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Sandia National Laboratories

# Quatnum Computing: NISQ and Beyond

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- Project Manager, Quantum Scientific Computing Open User Testbed
- Deputy Director, Quantum Systems Accelerator

October 18, 2021

Frontiers in Quantum Computing

U.S. DEPARTMENT OF ENERGY NNSA

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# Overview of Sandia QIS Program

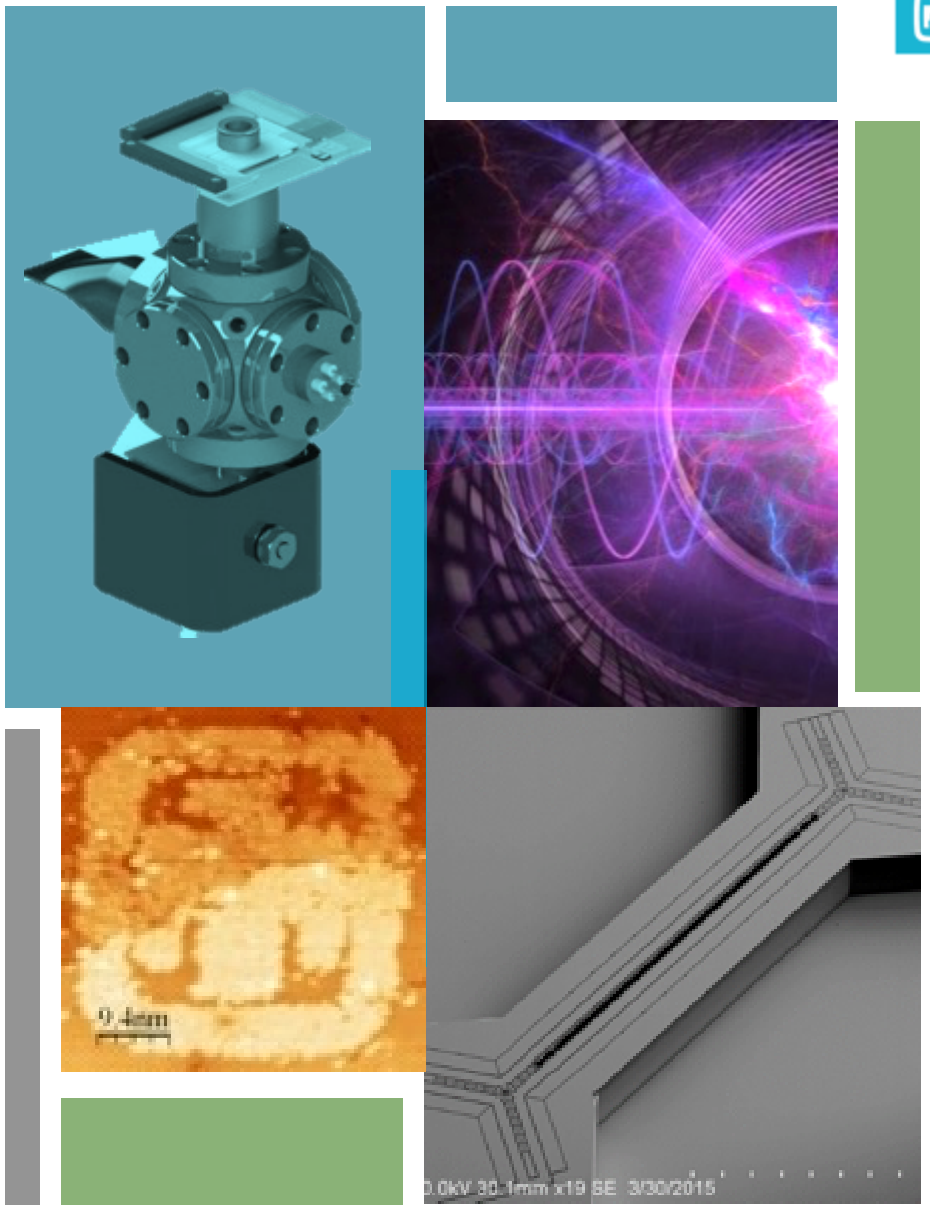
- Sandia has a **broad, mature quantum information science program**.

  *Notable elements of the program are:*

  - Working quantum devices in multiple technologies
  - Applications to quantum computation, sensing, and communications/networking
  - Expertise in characterizing quantum devices and estimating required quantum resources for high impact quantum applications

- We are always looking for bright graduate students, postdocs, and mid-career scientists and technitions.

  - Contact **quantumjobs@sandia.gov** for more information.



# Quantum testbeds are important for quantum infrastructure

- Building quantum systems is expensive and complicated
- Commercial systems, while excellent, limit ability to study system itself
- DOE/ASCR funded testbeds address both of these problems

  *Free to use and access to lower level control*

  *Characterization/benchmarking techniques of quantum systems*

  *Unique pulse shapes or gate types*

  *Unique compilation strategies*

  *Your custom problem!*

# Two testbeds based on different hardware compliment each other

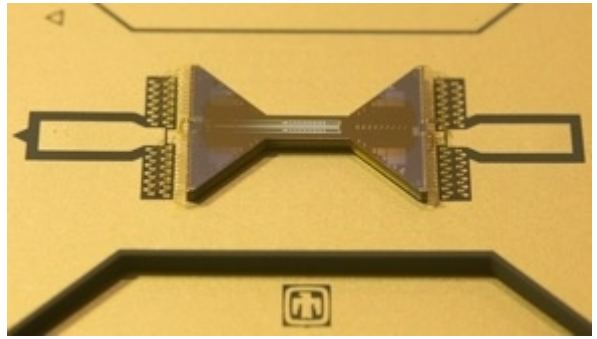


Every quantum system has strengths

## Trapped Ions

Fully connected
Parallelizable
Long coherence times
Low crosstalk

QSCOUT



## Superconducting

Fast
Excellent classical control
Configurable qubit connections
Qutrits or qubits

