OIST×UTokyo Symposium 2025
「Quantum Nexus」

UTokyo, August 19, 2025

Quantum Research Activities at the University of Tokyo: A Global Perspective

International Center for
Elementary Particle Physics (ICEPP),
The University of Tokyo

Koji Terashi

Introducing Myself

Koji Terashi

- Ph.D at University of Tsukuba (2000)
- Postdoc at Rockefeller University (~2007)
- Postdoc, Assistant/Associate Professor at UTokyo ICEPP (~2024)
- Professor at UTokyo ICEPP (2024~)

Researches on

- **Experimental high-energy physics** at Fermilab Tevatron and CERN LHC
- Quantum computing:
    - **Quantum machine learning** for physics application, collaboration with industries
    - **Quantum simulation** for high-energy physics
    - Quantum optimization (Charged particle tracking, Circuit optimization)

Leading/Serving

- Quantum Machine Learning in **SQAI (COI-NEXT) project**
- **UTokyo-IBM** and **UTokyo-UChicago partnerships** on quantum information science
- **ASPIRE quantum program** between UTokyo and UChicago funded by JST
- **IBM-UTokyo lab Head**, Special Advisor to the President

Future of Quantum: From Points to Lines to Surfaces

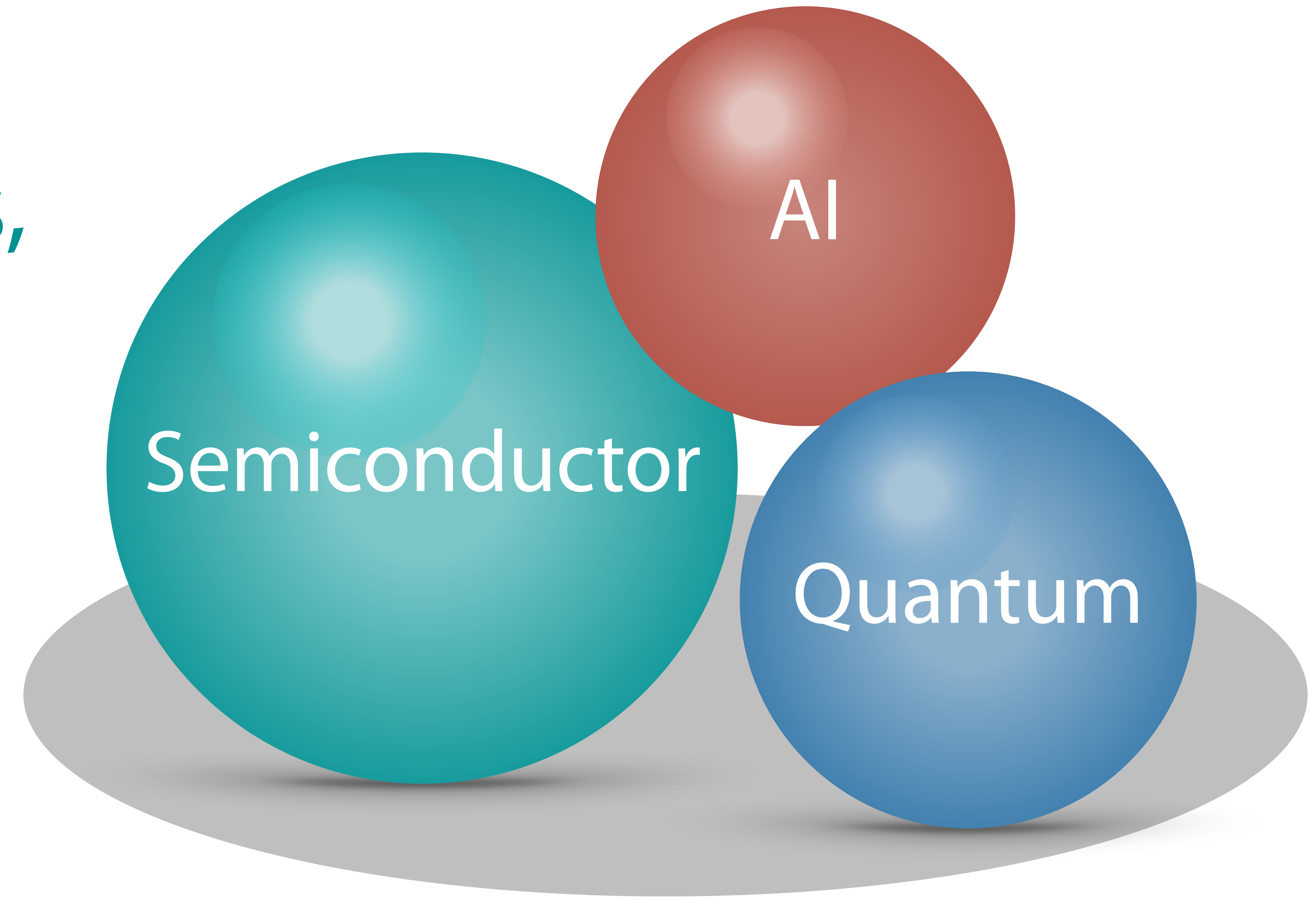
Quantum as a focus area at UTokyo, alongside semiconductors, AI and life sciences

UTokyo Quantum Strategy

Academic value of quantum as **points**	➡	Push the frontiers of quantum research
Connect the points to create new **lines**	➡	Quantum + AI as a new frontier
From points and lines to **surfaces**	➡	Next-generation Quantum AI emerging from advanced semiconductors and Quantum AI
Quantum education as a complex **point**	➡	Spanning the cultivation of top researchers, developers and users

Quantum at the core, fused with AI and semiconductors, forms ***surfaces*** for next-generation computing

Education connects these points, cultivating talent and driving academia-society innovation



UTokyo Perspectives on Quantum Computing

Use-case oriented research to develop applications and promote building a quantum ecosystem with partners

Initiated with Japan - IBM Quantum Partnership in Dec. 2019

IBM Quantum System One in Shin-Kawasaki


127-qubit Eagle processor

Under upgrade to 156-qubit Heron r2 processor

Hardware Test Center at UTokyo

5-qubit IBM Tsuru-processor for hardware/component development

UTokyo Gateway to IBM Quantum

IBM

UTokyo

Exclusive use by UTokyo and QIIC member companies

UTokyo Compass Steering Committee
Chair: President Teruo Fujii

Quantum Initiative
Chair: Vice-President Hiroaki Aihara

IBM-UTokyo Lab
Head: Koji Terashi

Building a quantum computing ecosystem in Japan with IBM quantum:
- IBM Sponsored Research
- Quantum Hardware Test Center
- Quantum Native Education Center

QIIC
Quantum Innovation Initiative Consortium

Chair:
Mitsunobu Koshiba

Project Leader:
Hiroaki Aihara

Full members

UTokyo, 慶應義塾, JSR株式会社, SONY, SoftBank, TOSHIBA, DIC Color & Comfort, TOYOTA, TOPPAN, IBM, HITACHI Inspire the Next, MIZUHO, SuMi TRUST SUMITOMO MITSUI TRUST GROUP, MITSUBISHI CHEMICAL, MUFG, 理化学研究所

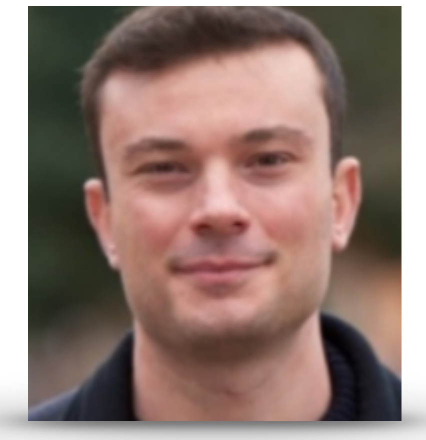
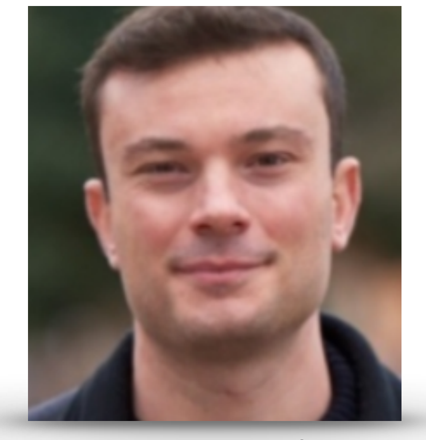
Academia member TAT 東京農工大学

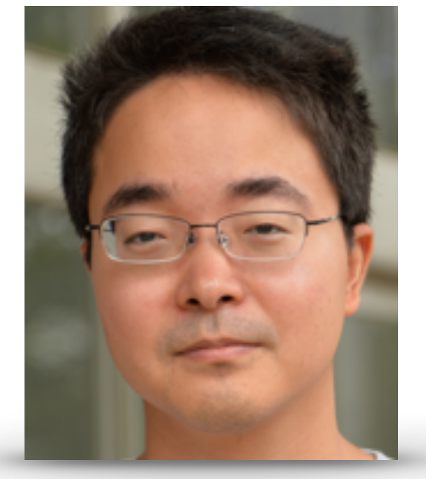
Associate members AJINOMOTO, AGC Your Dreams, Our Challenge, SUNTORY, muRata INNOVATOR IN ELECTRONICS

Market-in, Use case-oriented

IBM Sponsored Research

Algorithm, Application
Hardware

UTokyo	IBM	
 Nobuyuki Yoshioka	 Antonio Mezzacapo	Boosting near-term quantum computation by machine-learning post-processing
 Koji Terashi	 Francesco Tacchino	Towards Large-Scale Quantum Artificial Intelligence
 Mio Murao	 Antonio Mezzacapo	Quantum programming and algorithms based on higher-order quantum operations
 Takeshi Sato	 Yukio Kawashima	Quantum/classical hybrid simulation of intense laser-driven multielectron dynamics

UTokyo	IBM	
 Eiji Saito	 Naoki Kanazawa	Spintronics and AI physics research for large-scale quantum processors
 Atsushi Noguchi	 Masao Tokunari	Quantum transduction using optomechanical system
 Toshiaki Inada	 Masao Tokunari	Superconducting qubits with multi-junction architecture
 Masahito Yamazaki	 Atsushi Matsuo	Dynamic circuits for quantum simulations in High Energy Physics and beyond

IBM-UTokyo lab with IBM Sponsored Research

arXiv > quant-ph > arXiv:2312.00178

Quantum Physics

[Submitted on 30 Nov 2023]

Subspace methods for electronic structure simulations on quantum computers

Mario Motta, William Kirby, Ieva Liepuoniute, Kevin J. Sung, Jeffrey Cohn, An
Nam Nguyen, Nobuyuki Yoshioka, Julia E. Rice

Quantum subspace methods (QSMs) are a class of quantum computing algorithms wh
equation for a quantum system is projected onto a subspace of the underlying Hilbert
Schrodinger equation into an eigenvalue problem determined by measurements carrie
eigenvalue problem is then solved on a classical computer, yielding approximations to
wavefunctions. QSMs are examples of hybrid quantum-classical methods, where a qua
computational resources is employed to tackle a problem. QSMs are rapidly gaining tr
wavefunctions on quantum computers, and thus their design, development, and applic

arXiv > quant-ph > arXiv:2405.07720

Quantum Physics

[Submitted on 13 May 2024]

Symmetric Clifford twirling for cost-optimal quantum error mitigation in early FTQC regime

Kento Tsubouchi, Yosuke Mitsuhashi, Kunal Sharma, Nobuyuki Yoshioka

arXiv > quant-ph > arXiv:2405.14752

Quantum Physics

[Submitted on 23 May 2024 (v1), last revised 27 Jul 2024 (this version, v2)]

Qudit-Generalization of the Qubit Echo and Its Application to Qutrit-Based Toffoli Gate

Yutaro Iiyama, Wonho Jang, Naoki Kanazawa, Ryu Sawada, Tamiya Onodera, Koji Terashi

The fidelity of certain gates on noisy quantum computers may be improved when they are implemented using

arXiv > quant-ph > arXiv:2401.16884

Quantum Physics

[Submitted on 30 Jan 2024 (v1), last revised 8 Oct 2024 (this version, v2)]

Robust Error Accumulation Suppression for Quantum Circuits

Tatsuki Odake, Philip Taranto, Nobuyuki Yoshioka, Toshinari Itoko, Kunal Sharma, Antonio Mezzacapo, Mio Murao

We present a robust error accumulation suppression (REAS) technique to manage errors in quantum computers. Our method reduces the accumulation of errors in any quantum circuit composed of single- or two-qubit gates expressed as $e^{-i\sigma\theta}$ for Pauli operators σ and $\theta \in [0, \pi)$, which forms a universal gate set. For coherent errors -- which include gate overrotation and crosstalk -- we demonstrate a reduction of the error scaling in an L-depth circuit from $O(L)$ to $O(\sqrt{L})$. This asymptotic error suppression behavior can be proven in a regime where all gates -- including those constituting the error-suppressing protocol itself -- are noisy. Going beyond coherent errors, we derive the general form of decoherence noise that can be suppressed by REAS. Lastly, we experimentally demonstrate the effectiveness of our approach regarding realistic errors using 100-qubit circuits with up to 64 two-qubit gate layers on IBM Quantum processors.

arXiv > cond-mat > arXiv:2403.11618

Condensed Matter > Mesoscale and Nanoscale Physics

[Submitted on 18 Mar 2024]

Current-induced magnon trapping in spin torque oscillation

Takahiko Makiuchi, Naoki Kanazawa, Eiji Saitoh

Spin torque nano-oscillators realized by magnetization dynamics trapped in a current-induced potential are reported. We fabricated $Ni_{81}Fe_{19}$/Pt nanostructures and measured current-induced microwave emission from the structures. The result shows an increase in the magnitude and spectral narrowing of the microwave emission. We demonstrate that the current-induced magnetic field suppresses magnon radiation loss and significantly reduces the linewidth and the threshold current required for the spin torque oscillation.

