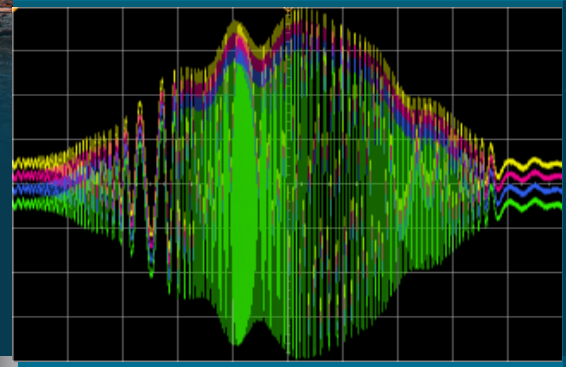
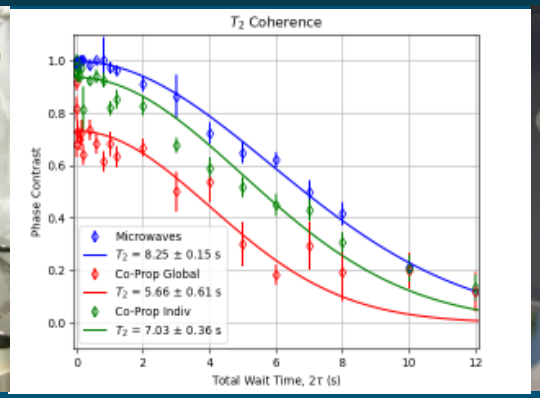
SAND2022-1067C

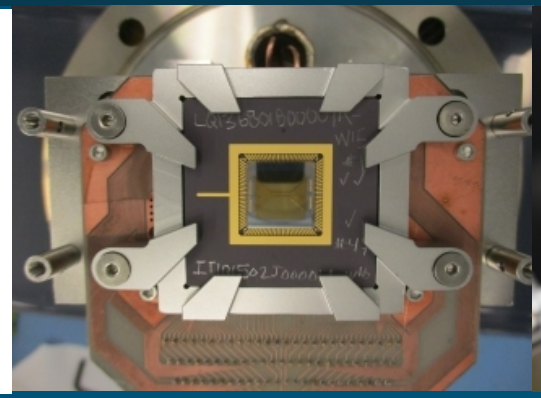
Sandia National Laboratories

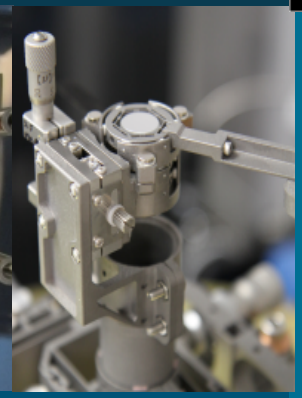


QSCOUT

The Quantum Scientific Computing Open User Testbed (QSCOUT)
2/4/2022



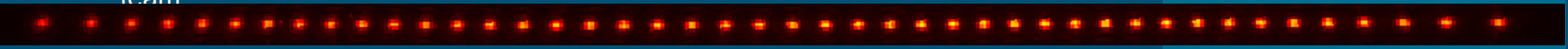




U.S. DEPARTMENT OF ENERGY
Office of Science

PRESENTED BY

Susan Clark and the QSCOUT team



U.S. DEPARTMENT OF ENERGY NNSA

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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

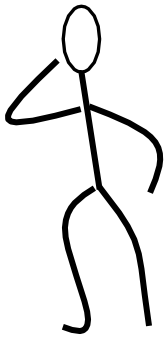
Sandia National Laboratories

AQT

BERKELEY LAB

Build your own

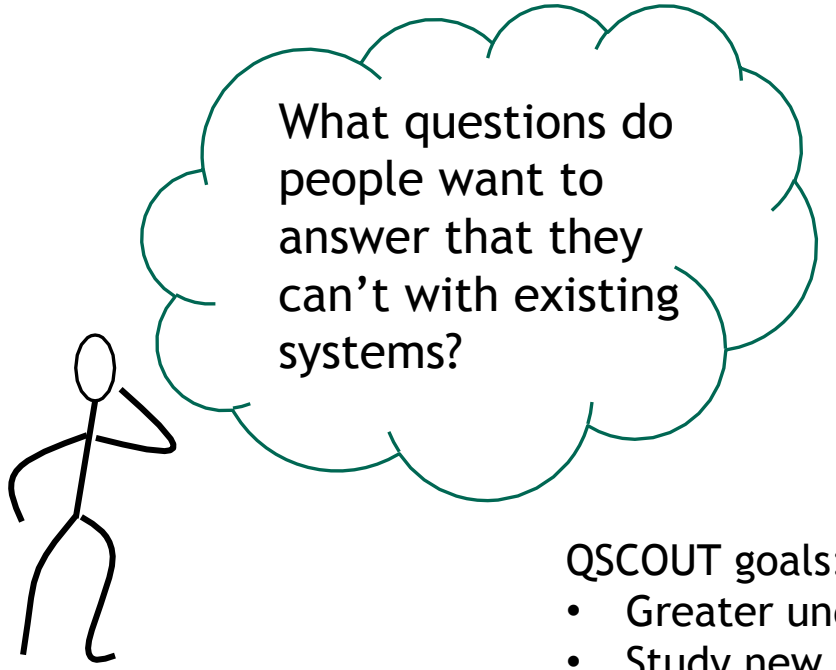
Total control, but expensive and difficult to build



