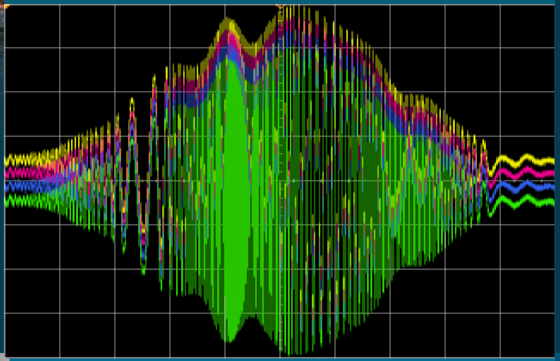
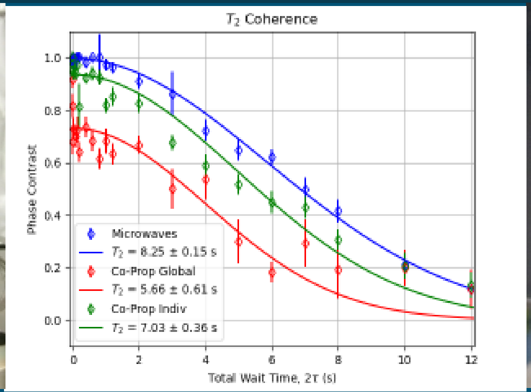
SAND2021-12825C

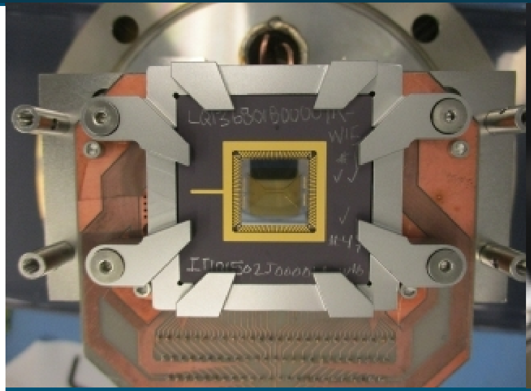
Sandia National Laboratories

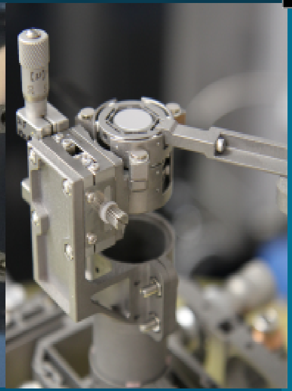
QSCOUT: A "White-Box" Quantum Testbed Based on Trapped Ions at Sandia National Laboratories



QSCOUT







U.S. DEPARTMENT OF ENERGY
Office of Science

PRESENTED BY

Susan Clark

U.S. DEPARTMENT OF ENERGY NNSA

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Quantum Scientific Computing Open User Testbed (QSCOUT)

U.S. DEPARTMENT OF ENERGY
Office of Science

Sandia National Laboratories

QSCOUT

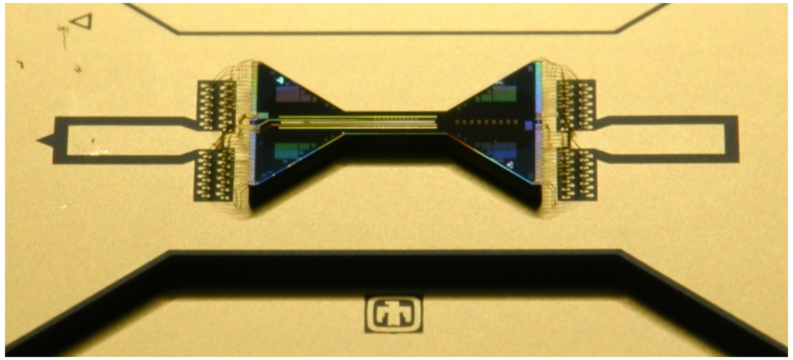
qscout.sandia.gov
qscout@sandia.gov

A quantum computing testbed based on trapped ions for the greater quantum scientific community

QSCOUT grants low-level access to quantum machines for free to researchers around the world to study their proposed research.