Applied Physics Letters

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23, Issue 18
2023

RESEARCH ARTICLE | NOVEMBER 01 2023

Detection of temporal fluctuation in superconducting qubits for quantum error mitigation

Yuta Hirasaki; Shunsuke Daimon; Toshinari Itoko; Naoki Kanazawa; Eiji Saitoh

Lett. 123, 184002 (2023)
g/10.1063/5.0166739

Split-Screen | Views | PDF | Share | Tools

investigated instability of a superconducting quantum computer by continuously monitoring
output. We found that qubits exhibit a step-like change in the error rates. This change is

Results since 2021 with IBM support

(as of Nov. 2024)

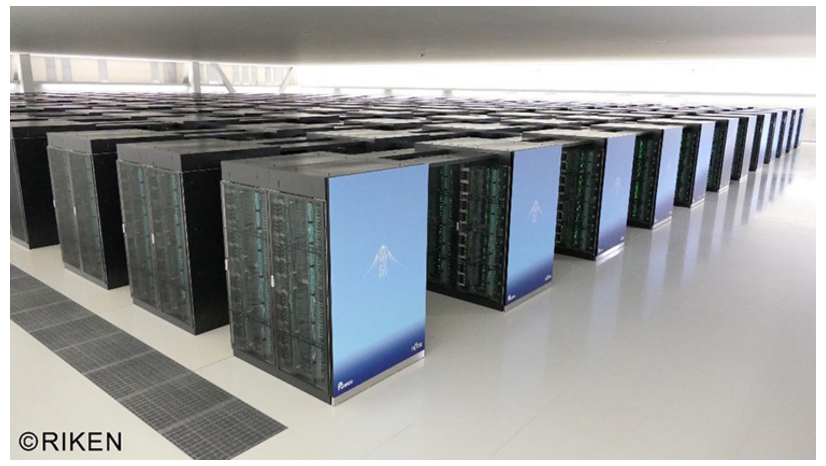
- 15 refereed papers (published)
- 23 preprints

Next phase starting in 2026

- Quantum algorithms and applications for Quantum Centric Supercomputing
- Building hardware, supply chain for QCSC

↓

- Utility-scale quantum computing
- Practical applications with quantum advantage



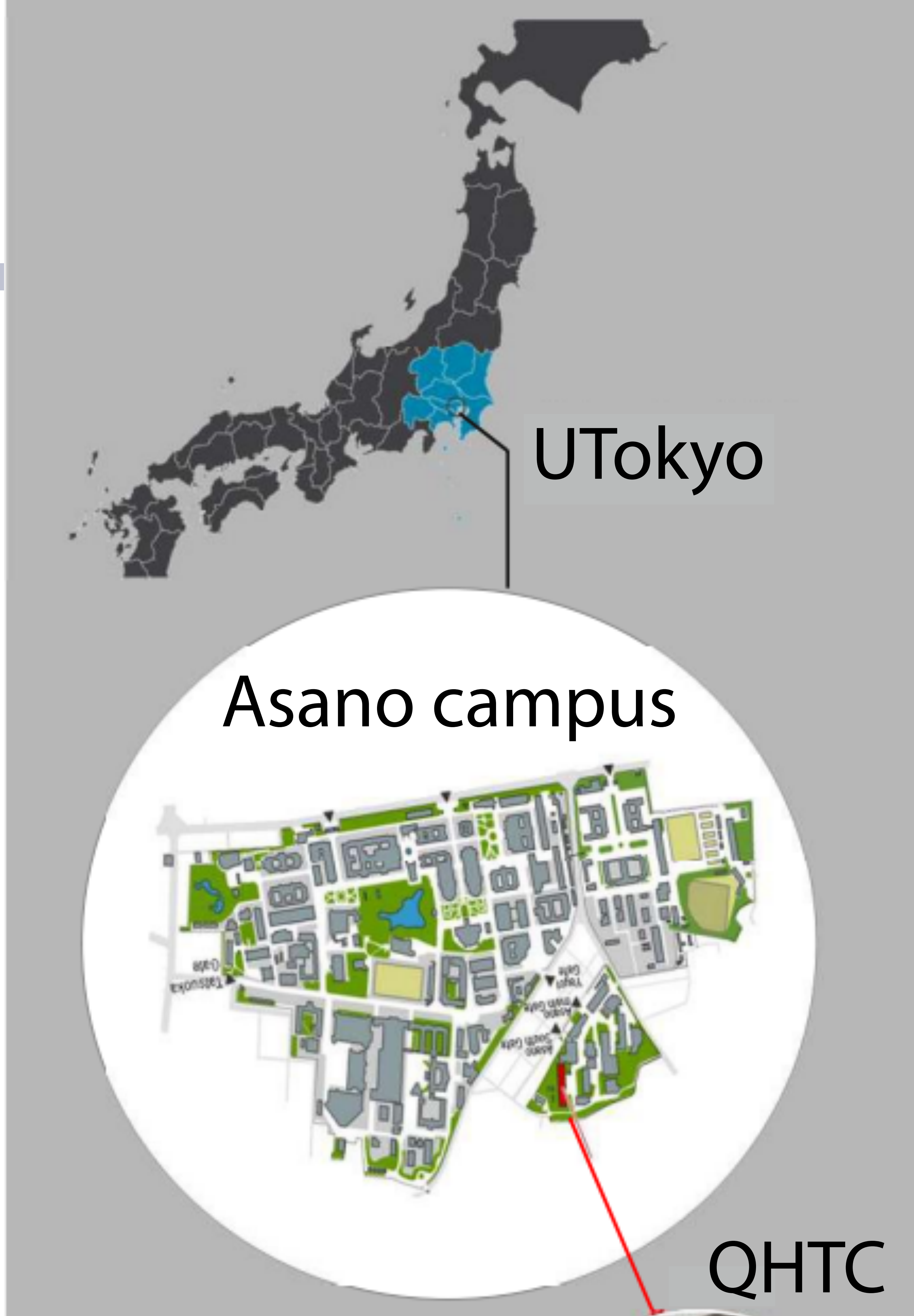
UTokyo-IBM Quantum Hardware Test Center

UTokyo
IBM

- Developing essential components for quantum computers
- Enable evaluation with standard qubits and rapid development feedback
- Various benchmark measurements at multiple temperatures (~10 mK to 4 K)
- Products can be brought to market at the discretion of the member company

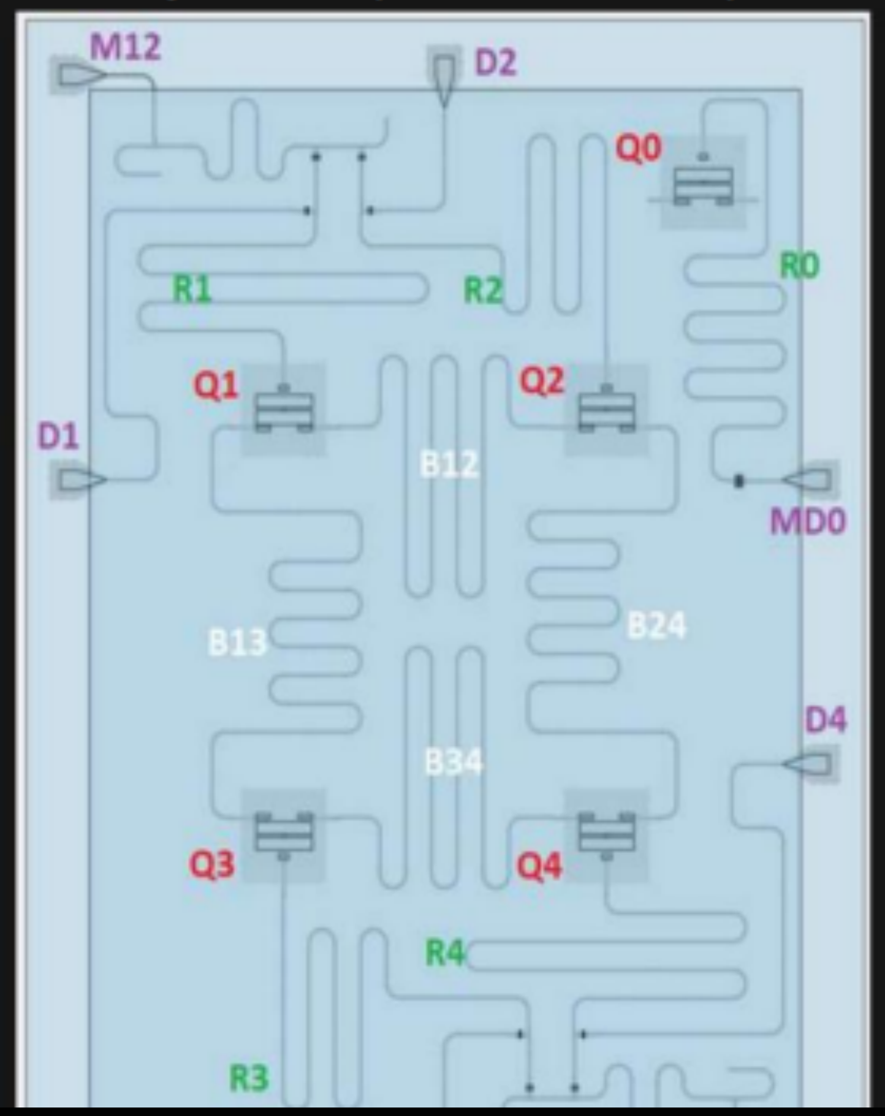
Currently utilized by 3 companies;
5 additional companies have expressed interest

Engaging industries to develop quantum computer components and commercialize



Established in 2021at UTokyo Asano Campus

東京大学大学院理学系研究科・理学部ニュース第54巻5号より
／Photo Koji Okumura(Forward Stroke Inc)



Quantum Processor (Tsuru chip)

Device Development with Hardware Test Center

Member Company

Proposal for device development

Review development plan:
Reach agreement or present revisions as needed

If accepted

Develop and prepare test device

Make improvement based on results and feedback if needed

Quantum Hardware Test Center

Examine the development proposal

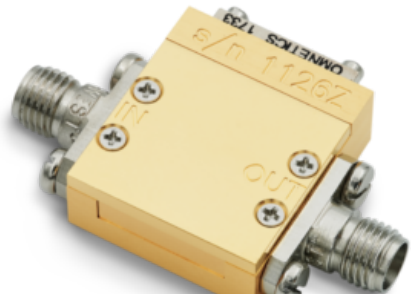
If accepted

Formulate device development plan:
Requirements, Schedule, Specifications

Conduct performance evaluation:
Measurement by IBM Engineers

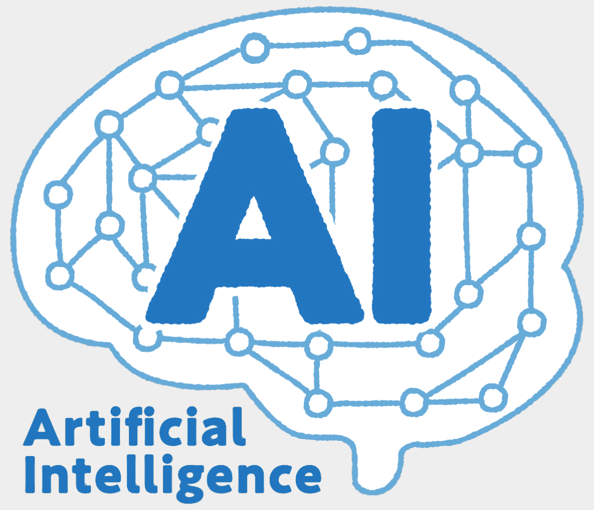
Return measurement results & device with feedback

