



LEADERSHIP
COMPUTING
FACILITY

August 6, 2025

An Introduction to Quantum Computing using Linear Solvers

2025 OLCF User Meeting Hands-On
Quantum Computing Training

OLCF Staff

Oak Ridge National Laboratory



U.S. DEPARTMENT OF
ENERGY

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FRONTIER



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Agenda

**Who are we?
Team Members**

**What is quantum
computing?
A brief Intro**

**What is QLSA?
A brief
Intro/Catchup**

**What quantum
resources?
QCUP, IQM & IonQ**

Demo Time!

OLCF Staff



Michael
Sandoval



Suzanne
Parete-Koon



MacKenzie
Boyd



Murali
Gopalakrishnan Meena

ORNL QCFD team and collaborators



[Group website](#)



Kalyan
Gottiparthi



Chao
Lu



Toño
Coello Pérez



Amir
Shehata



Michael
Sandoval



Seongmin
Kim



Pooja
Rao
NVIDIA



Justin
Lietz
NVIDIA



Xinfeng
Gao
UVA



In-Saeng
Suh



Antigoni
Georgiadou



Alessandro
Baroni



Ryan
Landfield



Matt
Norman



Tom
Beck



Paul
Lin
NERSC-LBNL



Yu
Zhang
LANL

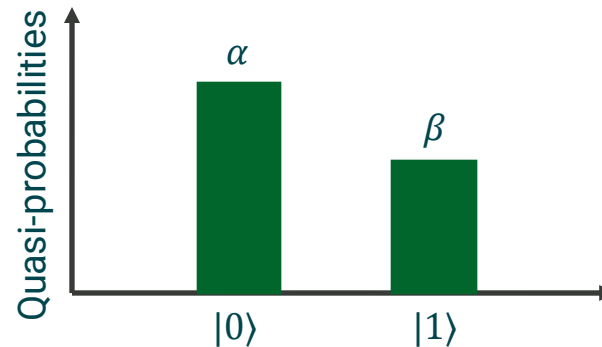
ORNL - OLCF

Quantum Computing

A very brief Intro to QC

Classical vs Quantum Computing

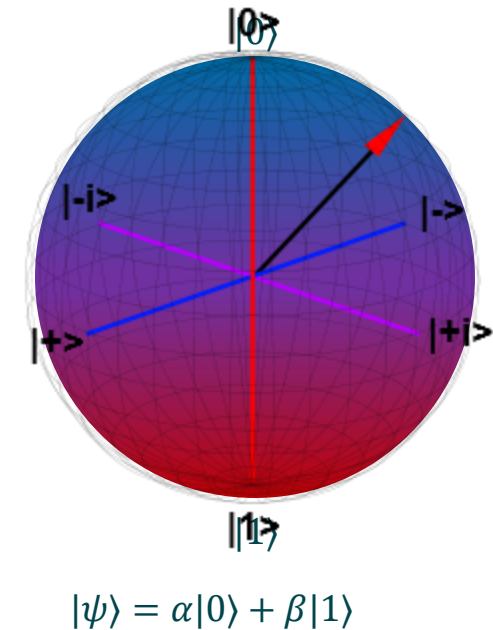
- Bit vs Qubit – information states
- State of superposition – a combination of all possible configurations
 - Store more information!
 - Measuring will lead to collapse to a binary state
- Types of qubits:
 - Superconducting
 - Trapped ion
 - Photons
 - Neutral atoms
 - Quantum dots



Classical computing -
Bit

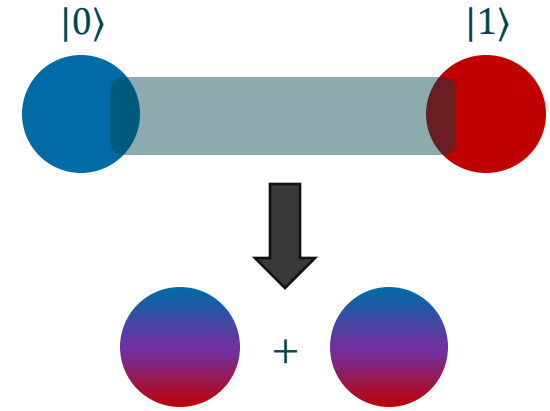


Quantum computing -
Qubit

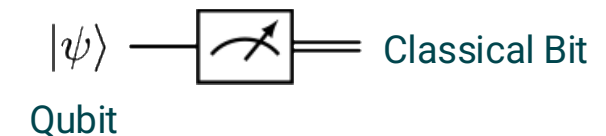
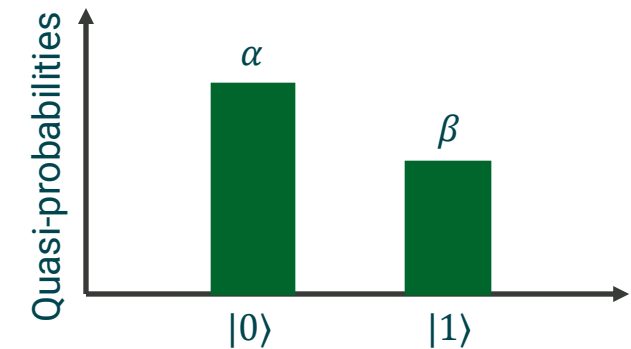


Key principles of quantum computing

1. **Superposition**
2. **Entanglement** – ability of qubits to correlate with each others' states
 - Store even more information!
3. **Interference** – information is structured like waves with amplitudes
 - Waves can amplify or cancel each other
 - Amplitudes: Probabilities of the outcomes of measurement
4. **Decoherence** – collapse from quantum to nonquantum state
 - Intentionally (measurement)
 - Allows quantum computers to interact with classical computers
 - Unintentionally (interaction with environment)