QSCOUT goals:

- Greater understanding of how quantum machines work (and fail)
- Study new techniques for encoding and compiling quantum circuits
- Construct a roadmap for building larger, more sophisticated machines



Learn more at IEEE Quantum Week:

- **Friday, October 22** Progress and Challenges in Quantum Intermediate Representations: Classical Control and Feedback Panel. Andrew Landahl will speak about Jaqal, the programming language for interacting with QSCOUT
- **Friday, October 22** Advancing the Performance of Engineered Trapped-Ion Quantum Systems. All-day workshop about trapped-ion quantum computing systems

Need quantum hardware accessible to as many people as possible
3 Tiers of accessibility:

QSCOUT

Industry

Works at maximum efficiency but more difficult to study how machine works

IONQ

rigetti

IBM

Honeywell

Open Quantum Testbeds

Versatile and configurable, but less optimized for performance

QSCOUT

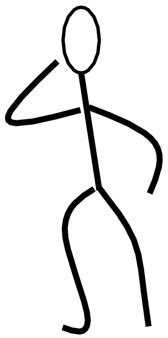
Sandia National Laboratories

AQT

BERKELEY LAB

Build your own

Total control, but expensive and difficult to build

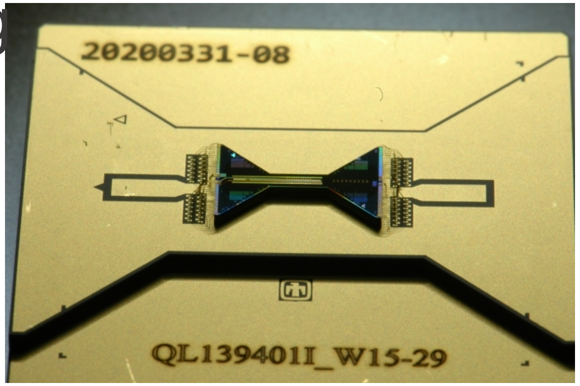


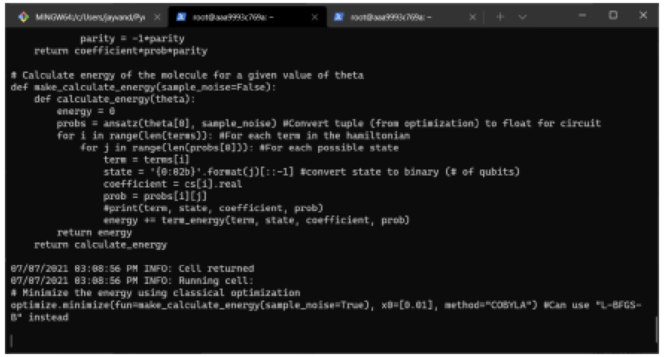
Low-level control →

← Ease of access

Quantum systems engineering

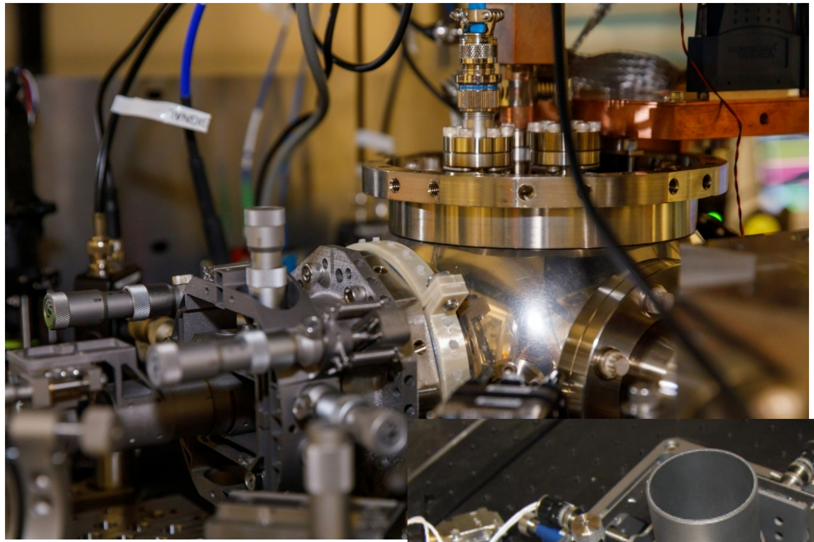
QSCOUT

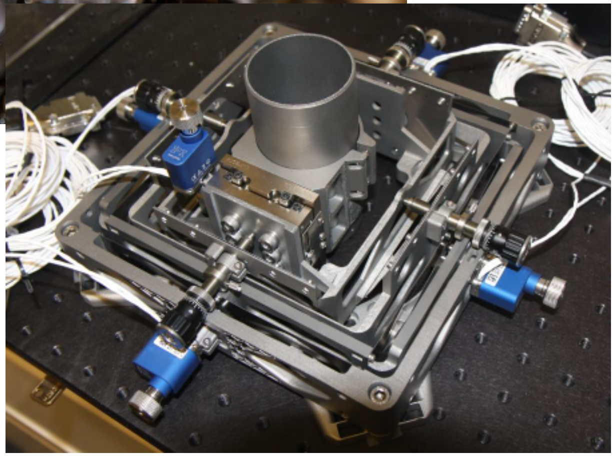


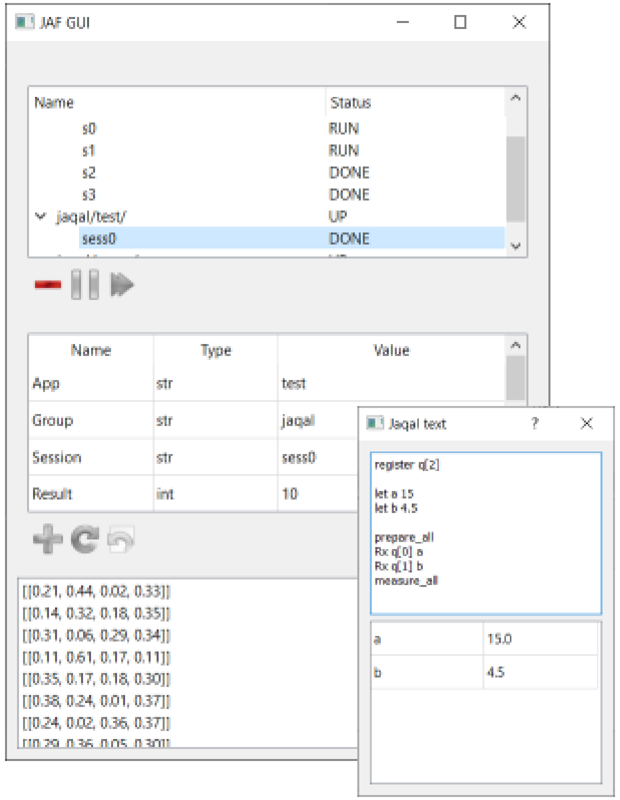


Complete quantum systems development requires:

- Physicists
- Fabrication specialists
    - RF electronics engineers
    - Electrical engineers
    - Materials scientists
- Mechanical engineers
- Optical engineers
- Software engineers
- And more!







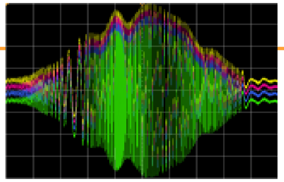
For running useful circuits, needed to bring 5 major capabilities to Sandia

