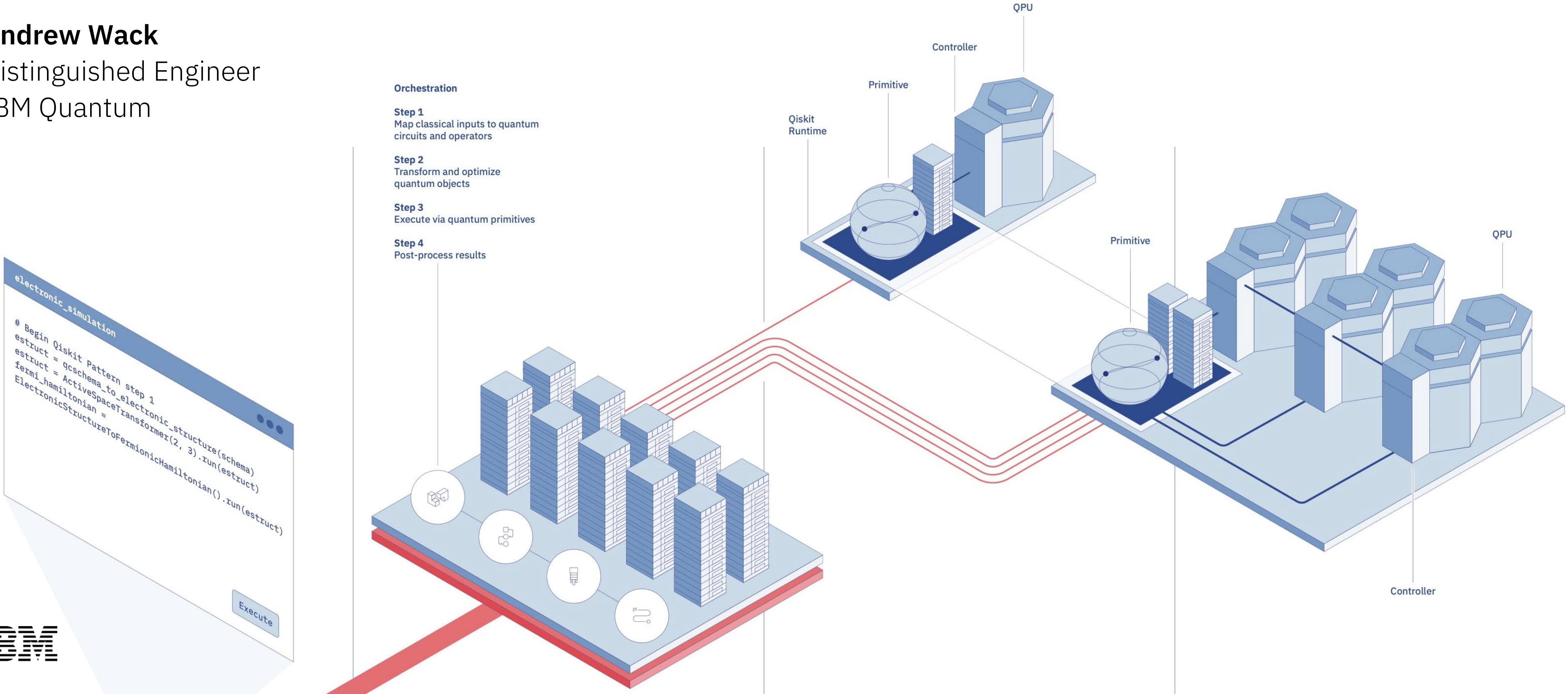
Quantum-Centric Supercomputing

A new perspective on computing

Andrew Wack
Distinguished Engineer
IBM Quantum



IBM

Quantum computing is the *2nd* quantum revolution in history.

What was first?

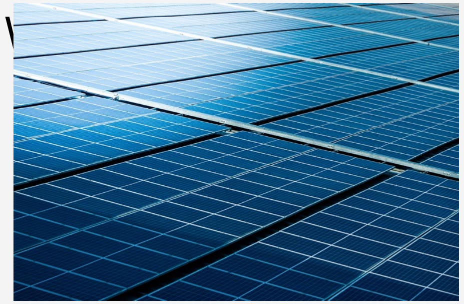
Nature is discrete

Energy, velocity, light, position, etc., at the fundamental limit are quantized →

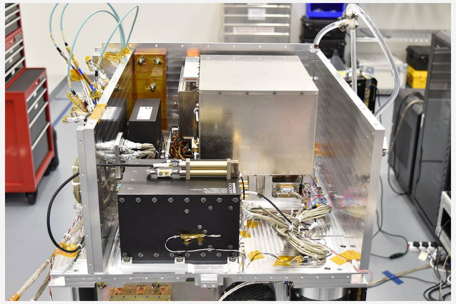
The first quantum revolution created tens of trillions of dollars’ worth of impact