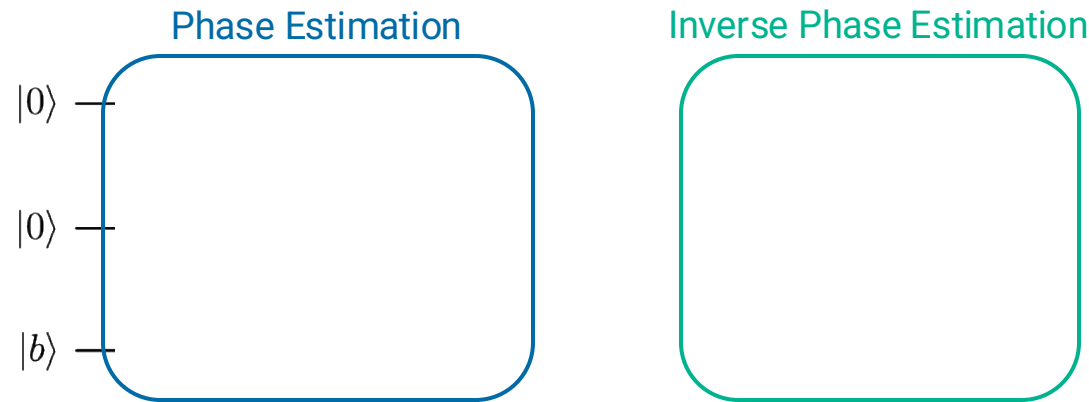


$$|\psi\rangle = \alpha_1|00\rangle + \alpha_2|01\rangle + \alpha_3|10\rangle + \alpha_4|11\rangle$$



Working of a quantum computer

1. **Qubits** are prepared as superposition of states
2. **Gates** used to operate on qubits and entangle them
 - Unitary operations
 - Reversible
 - Can operate on a single qubit or multiple (entanglement)
3. **Circuits** are collection of gates
4. **Quantum algorithms** are collection of circuits to create desired interference between states
5. **Measurement** (amplified outcomes) gives solution



Running a quantum algorithm

Backend	Mechanism	Functionality
Simulator	Classical	Classical program modeling a quantum system in an ideal scenario
Emulator	Classical	Classical program modeling actual behavior of a quantum system
Real	Quantum	Physical hardware performing real quantum computations

Quantum Linear Solvers

A brief Intro/Catchup

Governing equations are discretized to create a set of algebraic equations & assembled into $Ax = b$

$$\nabla \cdot \mathbf{u} = 0,$$

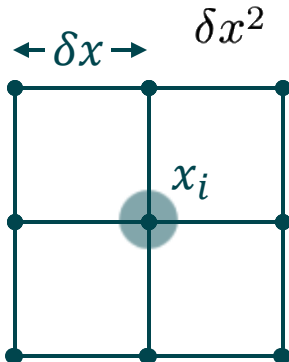
$$\frac{\partial \mathbf{u}}{\partial t} = - \underbrace{\mathbf{u} \cdot \nabla \mathbf{u}}_{\text{nonlinear term}} - \underbrace{\nabla p + \frac{1}{Re} \nabla^2 \mathbf{u}}_{\text{linear terms}} + \mathbf{s}$$

$$\nabla^2 p = - \underbrace{\nabla \cdot (\mathbf{u} \cdot \nabla \mathbf{u})}_{\text{nonlinear term}}$$

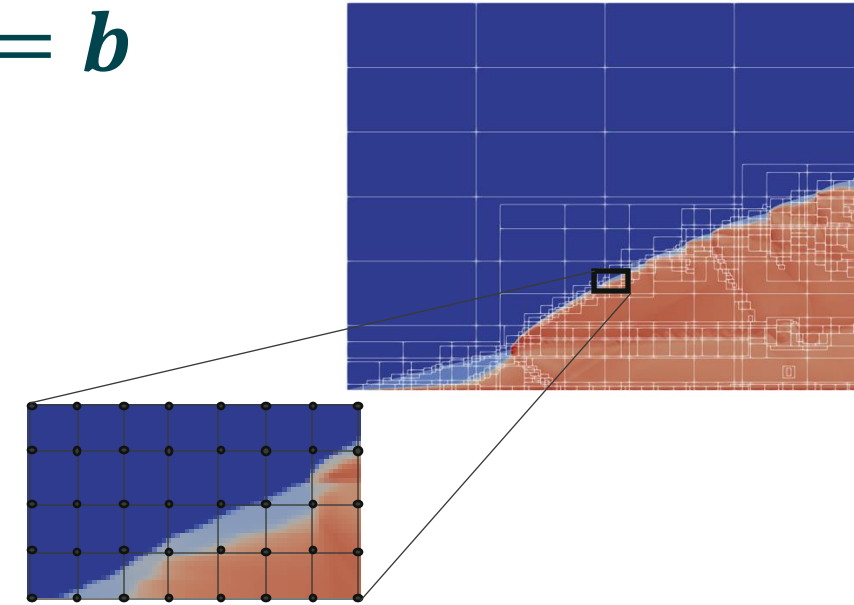
Finite difference approximation

$$\frac{\partial u_\alpha(x_i)}{\partial x} \simeq \frac{u_\alpha(x_i + \delta x) - u_\alpha(x_i - \delta x)}{2\delta x}$$

$$\frac{\partial^2 u_\alpha(x_i)}{\partial x^2} \simeq \frac{u_\alpha(x_i + \delta x) + u_\alpha(x_i - \delta x) - 2u_\alpha(x_i)}{\delta x^2}$$



