TQCI Seminar, 5th June 2024

JHPC Quantum Project

for Quantum-supercomputer hybrid computing platform

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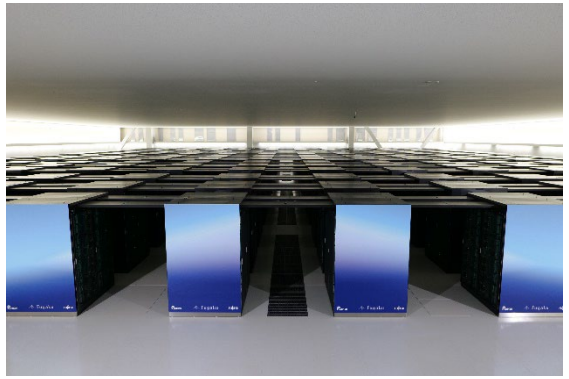
RIKEN Center for Computational Science (R-CCS)

JHPC-quantum

Supercomputer “Fugaku” at R-CCS



432 racks
158,976 general-purpose manycore processors Fujitsu A64FX, 7 Million Cores

Half exaflops in DP
1 Exaflops in SP!

Very power-efficient system with 20MW power-consumption!

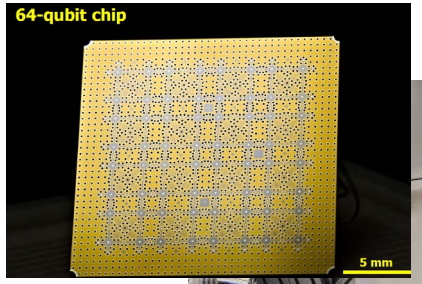
The Public Service has started from March, 2021

Quantum Computing Researches in RIKEN

- **RIKEN Center for Quantum Computing （RQC）**
  - The research and development of superconducting quantum computers
  - Research of optical quantum computers
  - Researches on quantum computing theory

- **RIKEN Center for Computational Science (R-CCS)**
  - R&D for hybrid computing system with Fugaku and quantum computers
  - Development of quantum computers simulators using Fugaku Supercomputer
  - Feasibility study on technologies for integration of quantum computers in the next flagship supercomputer project

- **iTHEMS (Interdisciplinary Theoretical and Mathematical Sciences Program), RIKEN Quantum**
  - Researches on theory and algorithm of quantum computing
  - Quantum computing applications



June 2024

Transformative Research Innovation Platform of RIKEN platforms (TRIP)

Value Creation by Quantum-Classical Advanced Computing Platform for Accelerating Research DX

Pioneer predictive control science of the future by linking new types of computers, predictive algorithms, and data maintenance

High-quality data acquisition

Bioresources
Measurements using synchrotron radiation
Research DX specialists

SPring-8
SACLA

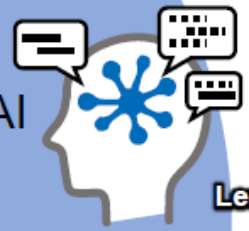
Bioresources

Pioneer prediction science with AI x mathematics

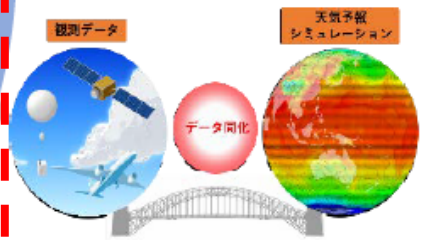
Electronic state prediction / New functional materials
Transmutation of elements prediction / New energy creation
Ecosystem prediction / Recycling-oriented society

Develop into a pioneering research DX initiative

Data
AI
Super computer



Learning theory

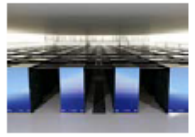


Data assimilation

Expansion of Computationally Viable Region

Quantum-classical hybrid computing

Improvement of usage environment
Next generation semiconductor
Development of EUV lithography



Supercomputer "Fugaku"

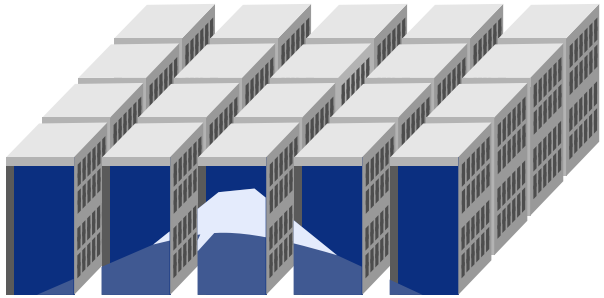
Quantum computing

Pioneer the "predictive control science of the future" across fields
(Predict social and global issues and control them through interventions)

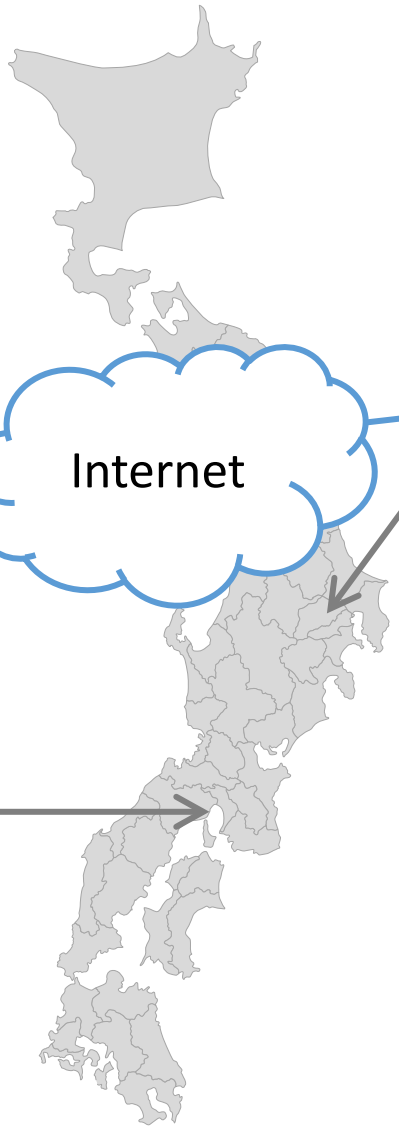
POC experiment: Fugaku and “A” QC

- **As Proof of Concept, we did successfully execute a simple QC-classical program with Fugaku and “A” RIKEN Quantum computer.**