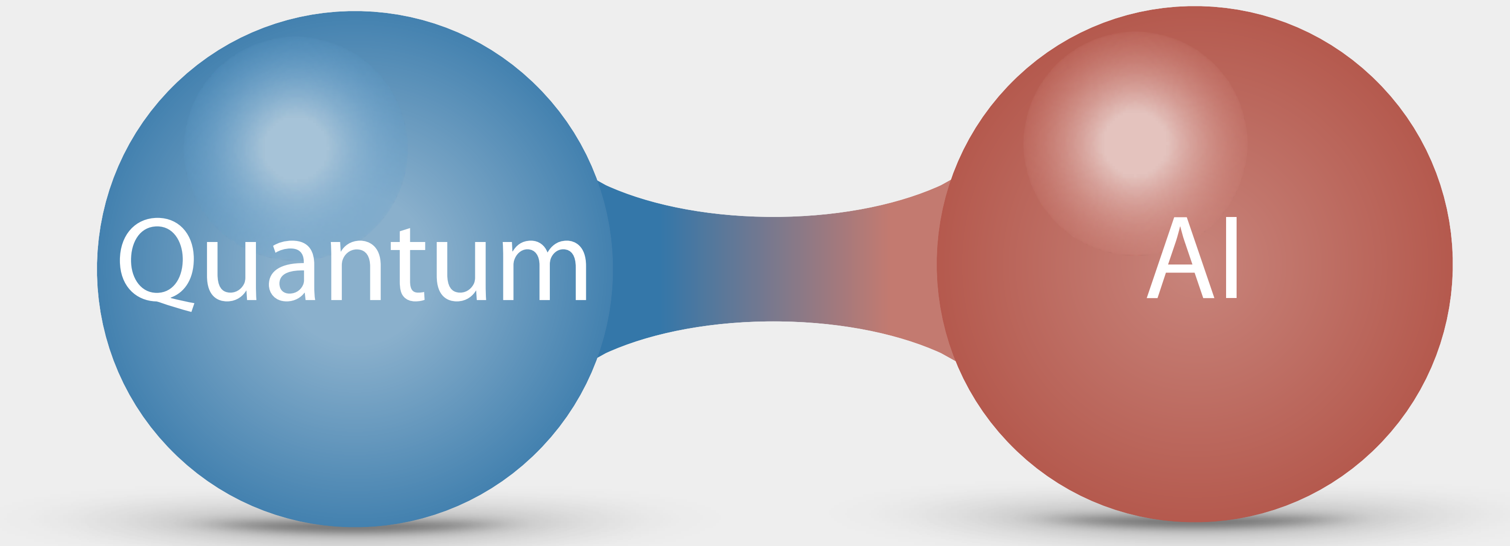
Market at the discretion of the member company



Innovation by Connecting Points : Quantum + AI

Quantum Computer + **AI**

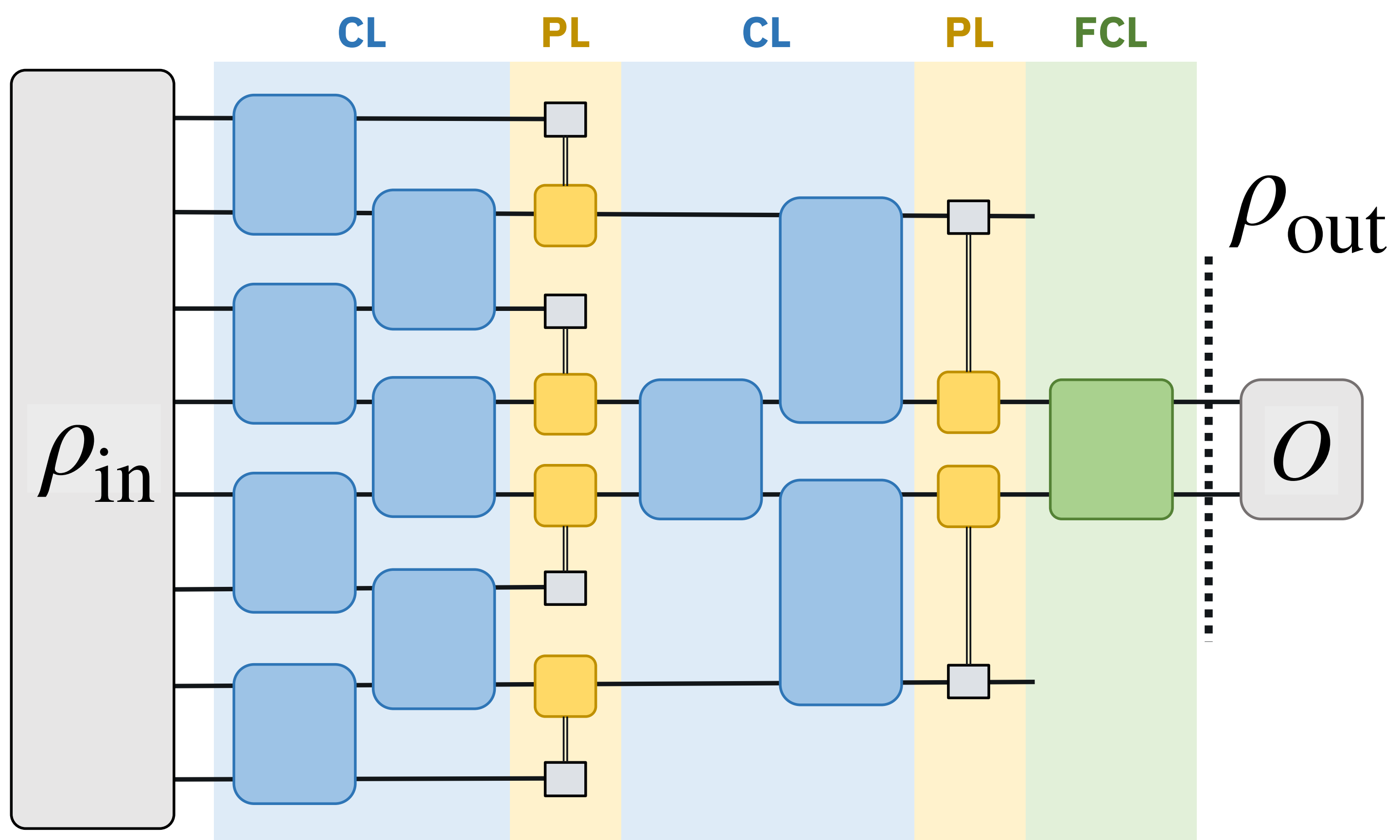




- Harness the representational power of quantum computer in high-dimensional Hilbert space
- Improve learning performance, generalization, and achieve advantages over classical models

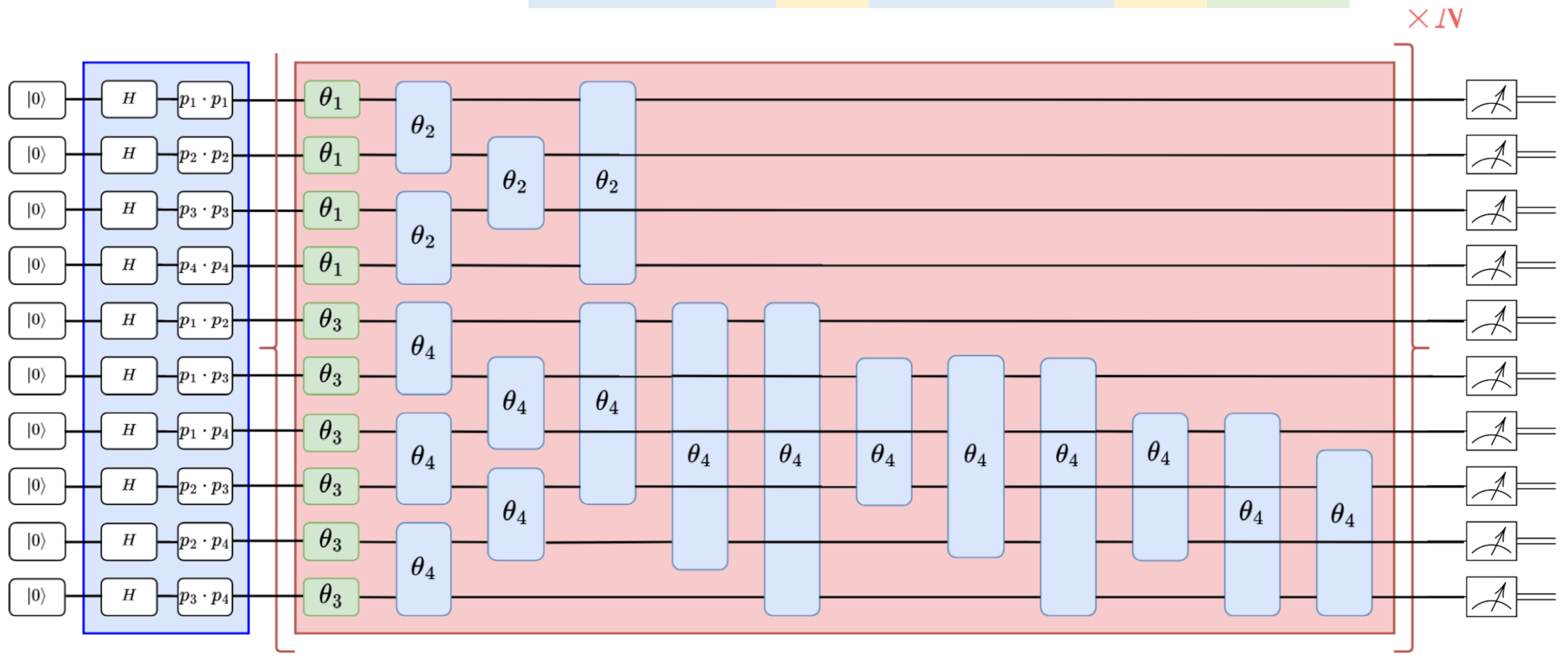
Quantum Neural Network for phase recognition with quantum data as inputs

L. Nagano, K. Terashi et al., [Phys. Rev. Res. 5, 043250 (2023)]



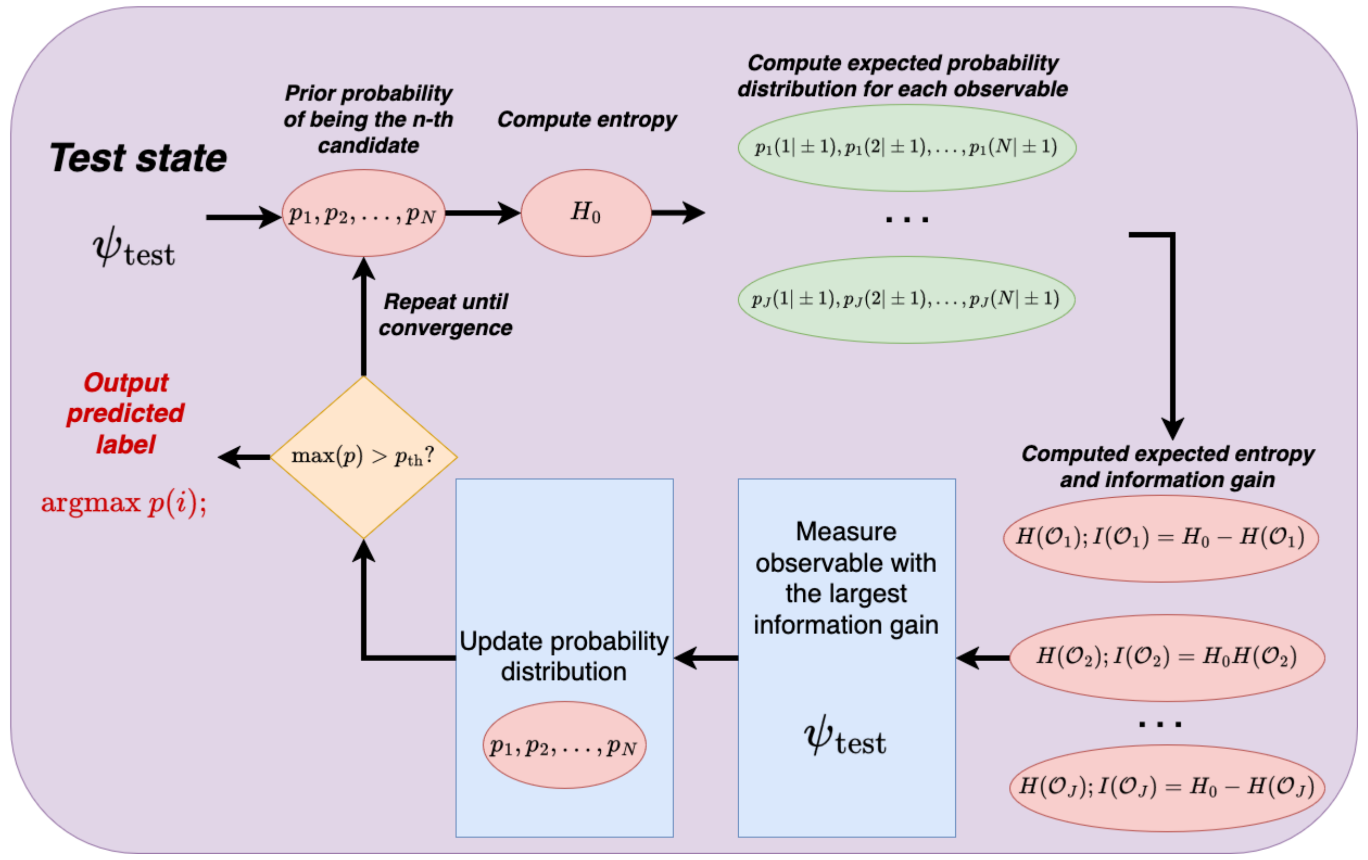
Resource-efficient QNN model with encoded symmetries