AQT

# QSCOUT: Quantum hardware based on trapped ions

Quantum processor based on trapped Ytterbium ions (3-32 qubits)

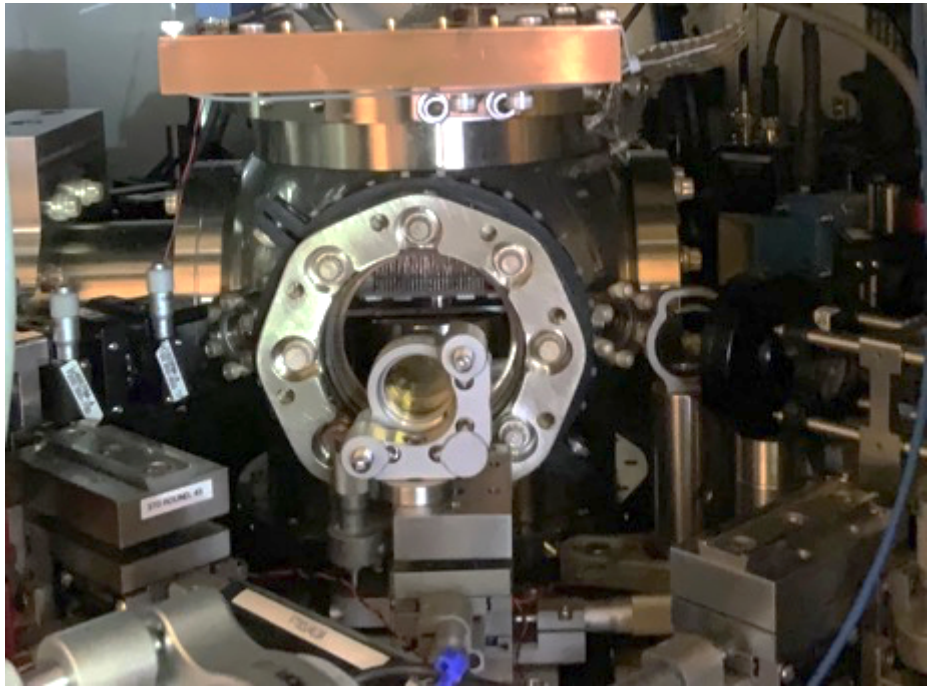
Quantum operations performed with Raman lasers

Users interact via programming language Jaqal

Access to Sandia scientists for assistance and interpretation

QSCOUT

JAQAL



Current Specifications

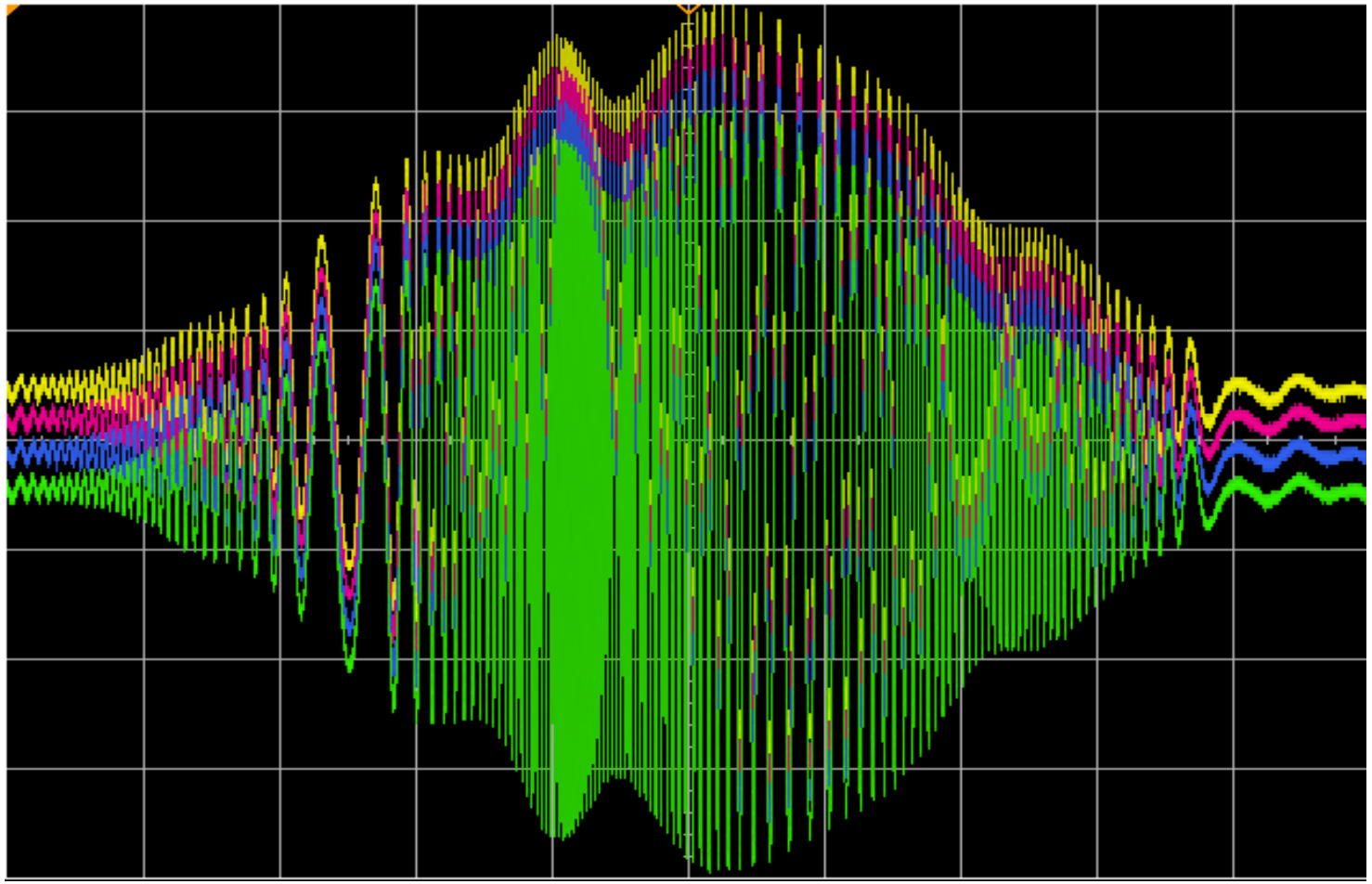
- 3-10 qubits
- Fully connected
- High fidelity (<5e-3, <2e-2 error for 1 and 2 qubit gates)
- Individually addressable
- Low crosstalk (<5e-3)
- Low prep,detect error (<1e-2)