Low-level control

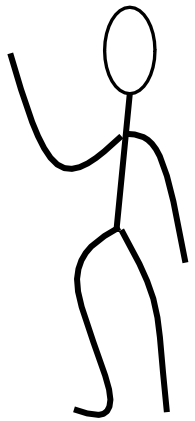
Ease of access

DOE Testbeds are excellent for problems that leverage low-level access



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

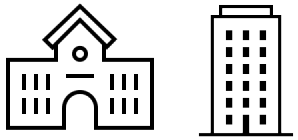


QSCOUT users are chosen via a competitive proposal process

QSCOUT

U.S. DEPARTMENT OF ENERGY
Office of Science

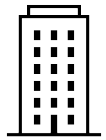
Potential users submit proposals



https://qscout.sandia.gov: for more information on how to apply

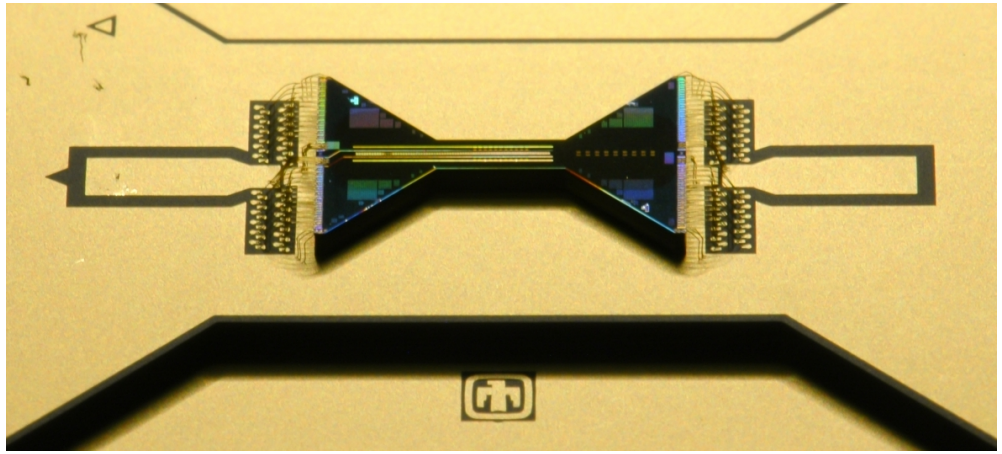
Sandia National Laboratories

Evaluated on technical merit

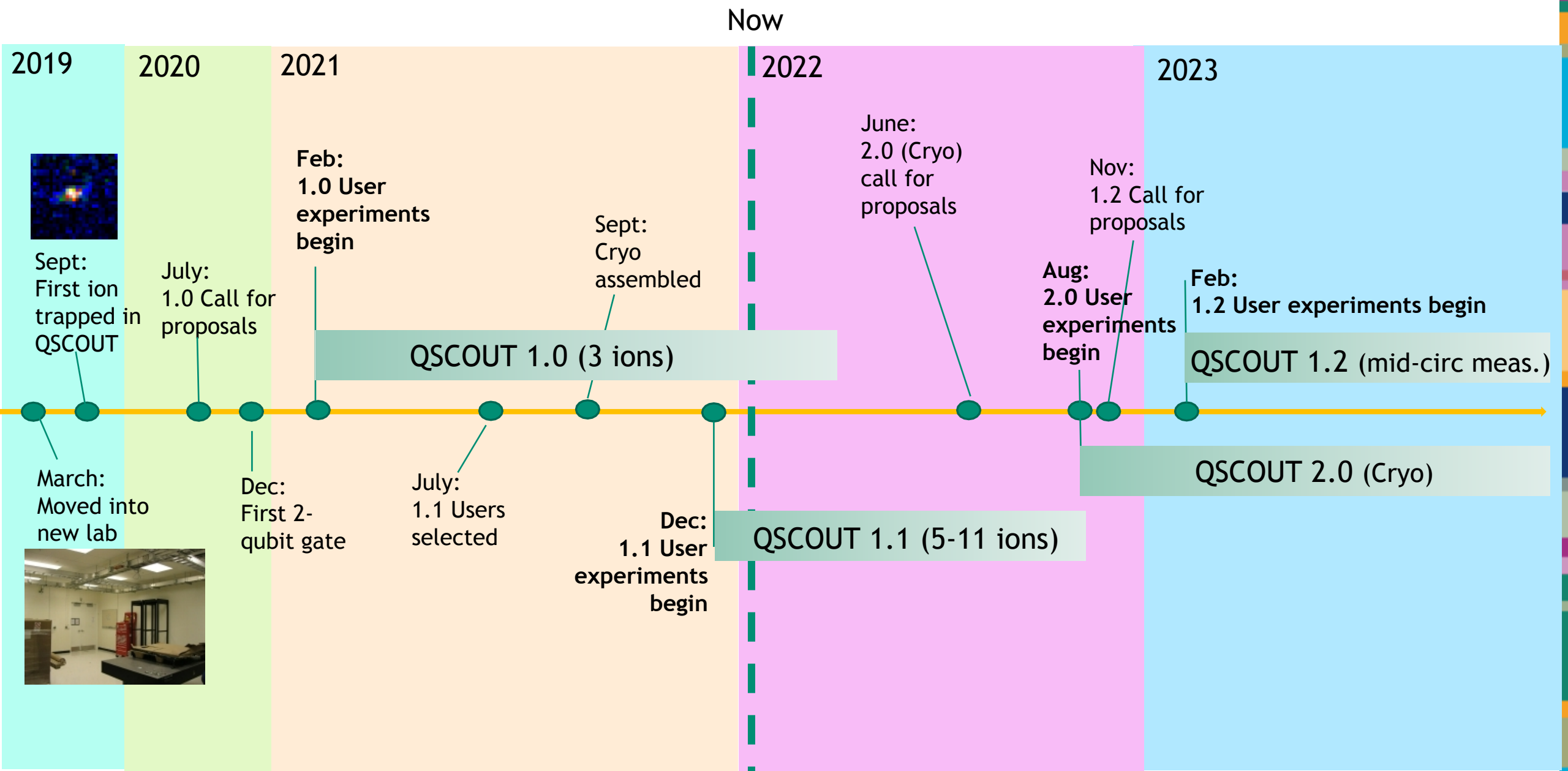


Successful proposals are run on the machine

Advance the field of quantum information



QSCOUT Timeline

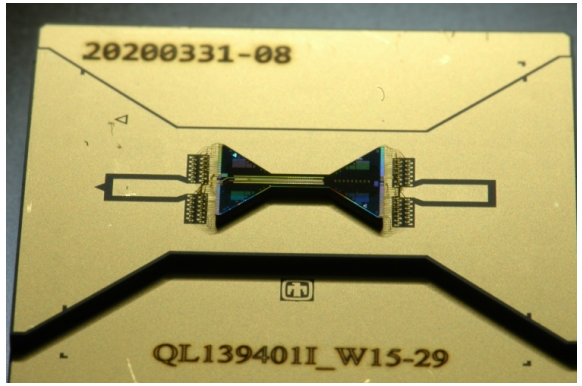


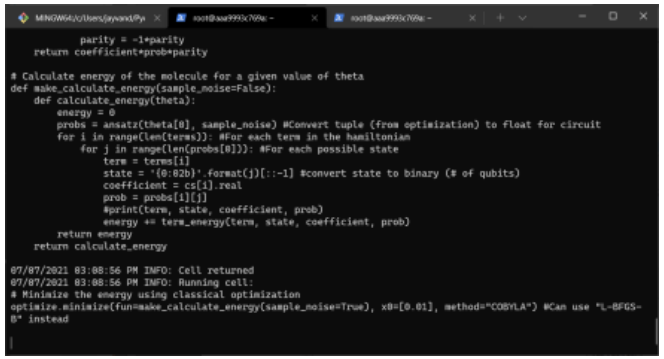
Quantum systems engineering requires a diverse skill set

QSCOUT

Complete quantum systems development requires:

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

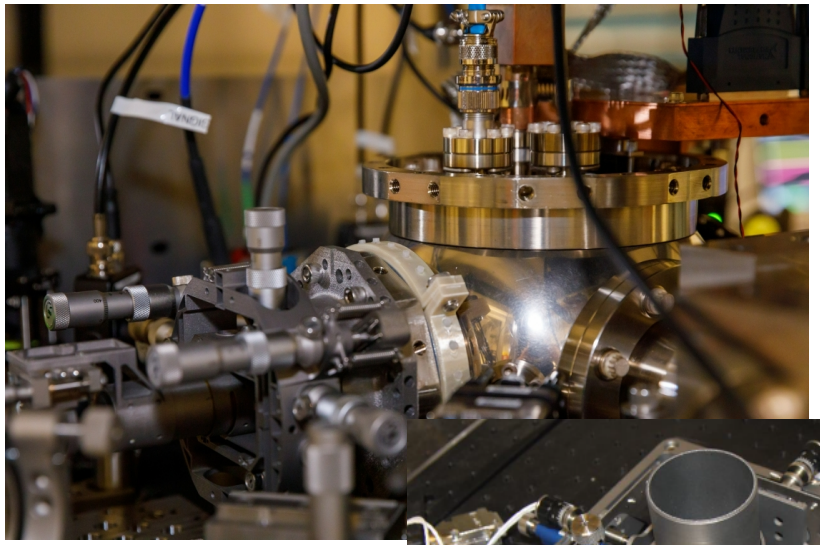


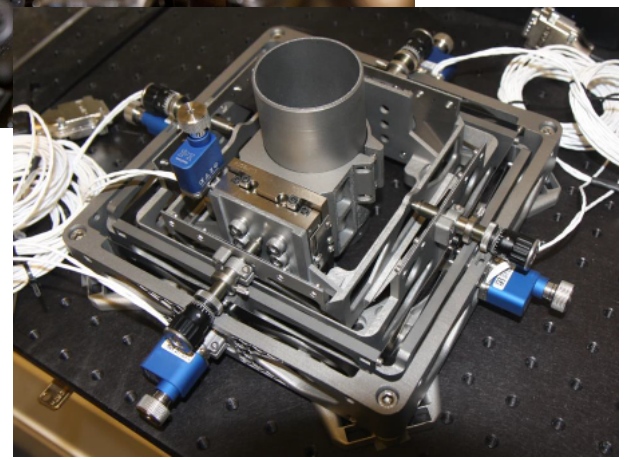


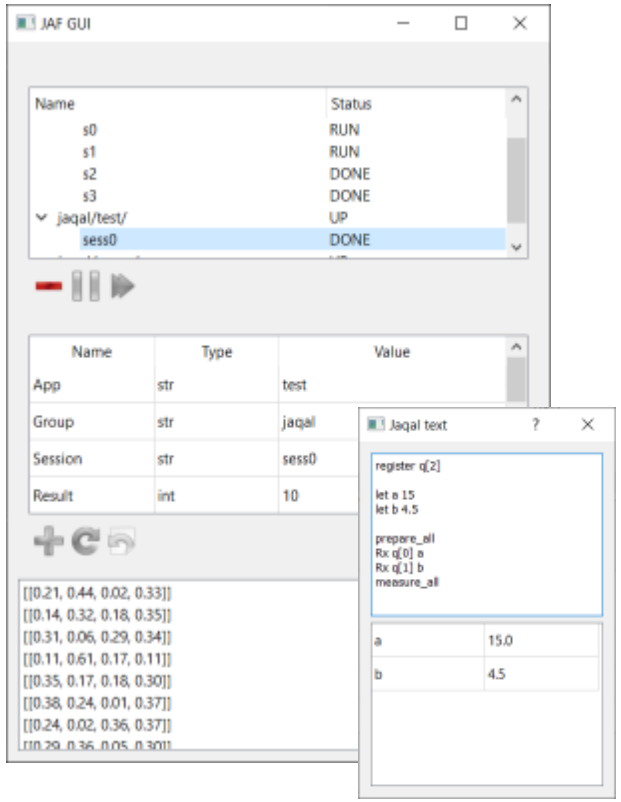
```
            parity = -1*parity
    return coefficient*prob*parity

# Calculate energy of the molecule for a given value of theta
def make_calculate_energy(sample_noise=False):
    def calculate_energy(theta):
        energy = 0
        probs = ansatz(theta[0], sample_noise) #Convert tuple (from optimization) to float for circuit
        for i in range(len(terms)): #For each term in the hamiltonian
            for j in range(len(probs[0])): #For each possible state
                term = terms[i]
                state = '{0:02b}'.format(j)[::-1] #convert state to binary (# of qubits)
                coefficient = cs[i].real
                prob = probs[1][j]
                #print(term, state, coefficient, prob)
                energy += term_energy(term, state, coefficient, prob)
        return energy
    return calculate_energy

07/07/2021 03:08:56 PM INFO: Cell returned
07/07/2021 03:08:56 PM INFO: Running cell:
# Minimize the energy using classical optimization
optimize_minimize(fun=make_calculate_energy(sample_noise=True), x0=[0.01], method="COBYLA") #Can use "L-BFGS-
B" instead
```