Z. Li, L. Nagano, K. Terashi, [Phys. Rev. Res. 6, 043028 (2024)]



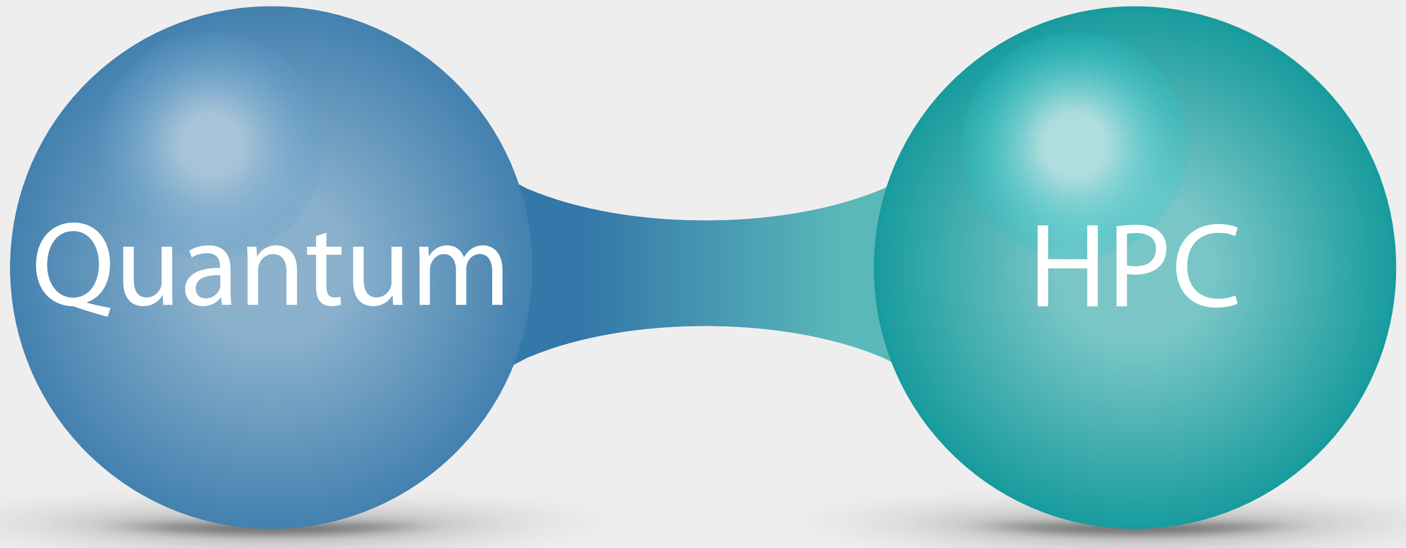
Bayesian quantum state classification with expected information gain

Z. Li, K. Terashi, [arXiv:2502.11412]



Innovation by Connecting Points : Quantum + HPC

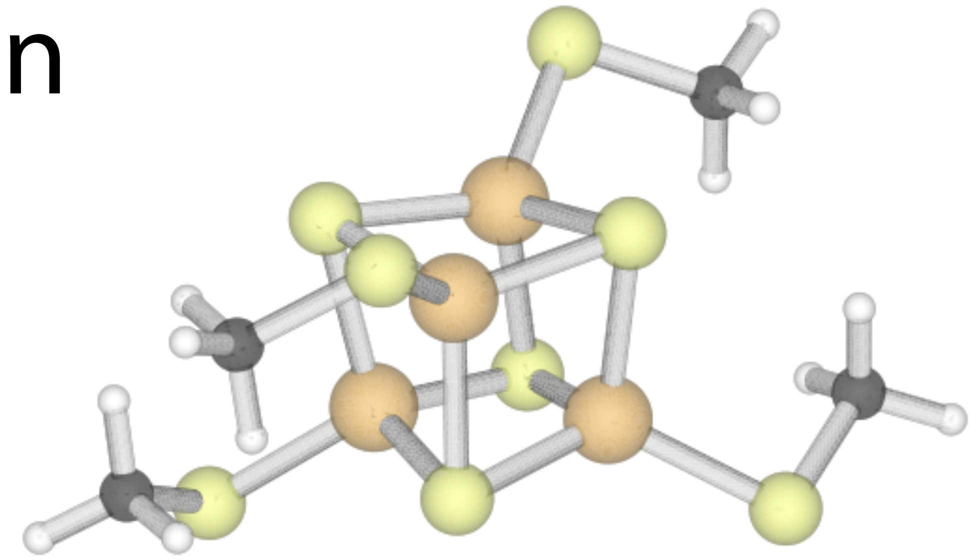
Quantum Computer + **Supercomputer**



Quantum Centric-Supercomputing

- Measure energy eigenvalues via quantum measurement + HPC computation
- Optimize quantum circuits with HPC and feed back results to quantum computers

Quantum chemistry calculation of Fe4S4 energies using IBM Quantum and RIKEN Fugaku supercomputer in 2024



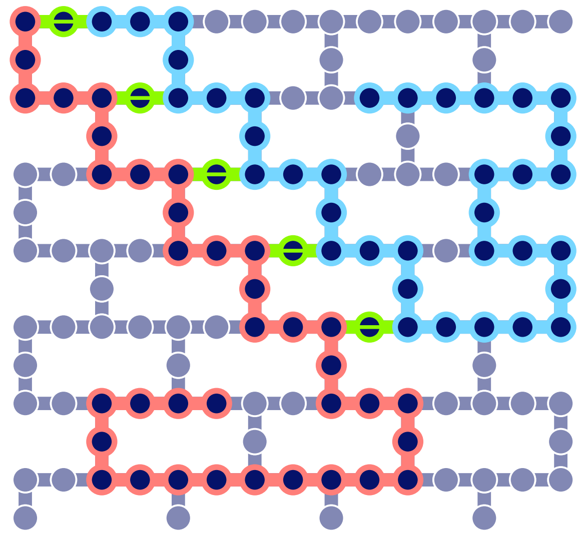
Quantum-Selected Configuration Interaction (QSCI)

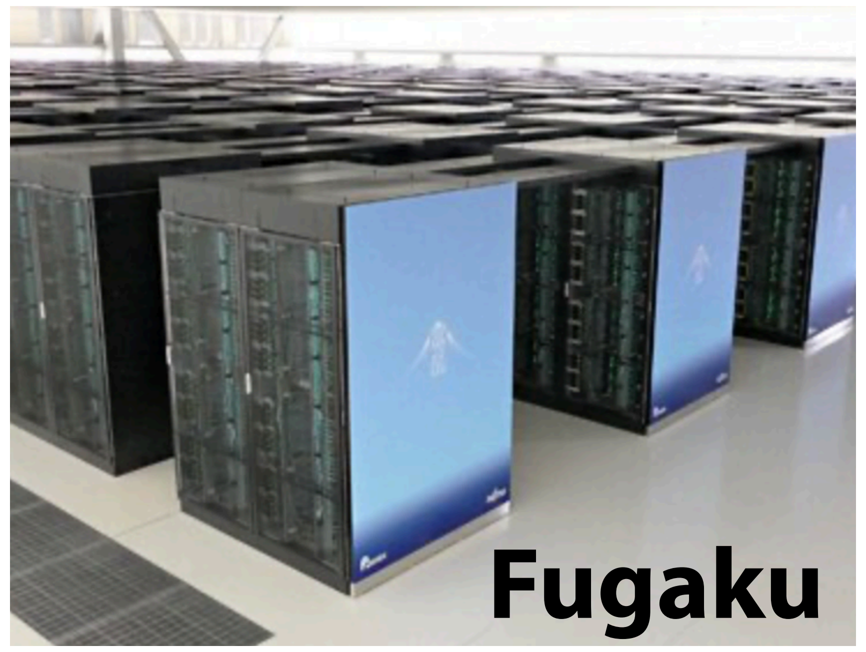
K. Kanno et. al, arXiv:2302.11320

Sample-based Quantum Diagnonalization (SQD)

J. Robledo-Moreno et. al, Sci. Adv. 11, 25 adu9991 (2025)

Used 77 qubits,
3500 2-qubit gates



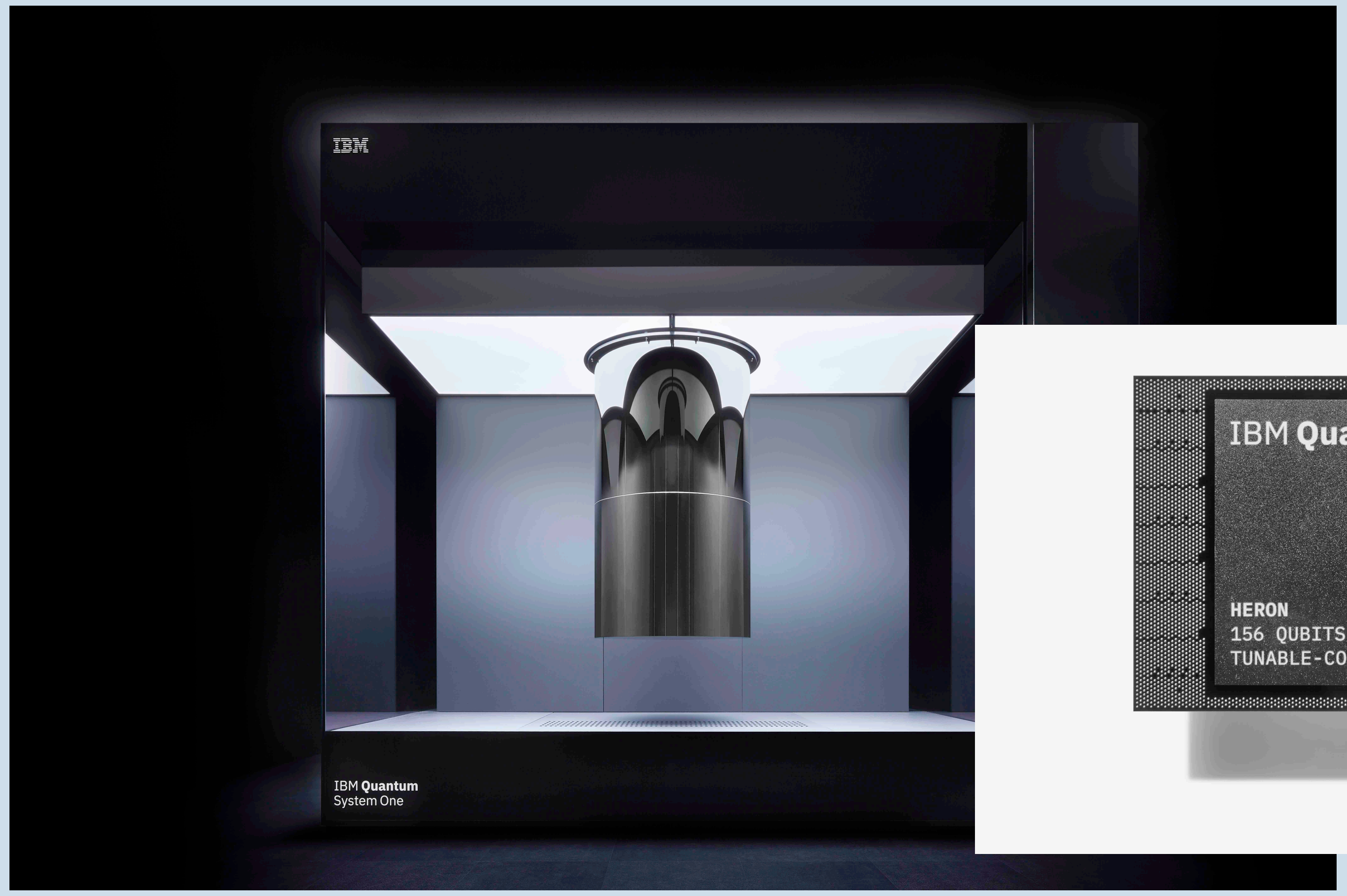


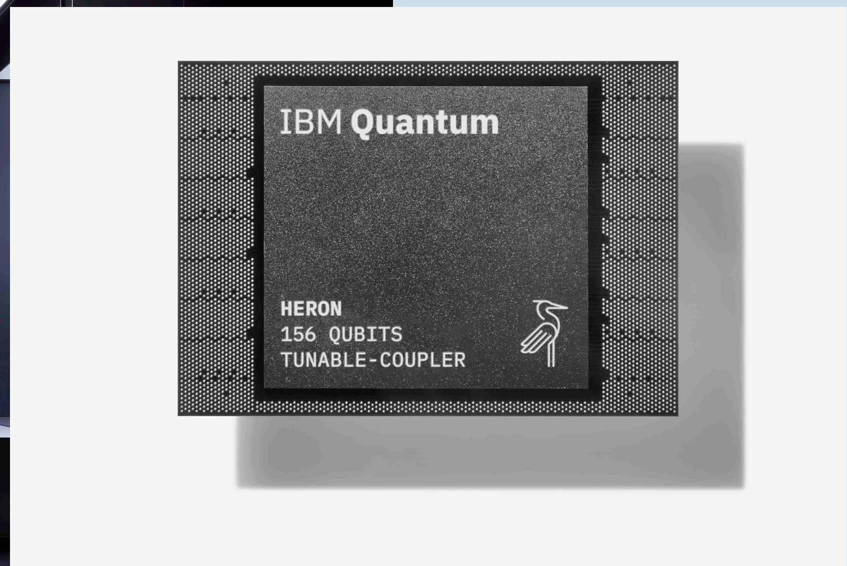
In 2025, combination of IBM Quantum Marrakesh and Fugaku demonstrated accuracy surpassing classical computational methods (CISD)