Linear Solver



Desai et al., Combust. Flame, vol 257, 2023

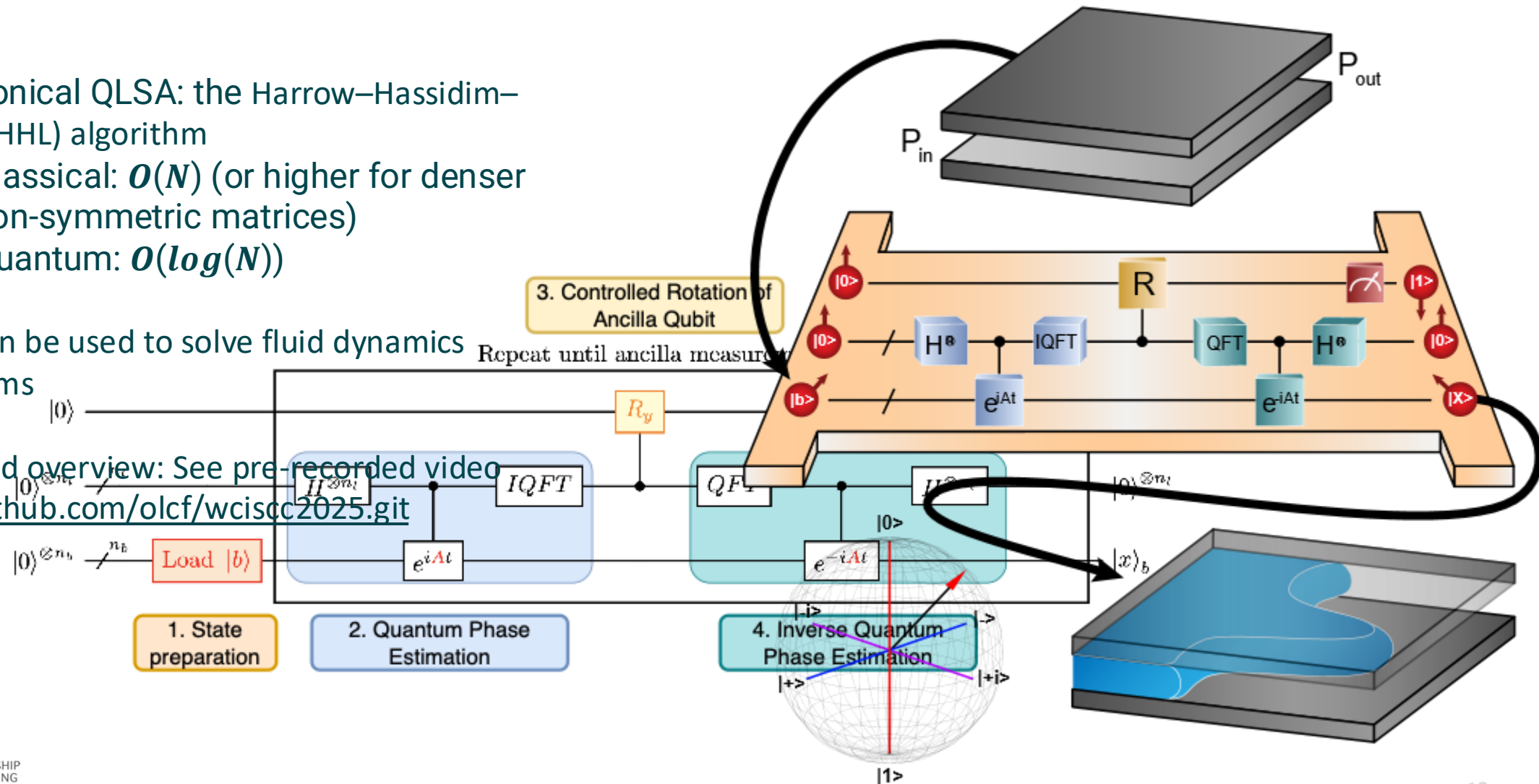
$$\begin{matrix} \text{[Blue Matrix]} \\ A \end{matrix} \times \begin{matrix} \text{[Green Vector]} \\ x \end{matrix} = \begin{matrix} \text{[Blue Vector]} \\ b \end{matrix}$$

Quantum Linear Systems Algorithms (QLSA) solve $Ax = b$ problems using quantum computers

- A canonical QLSA: the Harrow–Hassidim–Lloyd (HHL) algorithm
 - Classical: $O(N)$ (or higher for denser non-symmetric matrices)
 - Quantum: $O(\log(N))$

- HHL can be used to solve fluid dynamics problems

- Detailed overview: See pre-recorded video <https://github.com/olcf/wcisc2025.git>



Quantum Hardware Access with QCUP

IQM Resonance & IonQ Cloud

Quantum Computing User Program

Enable Research

Provide a broad spectrum of user access to the best available quantum computing systems