Laser

MRI

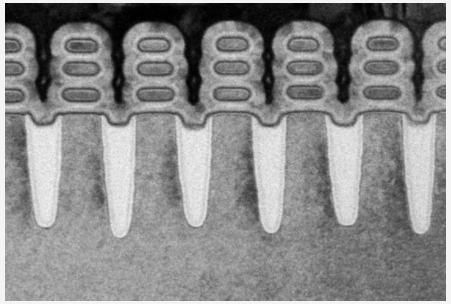


Solar cells

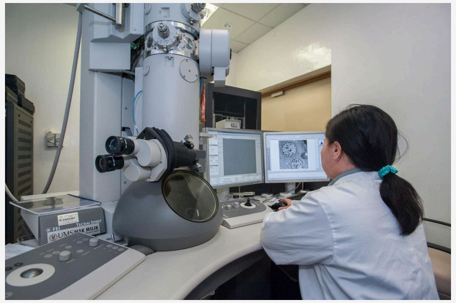


Atomic clocks

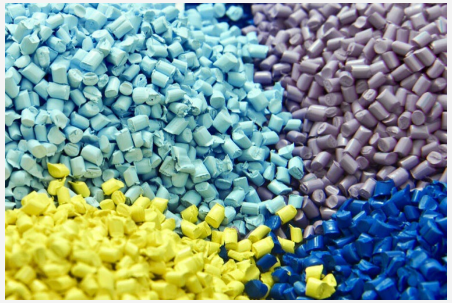
LEDS



Transistor



Electron microscope



Polymers

Quantum computing will have a similar impact

Nature is beyond arithmetic

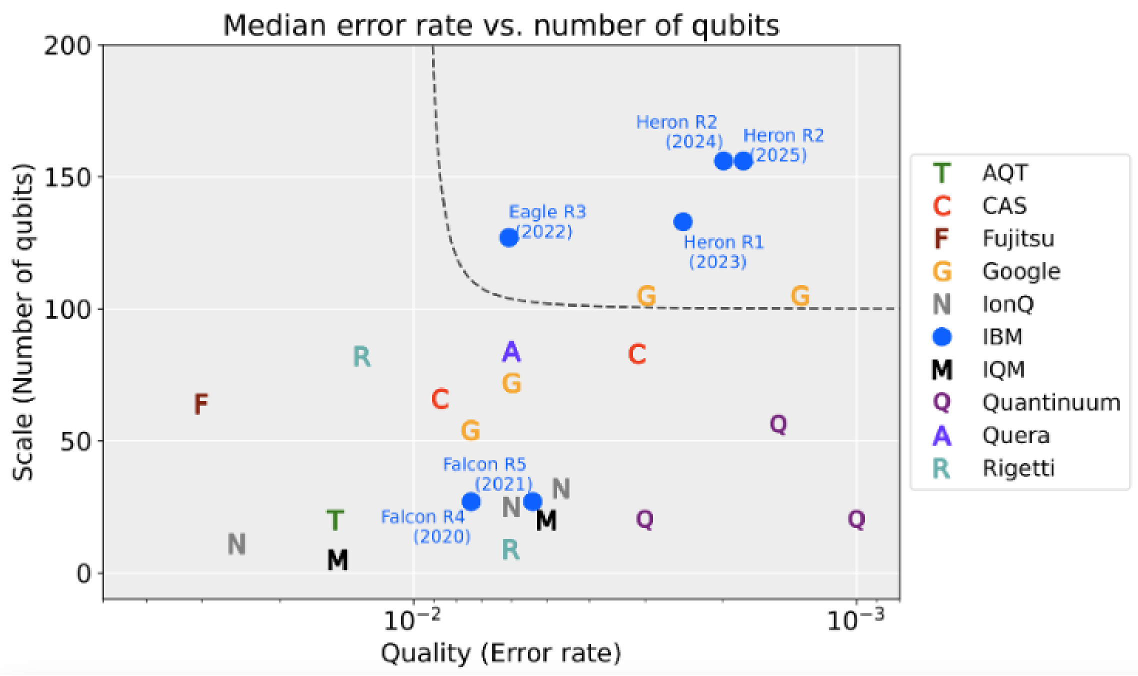
Quantum is the physical realization of mathematical group theory →