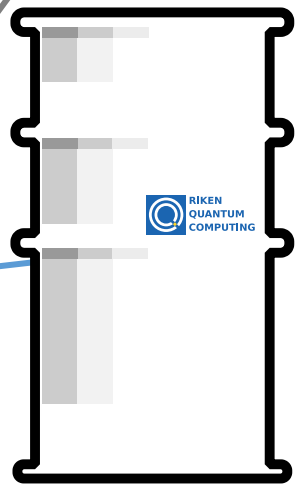
RIKEN R-CCS @ Kobe



富岳 (Fuagku) :
158,976 nodes supercomputer

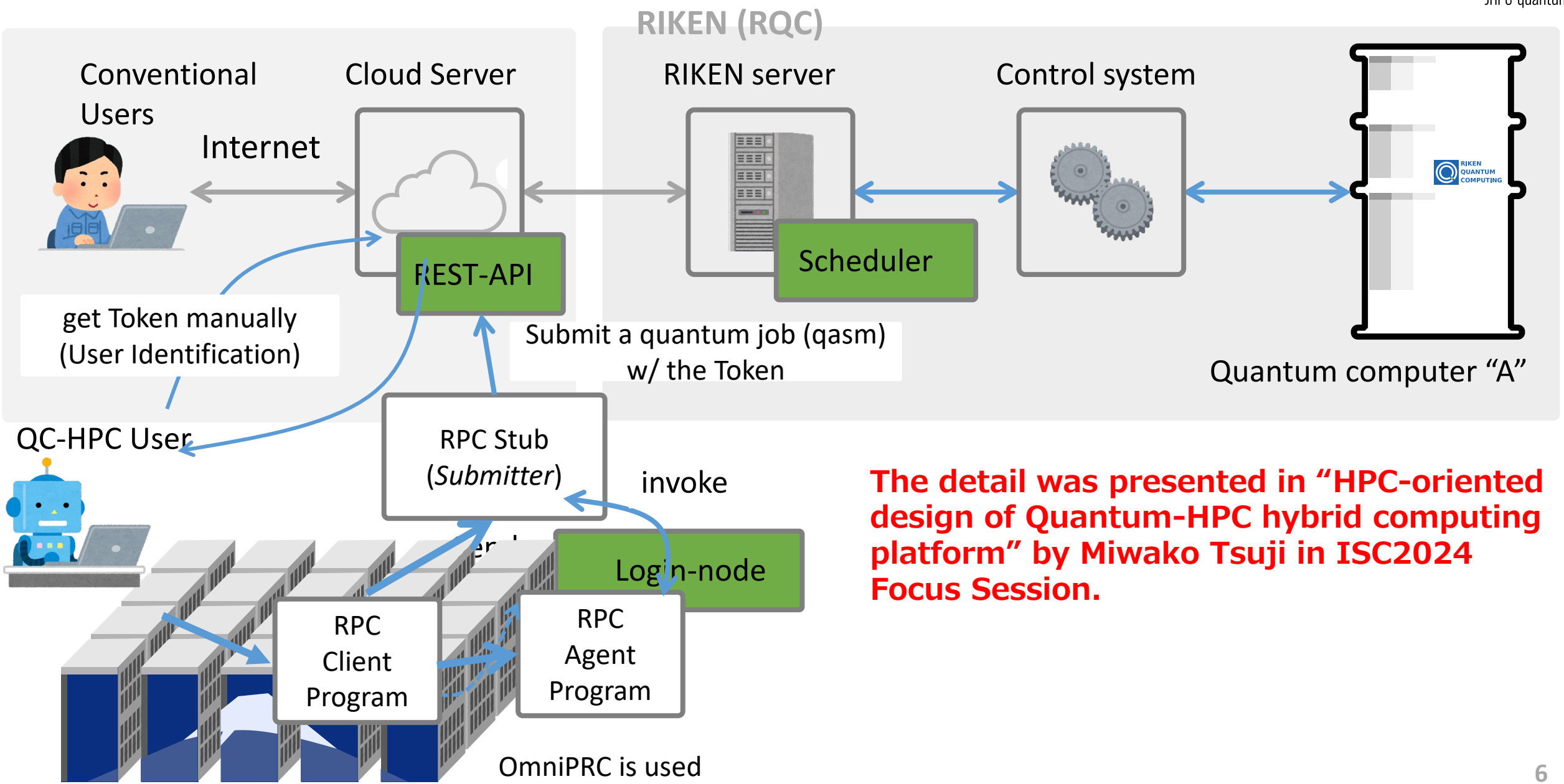


RIKEN Wako Campus @ Kobe



叡 (A) :
64 qubit superconducting quantum computer, available through the cloud

Prototype of QC-HPC hybrid prog. execution by RPC



The detail was presented in "HPC-oriented design of Quantum-HPC hybrid computing platform" by Miwako Tsuji in ISC2024 Focus Session.

JHPC-Quantum Project: Research and Development of quantum-supercomputers hybrid computing platform for exploration of uncharted computable capabilities

Participants	*RIKEN, Softbank Corp. Univ. of Tokyo (collaborators), Osaka Univ (collaborators)*
Overview	Research and development of quantum HPC hybrid system software for the integration of quantum computers and supercomputers (HPC) are conducted. Using the system software, a quantum-supercomputer hybrid platform will be built to enable exploration of uncharted computable capabilities. As well as demonstrating the superiority of quantum HPC hybrid applications against existing applications only by supercomputers, advanced internet technology will be developed to deploy the quantum HPC hybrid applications on this platform as a service in the post-5G era.

1. Objectives

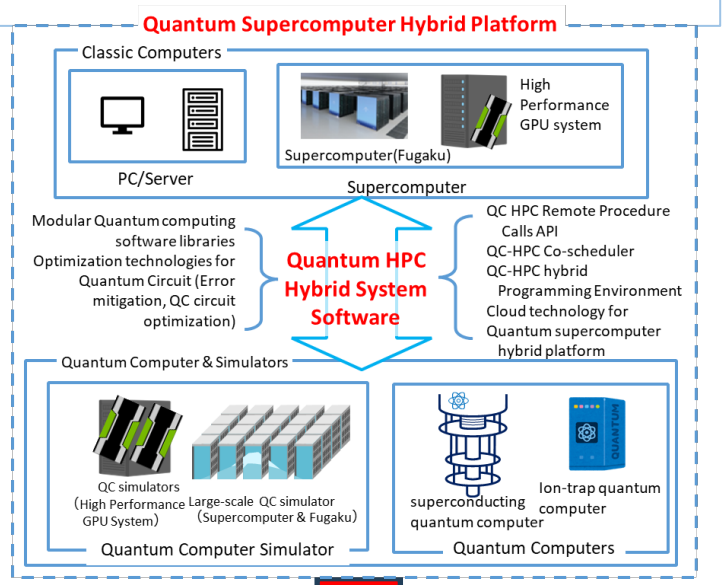
- Quantum computers operate on a completely different principle from conventional computers and are expected to dramatically speed up information processing. At present, however, as the scale of quantum computers increases, it will require more resource of conventional computers for pre-post processing such as error mitigation.
- On the other hand, with the advancement of digitalization in information society, the utilization of quantum computers are urgently demanded. It is promising to use the quantum computers in combination with classical computers.
- In this project, we are aiming to be the first in the world to develop and build software, platforms, and applications for the integrated use of quantum computers and supercomputers and demonstrate their advantages as technologies to be deployed as services in the post-5G era.