Evaluate Technology

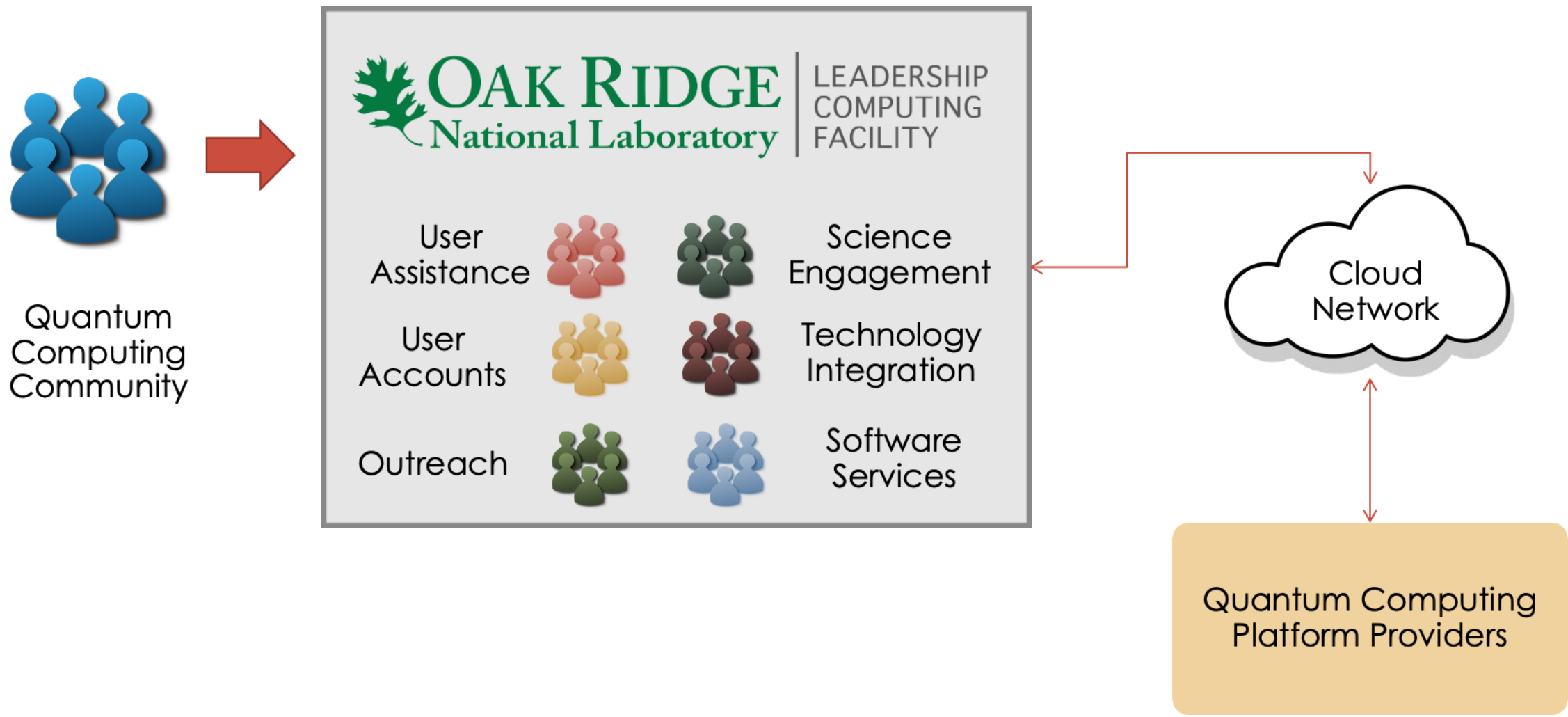
Monitor the breadth and performance of early quantum computing applications

Engage Community

Support growth of the quantum ecosystem by engaging with users, developers, vendors, and providers



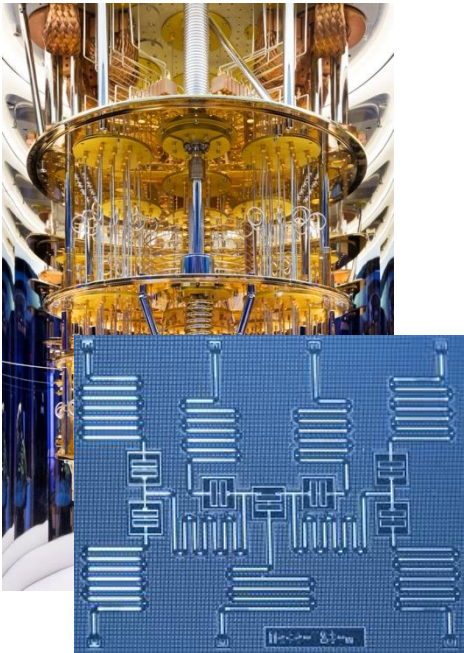
QCUP Operations Model: Cloud Access



Multiple Quantum Computing Resources

IBM Quantum

General-purpose transmon systems provide up to 156 qubits



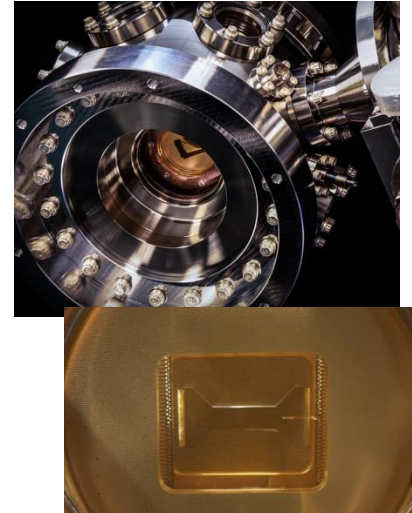
IQM

General-purpose transmon systems provide up to 56 qubits



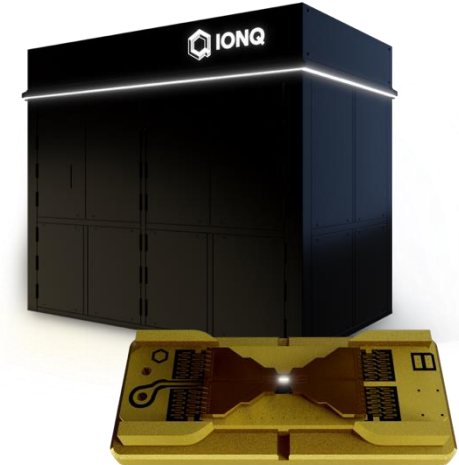
Quantinuum

General-purpose ion trap systems provide up to 56 qubits



IonQ

General-purpose ion trap systems provide up to 36 qubits



IQM Resonance

- IQM provides access to quantum computing resources through their cloud platform, IQM Resonance.
 - The 20 qubit **Garnet**, 16 qubit Sirius, and 54 qubit Emerald systems.
 - IQM's quantum processors are made up of superconducting transmon qubits, utilizing multiple topologies.
 - User dashboard: <https://resonance.meetiqm.com/>
- OLCF Documentation: https://docs.olcf.ornl.gov/quantum/quantum_systems/iqm.html
- We'll be submitting jobs to Garnet via Python from Frontier
 - "Pay-as-you-go" mode
 - Certain windows where a queue is open
 - "Timeslot" mode
 - Reserved for today from 2-3 PM (Eastern)
- Should've received an invite from me to create your account (**not the same account as Frontier!!**)