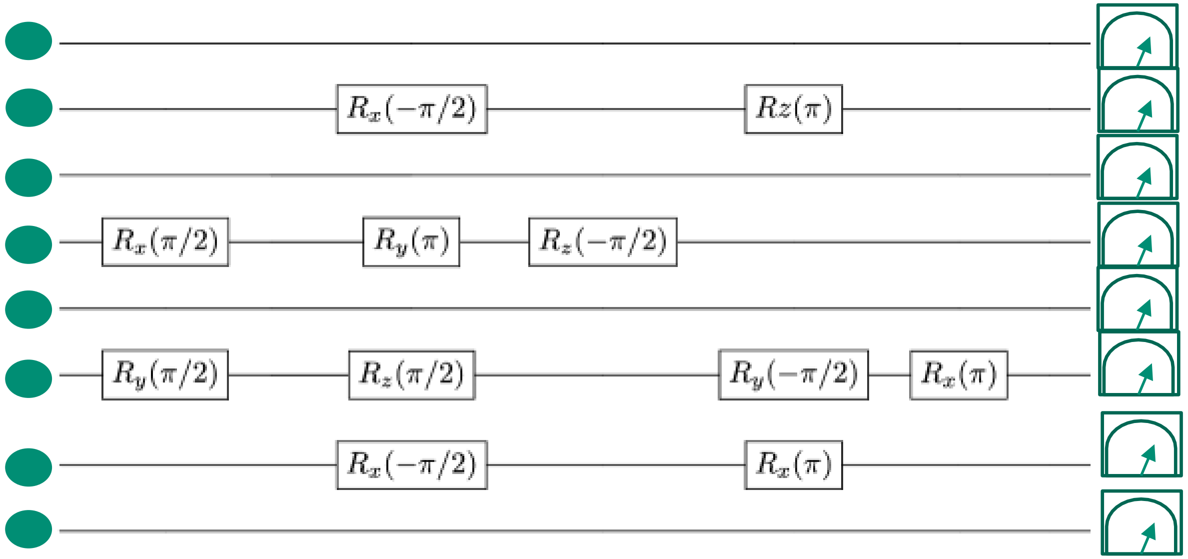
Multiple ion techniques

Individually address ions or pairs of ions

A quantum assembly language to specify gates

New hardware for advanced pulse/gate generation



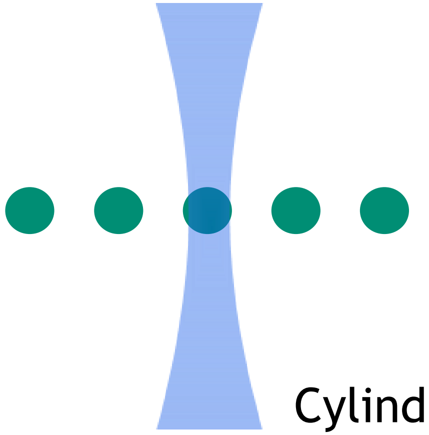


Distinguishable detection of each ion (*which* ion is in 1 or 0)

"Engineering QSCOUT, design details and user guide." Susan Clark et al. https://arxiv.org/abs/2104.00759