2. R&D topics

- Quantum HPC hybrid software: Development of system software for seamless and efficient use of quantum computers and supercomputers by coordinating computing resources optimally.
- Modular quantum software libraries: Developing modular software tailored to application fields and developing high-level software libraries for error mitigation and circuit optimization processing specialized to the characteristics of quantum computers. The software enables to develop advanced quantum applications by combining them as modules.
- Cloud computing technology for quantum supercomputer hybrid platform: Develop cloud infrastructure software to support the use of quantum applications for business development using quantum computer.

3. Planned quantum supercomputers hybrid platform

Two types of quantum computers with different characteristics will be installed at the RIKEN Center for Computational Science (Kobe) and (Wako). Planned quantum supercomputers hybrid platform consist of these quantum computers, Fugaku supercomputer, and supercomputers of the University of Tokyo and Osaka University.



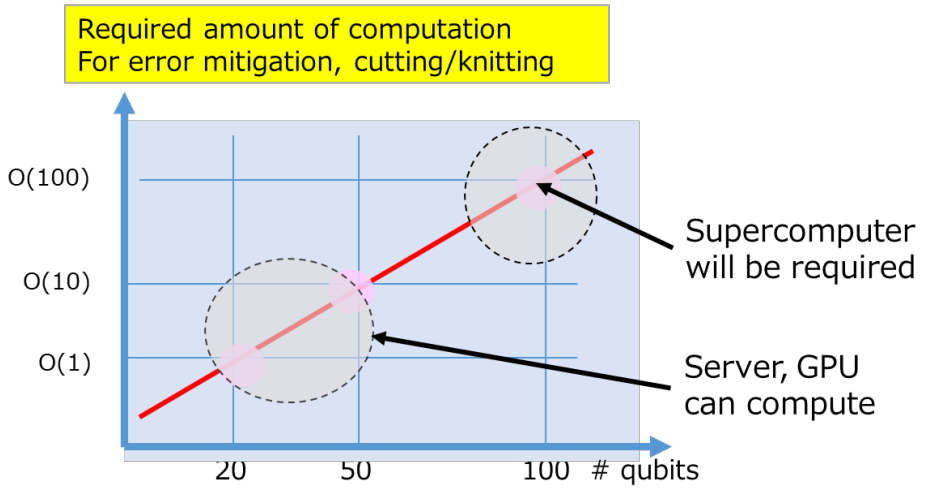
- **In FY2026, operation of the quantum supercomputer hybrid platform will be started and used to demonstrate the effectiveness of quantum and HPC hybrid applications.**
- **The pre-release of the quantum supercomputer hybrid platform is planned in the second half of FY2028.**

JHPC Quantum project: Overview

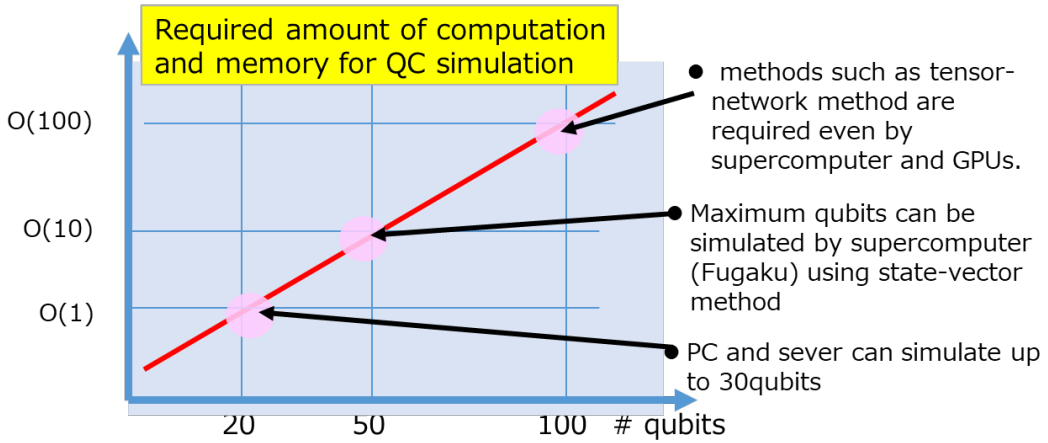
- **Title: "*Research and Development of quantum-supercomputers hybrid computing platform for exploration of uncharted computable capabilities*"**
- **Project Period**: Nov 2023 – Oct 2028 (5years)
  - Mid evaluation will be done in the middle in May 2026
- **Members: RIKEN, Softbank, U. Tokyo and Osaka Univ.**
- **Mission**
  - Research and development of quantum HPC hybrid system software for the integration of quantum computers and supercomputers (HPC) will be conducted.
  - Using the system software, a quantum-supercomputer hybrid platform will be built to enable exploration of uncharted computable capabilities.
  - As well as demonstrating the superiority of quantum HPC hybrid applications against existing applications only by supercomputers, advanced internet technology will be developed to deploy the quantum HPC hybrid applications on this platform as a service in the post-5G era.

Why QC-HPC (supercomputer) hybrid computing?

- **From HPC's point of view**
  - Offloading some useful computation onto QC from large-scale HPC applications
  - Like GPUs?! – not each node, but system-to-system integration.
  - Offloading at algorithm-level.
- **Demands From QC**
  - Error mitigation for NISQ by HPC
    - Error analysis requires the results by QC simulator on HPC
    - QC simulation with noise will be useful to study NISQ
  - Optimization and cutting/knitting of large quantum circuits will need computation by HPC
- **Supercomputers for large-scale QC simulation**
  - QC simulation is very important to design QC algorithms such as error mitigation
  - QC simulation with noise model, simulation for QC physical device will be useful.