Giving us new ways to solve problems that are impossible for digital computers

Quantum mechanics is the operating system of the universe

Two key prerequisites

Performant hardware



Superconducting vs Ions

Speed

400x-2000x faster

@ 500 shots & 56 Qubits

Cost

1200x-70000x cheaper

@ 500 shots & 56 Qubits

Performant software

Qiskit SDK

- Preferred by more than 70% of the developer community
- 4000+ dependent projects
- 13x faster average transpile time than nearest competitor TKET

Qiskit Runtime

- Accurately and efficiently execute estimation and sampling tasks in a near-time environment
- Accurate: Up to 5K gates
- Speed: 200k+ CLOPS

Qiskit Serverless

- Run quantum-centric supercomputing workloads across QPUs, CPUs, and GPUs in the cloud
- Simplifies heterogeneous application development for researchers

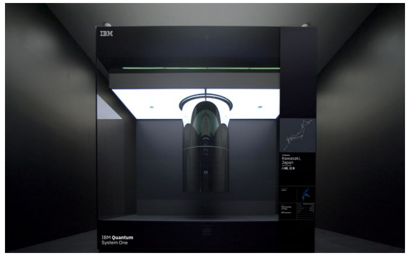
IBM has deployed 75+ systems since 2016.

Today, we have 13 utility-scale quantum computers (100+ qubits) operational in Poughkeepsie, NY; our European data center; and in client locations around the world.

Network – We are a strategic partner to nations

Quantum Computational Center
University of Tokyo

Shin-Kawasaki, Japan
June 2021

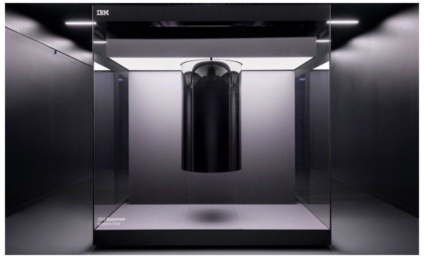


Discovery Accelerator
Cleveland Clinic

Ohio, USA
March 2023

Discovery Accelerator
PINQ[2]

Bromont, Canada
September 2023

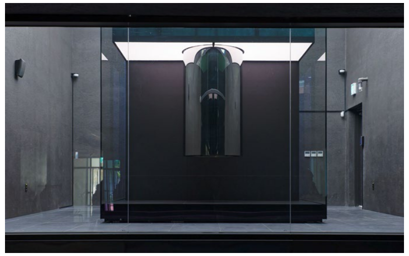


Quantum Computational Center
Rensselaer Polytechnic

Troy, New York
April 2024

Quantum Computational Center
Yonsei University

Seoul, South Korea
September 2024



JHPC-quantum
Riken

Kobe, Japan
Projected May 2025

IBM-Euskadi Quantum Computational Center

San Sebastián, Spain
Projected 2H25

National Quantum Algorithm Center

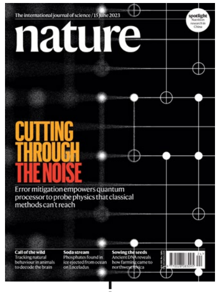
Chicago, USA
Projected September 2025

The case for quantum utility

Quantum utility →

Gates		3K	5K		100M	
Pre-utility		Error mitigation			Fault Tolerant Quantum Computers	
Year		2023	2024		2029	