Innovation by Connecting Points : Quantum + HPC

IBM Quantum Computer

Shin-Kawasaki





Under upgrade to 156-qubit Heron processor

Most advanced and largest quantum computer in Japan

+

Miyabi Supercomputer

Collaboration between UTokyo and University of Tsukuba

JCAHPC

Joint Center for Advanced High Performance Computing

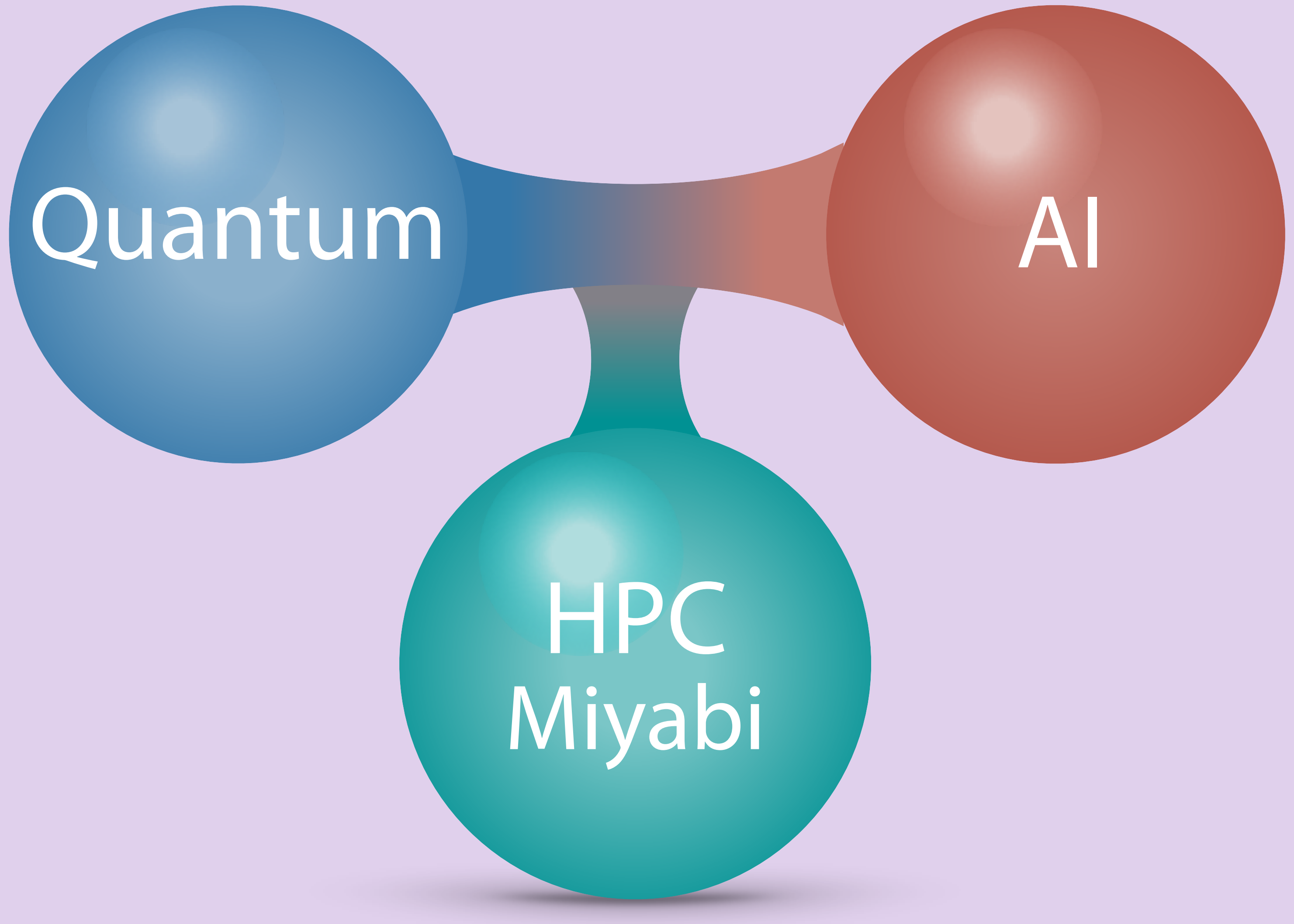
1120 CPU+GPU nodes in Miyabi-G

Practical prototype of post-Fugaku supercomputer

Towards the flagship quantum integrated computing environment of 2030s

Innovation by Connecting Points : Quantum + HPC

Next-generation Quantum AI Supercomputer



- Quantum state sampling with classical ML on HPC
- Generative Quantum AI (e.g, prediction of material properties)

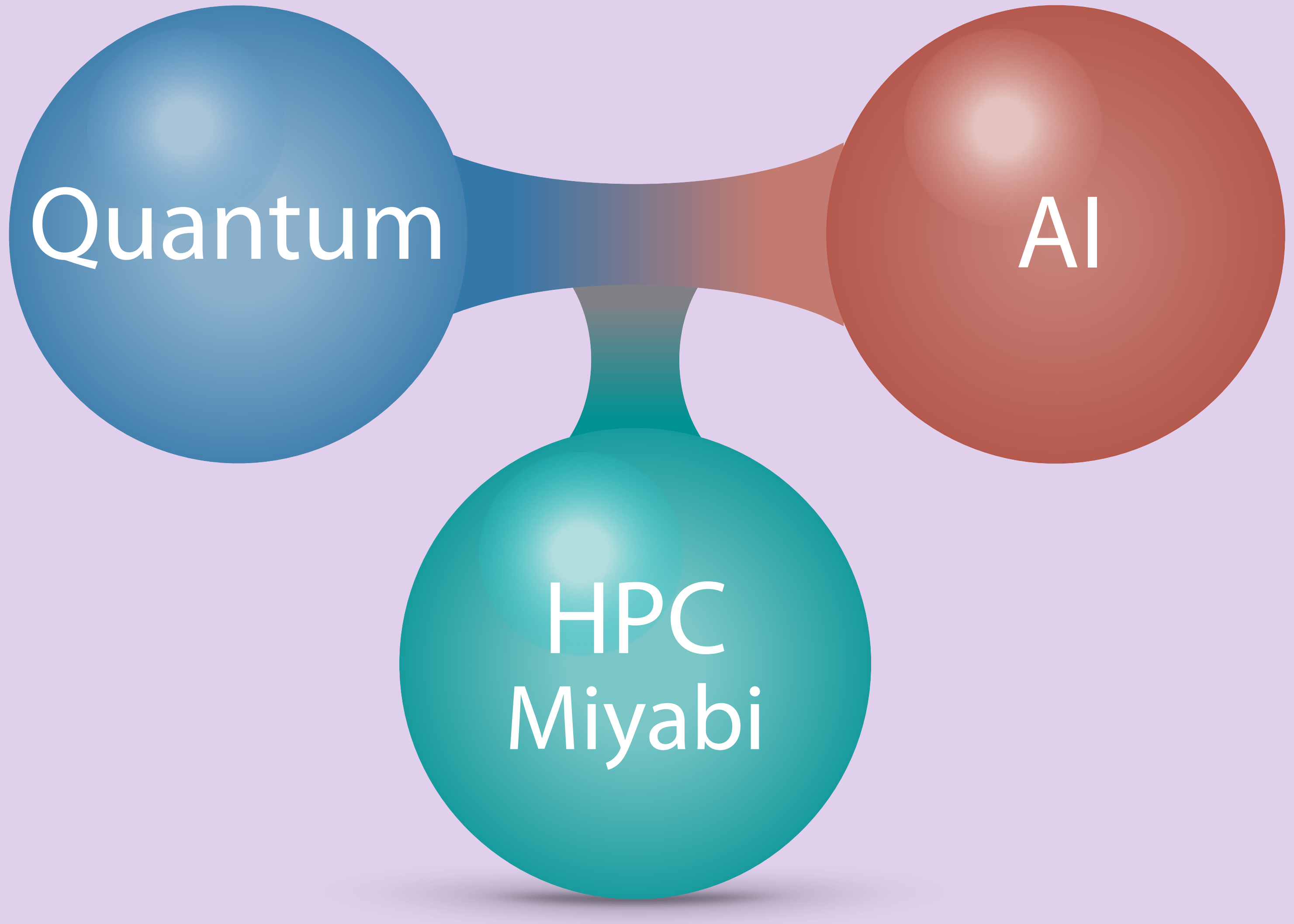
AI with Quantum + HPC hybrid

Expanding the capability of Quantum + HPC with power of AI

	Quantum Computer	HPC
NISQ	Quantum state sampling	Classical ML using quantum samples
	Optimizing training of classical ML model	Implementation of trained ML model
	Quantum phase estimation	Obtaining approximated eigenstates in quantum subspace
FTQC	Quantum signal processing Quantum singular value transformation	Preprocessing/ Spursification of matrices

Looking Beyond Quantum + HPC Integration

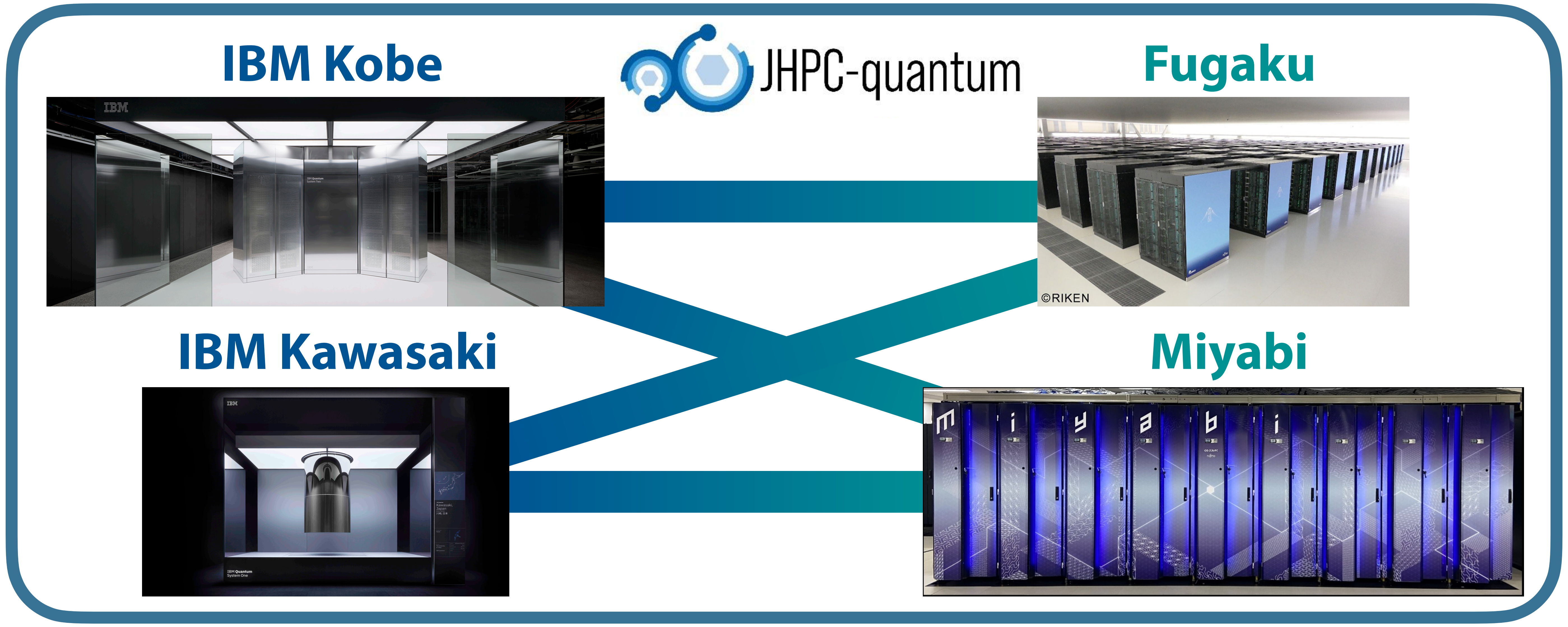
Next-generation Quantum AI Supercomputer



- Quantum state sampling with classical ML on HPC
- Generative Quantum AI (e.g, prediction of material properties)

AI with Quantum + HPC hybrid

Building an environment with multiple quantum computers connected with multiple HPCs



Prof. K. Nakajima (ICT, UTokyo)

Quantum state sampling on quantum computers

＋ **Eigenvalue computation**:

Fugaku to determine ground state energies in chemistry

＋ **AI/ML processing**:

Miyabi to train models with estimated energies and predict properties/propose new structures

Perspectives on Quantum Education

Human development essential for social implementation of quantum applications

Providing quantum computing courses to 300 students per year

(In cooperation with IBM Quantum Education Program)

Expand to 8,000 in 10 years

Innovators / Leaders
(Experts)