- PEC and M3 error mitigation algorithm will require supercomputer for more than 100 qubit
- Circuit cutting algorithm is a mixed-integer linear programming problem



JHPC Quantum Project: R&D Topics

- **Quantum HPC hybrid software:** Development of system software for seamless and efficient use of quantum computers and supercomputers by coordinating computing resources optimally.
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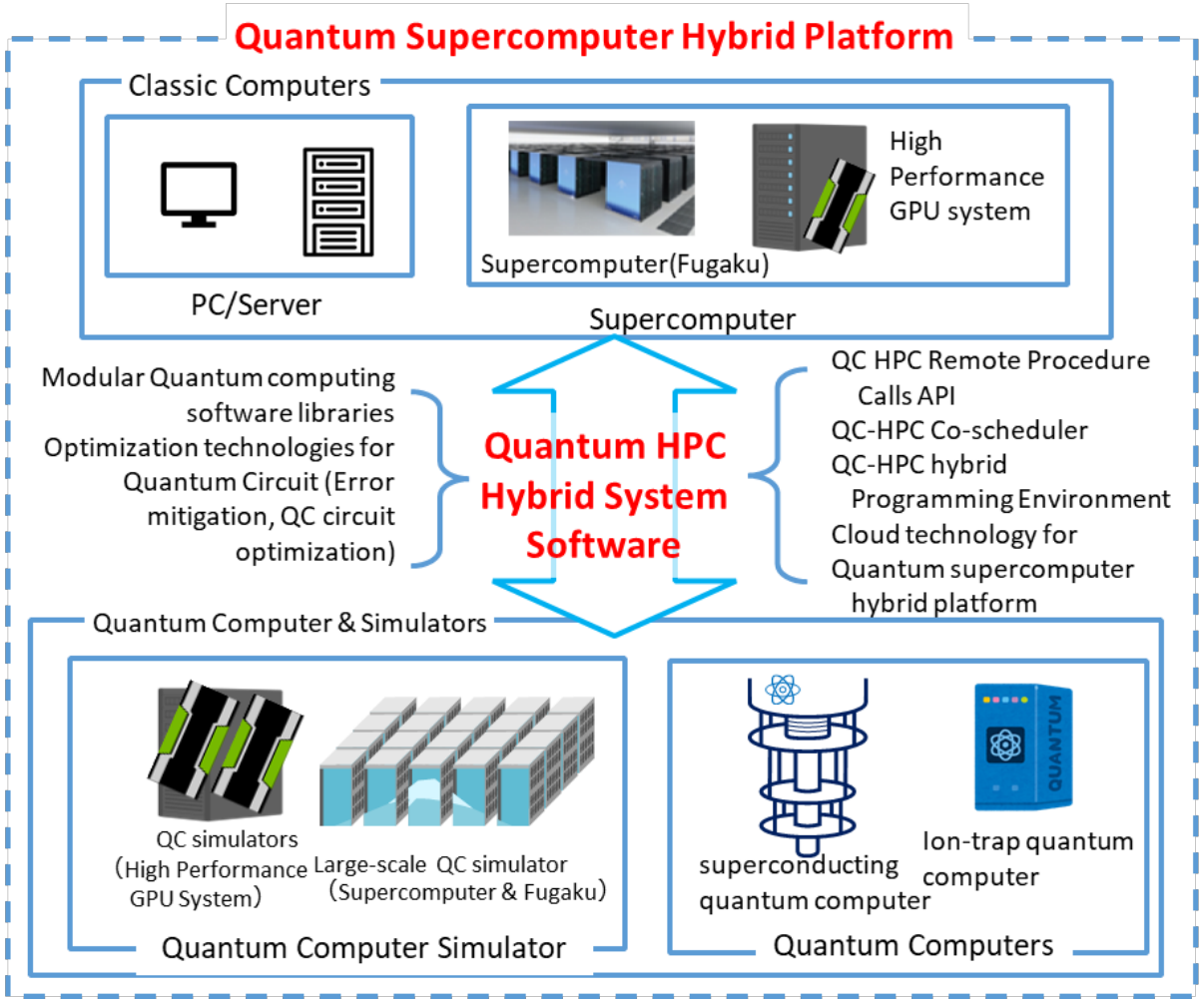
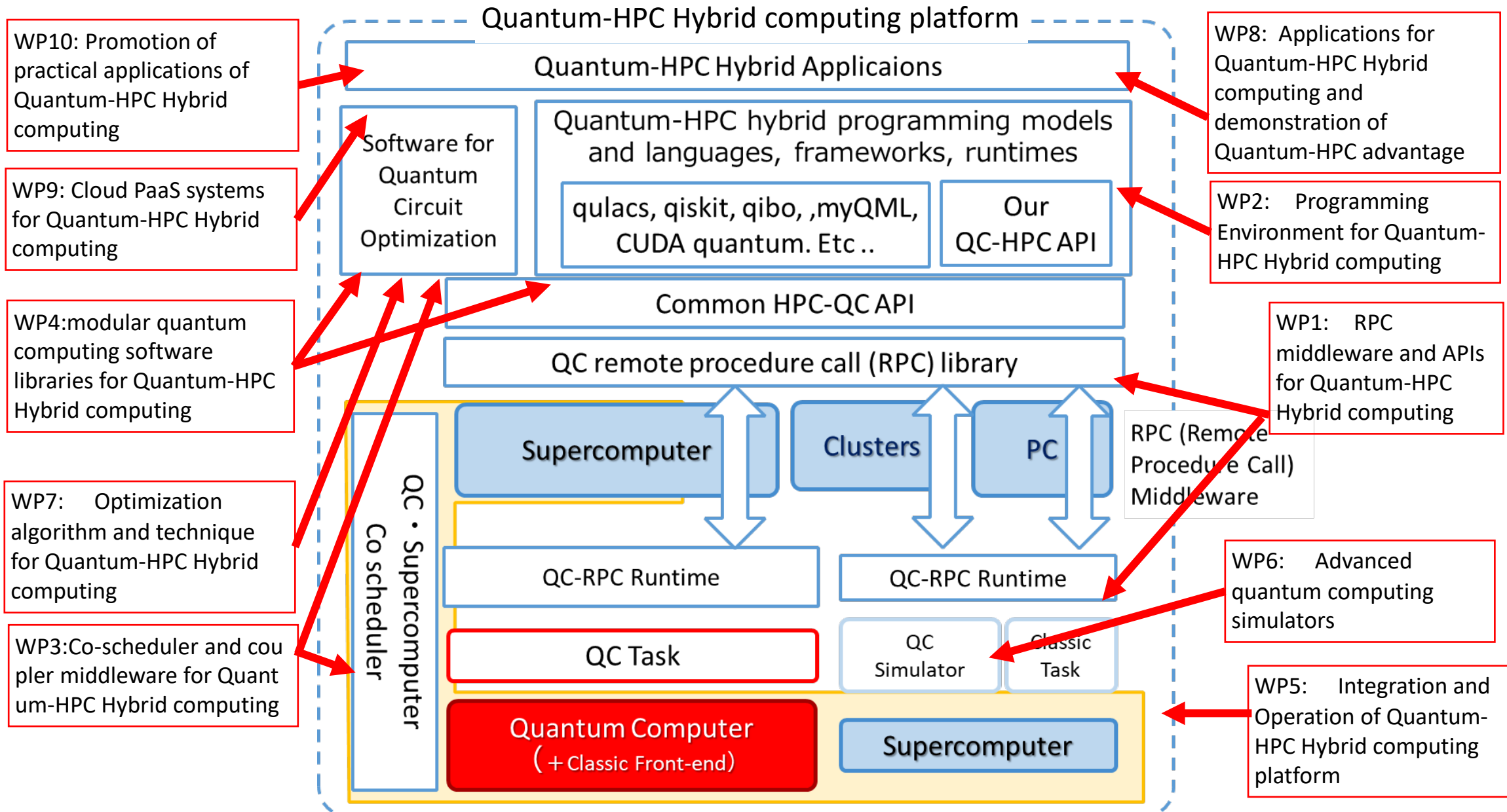
- **Cloud computing technology for quantum supercomputer hybrid platform:** Develop cloud infrastructure software to support the use of quantum applications for business development using quantum computer for post-5G era.