The IQM Resonance Dashboard - I

IQM Resonance

Dashboard

Jobs

Documentation

Account

MG

QUANTUM COMPUTERS

IQM Emerald

54

Pay-as-you-go

-

Jobs in queue

102

Pulse

IQM Garnet

20

Pay-as-you-go

Active

Jobs in queue

0

Pulse

IQM Sirius

16

Pay-as-you-go

-

Jobs in queue

11

Pulse

AVAILABILITY

IQM Garnet

Full Calendar

W31

Mon

Tue

Wed

Thu

Fri

Sat

Sun

9:00

11:00

13:00

15:00

17:00

Pay-as-you-go

Booked timeslot

Unavailable

YOUR LATEST JOBS

Job ID	Created	Completed	Runtime	QC	Status	Mode
e8e71d	28 Jul, 14:27	28 Jul, 14:27	2 s	IQM Garnet	Completed	Pay-as-you-go
ea6685	28 Jul, 13:35	28 Jul, 13:35	4 s	IQM Garnet (mock)	Completed	Mock run
49c0ae	13 May, 14:16	13 May, 14:16	4 s	IQM Garnet (mock)	Completed	Mock run

→ See all jobs

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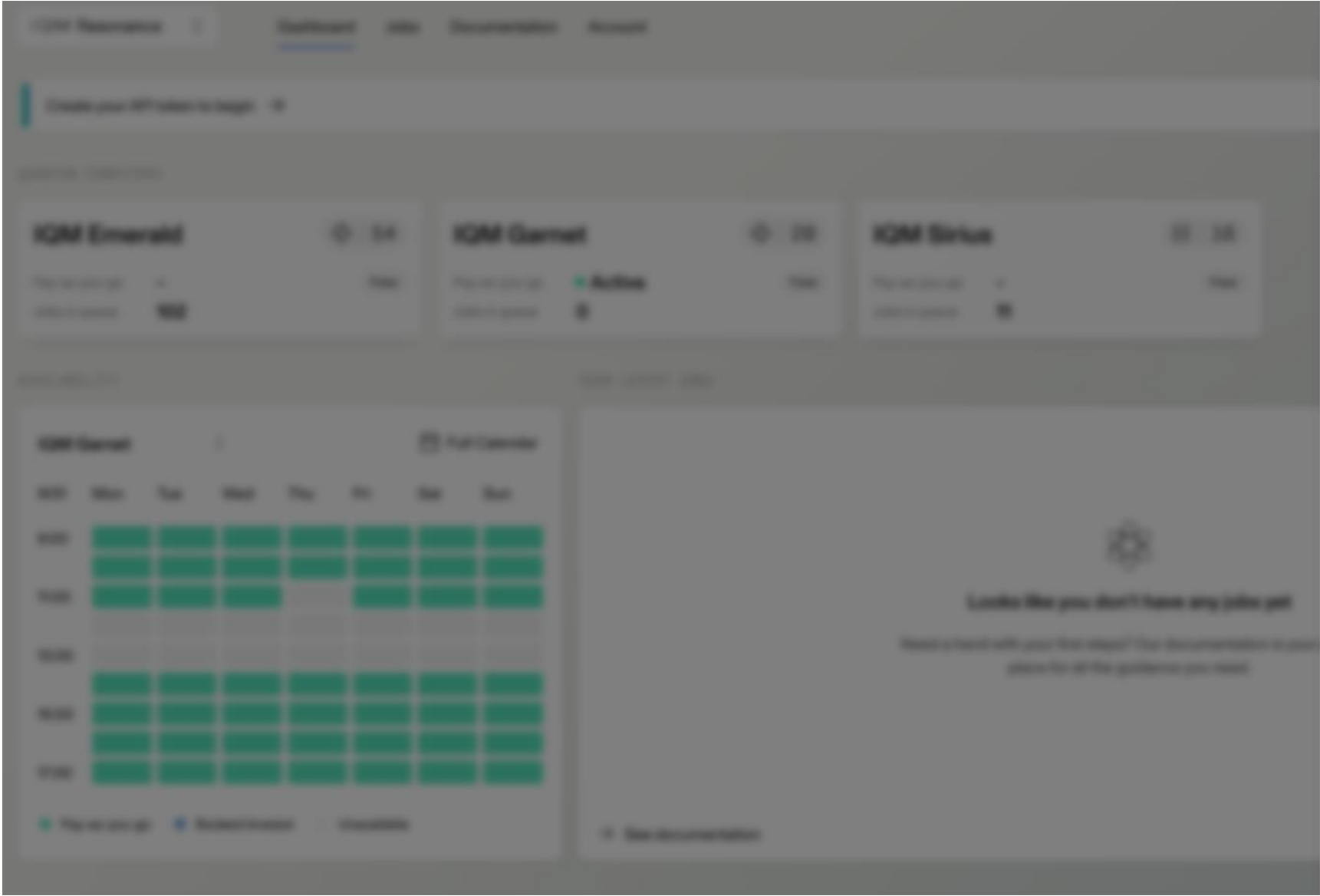
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The IQM Resonance Dashboard - II



Your profile ×

MG

Muralikrishnan

Gopalakrishnan Meena

gopalakrishm@ornl.gov

>

Workspace

O

Team

OLCF-UM-25

⌵

API Token

↻

Generate Token

Email preferences

Required service notifications ☒

IQM newsletter ☐

Log out

The IQM Resonance Dashboard - III

Availability calendar

×

IQM Garnet

① Pay-as-you-go slots are updated in real-time and may change as timeslot bookings are made.

