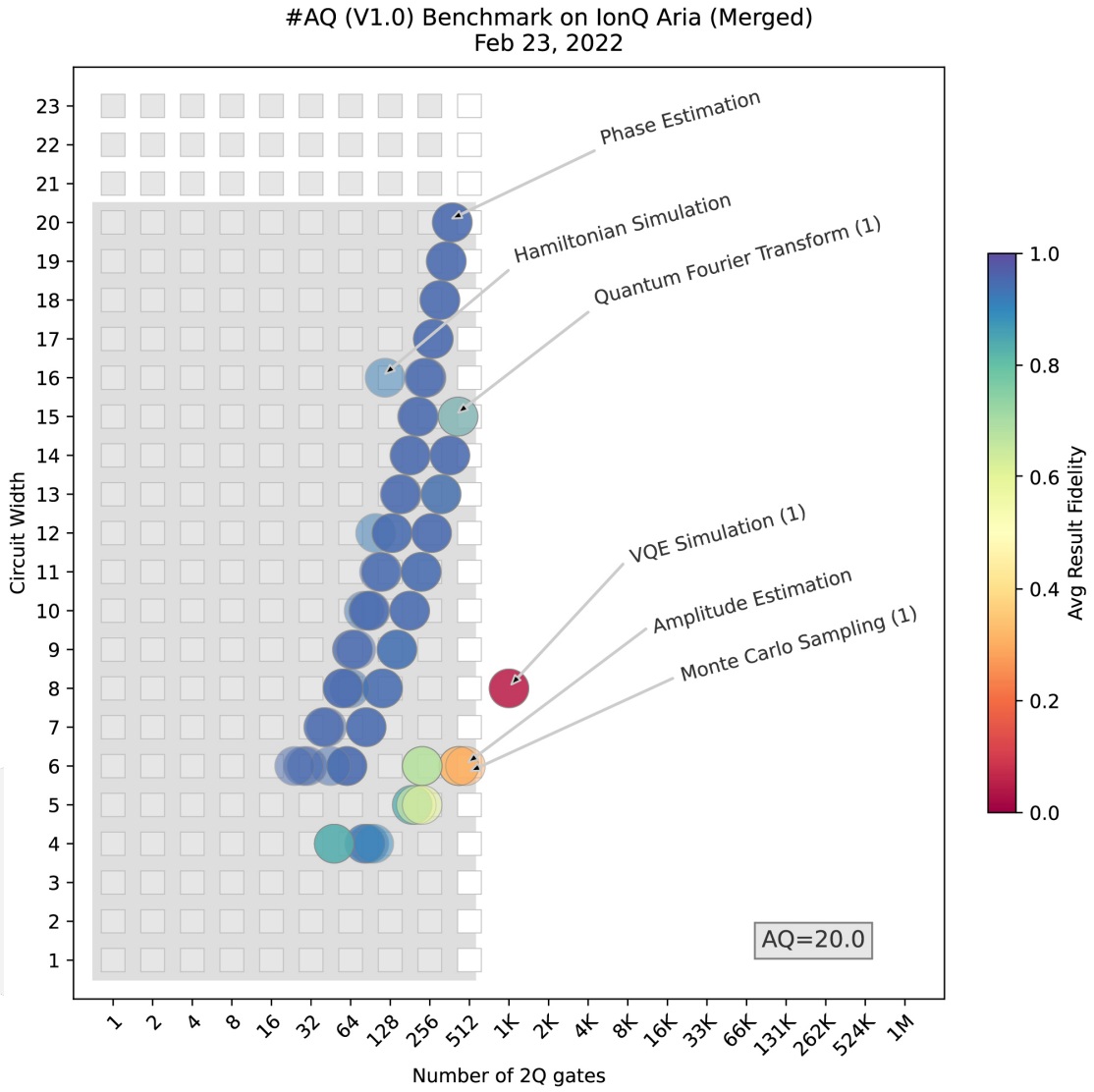
Results

- We demonstrate that the **dynamical uncertainty principle** governs the **programmability** of quantum processors in both deterministic and probabilistic scenarios.
- We propose a novel, computable **metric** for assessing the **performance of quantum processor programming**.

Conclusion



QC Benchmark is at the heart of our quantum computing efforts to deliver end-to-end solutions

BUT

Characterization consensus is badly needed

The LINPACK Benchmark for Top500 is still far!

e.g., effort by QED-C in USA

What's the 4th dimension besides space, time and fidelity?

#QEI workshop 2023 nov 20-24 Singapore
the quantum energy initiative

Thank you!

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