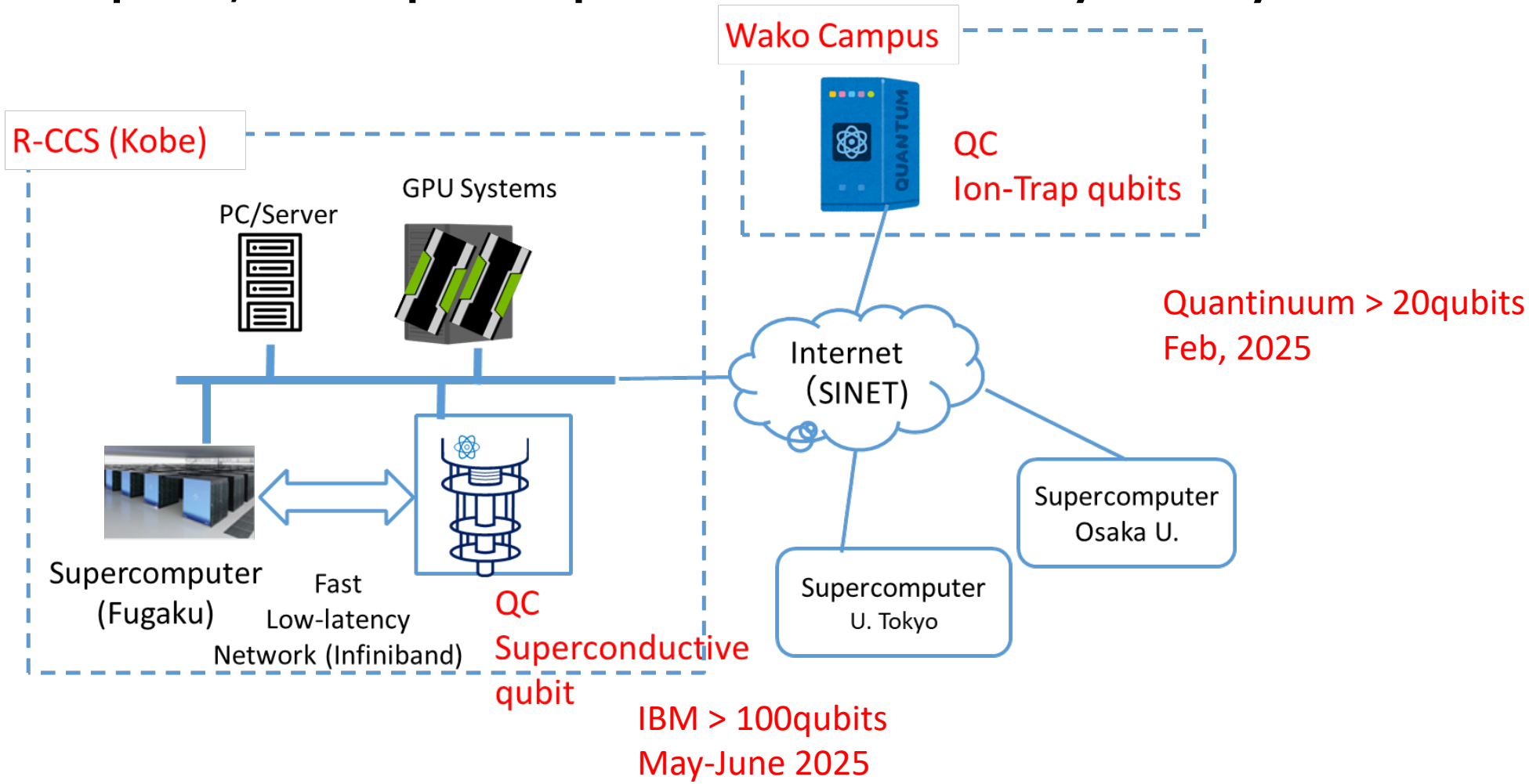


JHPC quantum software structure and work package

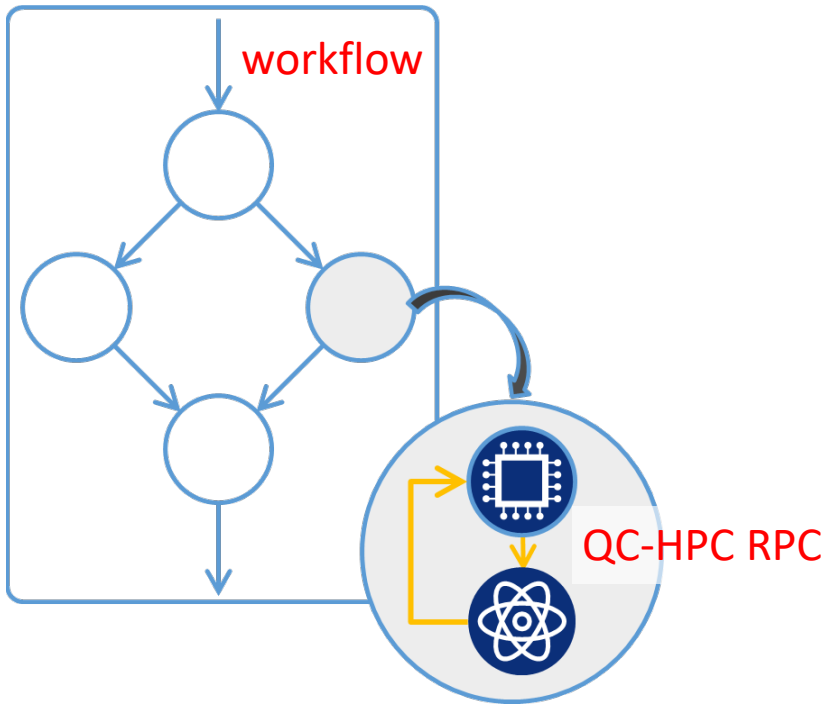


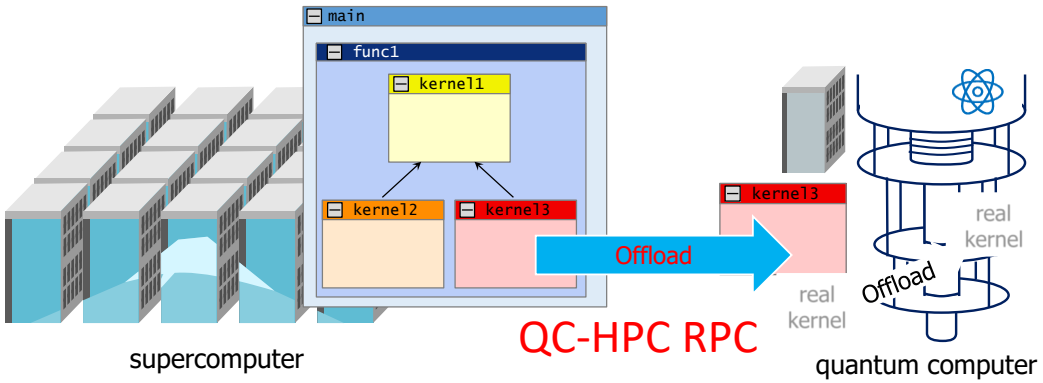
Overview of our QC-supercomputer hybrid platform

- **Two types of quantum computers with different characteristics will be installed at the RIKEN Center for Computational Science (Kobe) and (Wako). Planned quantum supercomputers hybrid platform consist of these quantum computers, Fugaku supercomputer, and supercomputers of the University of Tokyo and Osaka University.**



Two-level programming models for QC-HPC applications





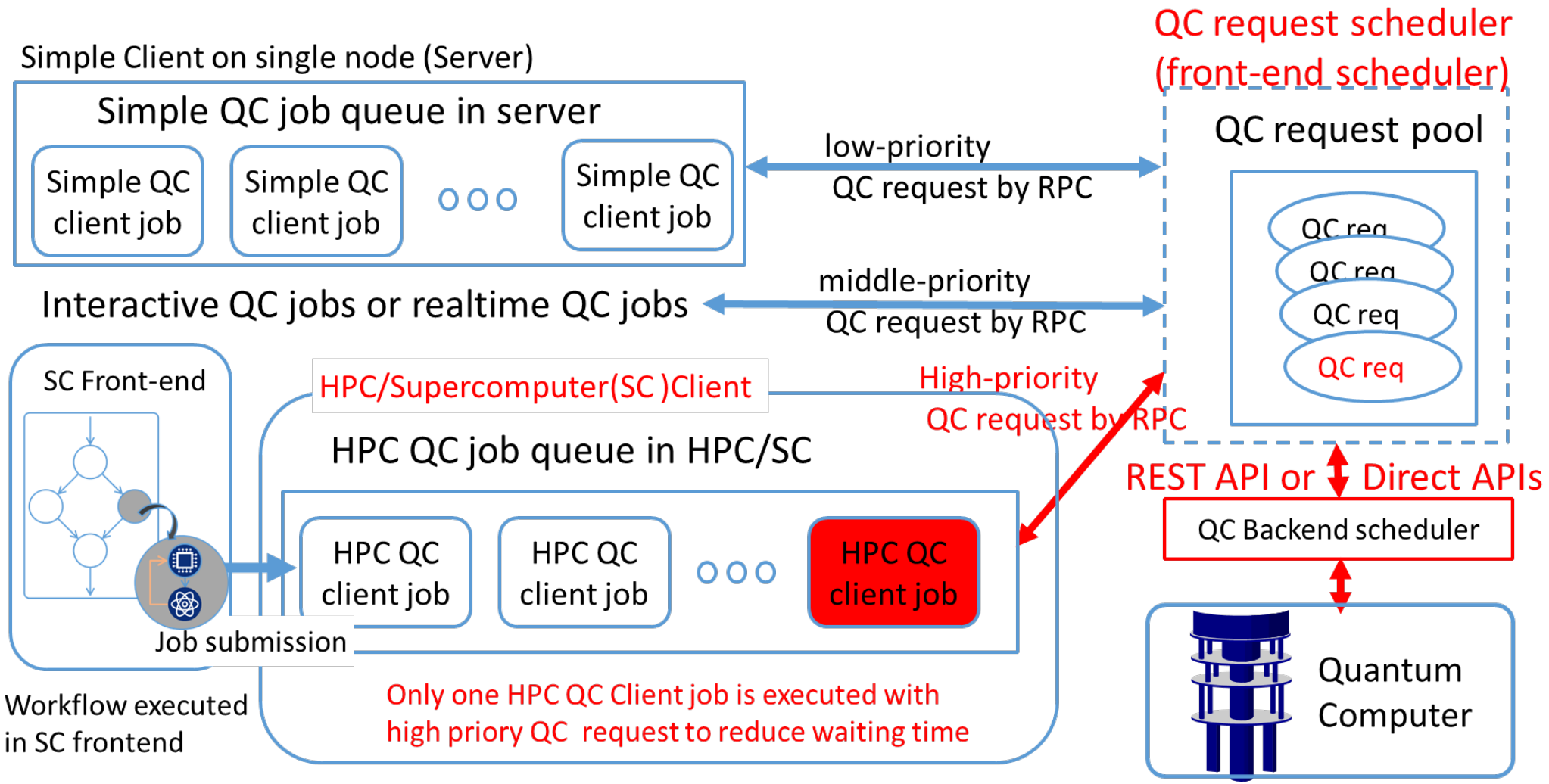
- **Workflow execution model**
  - Describe jobs (tasks) in a dependency graph and execute them using a workflow execution tool
  - Each job is an independent program execution, sometimes a parallel program with multiple nodes using MPI. Each job is a program that takes the output of the preceding job as input.
  - Some of the jobs are programs that include offloading to QC by the RPC API, which we call a QC job.

- **Programming model with offloading of QC computation by (asynchronous) RPC (remote procedure call)**
  - Offload QC computation by RPC API.
  - Programs executed by a QC job are described by this programming model.
  - RPC can also be executed asynchronously. In this case, it can overlap with execution on host-side.