National Labs are a great environment

A new quantum programming language for flexibility and control: Jaqal

QSCOUT

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

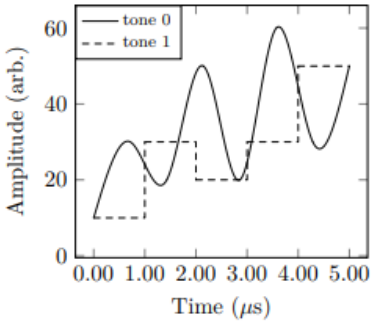
Meta programming with python, emulator, transpiliers

```
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 Jaqal for QSCOUT?

- **Transparency:** Fully specify native gates
- **Schedulability:** Full control of sequential and parallel execution of quantum gates
- **Extensibility:** Pulse level control of laser gates (intimately tied to hardware)

B. C. A. Morrison, *et al.*, "Just Another Quantum Assembly Language (Jaqal)," *2020 IEEE International Conference on Quantum Computing and Engineering (QCE)*, 402-408 (202

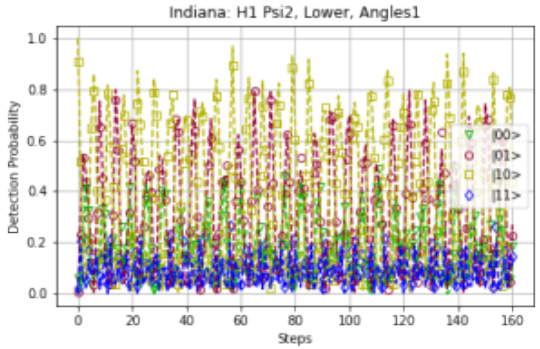
How have users interacted with low-level access?

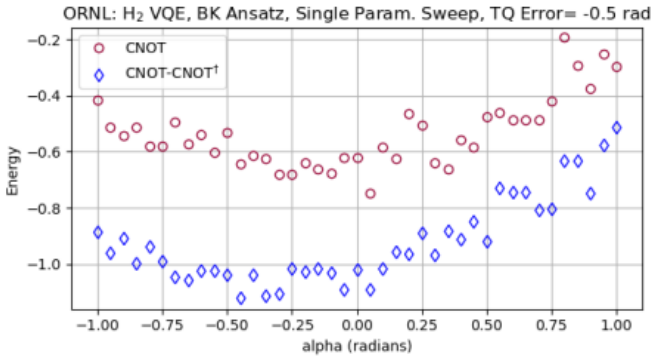
QSCOUT

- We offer single qubit rotations about any axis of any angle
- We offer “small-angle” two-qubit gates, which have higher performance than CNOTs

INDIANA UNIVERSITY BLOOMINGTON

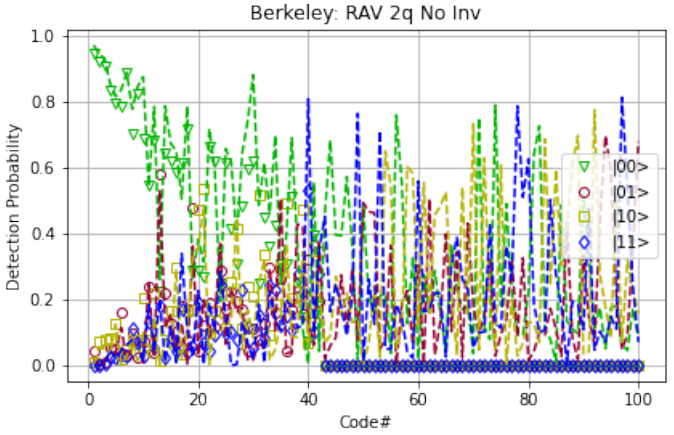
Used composite CNOT gates, which were added to our calibration routine.





OAK RIDGE National Laboratory

We were able to purposefully introduce noise and miscalibration to test robustness

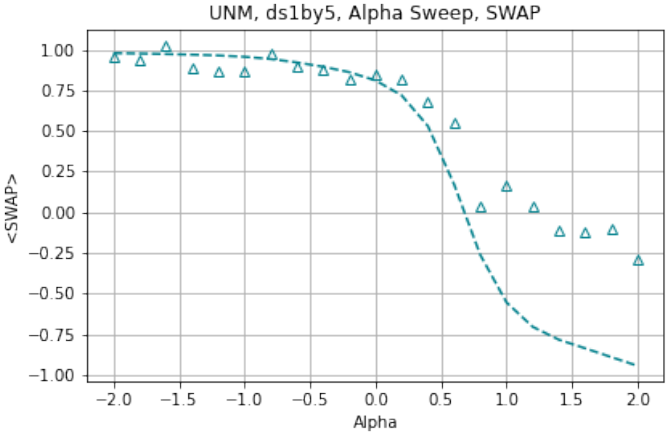


Berkeley UNIVERSITY OF CALIFORNIA

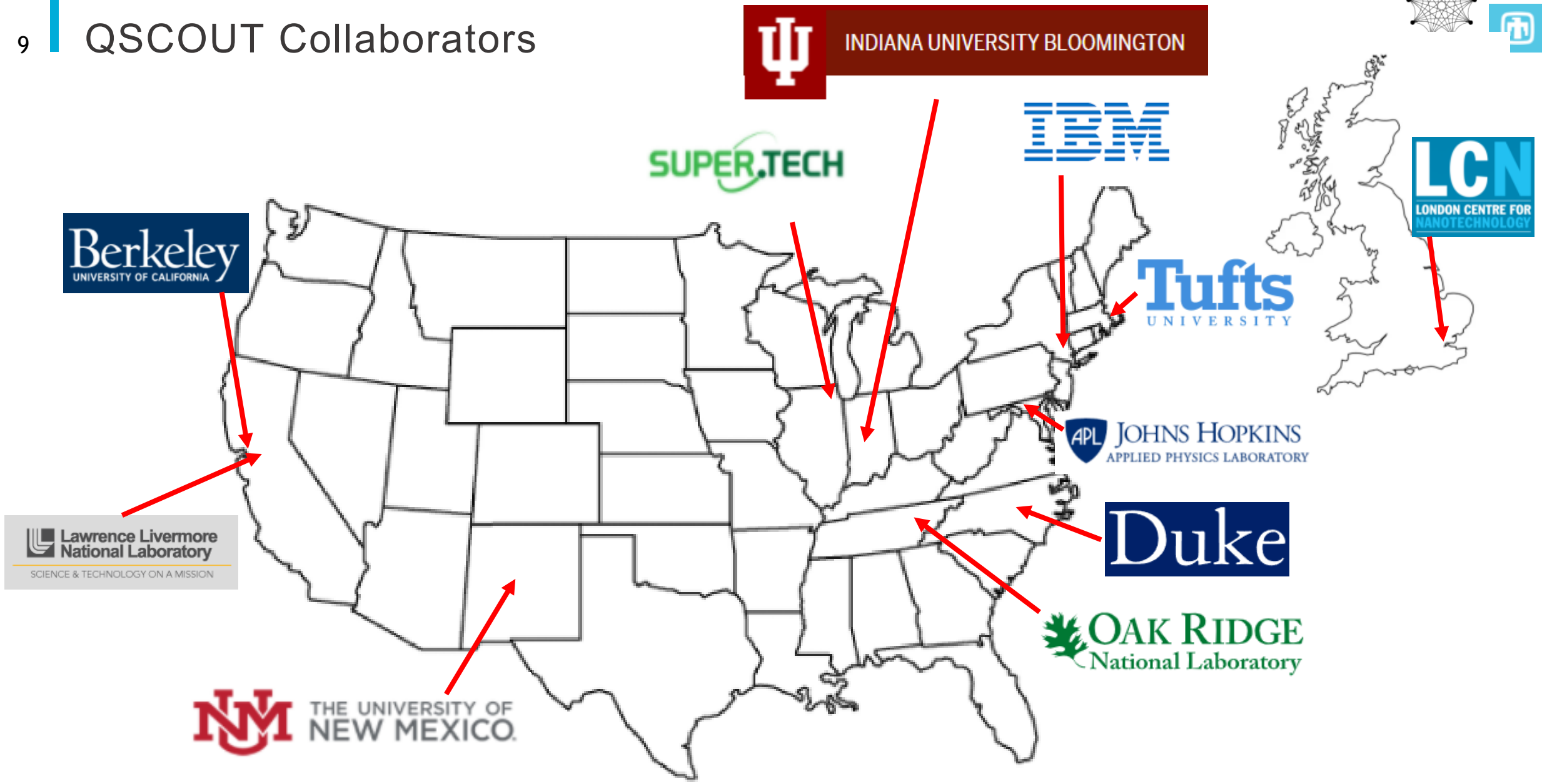