Future Capabilities

- More qubits ~32
- Partial measurements
- Higher fidelity gates

# QSCOUT provides under-the-hood access

Fully specify exactly what and when gate operations are performed



Our specification offers full amplitude, frequency, phase, and duration control of signals applied to qubits

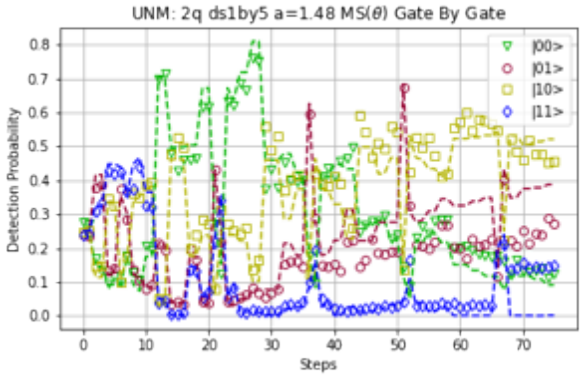
# QSCOUT Round 1 users

- First round of user code began Spring 2021 (even before our two-qubit gates were up and running)
- Combination of benchmarking, simulation, and gate optimizations
- System development directly tied to user input

THE UNIVERSITY OF NEW MEXICO

Tameem Albash
Elizabeth Crosson
Milad Marvian
Namitha Pradeep

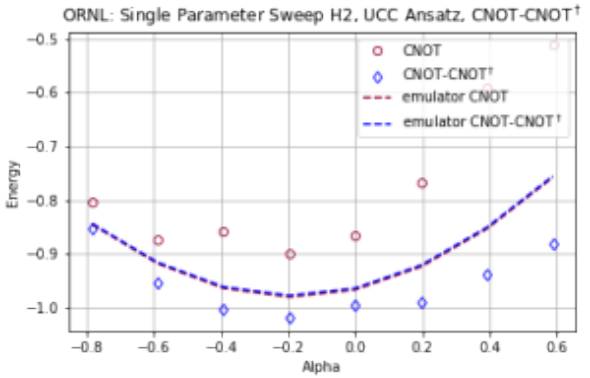
Digital simulation of non-stoquastic Hamiltonians




OAK RIDGE National Laboratory

Raphael Poozer
& the MIQASA team

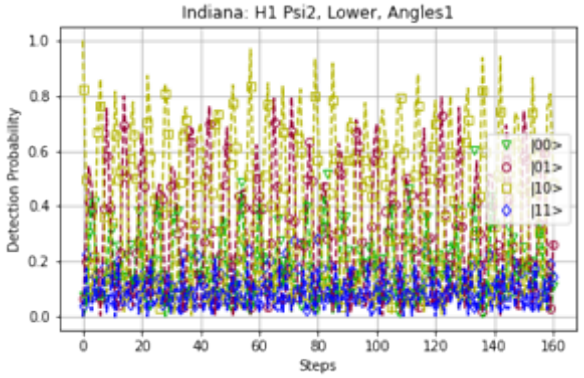
Connecting low level characterization metrics to higher level algorithmic performance with a tractably small simulation




INDIANA UNIVERSITY BLOOMINGTON

Philip Richerme
Debadrita Saha
Amr Sabry
Sam Norrell
Srinivasan Iyengar

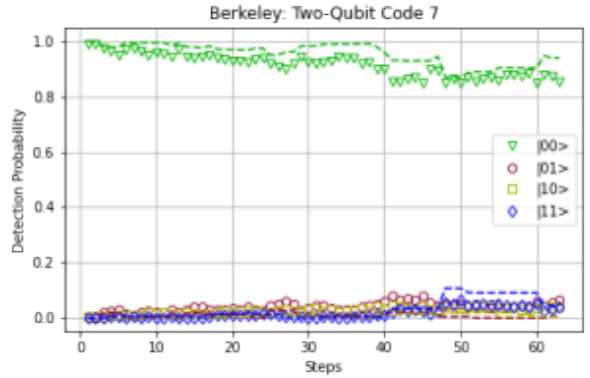
Simulating the quantum dynamics of proton-coupled electron transport problems in quantum chemistry




Berkeley UNIVERSITY OF CALIFORNIA

Ryan Shaffer
Hang Ren
Hartmut Haffner

Assessing the Performance of the Randomized Analog Verification protocol for gate-based devices



# QSCOUT Round 2 users

- Second round of user code slated to begin shortly along with first round users
- Combination of benchmarking, simulation, gate optimizations, & **pulse-level control**
- Once again system development will follow along with our users

Johns Hopkins APL Applied Physics Laboratory

Characterization and optimal control of time-correlated amplitude control noise

SUPER.TECH

Native gate optimizations and performance benchmarking

LCN London Centre for Nanotechnology

Simulating quantum evolution of infinite systems using tensor networks

Lawrence Livermore National Laboratory — Science & Technology on a Mission

Using control pulse engineering to improve the effective fidelity of ion trap quantum computers