Technology developers
(Core of the ecosystem)

Application users
(IP management, implementation)

ASPIRE top talent cultivation

ASPIRE

Graduate
Specialized instructions

Recurrent education
Quantum computing

Undergraduate (yr 3&4)
Quantum technologies and computing

Quantum initiative

Undergraduate (yr 1&2)
Advanced sciences

Undergraduate (yr 1)
Freshman seminar
How to make a quantum processor

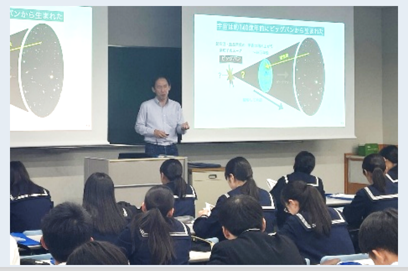
Humanities

IBM-UTokyo lab

QIIC

Industry partnerships

High school / colleges of technology Quantum experience



Expanding into a university-wide education system

Perspectives on Quantum Education

Education of Quantum Natives for future generation

Advanced class for qualified early undergrads

- 1st-2nd year undergrads
- College of Arts and Science (Komaba)

Interdisciplinary class opened to all faculties

- 3rd-4th year undergrads
- Dept of Physics, Faculty of Science

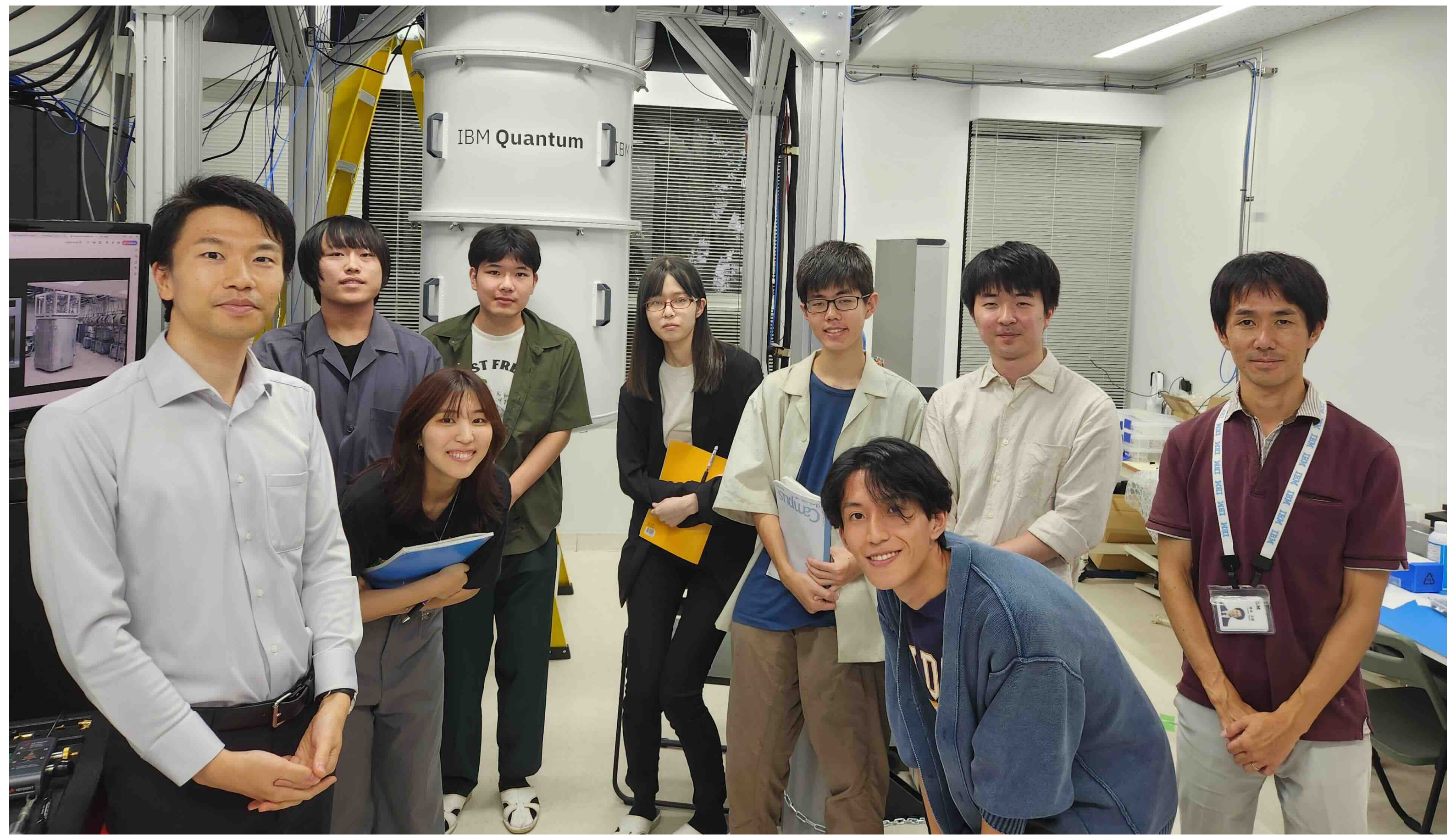
Most advanced class
Global human resources/workforce development

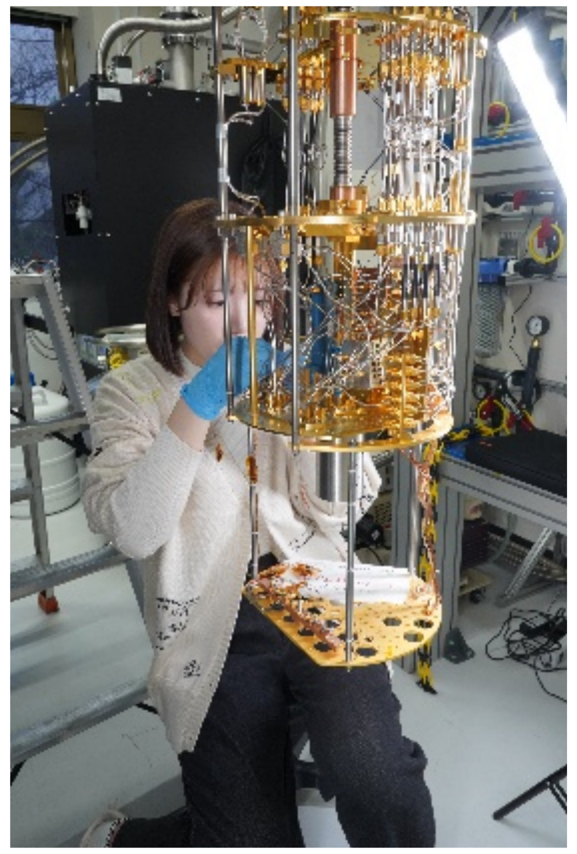
- Graduate students
- School of Information Science and Technology

Aim to integrate UChicago education program and advanced technologies in IBM/Google

Hands-on IBM quantum computer with selected students since 2022

Research with quantum devices





UTokyo Partnerships on Quantum Technologies

3 partnerships with UTokyo announced at G7 Hiroshima Summit in May 2023 for the development of quantum technologies and education:

UTokyo-UChicago-Google for cooperation in quantum research and education

- Quantum computing research; Student career mentorship, workforce development
- Entrepreneurship and business

UTokyo-UChicago for partnership on quantum information science and engineering

- Quantum computing and sensing development; Exchange of students and researchers
- Entrepreneurships, startups in cooperation with industries

UTokyo-IBM for cooperation on research and education in the quantum field

- Quantum research with IBM quantum computers, software and application development
- Hardware development with testbed; Education program

ASPIRE Quantum Program

Feb. 2024 – Mar. 2029

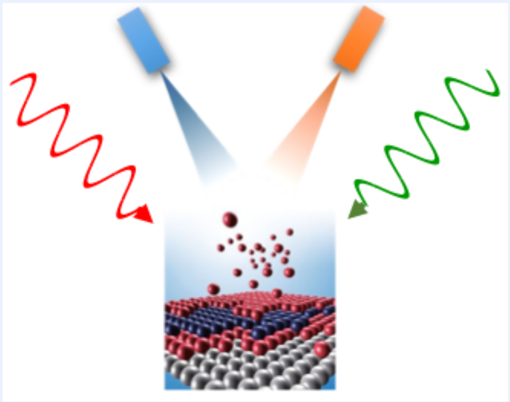
ASPIRE 先端国際共同研究推進事業
Adopting Sustainable Partnerships for Innovative Research Ecosystem

Researches in Quantum Sensing, Software, Hardware and Interconnect

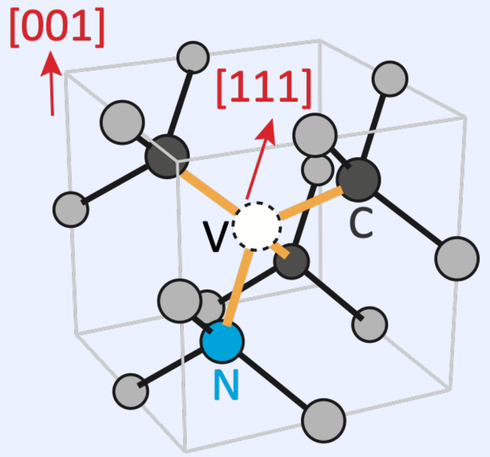
Quantum Sensing

Advanced Sensor
Quantum Material
Sensor Applications

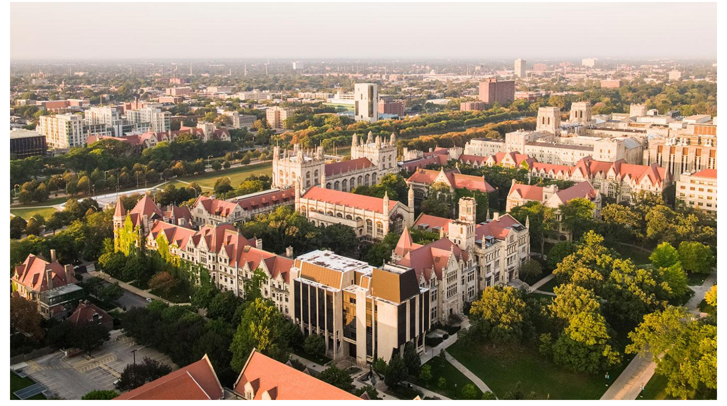
Material Synthesis



Spin System



THE UNIVERSITY OF CHICAGO

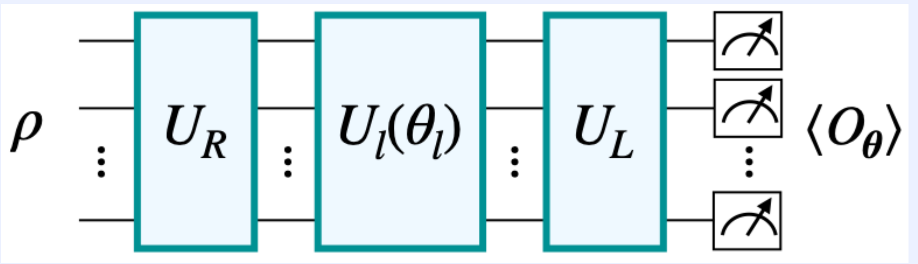


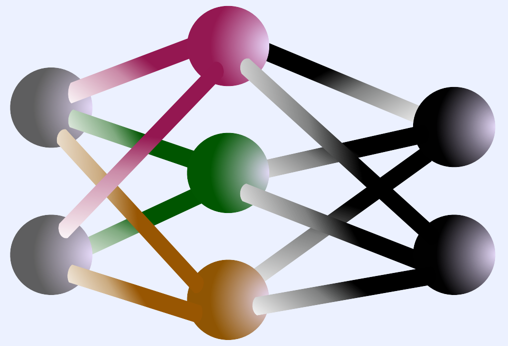
UTokyo

Quantum Software

Quantum Simulation
Tensor Networks
Error Correction

Quantum Algorithm



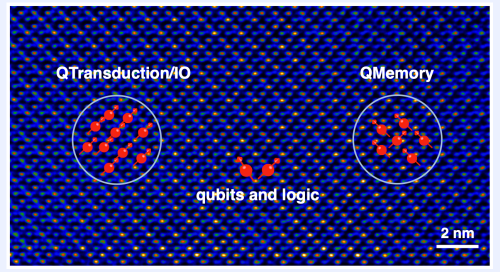


Quantum Neural Networks

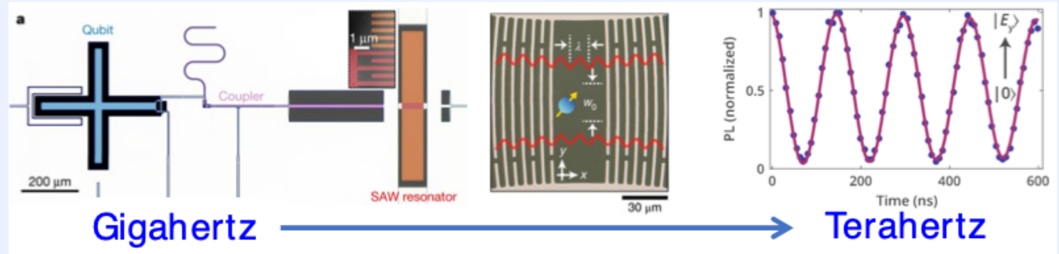
Quantum Interconnect

Quantum Transduction
Hybrid Quantum System
Quantum Network

Quantum Memory



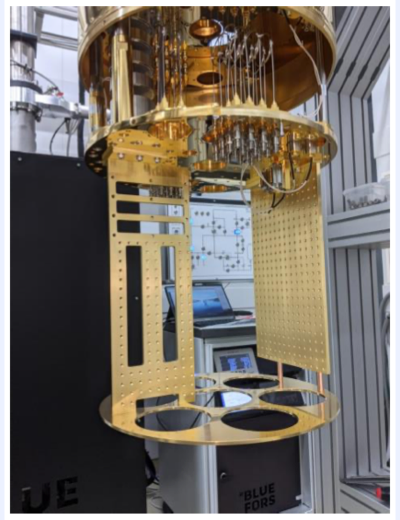
Quantum Transduction



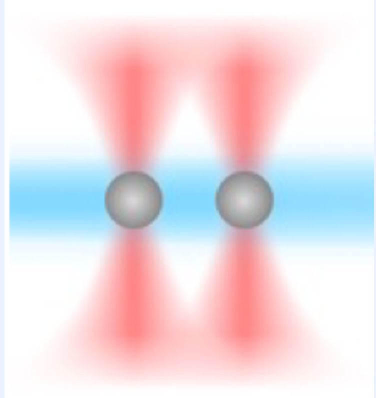
Quantum Hardware

Qubit Technology
Spin System
Scalable Hardware

Superconducting Qubits



Cold Atoms



Transformative Quantum Technology Platform

- Practical applications of quantum computing beyond NISQ
- Quantum connectivity for hybrid quantum-quantum, quantum-classical system