Analog benchmarking > 1000 unique gates (axes and angles)

THE UNIVERSITY OF NEW MEXICO

Used variable “small-angle” gates to test different amounts of Trotterization



QSCOUT Collaborators

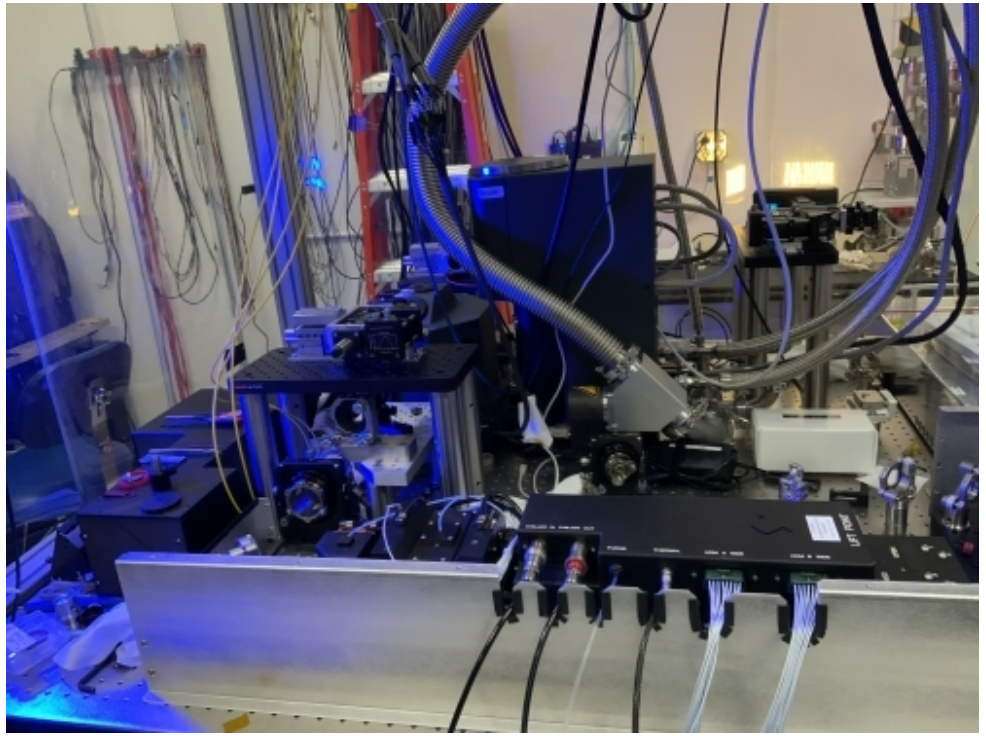


Upcoming dates:

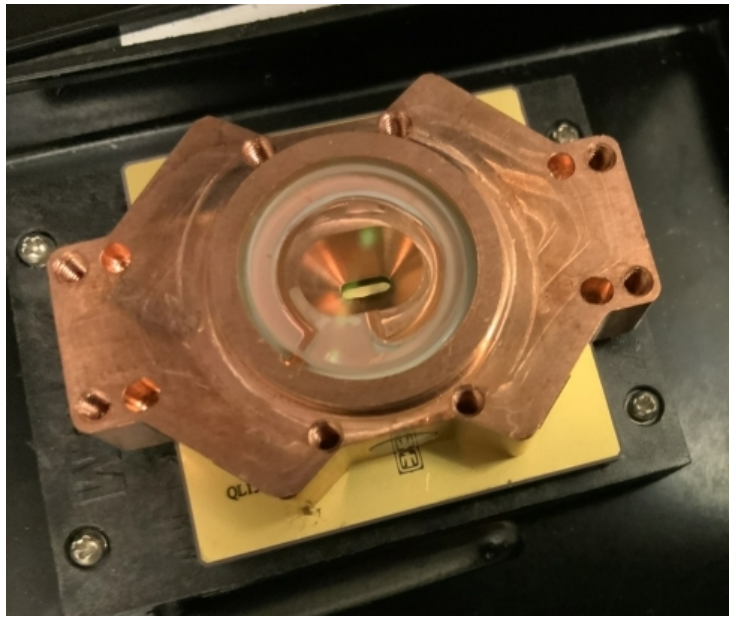
qscout@sandia.gov: to be added to the mailing list to be notified

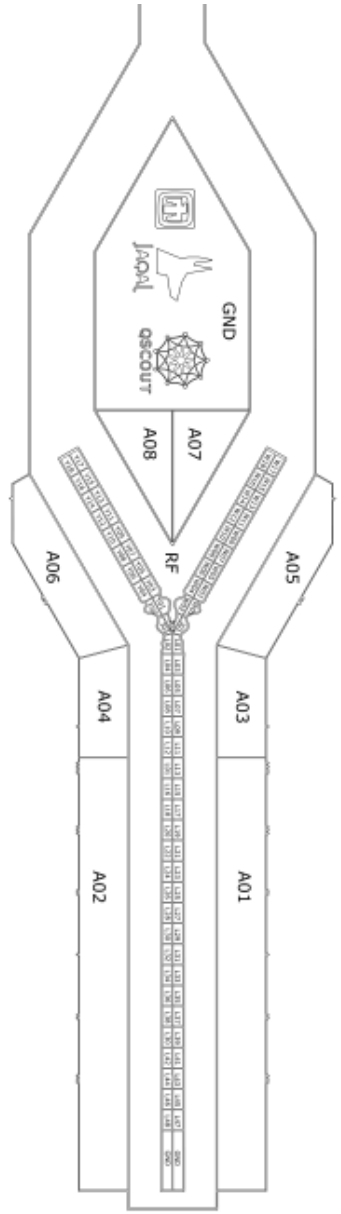
https://qscout.sandia.gov: check for application information

March 2022	June 2022	Aug 2022	Nov 2022	Feb 2023
Round 1 Users Exchange Meeting	**Call for proposals:** Cryogenic system	Cryogenic experiments begin	**Call for proposals:** Mid-circuit measurements	Mid-circuit measurement experiments begin



Cryogenic System



