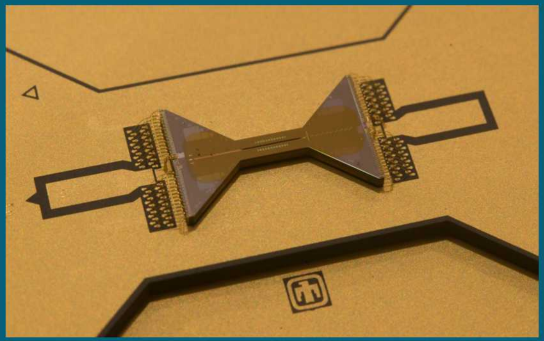
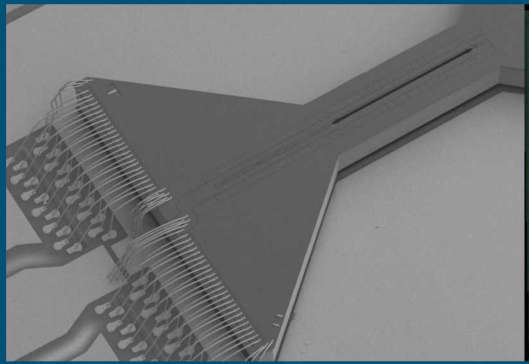
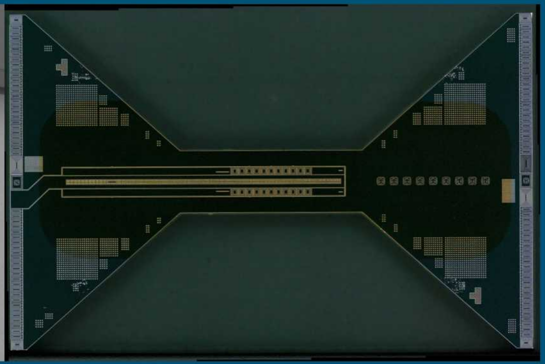
SAND2020-3059PE

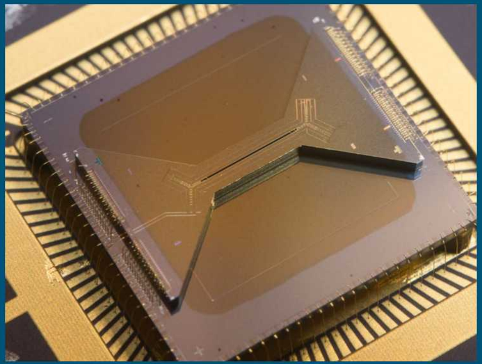
Quantum Testbed for Science:

Quantum Scientific Open User Testbed (QSCOUT)









QSCOUT

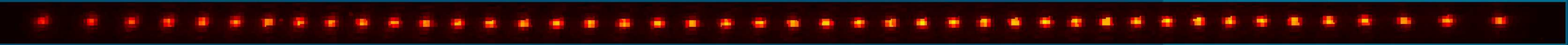
IARPA

BE THE FUTURE

PRESENTED BY

Peter Maunz, Matthew G. Blain, Susan M. Clark, Andrew Landahl, Daniel Lobser, Benjamin Morrison, Jessica M. Pehr, Melissa C. Revelle, Kenneth Rudinger, Antonio Russo, Brandon Ruzic, Christopher Yale

Sandia National Laboratories



https://qscout.sandia.gov https://qscout.us qscout@sandia.gov

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QSCOUT Quantum Scientific Open User Testbed

Testbed system from Scientists for Scientists

- Quantum processor optimized for and dedicated to scientific applications
- High-fidelity operations $\#gates \propto (\#qubits)^2$
- Gate-level access
- Open system with fully specified operations and hardware
- Low-level access for optimal control down to gate pulses
  - Open for comparison and characterization of gate pulses
  - Open for vertical integration by users
- Exemplar applications to demonstrate system capabilities
- User support by Sandia scientists
- User access via call for proposals

Tufts University

Peter Love et al.