Individual ion addressing, non-trivial optics problem

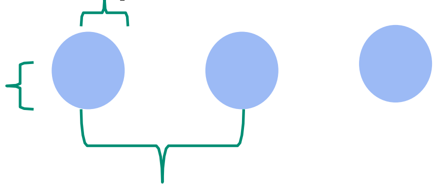
QSCOUT



Out of AOM

80 µm

80 µm

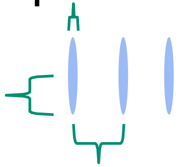


450 µm

At ion

0.8 µm

8 µm



4.5 µm

Cylindrical lens pair

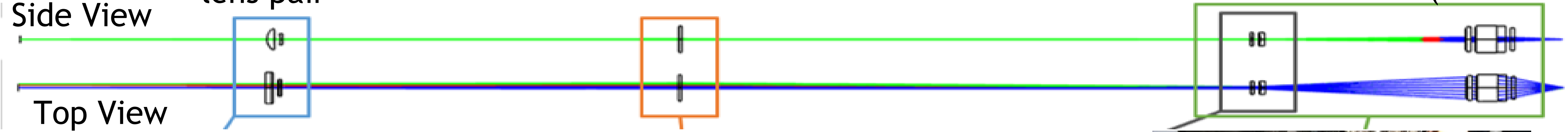
Spherical lens

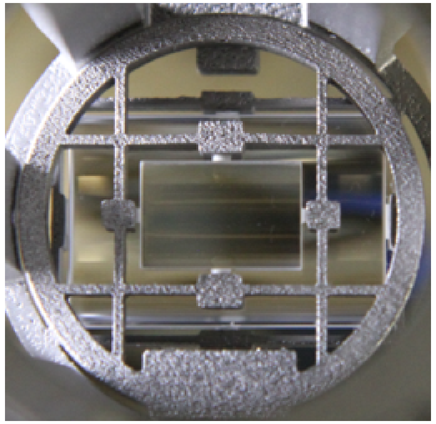
Spherical lens pair

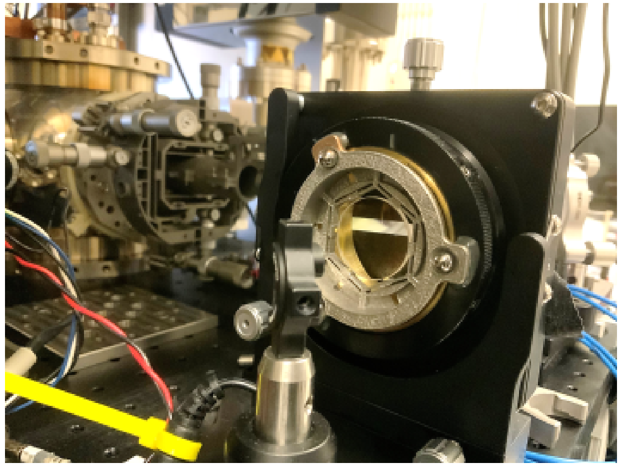
Custom imager (Photon Gear)

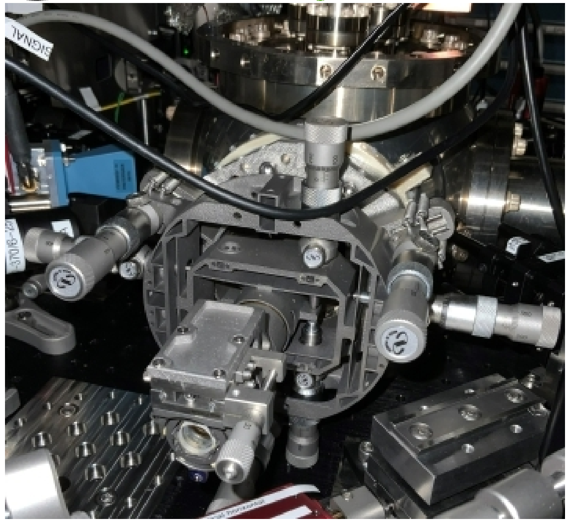
Side View

Top View









A new quantum programming language: Jaqal

QSCOUT

Jaqal

JAQAL

The quantum part

```
register q[2]

prepare_all
hadamard q[0]
cnot q[1] q[0]
measure_all
```

JaqalPaq:

https://gitlab.com/jaqal/jaqalpaq

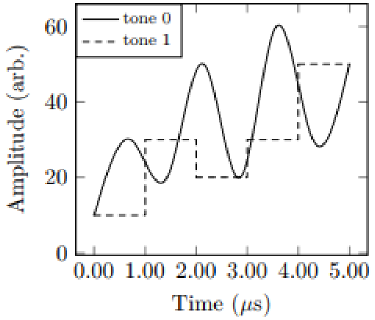
Meta programming with python, emulator, transpiliers

```
JaqalCircuitObject = parse_jaqal_file("jaqal/Sxx_circuit.jaqal")
JaqalCircuitResults = run_jaqal_circuit(JaqalCircuitObject)
print(f"Probabilities: {JaqalCircuitResults.subcircuits[0].probabil
JaqalProgram = generate_jaqal_program(JaqalCircuitObject)
```

JaqalPaw

Pulse level control

```
def gate_G(self, qubit):
    spline_amps = (10,30,20,50,20,60,30,50)
    discrete_amps = [10,30,20,30,50]
    return [PulseData(qubit,
                      5e-6,
                      freq0=200e6,
                      freq1=230e6,
                      amp0=spline_amps,
                      amp1=discrete_amps)]
```



There are many programming languages out there. Why *another* one?