ASPIRE Research Project

Quantum Sensing:

Development of quantum sensing device, application to Biological/Medical science

- Quantum sensing in Homotypic Targeting via Extracellular Vesicles (EVs)
- Method to enhance targeting, accelerating selective EV capture


K. Goda


P. Maurer


A. Squires

Quantum Hardware:

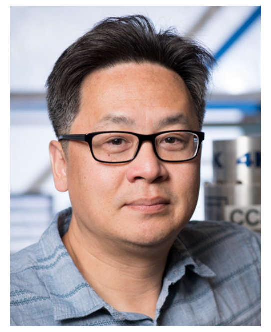
Microwave control technology at low temperature, superconducting qubit device

- Spin-torque oscillators, Ultra-cold spintronics microwave generator
- Superconducting qubit fabrication, application to particle physics


E. Saito


T. Nitta


D. Awschalom


A. Chou (Fermilab)

Quantum Software:

Quantum-classical hybrid computing, software/application development

- Quantum circuit simulation with Tensor Networks
- Development of TN-based machine learning, error corrections


S. Todo


N. Yoshioka


Y. Mat-sushita


G. Galli


L. Gagliardi


L. Jiang


B. Fefferman

Quantum Interconnect:

Quantum interface/connection technology for hybrid quantum systems

- Development/evaluation of phononic nano-oscillator
- Quantum transduction with diamond-based optomechanical system


M. Nomura

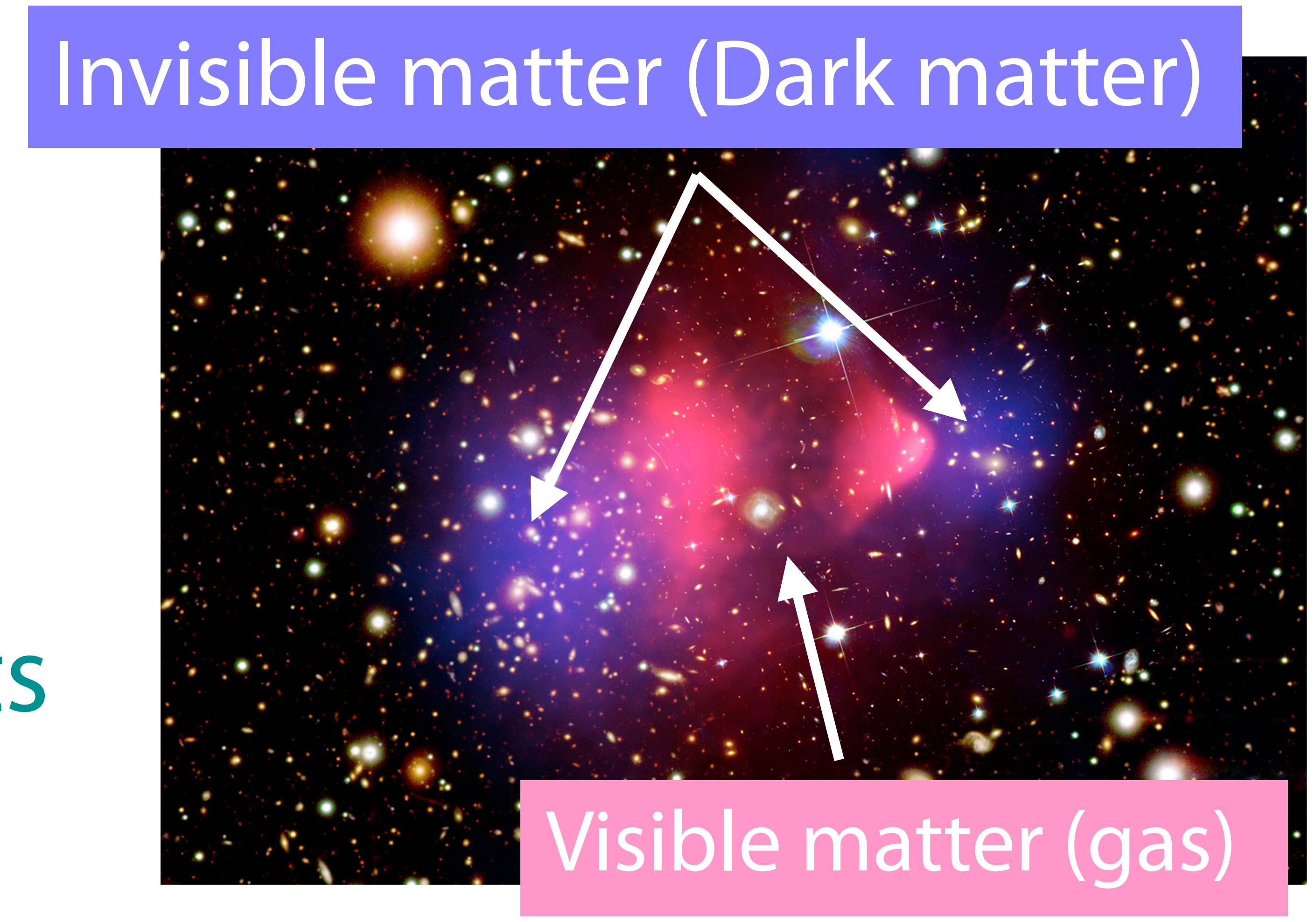

A. Cleland

Qubits with Application to Particle Physics

K. Watanabe, K. Nakazono, T. Inada, Y. Mino, T. Nitta (KEK), S. Chen (Kyoto)

Superconducting Qubit Technologies and Application to Particle Physics

25% of the mass of the universe not explained in standard model of particle physics ➡ Dark Matter

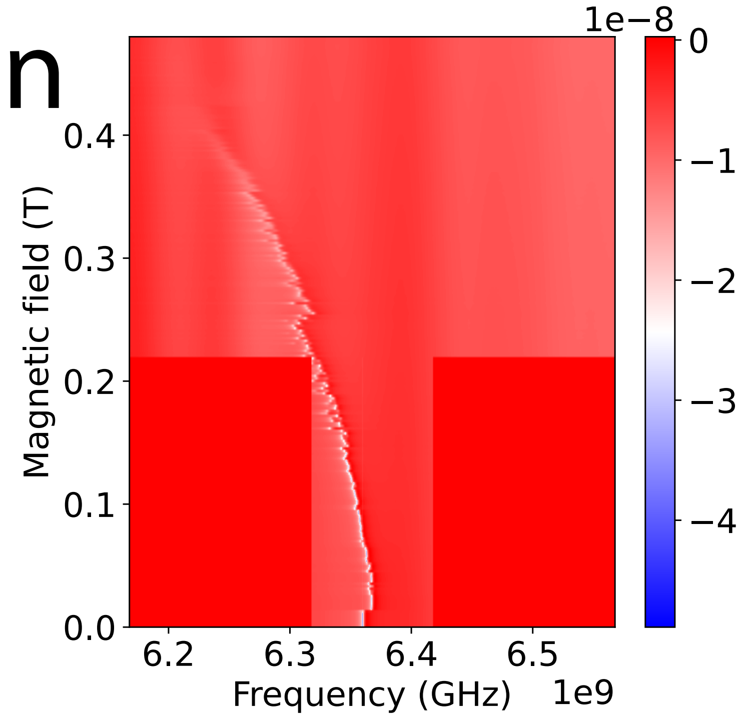


Certain type of light DM could be probed by superconducting qubits

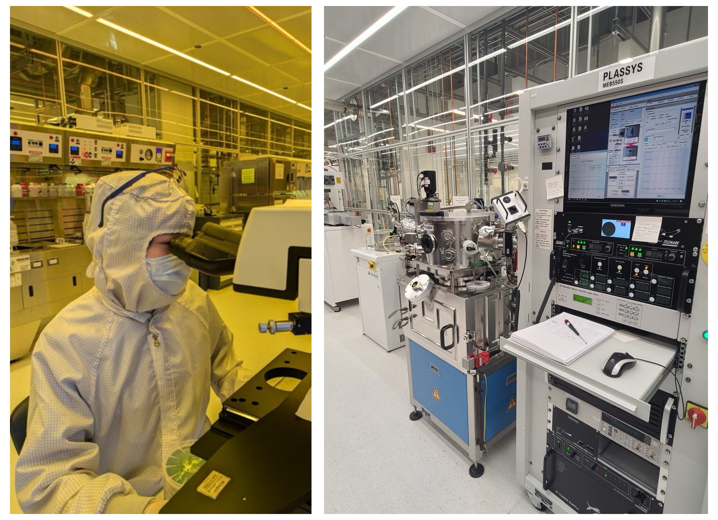
➡ Karin Watanabe's talk for DM detection with qubit excitation

Superconducting Qubit Fabrication:

- Specific qubit design/fabrication for application to physics
  - **Magnetic-field tolerance for Axion dark matter search**



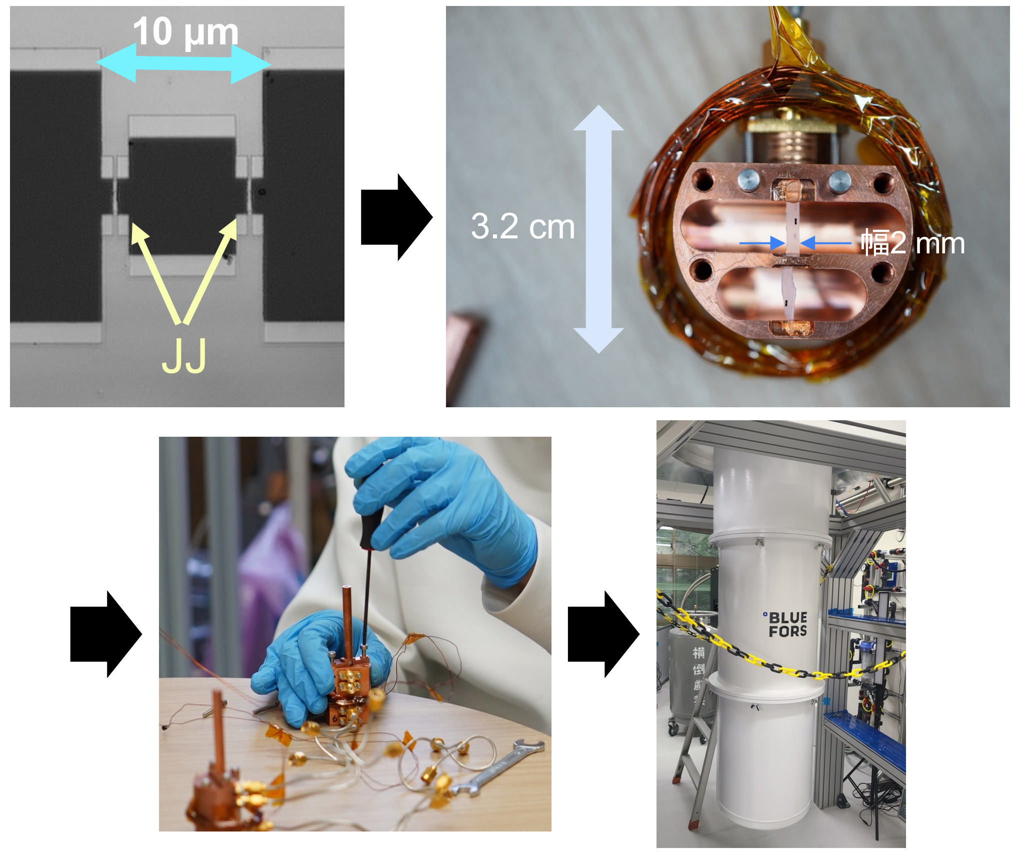
- Establish process control of Josephson junctions
- Build cryo-compatible system (10 mK, 3 T in-plane field)