IBM

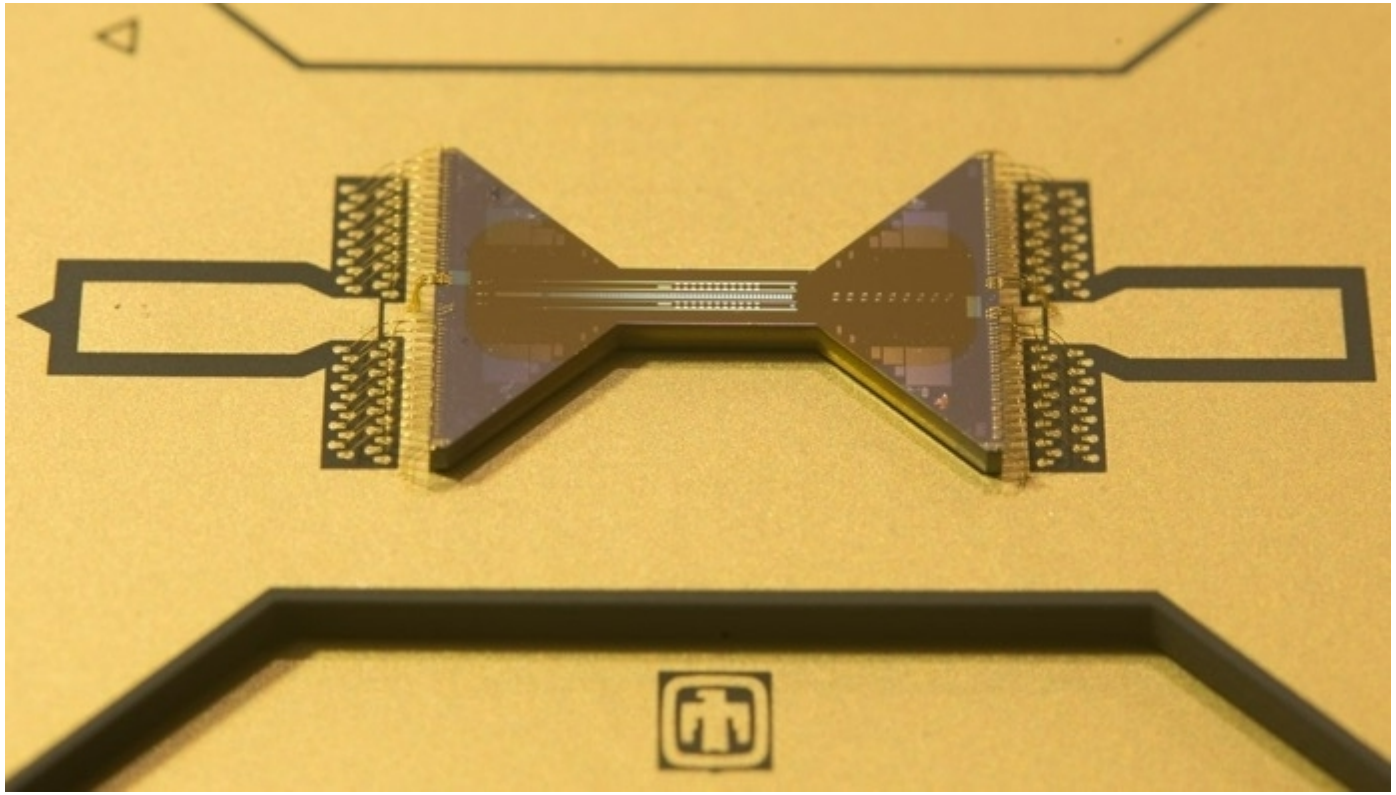
Quantum volume benchmarking

Indiana University Bloomington

Simulating quantum chemical nuclear dynamics problems

# How to interact with QSCOUT

- Call for proposals (multiple calls per year, next one expected in Spring 2022)
- 2 page proposal (more instructions on website)
- Technical and feasibility evaluation
- Individually meet with teams to discuss implementation and share data



We look forward to hearing from you!

https://qscout.sandia.gov

qscout@sandia.gov

# The Advanced Quantum Testbed

## Platform Overview

Director Irfan Siddiqi

An integrated experimental platform funded by the DOE to explore and define the future of superconducting quantum computers end-to-end, from quantum processor technology to quantum algorithms.

### Unique Quantum Resource

An open, reconfigurable architecture to codesign computational solutions for a broad suite of DOE mission applications.

### Deep User Collaborations

We have a highly-qualified team to assist and partner on the execution and optimization of short and long-term scientific projects.

### Growing QPU Library

We leverage in-house fabrication capability and a partnership with MIT-LL to access different qubit designs, connectivity, and gate architectures.

aqt.lbl.gov

### Broad Exploration of Quantum Technology

We strive to deploy and benchmark an evolving suite of quantum circuits, control hardware, and algorithms, developed at Berkeley and via partners across the US.

### Advanced Quantum Compilation & Control

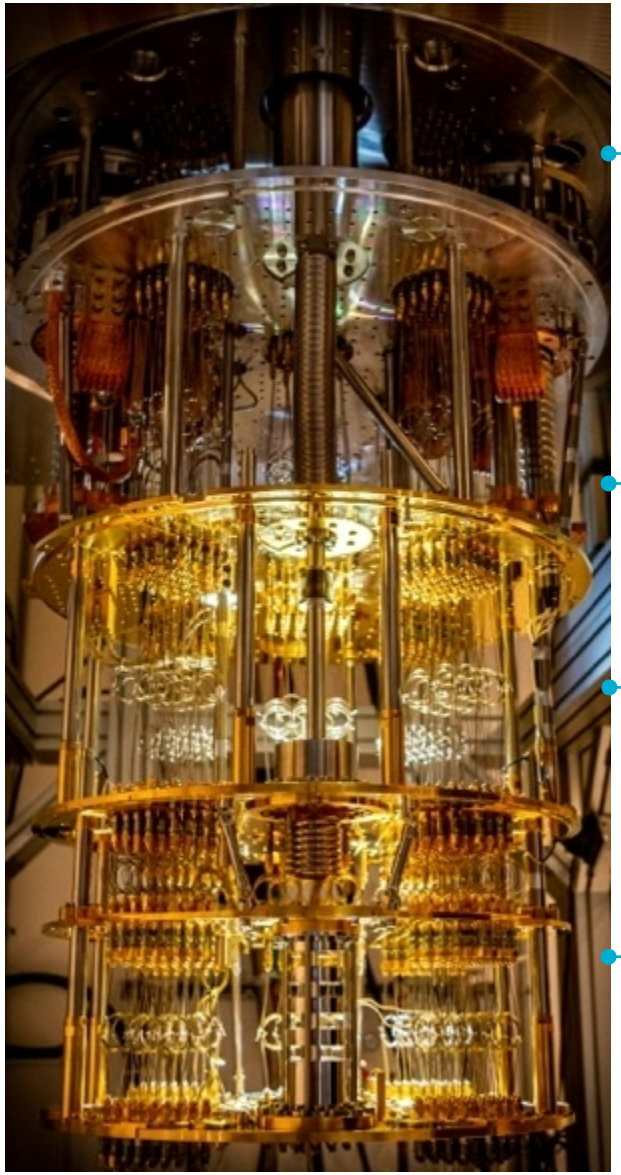
We employ application-specific circuit synthesis, programming sequences, readout, feedback, and noise mitigation for maximizing circuit depth and learning outcomes.