- Match needs of testbed: flexibility and control
- Specify parallel gates and loops (natural in our system)
- Other languages had operations we couldn't support, so we wanted to be upfront about it (and tailor it to track our capabilities)
- Pulse level control is intimately connected to hardware pulse generation

B. C. A. Morrison, *et al.*, "Just Another Quantum Assembly Language (Jaqal)," *2020 IEEE International Conference on Quantum Computing and Engineering (QCE)*, 402-408 (2020

Engaging with universities, National Labs, and private companies

QSCOUT

Round 1

- The University of New Mexico
- Indiana University Bloomington
- Oak Ridge National Laboratory
- IBM
- Berkeley University of California

Round 2

- Johns Hopkins Applied Physics Laboratory
- IBM
- Super.Tech
- LCN London Centre for Nanotechnology
- Lawrence Livermore National Laboratory — Science & Technology on a Mission
- Indiana University Bloomington

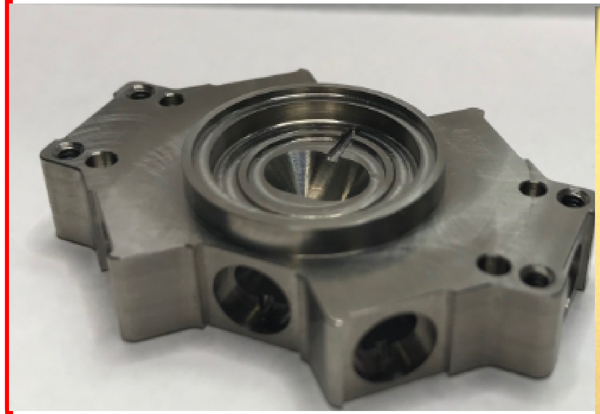
Collaboration works both ways!

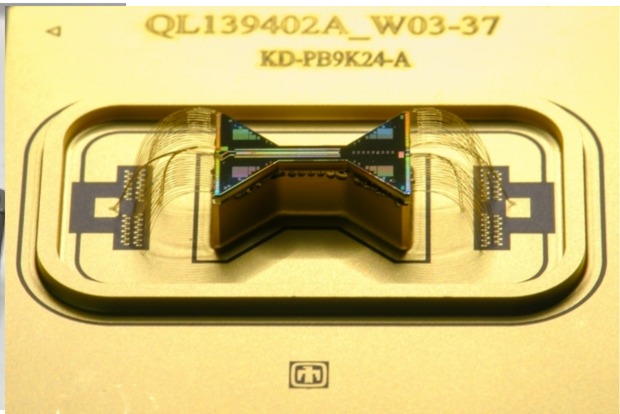
- Requests from users allowed us to rethink some calibrations and overall make the system better
- Requests from users show us new ways to break the system!

Future upgrades: more ions, partial measurements

QSCOUT 1.0 (current)	QSCOUT 1.1 (10 ion goal) 10/2021	QSCOUT 2.0 (cryo) 8/2022	QSCOUT 1.2 (Mid-Circuit Measurements) 2/2023	Beyond QSCOUT >9/2023
3 ions	5-11 ions	>10 ions	>10 ions	QSA 32 ion machine