All circuits can be brute-force run on classical hardware



Only approximate solutions exist in this regime for exploring quantum advantage

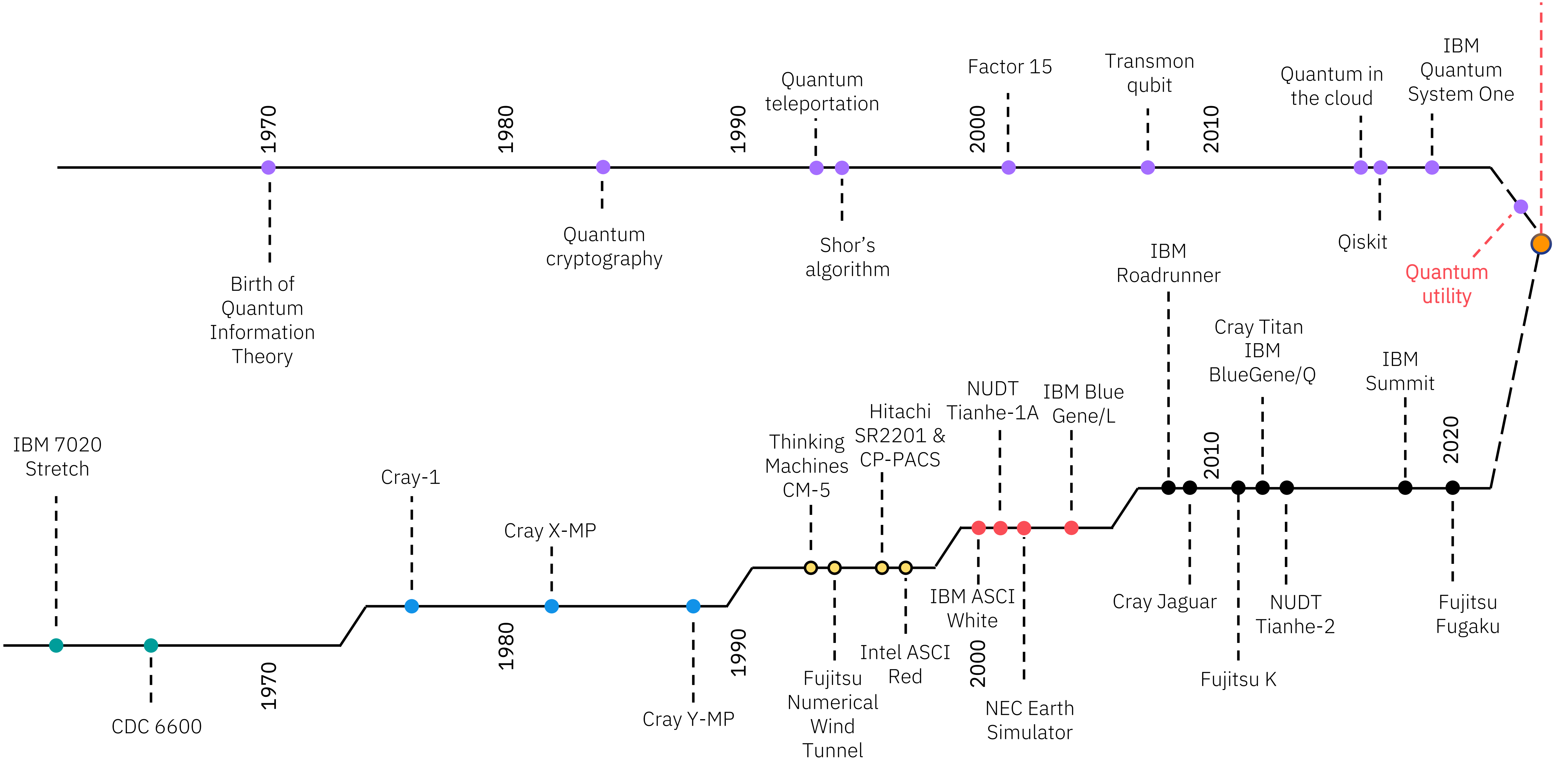
Well into the fault-tolerant regime, where today's known quantum algorithms exist

The estimated cost of simulating a 40-qubit spin chain Schrödinger equation using 1024 H100 GPUs[1,2] is in the order of $30M.

The cost of running the 120-qubit, 3k gate 2023 Nature paper on current quantum hardware is roughly $4.8k[3].

1. Accelerating Google's QPU Development with New Quantum Dynamics Capabilities, NVIDIA Developer, 18 November 2024.
2. Nvidia Hopper H100 80GB Price Revealed, Future US, 29 April 2022.
3. Running in session mode as a premium user of IBM Quantum Platform

Timeline of Advance Computing



(*) Adapted from Reed *et al.* *arXiv*: 2203.02544 (2022)

Quantum-Centric Supercomputing

Problems that require scalable, distributed quantum and/or classical resources for massively parallel computations define the *quantum-centric supercomputing* landscape