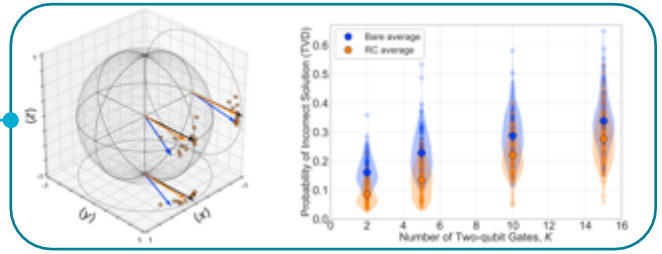
### Hardware Integration Pathway

We partner with companies developing specialized quantum components giving testbed users early access to advanced tech and establishing a testing resource.

# The Advanced Quantum Testbed

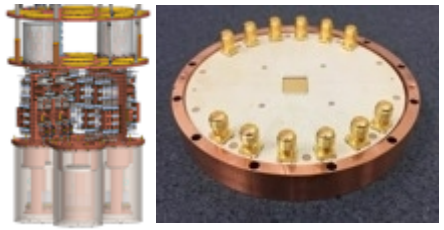
## Current Capabilities



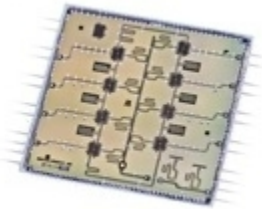



- Open programming stack and flexible user interface, with demonstrated tailoring and mitigation of coherent errors to improve algorithmic performance. Can support non-standard user software needs.

- Cutting-edge controls equipment capable of fast feedback and on-the-fly state detection, which can accommodate custom user needs. Both commercial Zurich Instrument solutions and an in-house custom modular solution called QubiC are available.



- Bluefors dilution fridge with 160 RF lines, operating at 10mK. Modular and extensible cryopackaging, developed in partnership with Bleximo, mitigates crosstalk, provides control and readout for 128 qubits, and can accommodate multiple chips.



- Current chip is an 8-qubit transmon ring design with high-coherence qubits ($T_1$ and $T_2$ >100 μs). A novel 8-qubit QPU with arbitrary dynamically reconfigurable (up to all-to-all) qubit-qubit connectivity will soon be available.

# The Advanced Quantum Testbed
## User Program

The testbed is open to teams from academia, industry, and government laboratories, with user projects executed in close collaboration with the AQT team.

User access is available to any point in the quantum computing stack:

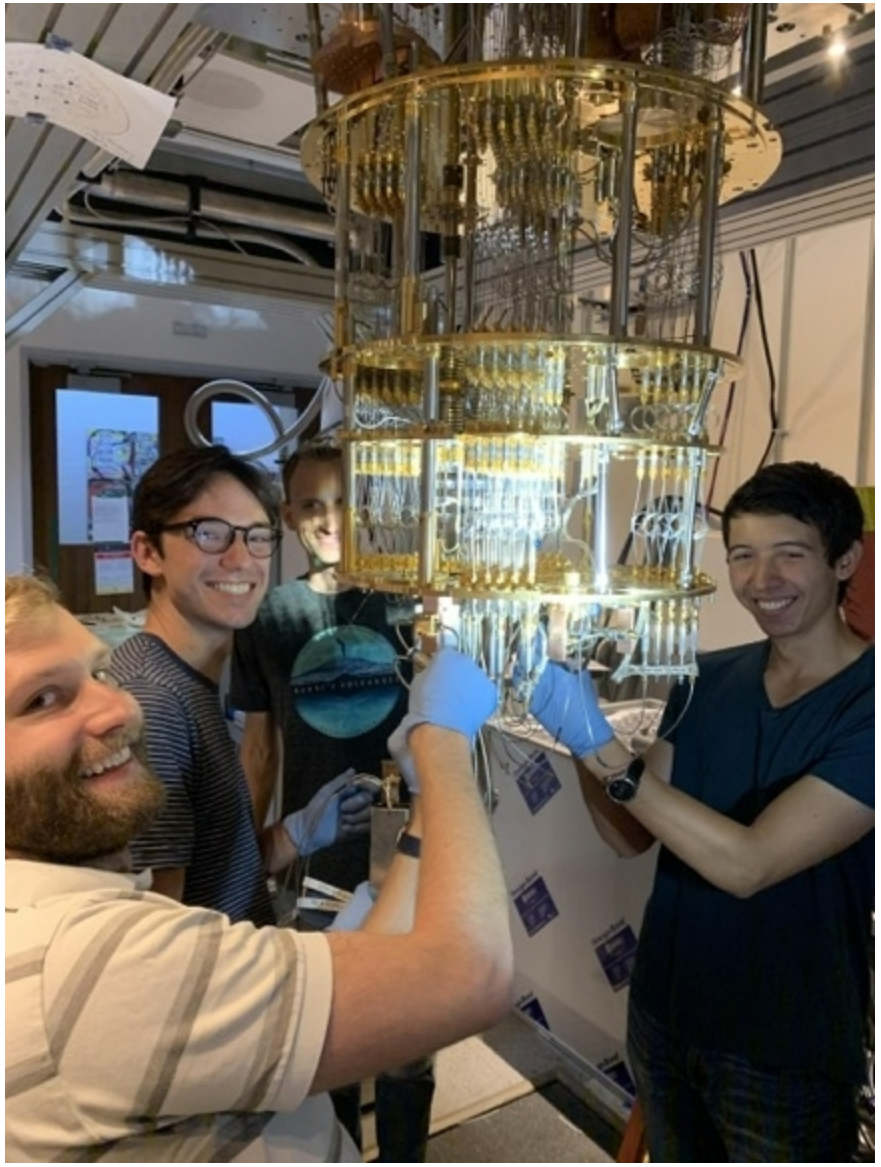
- Implementations of quantum computation algorithms or quantum simulations
- Quantum characterization, validation, and control routines
- Novel control hardware / firmware / software
- Novel superconducting quantum processor architectures