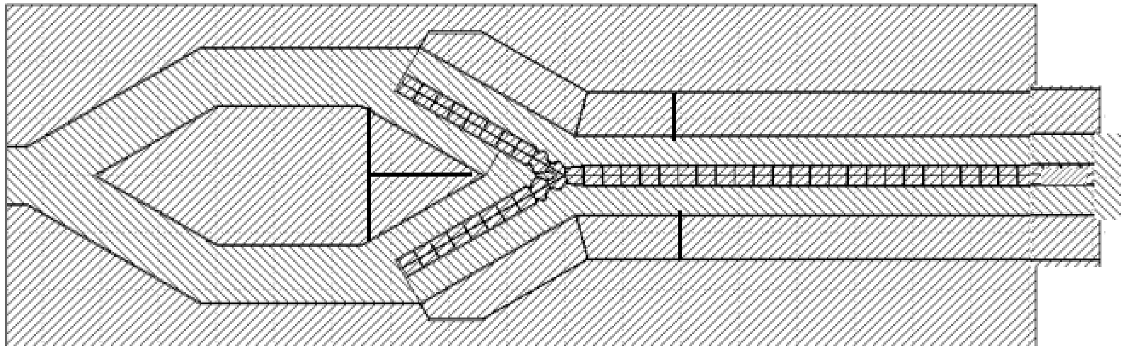
Cryo, *under development*
(better ion lifetime,
less ion heating = higher fidelity gates)





Cold Quanta

New trap design for re-ordering ions, enables mid-circuit measurements



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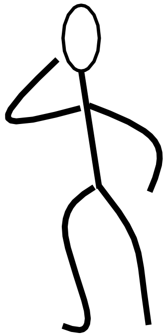
QSCOUT
Sandia National Laboratories
AQT
BERKELEY LAB