Map

Parallel distributed classical resources for mapping classical

Optimize

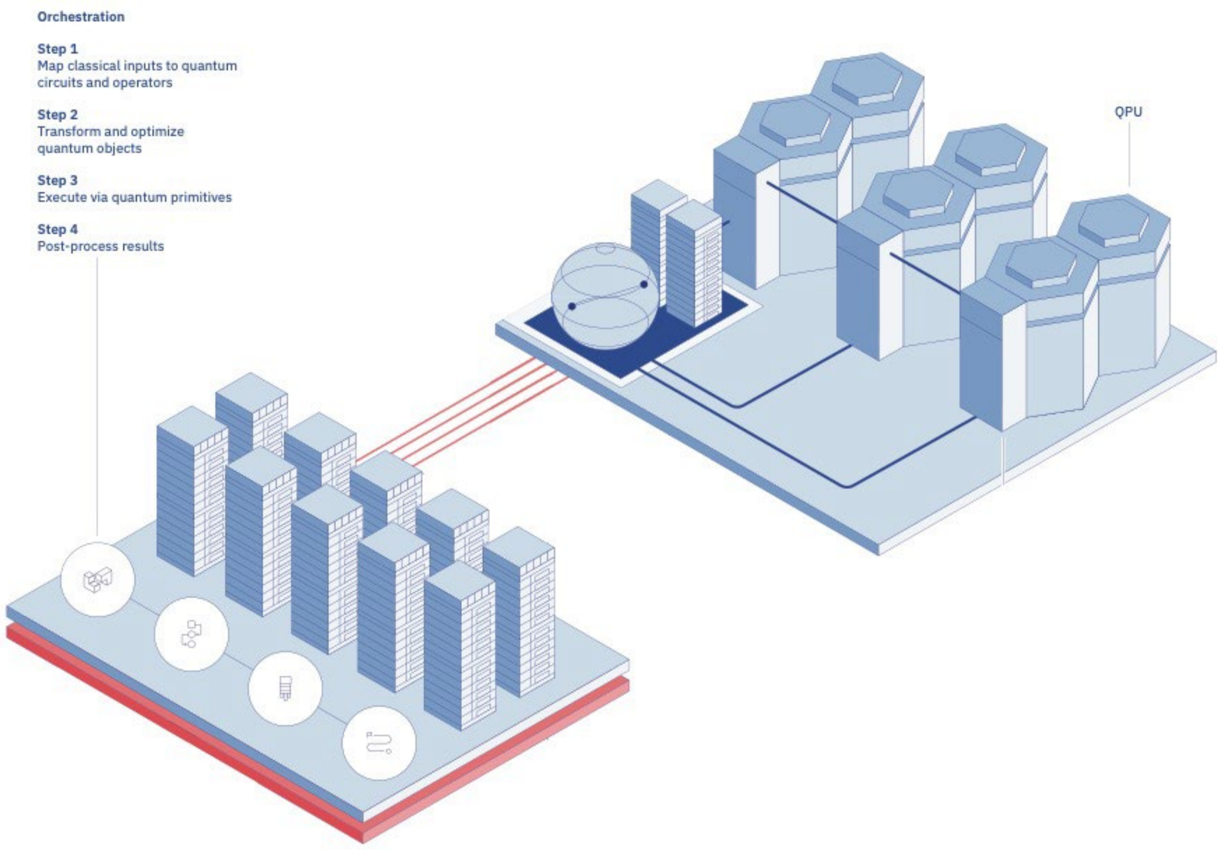
Parallel distributed classical circuit and operator optimization

Execute

Parallel distributed circuit execution on multiple QPUs

Post-process

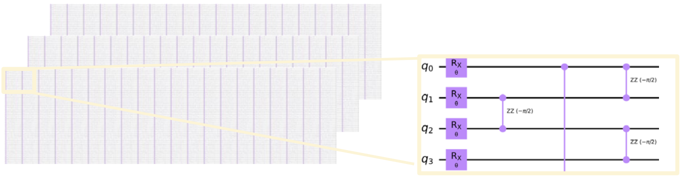
Parallel distributed classical processing of output data