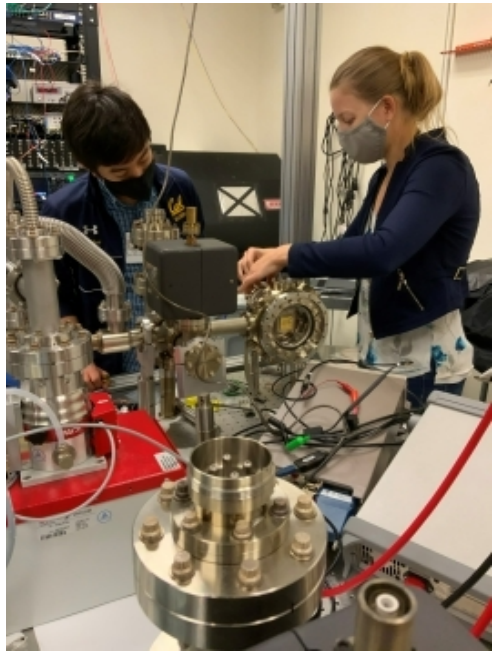


New Y-Trap, Out of Fab March 2022

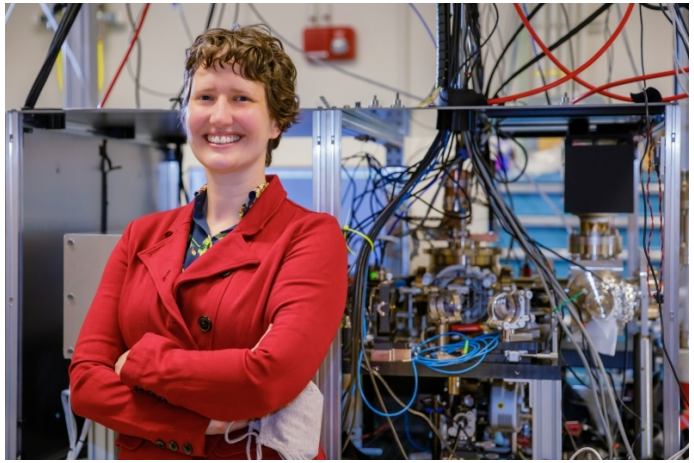
Ion reordering and protection

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



Melissa Revelle and Matt Chow



Ray Haltli and Josh Wilson

Susan Clark
Ashlyn Burch
Matt Chow
Craig Hogle
Megan Ivory
Dan Lobser
Melissa Revelle
Dan Stick
Josh Wilson
Chris Yale

Brad Salzbrenner
Madelyn Kosednar
Ted Winrow
Bill Sweatt
Dave Bossert

Andrew Landahl
Ben Morrison
Tim Proctor
Kenny Rudinger
Antonio Russo
Brandon Ruzic
Jay Van Der Wall
Josh Goldberg
Kevin Young

Matt Blain
Ed Heller
Chris Nordquist
Ray Haltli
Tipp Jennings
Ben Thurston
Corrie Sadler
Becky Loviza
John Rembetski
Eric Ou
Matt Delaney