Duke University

Ken Brown et al.

https://qscout.sandia.gov https://qscout.us qscout@sandia.gov

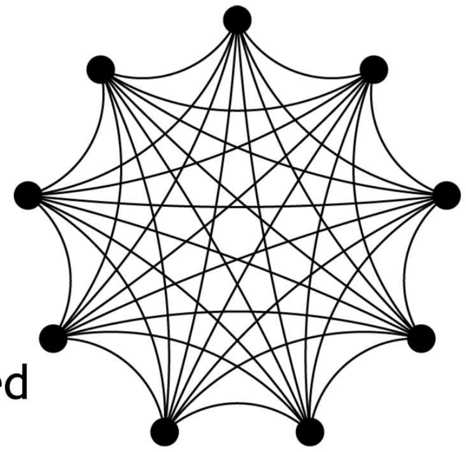
Trapped Ion Quantum Processors

Best available qubits with history of reliability and quality

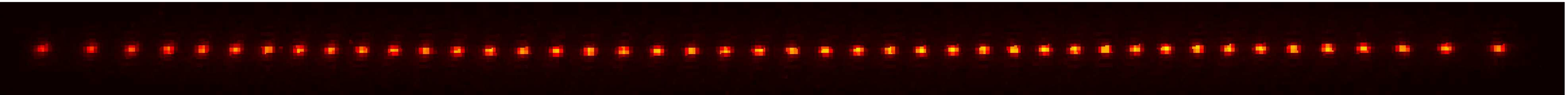
- Ions (qubits) are identical
- Near-ideal prep and measure
  - Error < 8×10^{-4}
- No idle errors (long coherence times)
  - Coherence time > 15min possible
- Lowest gate errors
  - Single-qubit error < 1×10^{-4}
  - Two-qubit error < 1×10^{-3}
- Single chain qubit registers demonstrated
- Low crosstalk

Reconfigurable in software

- Optimal for any application
- Change between quantum computer and quantum simulator is change in control
- All-to-All Connectivity
- Ideal for emulating other qubit systems