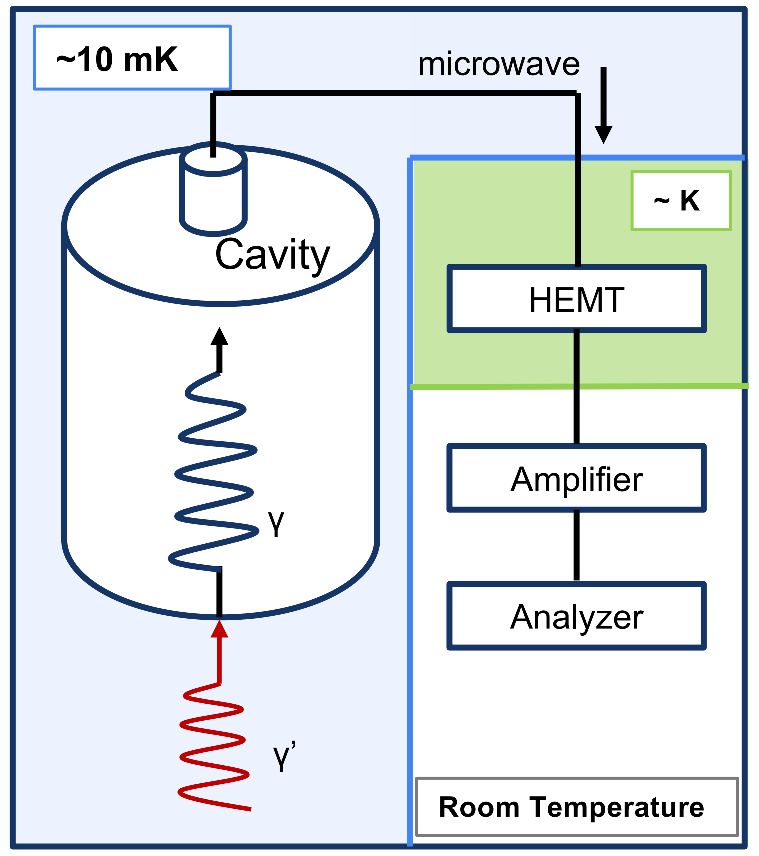


Cavity haloscope experiment for DM search:

- Photons converted from DM with a mass resonant to the cavity frequency
- Read out induced voltage by antenna

SQUID-type qubit





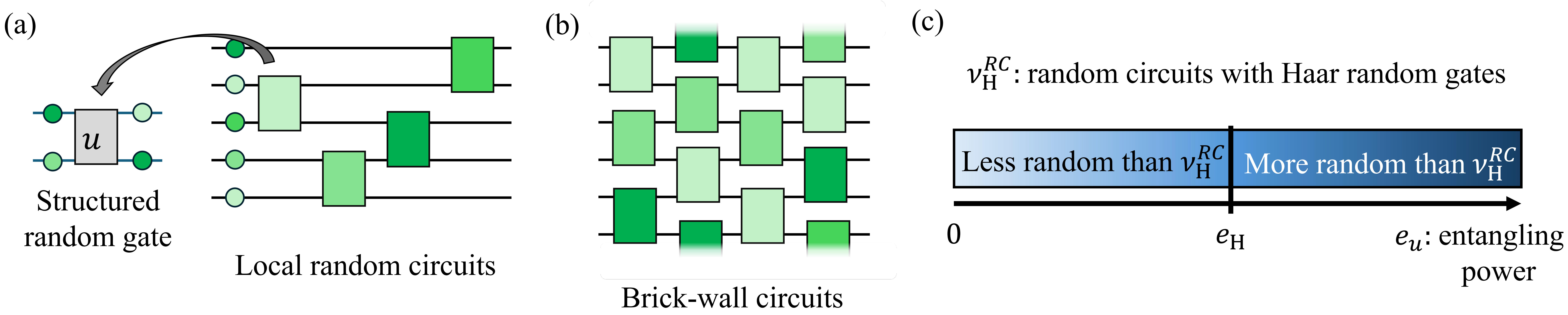
Quantum Algorithms

K. Tsubouchi, N. Yoshioka

Quantum algorithm with efficient randomness generation arXiv:2410.24127

Showed that Haar-like randomness can be approximated using circuits where only single-qubit gates are randomized and entangling gates are fixed

→ Accelerated generation of pseudo-Haar randomness (Oral presentation at QIP2025)



Quantum sensing under unknown noise arXiv:2503.17362

Unknown noise disturbs the signal → Using entanglement to protect signals from noise

Efficient benchmarking using two logical magic states arXiv:2505.09687

Benchmarking using Stabilizer operators

→ Sampling overhead improvement from $N = \mathcal{O}(1/\epsilon^2)$ to $N = \mathcal{O}(1/\epsilon)$

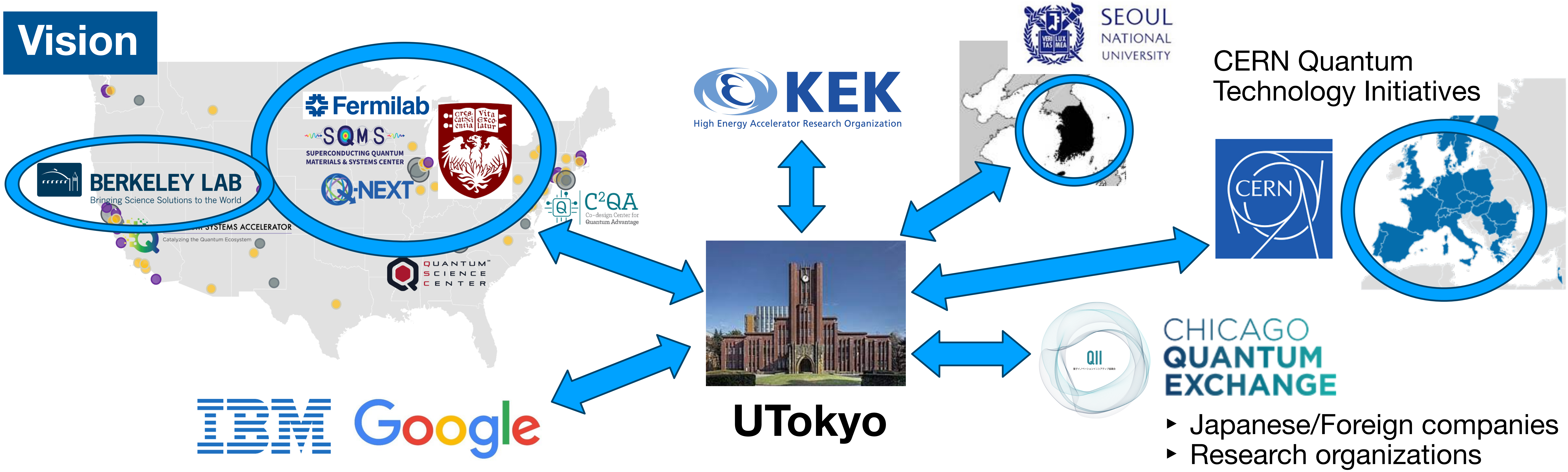
Vision of International Quantum Research Network

Quantum research network with UChicago, US-QIS lab's, SNU, IBM/Google & CERN

- UTokyo-UChicago-IBM/Google collaborative research on superconducting qubit technology
- Quantum computing/sensing applications in high-energy physics (CERN, KEK)
- Engaging UTokyo graduate students/postdocs in the network

Establish research environment with **industry partners for applications**

- QIIC, Chicago Quantum Exchange for industrial applications
- Joint education program between UTokyo and UChicago under discussion



COI-NEXT Project on Quantum Software

Center of Innovation for Sustainable Quantum AI

- Aim to realize sustainable quantum AI by integrating quantum software, HPC and simulation
- 10-year project (Oct. 2022 - Mar. 2032) supported by JST

Prof. Synge Todo
(Project Leader)

SQAI
Center of Innovation for Sustainable Quantum AI

UTokyo, Keio, RIKEN, OIST, UChicago,
Kawasaki City and Companies

Targets:

- Sustainable quantum machine learning
- Many-body simulation for quantum AI
- Quantum-Classical HPC

Research Topics/Groups:

Quantum Machine Learning
➡ Highly trainable and generalizable quantum ML

Quantum Simulation
➡ Multi-body simulation for material informatics

Quantum Embedding
➡ Integration of quantum-classical algorithms

Quantum Optimization
➡ For quantum ML and multi-body simulation

Quantum HPC
➡ Integration of CPU-GPU-QPU environment

Summary

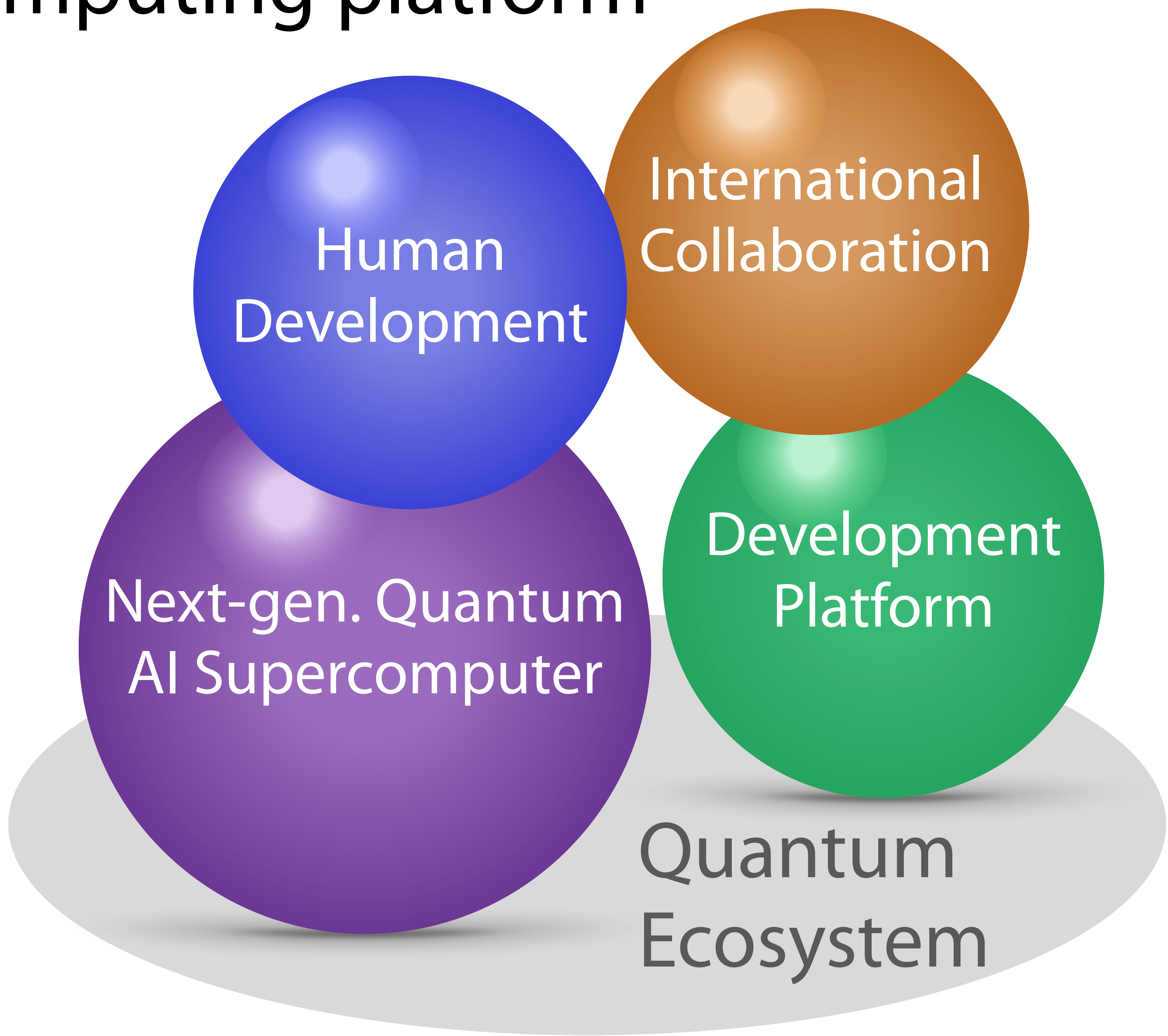
From Innovation to Social Implementation

Connecting the Dots: Linking major initiatives to address societal challenges

Flagship Environment: Next-generation Quantum AI Computing platform

Key Pillars:

- Human resource development
- Development platform for quantum and AI technologies
- International collaborative research with global partners



Application Areas:

- Quantum AI, Quantum simulation
- Quantum materials and properties
- Quantum optimization, Mathematical computation

Integrating Quantum AI Computing with a broader quantum ecosystem

Accelerating the creation of use cases and implementations in society