We are actively building toward the quantum-centric supercomputing future

Resource management for hybrid classical and quantum workflows

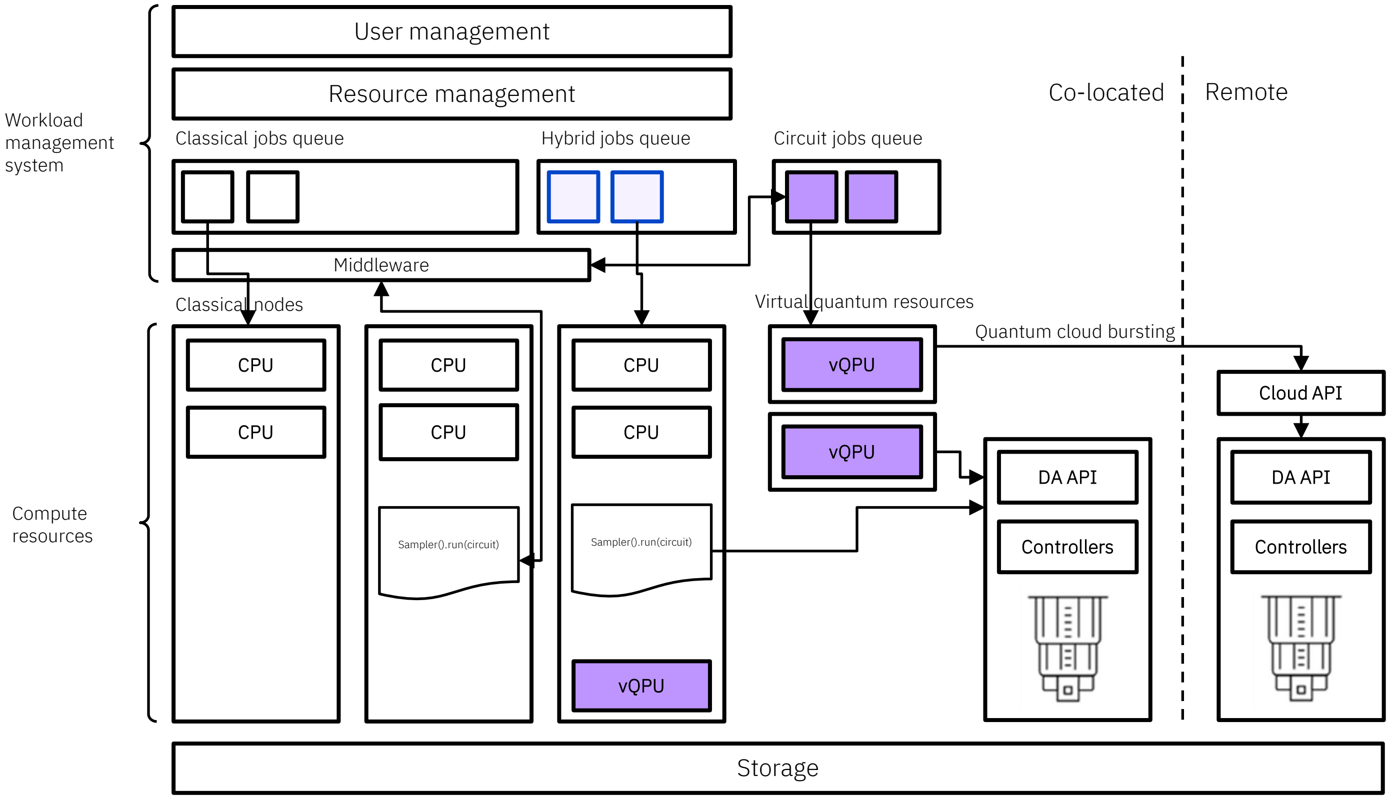
= Utility-scale circuit(s):



We have the tools today to integrate HPC and quantum workflows to create a tightly integrated and efficient quantum-centric supercomputer.

Enables both direct local access as well as bursting to quantum resources in the cloud using standard primitives interface.

The same workflows will work today and as quantum systems mature. The complexity of fault tolerance methods remains inside the quantum computer and is opaque to resource management.



Quantum-centric supercomputing

77 qubits
10570 quantum gates
3590 two-qubit gates

富岳
Fugaku

6400 nodes @
32 GB
1024 GB/s
48 cores

Pushing boundaries of Quantum-centric supercomputing

Re-computation of Fe_4S_4

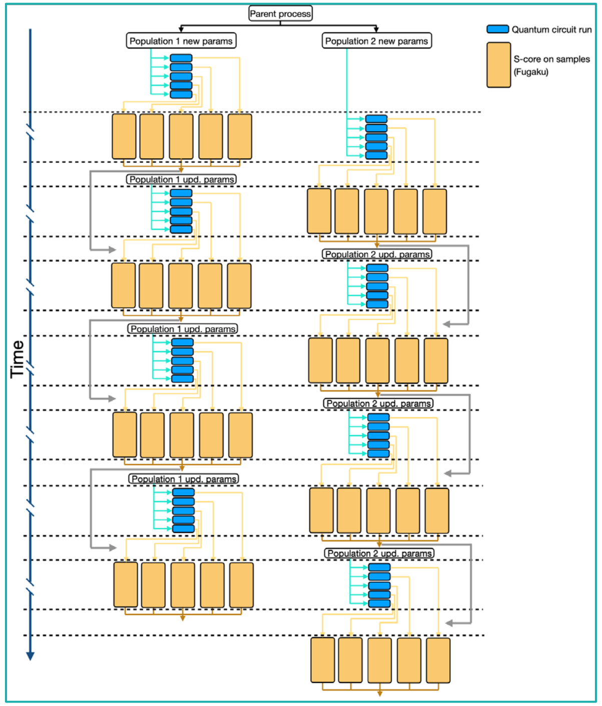
Energy-variance extrapolations for Fe_4S_4 currently do not agree with SOTA. Various changes to our approach have led to improvements over last year's experiments:

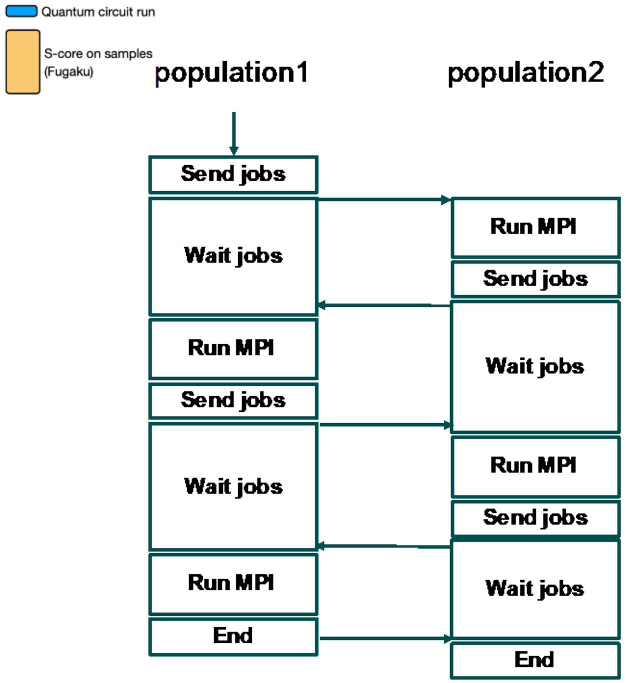
Algorithms
Optimize parameters of LUCJ circuits with iterations

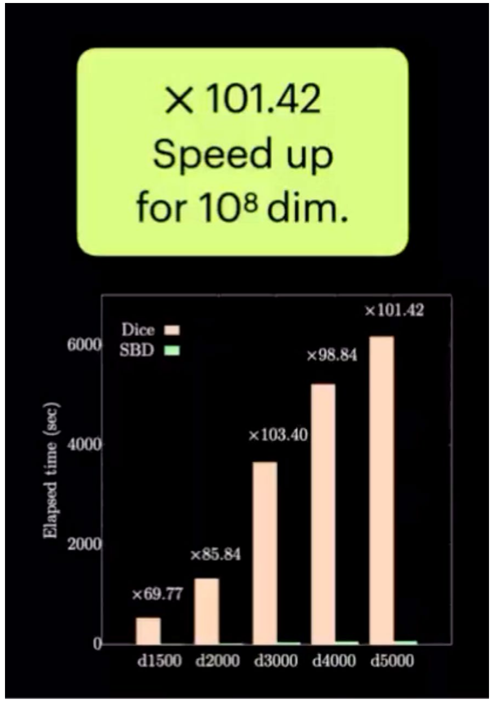
QCSC workflow
Implementing the algorithms with feedback loop, tight coupling, orchestration of resources.

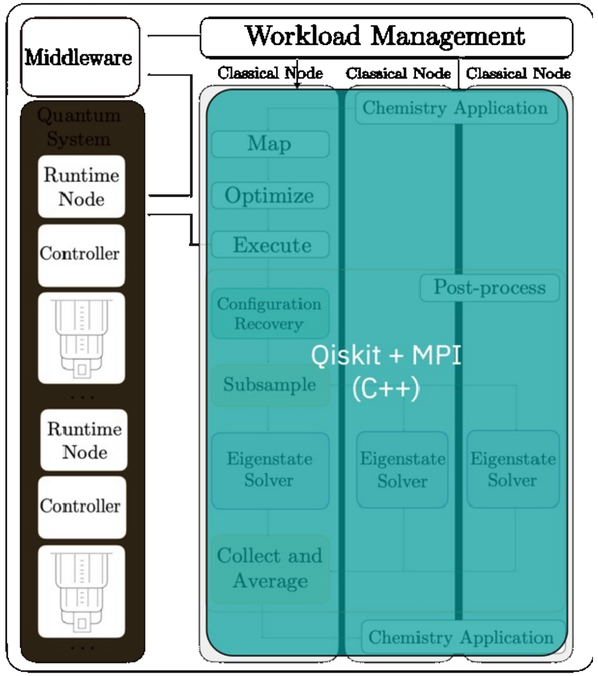
Classical software
Fast diagonalization tool. 100x speedup

Programming environment
Allocate computation resources only once with minimum latency