Today<>

4.8-10.8.2025 Week 32

MonthWeekList view

	04 Mon	05 Tue	06 Wed	07 Thu	08 Fri	09 Sat	10 Sun
12:00 AM	12:00 AM – 12:30 AM	12:00 AM – 12:30 AM	12:00 AM – 12:30 AM	12:00 AM – 12:30 AM	12:00 AM – 12:30 AM	12:00 AM – 12:30 AM	12:00 AM – 12:30 AM
1:00 AM							
2:00 AM							
3:00 AM							
4:00 AM	3:30 AM – 11:30 AM Pay-as-you-go	3:30 AM – 11:30 AM Pay-as-you-go	3:30 AM – 11:30 AM Pay-as-you-go	3:30 AM – 11:30 AM Pay-as-you-go	3:30 AM – 11:30 AM Pay-as-you-go	3:30 AM – 11:30 AM Pay-as-you-go	3:30 AM – 11:30 AM Pay-as-you-go
5:00 AM							
6:00 AM							
7:00 AM							
8:00 AM							
9:00 AM							
10:00 AM							
11:00 AM							
12:00 PM							
1:00 PM							
2:00 PM	2:00 PM – 11:59 PM Pay-as-you-go	2:00 PM – 11:59 PM Pay-as-you-go	2:00 PM – 3:00 PM Booked Timeslot	2:00 PM – 11:59 PM Pay-as-you-go	2:00 PM – 11:59 PM Pay-as-you-go	2:00 PM – 11:59 PM Pay-as-you-go	2:00 PM – 11:59 PM Pay-as-you-go
3:00 PM			3:00 PM – 11:59 PM Pay-as-you-go				
4:00 PM							

IonQ Cloud Console

- IonQ provides access to quantum computing resources through their cloud platform, IonQ Quantum Cloud.
 - The 25 qubit **Aria** and 36 qubit Forte systems.
 - IonQ's quantum processors are made up of trapped-ion qubits, utilizing multiple topologies.
 - User dashboard: <https://cloud.ionq.com/>
- OLCF Documentation: https://docs.olcf.ornl.gov/quantum/quantum_systems/ionq.html
- We'll be submitting jobs to Aria via Python from Frontier
 - Run using credits
 - Priority window for today from 2-3:30 PM (Eastern)
 - Limited credits for this tutorial – **only run up to 500 shots**
- Should've received an invite from me to create your account (**not the same account as Frontier!!**)

The IonQ Cloud Dashboard - I

IONQ

My Jobs

Projects

Backends

Settings

API Keys

Support

Documentation

API Reference

Support Requests

My Jobs

Filter

Export

31 Jobs

	Date ↓	Status	Name	Backend	ID	Type	Project	Cost	
<input type="checkbox"/>	2025-07-31 15:57:09 EDT	completed	circuit-194	simulator	0198620f	circuit	CFD181	\$0.00	...
<input type="checkbox"/>	2025-07-31 15:55:57 EDT	completed	circuit-194	simulator	0198620e	circuit	CFD181	\$0.00	...
<input type="checkbox"/>	2025-07-31 15:40:51 EDT	completed	circuit-194	simulator	01986200	circuit	CFD181	\$0.00	...
<input type="checkbox"/>	2025-07-31 15:40:33 EDT	completed	circuit-194	simulator	01986200	circuit	CFD181	\$0.00	...
<input type="checkbox"/>	2025-07-28 14:45:41 EDT	completed	circuit-194	simulator	0198525a	circuit	CFD181	\$0.00	...
<input type="checkbox"/>	2025-07-28 14:42:38 EDT	completed	circuit-194	simulator	01985258	circuit	CFD181	\$0.00	...
<input type="checkbox"/>	2025-07-28 14:41:26 EDT	completed	circuit-194	simulator	01985256	circuit	CFD181	\$0.00	...
<input type="checkbox"/>	2025-07-28 14:40:56 EDT	completed	circuit-194	simulator	01985256	circuit	CFD181	\$0.00	...
<input type="checkbox"/>	2025-07-28 14:39:41 EDT	completed	circuit-194	simulator	01985255	circuit	CFD181	\$0.00	...
<input type="checkbox"/>	2025-07-28 14:38:45 EDT	completed	circuit-194	simulator	01985254	circuit	CFD181	\$0.00	...
<input type="checkbox"/>	2024-10-24 15:40:41 EDT	completed	circuit-193	simulator	c3c2f4ea	circuit	Personal Workspace (gopalakrishm@ornl.gov)	\$0.00	...
<input type="checkbox"/>	2024-06-21 12:07:20 EDT	completed	circuit-193	simulator	ca24d088	circuit	Personal Workspace (gopalakrishm@ornl.gov)	\$0.00	...
							Personal Workspace (gopalakrishm@ornl.gov)		

The IonQ Cloud Dashboard - II

IONQ

Return Home

Account

Settings

API Keys

Organization

Members

API Keys

Check out our guide to [generating and storing API keys](#).

CFD-181

Never used

Revoke

OLCF-UM-25

Never used

Revoke

Oak Ridge National Laboratory Organization

Generate key

Generate API key

Give your key a descriptive name

What is this key for?

Choose a project this key will connect to

You need to be added to the project to generate an API key for it.

Choose project

Cancel

Generate key

The IonQ Cloud Dashboard - III

IONQ

My Jobs

Projects

Backends

Settings

API Keys

Support

Documentation

API Reference

Support Requests

Oak Ridge National Laboratory Organization

Projects / OLCF-UM-25

Jobs

Members

Project Jobs

Total project cost

\$0.00 / \$0.00

Filter

Export

0 Jobs

Date	Status	Name	Backend	ID	Type	Submitted by	Cost
<div><div></div><div>No jobs exist with your filter criteria</div><div>Try a different filter criteria.</div></div>							