Trapped Ions:
fully connected

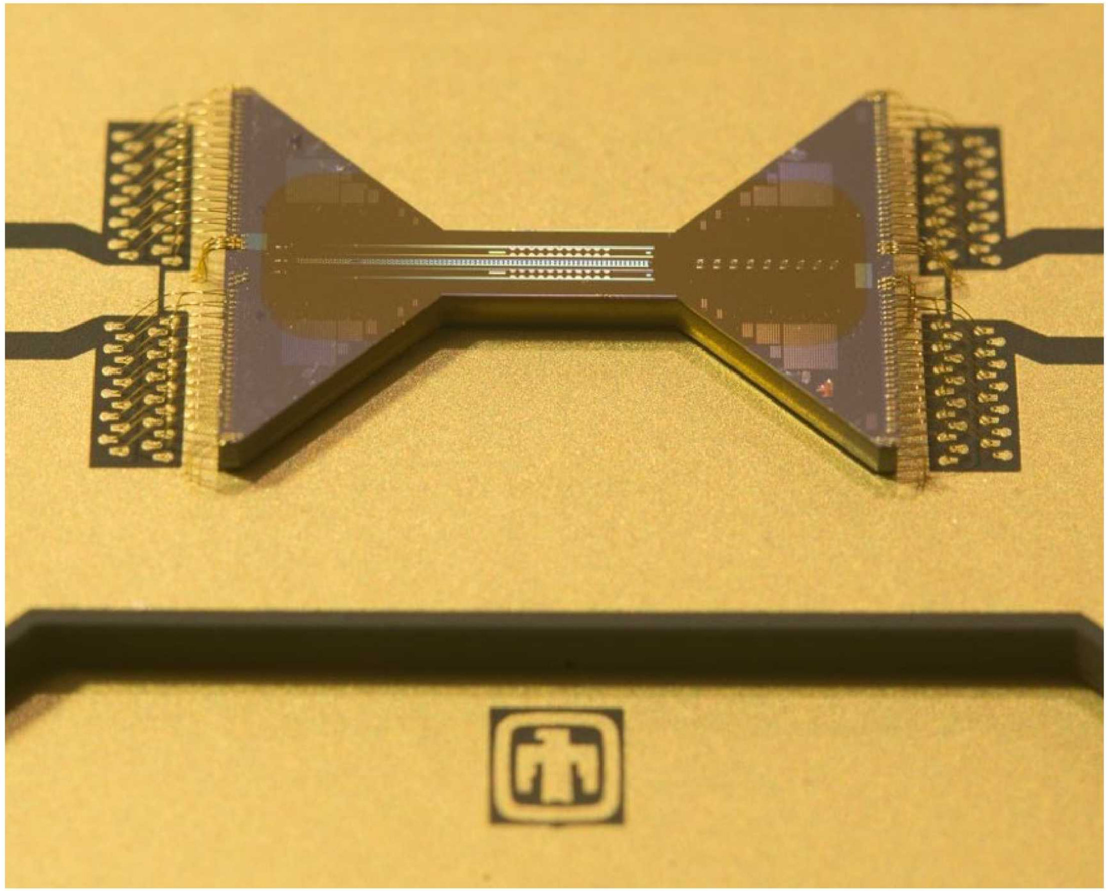


Quantum Computing Hardware

- Chain of ytterbium ions trapped in surface trap
- Qubits encoded in chain of $^{171}Yb^{+}$
- Hyperfine clock state qubits
- Quantum gates realized via Raman transitions induced by 355nm pulsed laser
- Individual addressing using 32-channel AOM
- Coherent pulses generated using RFSoC system
- Individual detection by imaging ion chain onto multi-mode fiber array

System envisioned for 1st stage

- Register of 3 qubits (Spring/Summer 2020)
- Parallel single qubit gates: 99.5% target fidelity
- Sequential two-qubit Mølmer-Sørensen gates between any pair: 98% target fidelity
- Gate-level access as well as pulse-level access to realize custom gates



Jaqal (Just Another Quantum Assembly Language)

Objectives

- **Extensibility:** Pulse definitions can be programmed to generate custom trapped-ion gates.
- **Transparency:** Full implementation specifications of the underlying native trapped-ion quantum gates.
- **Schedulability:** Users have full control of sequential and parallel execution of

```
let repeats 7

macro hadamard target { // A Hadamard gate can be implemented as
    Sy target           // a pi/2 rotation around Y
    Px target           // followed by a pi rotation around X.
}

macro cnot control target { // CNOT implementation from Maslov (2017)
    Sy control
    Sxx control target
    <Sxd control | Sxd target>  // we can perform these in parallel
    Sy control
}

register q[3]
usepulses builtin
map target q[0]
map control q[1]

prepare_all         // Prepare each qubit in the computational basis.
loop repeats {
    hadamard q[0]
    cnot q[1] q[0]
}
measure_all         // Measure each qubit and read out the results.
```