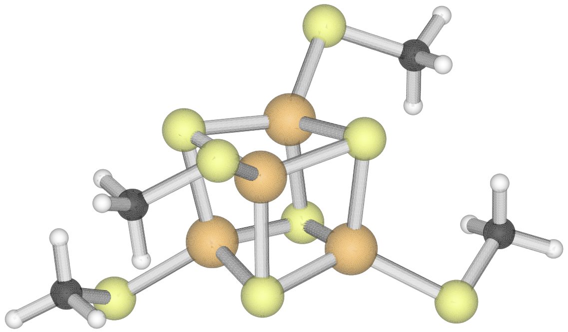








Quantum-centric supercomputing: a new computational framework



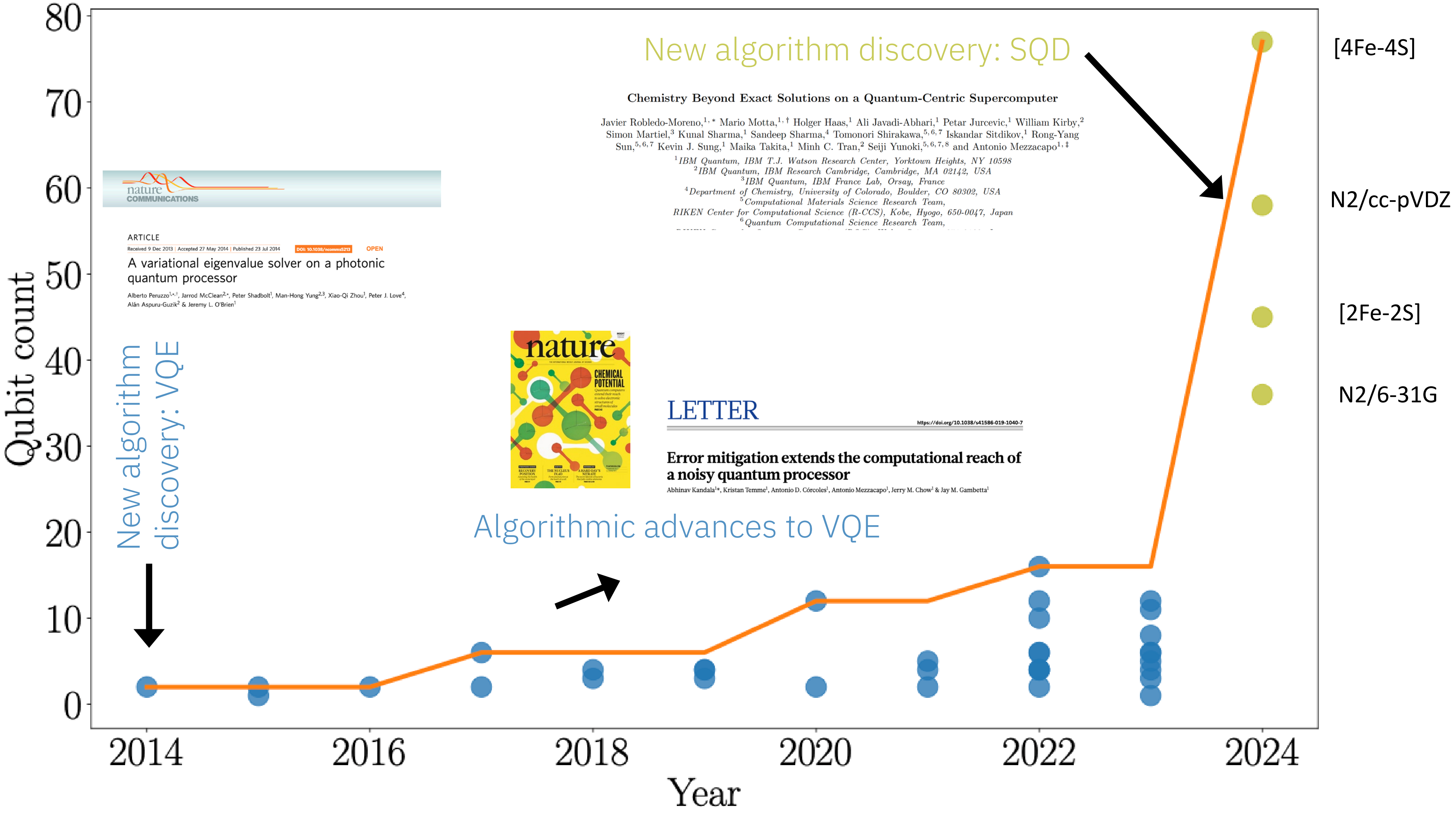
Fe_4S_4 on **77** qubits (TZP-DKH basis set): **6.7M** Pauli operators

Fault-tolerant	Phase estimation qubits: **4.53M** **13 days** runtime *
Pre-fault tolerant	VQE estimation at 10µs/circuit ~**3M years**
Quantum-centric supercomputing	Subspace estimation at 10µs/circuit ~**2 hours**

QCSC enables new classes of fault-tolerant use cases such as quantum chemistry on current quantum processors

*Estimation done using surface code

Quantum chemistry on quantum computers



Data Sources: https://arxiv.org/pdf/2212.02482, https://arxiv.org/pdf/2312.00178, https://arxiv.org/abs/2405.05068

My Prediction:

Quantum Advantage will happen within the next 2 years.

But only if HPC and Quantum communities work together

IBM