Jobs per page

50

0 - 0 of 0 jobs

Previous

Next

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The Hands-On Tutorial

Demo & Challenge

Run the HHL circuit on simulators, emulators, and real devices

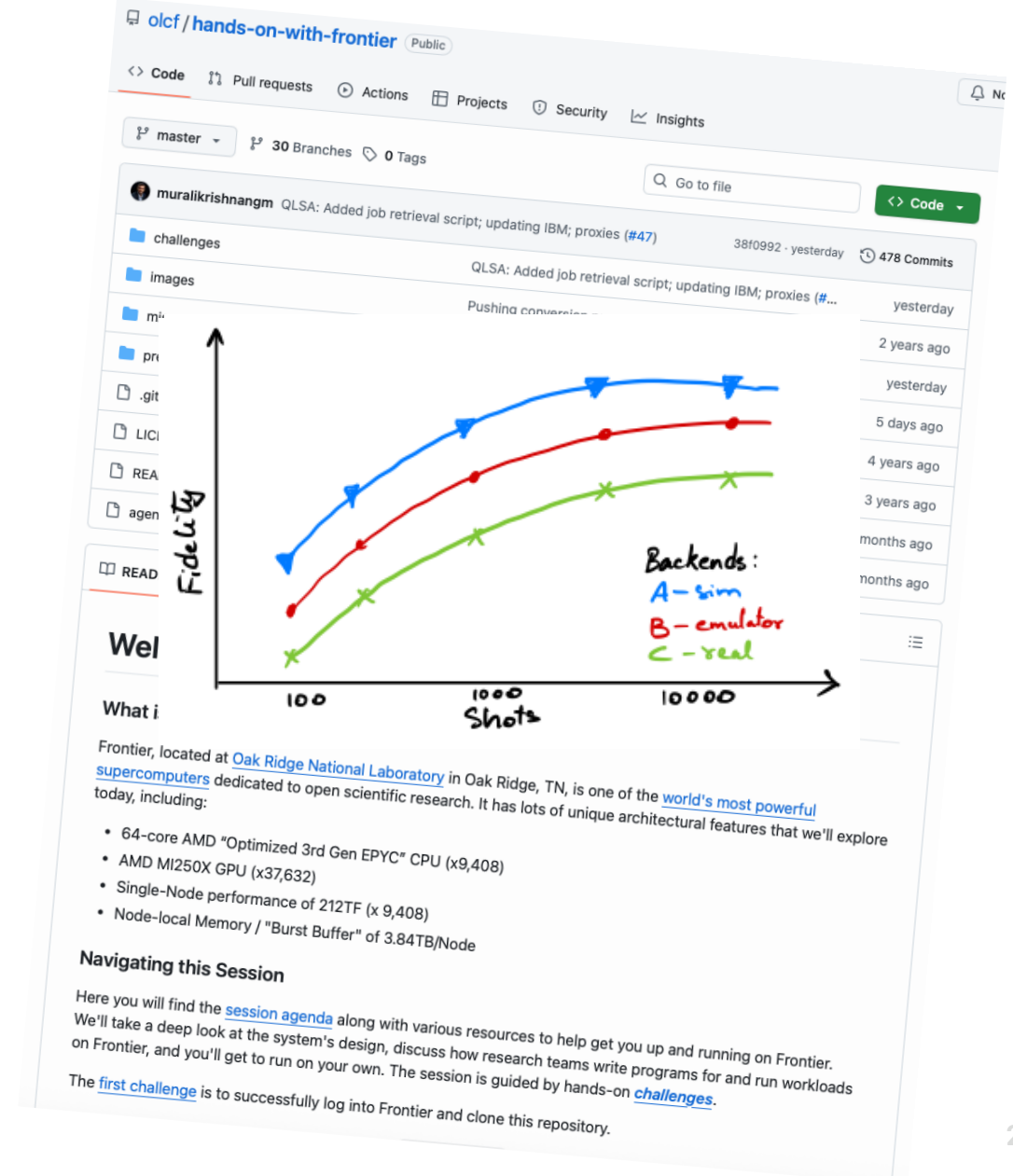
Demo Time!

<https://github.com/olcf/hands-on-with-frontier>

- Go to: challenges/Python_QLSA

Challenge Time! Two Tasks:

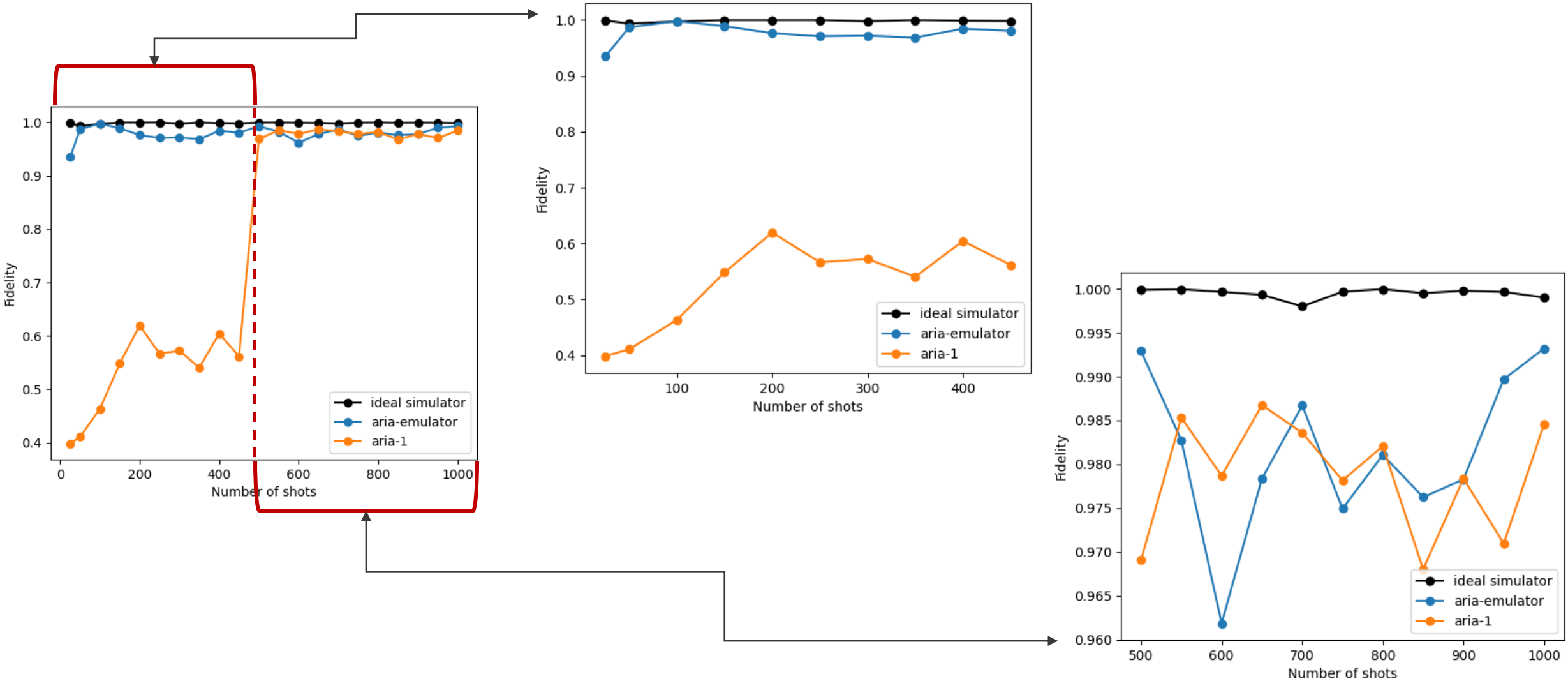
- Shots-based study
- Backend evaluation