Two-stage competitive user application process:

- *Letters of Intent* briefly describe a project concept
- *Full Proposals* include a two-page technical project description

Access is provided at no cost for non-proprietary work that will be published in the scientific literature.

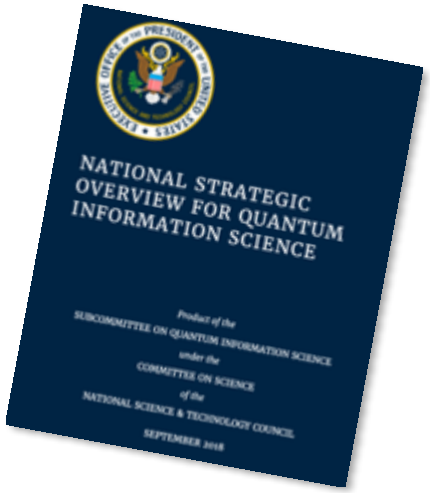
Full information is available at **aqt.lbl.gov/new-users**
*LOIs are accepted on a rolling basis*



# National Quantum Information Science Research Centers

## National Quantum Initiative

- All-of-government approach to sustain national and economic security.
- National Quantum Initiative Act (HR 6227) by DJT 12/21/2018.
- Opportunities for NSF, NIST, and DOE.