JHPC quantum system design policies

- **1. Support quantum HPC hybrid programs by making quantum programs available as a part of HPC application programs. The system should enable efficient use of HPC systems and supercomputers as well as quantum computers.**
  - Use RPC (remote procedure call) programming model as APIs for quantum device
  - Coordinated Scheduling with HPC scheduler (job management system) and QC-HPC RPC request scheduler
    - Restrict the number of QC-HPC job (to one?) by HPC-scheduler
    - RPC requests from QC-HPC hybrid job should be executed with high-priority
- **2. Support execution of not only quantum HPC hybrid programs, but also quantum programs that run on a single node of a regular server, such as programs written in python frameworks such as qiskit and TKET. It provides compatible programming environments with other conventional quantum programming environments.**
- **3. Enable to share multiple quantum computers from multiple HPC systems and servers. It should allow operations under our user management policies, user authentication, accounting, etc.**
  - QC-HPC RPC scheduler (front-end scheduler) and QC-vender's backend scheduler
  - QC-HPC RPC scheduler takes core of user authentication/accounting

Coordinated scheduling with HPC scheduler and QC request scheduler by priority control

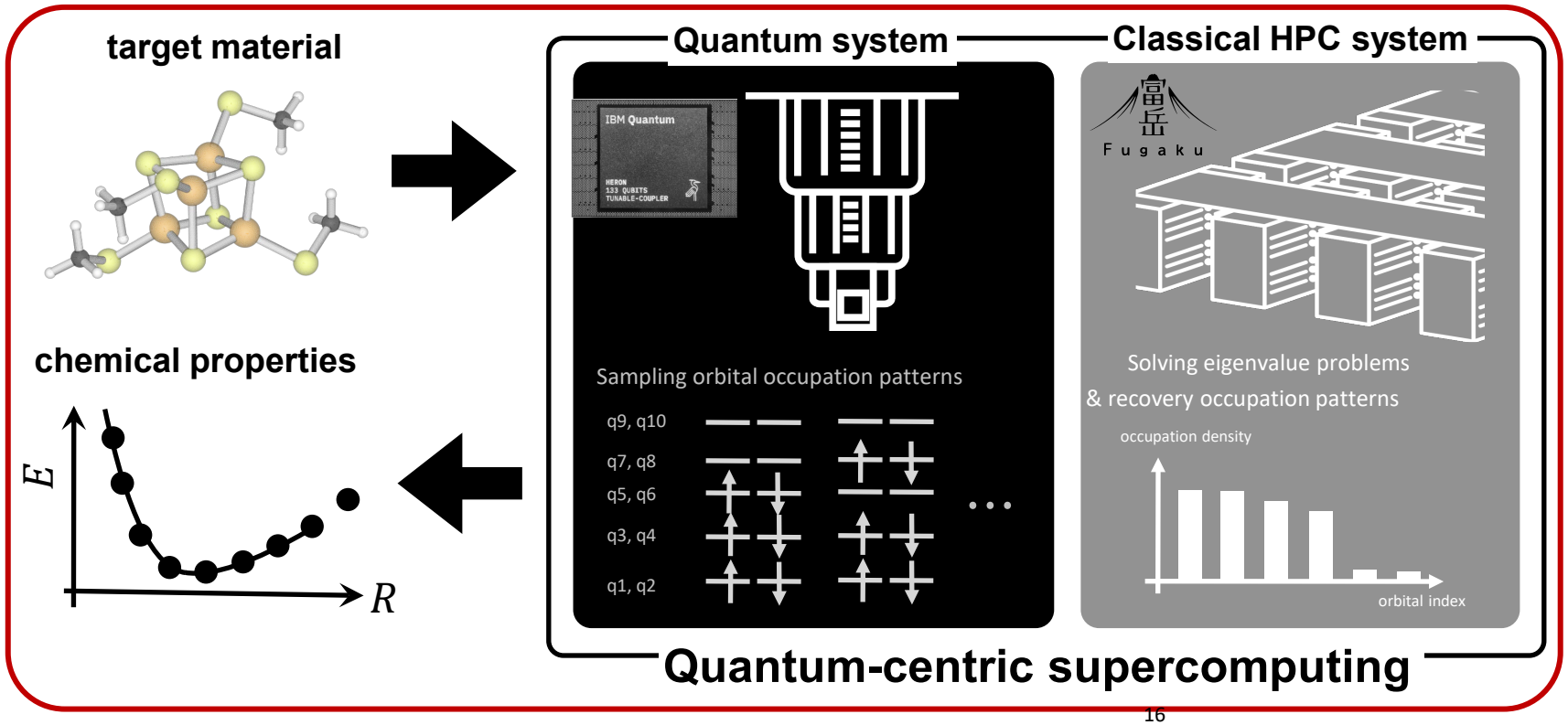


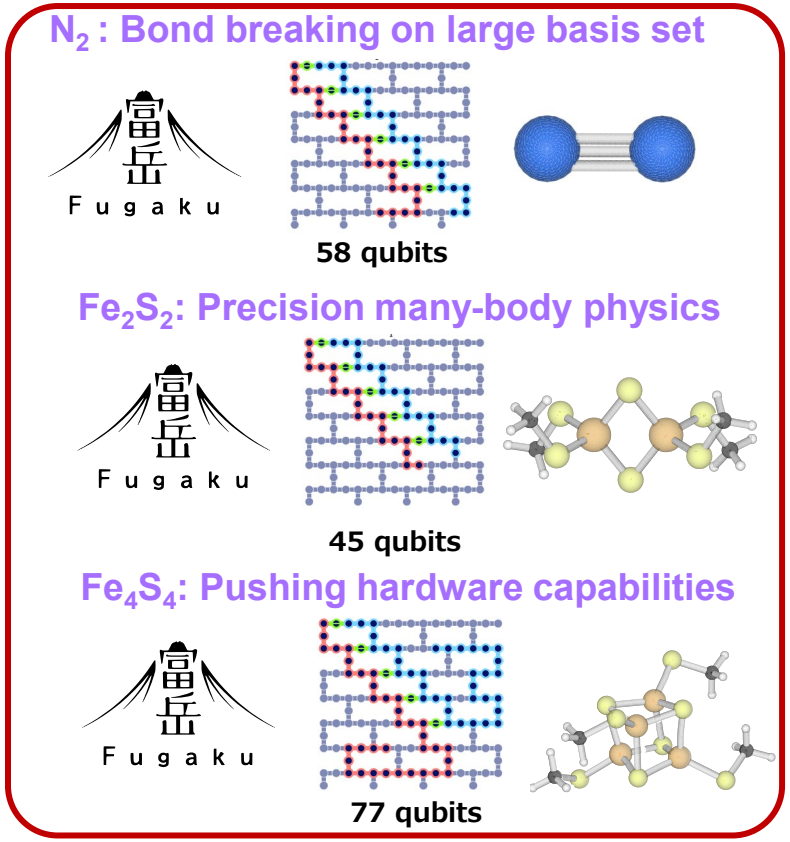
Quantum-centric Supercomputing for quantum chemistry