Build your own

Total control,
but expensive and
difficult to build

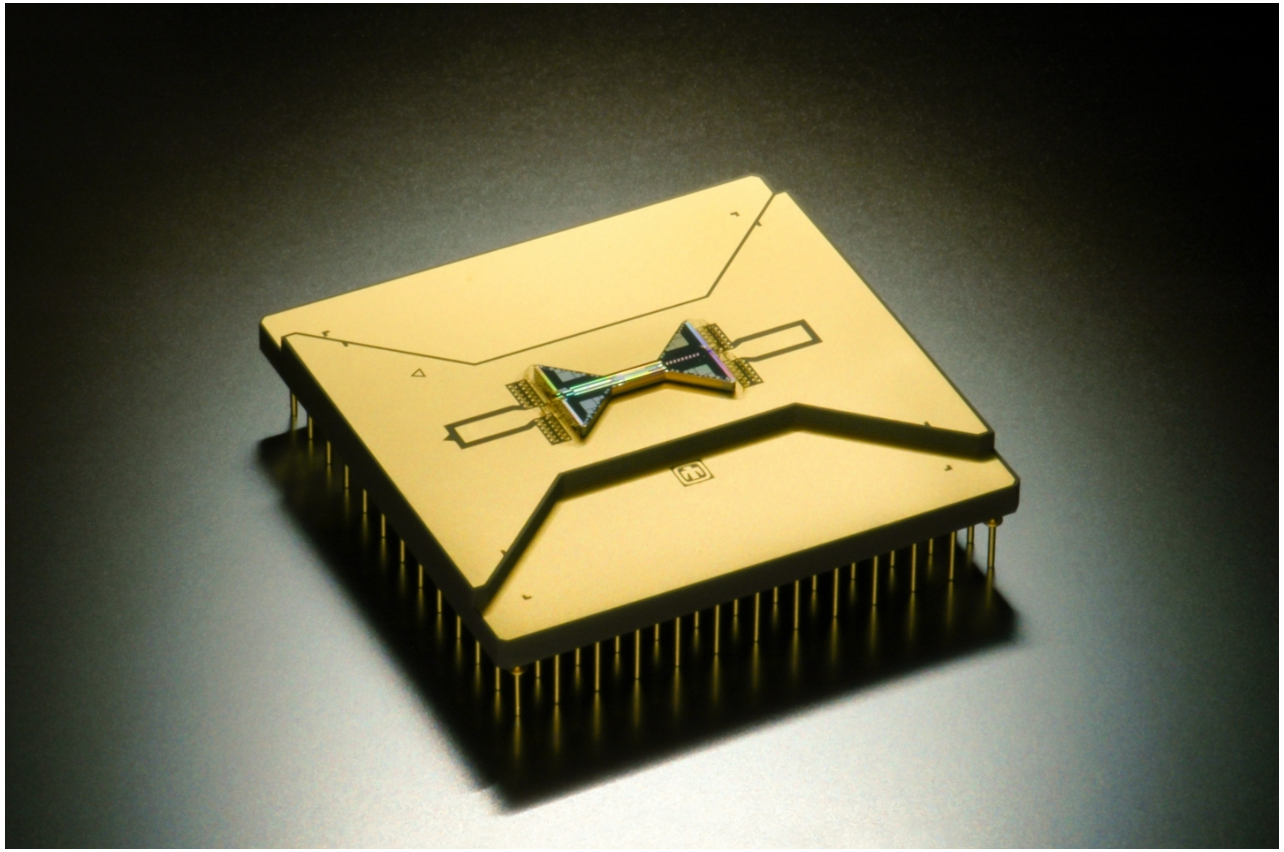


Low-level control →

← Ease of access

Sandia surface ion traps for research

100 pin package standard



Currently demand exceeds supply

Wish list 1: **Large, broad program that would get Sandia traps to more users**

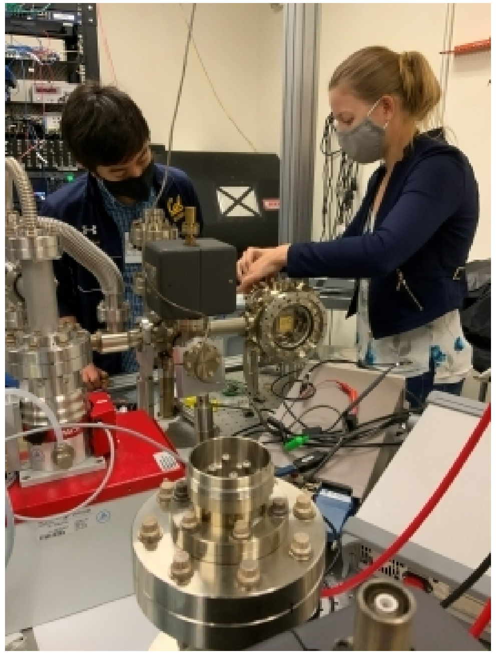
- Traditional ion trapping groups
- New ion trapping groups
- Hybrid quantum systems
- Quantum networking applications

Wish list 2: **Give a complete vacuum system to outside groups**

Getting involved, more information

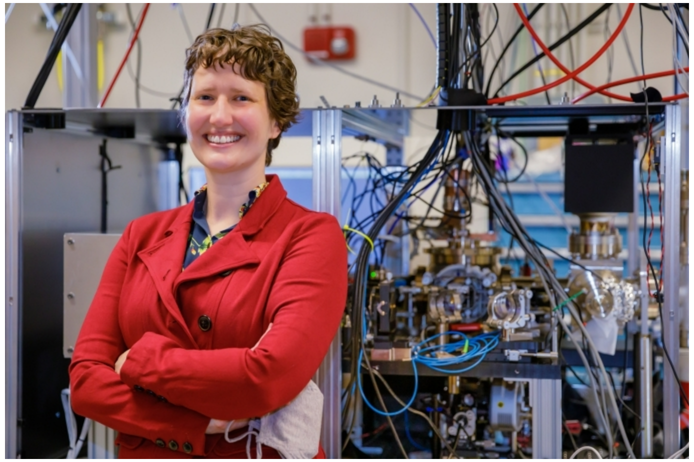
Email: qscout@sandia.gov to be added to mailing list
Website: https://qscout.sandia.gov
Jaqal: https://gitlab.com/jaqal/jaqalpaq

QSCOUT



Melissa Revelle and Matt Chow

Ray Haltli and Josh Wilson



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