## DOE/SC Funded 5 NQI Centers in 2020:

- LBNL-SNL leads Quantum Systems Accelerator

QUANTUM SYSTEMS ACCELERATOR
Catalyzing the Quantum Ecosystem

C²QA
Co-design Center for Quantum Advantage

Q-NEXT
NEXT GENERATION QUANTUM SCIENCE AND ENGINEERING

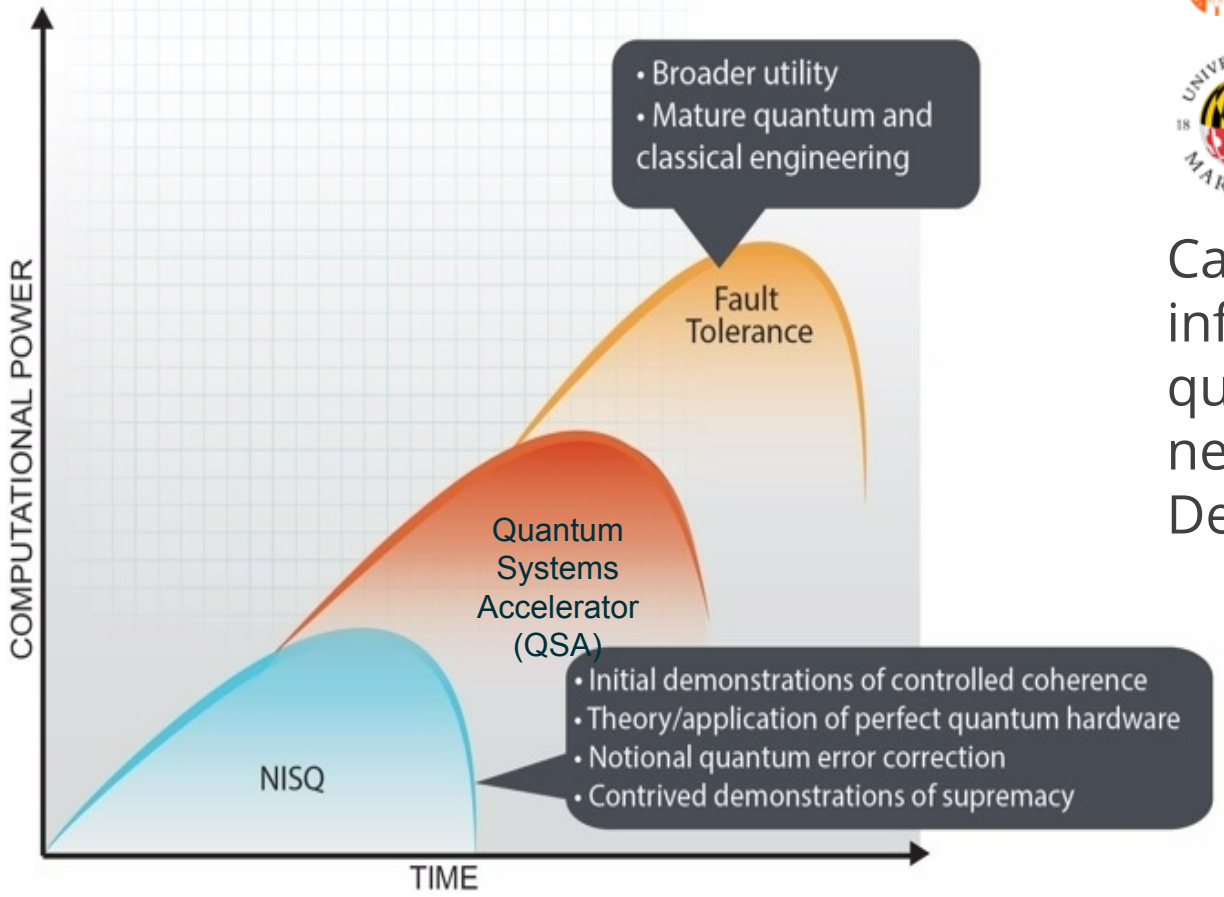
SQMS

QUANTUM SCIENCE CENTER

# QSA Addresses the Scientific Foundations for Quantum Computation

QUANTUM SYSTEMS ACCELERATOR

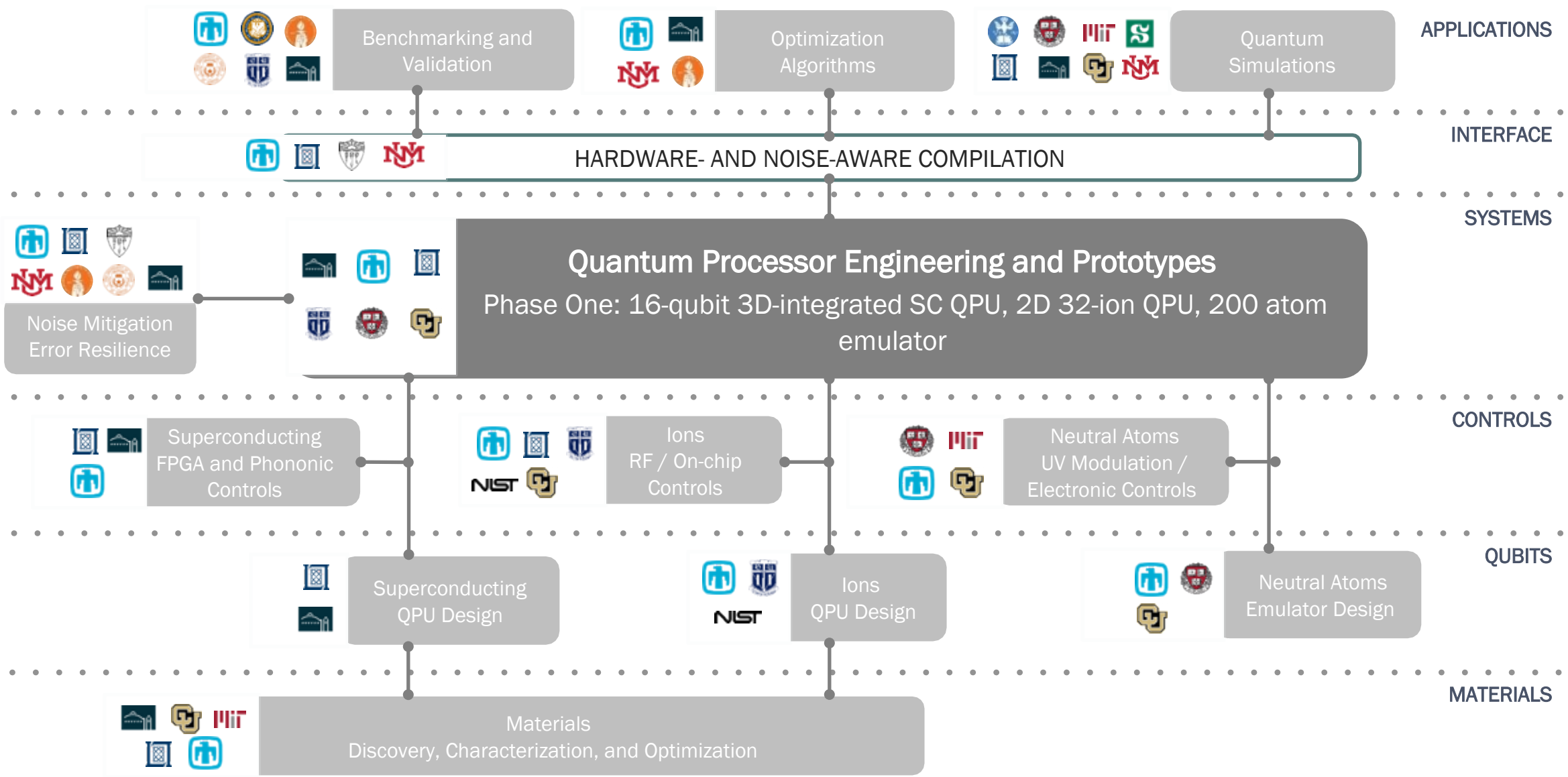
Catalyzing the Quantum Ecosystem




BERKELEY LAB · Sandia National Laboratories · Berkeley · MIT · Caltech · HARVARD UNIVERSITY · Duke UNIVERSITY · Boulder · THE UNIVERSITY of NEW MEXICO · UNIVERSITY OF MARYLAND · Tufts UNIVERSITY · THE UNIVERSITY OF TEXAS AT AUSTIN · USC · UNIVERSITÉ DE SHERBROOKE

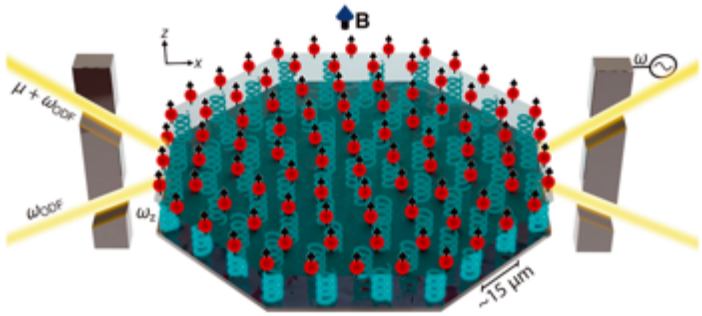
Catalyzing **national leadership** in quantum information science to co-design the algorithms, quantum devices, and engineering solutions needed to deliver certified quantum advantage in Department of Energy scientific applications.