IBM Quantum RIKEN

J. Robledo-Moreno et al., arXiv:2405.05068

Although universal quantum computers are promising for predicting electronic structure problems in quantum chemistry, the deep circuits and huge amount of measurements required by current quantum computers make realistic quantum chemistry calculations difficult. In this study, **the 6400 nodes of the supercomputer "Fugaku"** are used to assist **IBM's latest quantum processor, Heron**, to study large molecules that cannot be handled by conventional quantum-classical hybrid calculations, and molecules that are difficult to calculate only by HPC-based classical computers (N2 triple bond breaking and the electronic structure of iron-sulfur clusters), which are difficult to calculate using only HPC computers. As a result, it was shown that the combination of supercomputer and quantum processors **(quantum-centric supercomputing)** can provide good approximate solutions for practical quantum chemical calculations. In this study, the quantum circuits representing the quantum states of molecules were fixed, and large data were transferred only from the quantum computer to the supercomputer. For more accurate computation, future tasks include the improvement of quantum circuits by data transfer between the quantum computer and the supercomputer, and the development of algorithms on the classical computer side that are suitable for quantum-centric supercomputing.





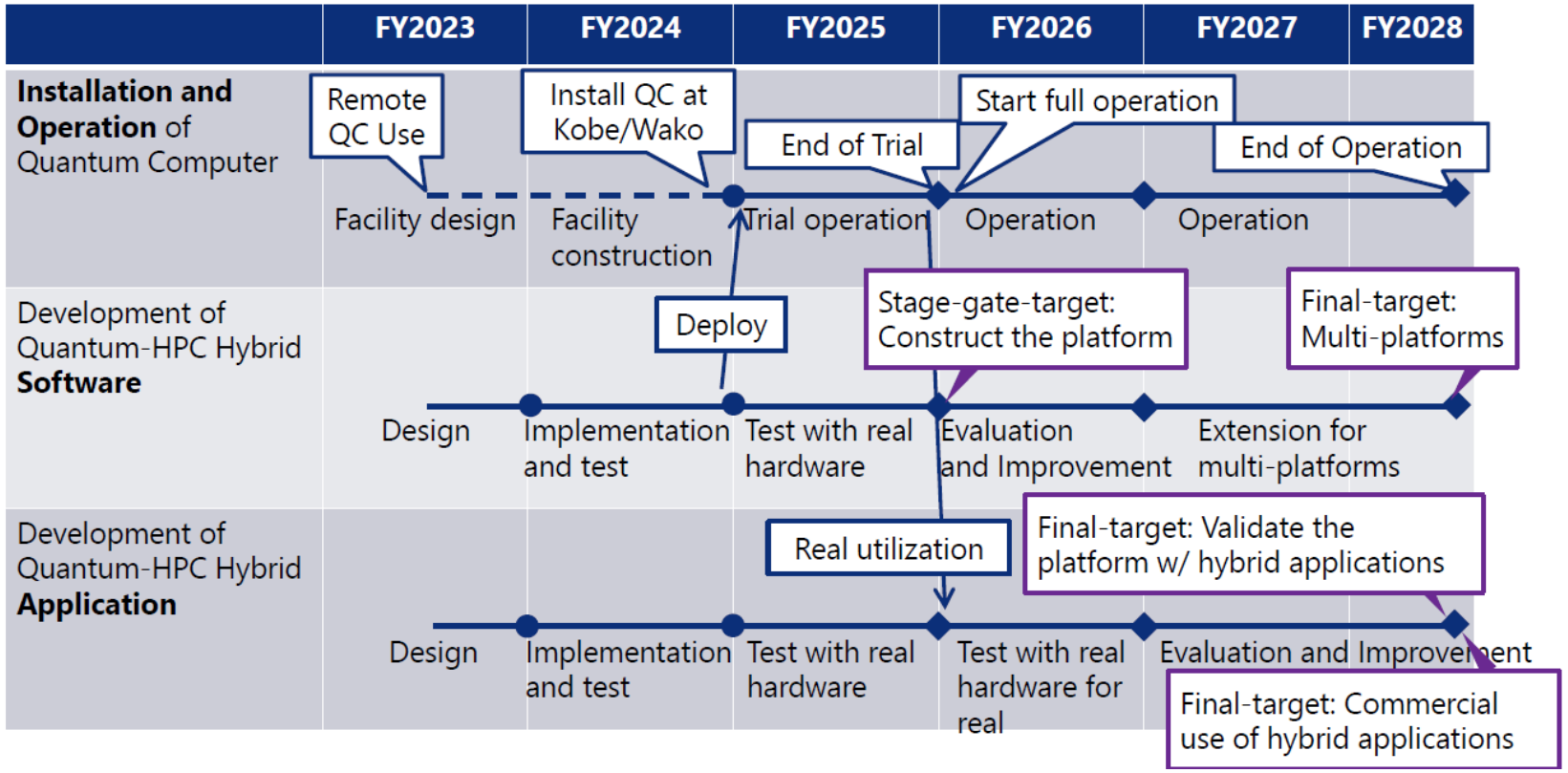
(real) “quantum computer” now, and benchmarking

- **Some types of QC hardware have more than 100 qubits**
  - Cannot be simulated by even supercomputers any more
  - QC is now in engineering phase. The number of qubits will be increased year by year!
- **100 qubits is not large enough for practical use!**
  - Fidelity is getting improved, but it’s NISQ
  - FTQC will be available in more than 10 years?
  - Optimization problems such as annealer or QAOA may be promising areas, but it is not clear that they are better than “semi-optimal” solution by supercomputer.
- **QC is an accelerator (at algorithm level) from supercomputer’s point of view**
  - Many computational science applications may be accelerated by QC
- **Benchmarking is an important element for the development of technologies**
  - Like “top500” in HPC, evaluation and improvement, …. Projection.

JHPC quantum project schedule

- **Our project, JHPC quantum, was accepted and started from Nov. 2023.**
- **Installation of QC hardware in 2Q 2025**
- **In 1st Q of 2026, operation of the quantum supercomputer hybrid platform will be started and used to demonstrate the effectiveness of quantum and HPC hybrid applications in the later half of our project.**

International collaboration is welcome, esp. for benchmarking and standardization.



Thank you for your attention.
Q & A