Logistics

1. When requesting Frontier node,
 1. Use the reservation flag: **--reservation=usermeeting2**
 2. Please request only **1 node** per user
2. Due to limited resources, **IonQ runs are capped at 500 shots** – try to use the resource sparingly

Sample results of running on IonQ



Run the HHL circuit on simulators, emulators, and real devices

<https://github.com/olcf/hands-on-with-frontier>

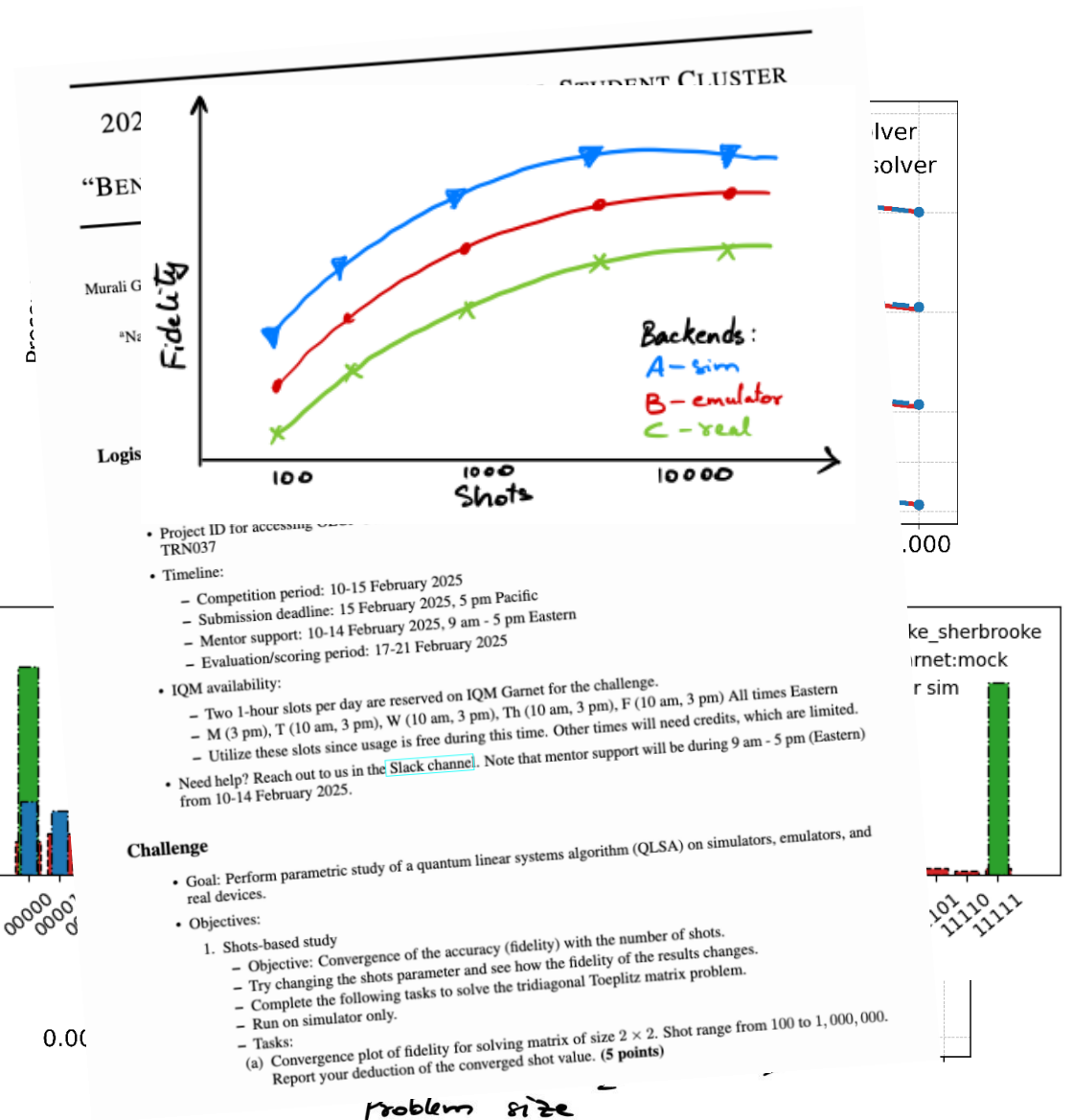
- Go to: challenges/Python_QLSA

Explore more!

1. Shots-based study – uncertainty in results
2. Backend evaluation – quasi-probability distribution
3. *Bonus: Solve the Hele–Shaw flow*

Try out our 2025 WCISCC student challenge!

<https://github.com/olcf/wciscc2025.git>



Questions?

<https://github.com/olcf/hands-on-with-frontier>