# Center Approach: Co-Design Across the Stack



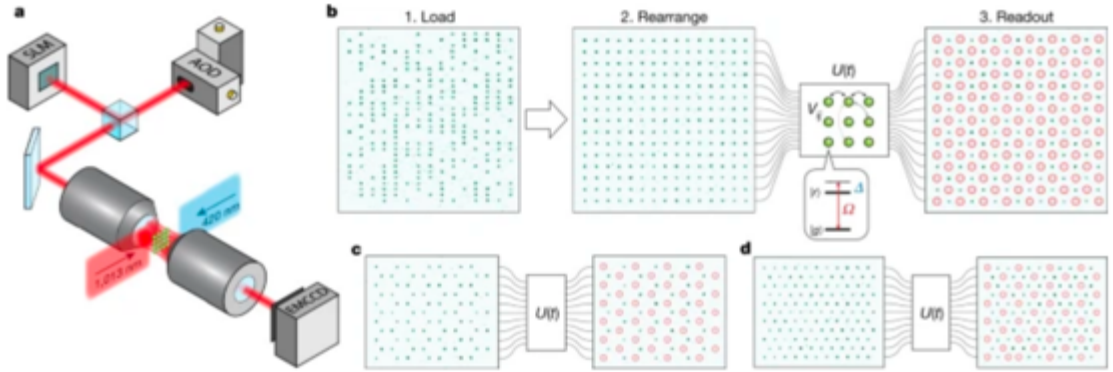
# Science Emerging from the QSA

## Quantum-enhanced sensing of displacements and electric fields with two-dimensional trapped-ion crystals



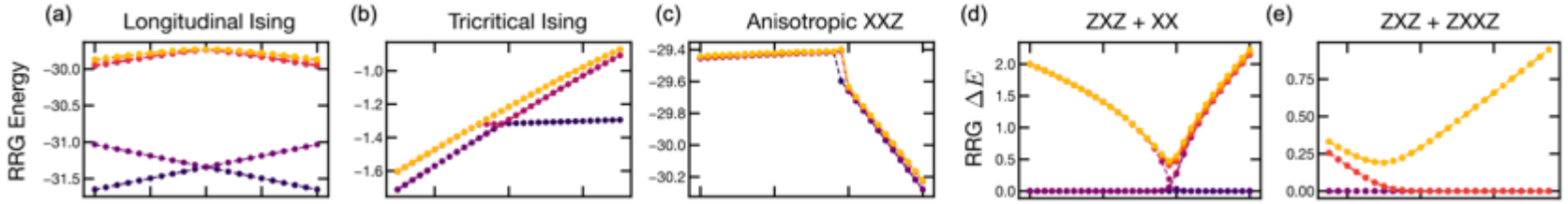

Gilmore *et al.*, Science 373, 6555

## Quantum phases of matter on a 256-atom programmable quantum simulator




Ebadi *et al.*, Nature 595, 227–232

## Performance of the rigorous renormalization group for first-order phase transitions and topological phases

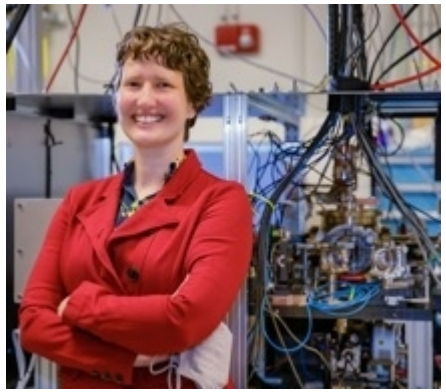



Block *et al.*, Phys. Rev. B 103, 195122

# Thank you

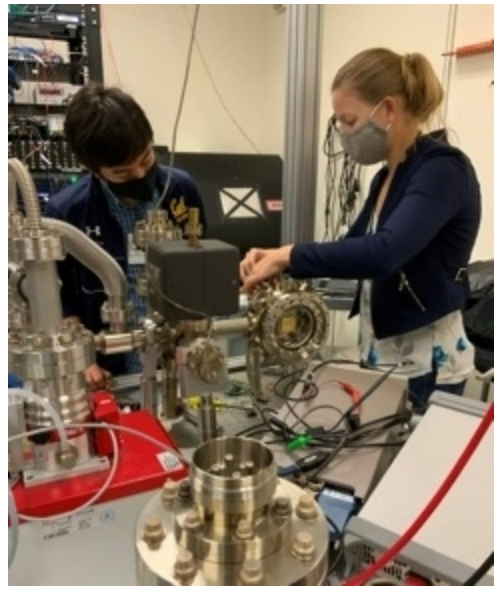
**Email:** qscout@sandia.gov (mailing list) **Web:** https://qscout.sandia.gov **Jaqal:** https://gitlab.com/jaqal/jaqalpaq

## *QSCOUT Experimental Team*









***Experimental Team***
Susan Clark, PI
Christopher Yale
Dan Lobser
Melissa Revelle
Ashlyn Burch
Matt Chow
Craig Hogle
Megan Ivory
Peter Maunz
Dan Stick
Andrew Van Horn
Josh Wilson

***Mechanical & Optical Engineering***
Brad Salzbrenner
Madelyn Kosednar
Jessica Pehr
Ted Winrow
Bill Sweatt
Dave Bossert

***Theory & Software Team***
Andrew Landahl
Ben Morrison
Tim Proctor
Kenny Rudinger
Antonio Russo
Brandon Ruzic
Jay Van Der Wall
Josh Goldberg
Kevin Young
Collin Epstein

***Trap Fabrication and Packaging***
Matt Blain
Ed Heller
Jason Dominguez
Chris Nordquist
Ray Haltli
Tipp Jennings
Ben Thurston
Corrie Sadler
Becky Loviza
John Rembetski
Eric Ou
Matt Delaney

***Collaborators***
Ken Brown, Duke
Peter Love, Tufts
Oliver Maupin, Tufts

# Thank you!

AQT

QUANTUM SYSTEMS ACCELERATOR

Catalyzing the Quantum Ecosystem

Berkeley Lab · Sandia National Laboratories · Berkeley · MIT · Caltech · Harvard University · Duke University · Boulder · The University of New Mexico · University of Maryland · Tufts University · The University of Texas at Austin · USC · Université de Sherbrooke