Circuit Emulator will be available

- Pure state evoluation as tool to debug quantum programs

Integration with other Quantum packages

- Cirq
- Qiskit
- Quil
- ProjectQ
- t|ket>
- Q#

https://qscout.sandia.gov/jaqal.html

Hardware approach

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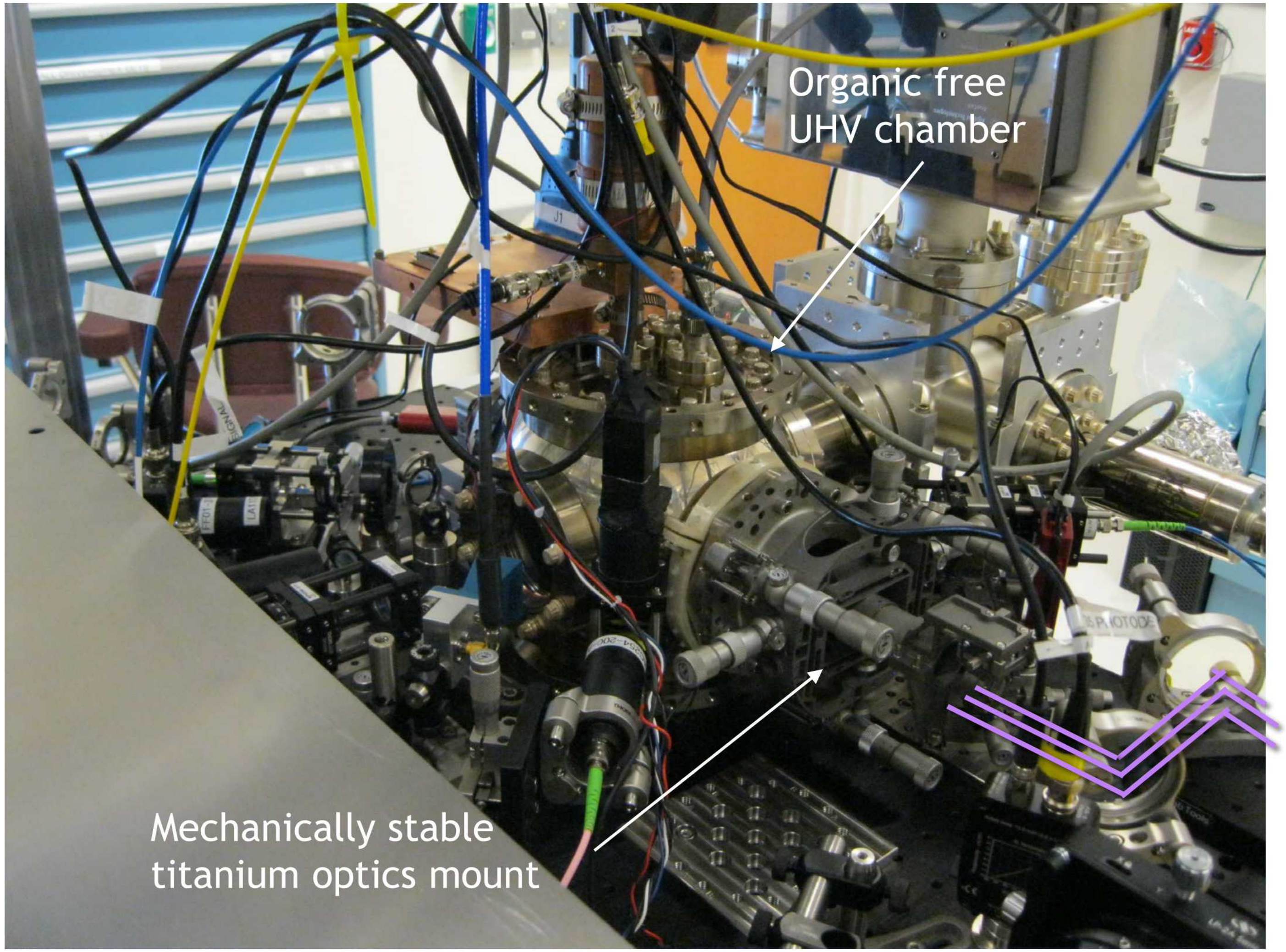
- Based on previous experience with single- and multi-qubit gates in micro-fabricated ion traps
- Improved design for stability
- Improved vacuum system
  - No organics
  - High temperature bake to reduce hydrogen load
- Interferometrically aligned imaging system to image 32-channel AOM onto ion chain for individual addressing
- Radio-frequency system on a chip RFSoC system to generate coherent control signals



Current Status:

- Coherence time (microwaves) >12s
- 0.8μm waist of individual addressing beams
- Intensity on neighboring sites <0.1%
- Single qubit gate crosstalk ≈ 2%
  - With compensation <0.5%

Outlook and Timeline

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- Call for Collaboration proposals open, submit proposal by 4/10/2020
  - Collaboration with Sandia scientists is encouraged
  - Proposals are reviewed by scientists external to QSCOUT
  - Email: qscout@sandia.gov for questions

- First stage experiments (3 qubits, gates between any pairs of qubits) June 2020
  - Gate level access (Jaqal specification at https://qscout.sandia.gov/jaqal.html
  - Pulse level access in collaboration with Sandia scientists
  - Execution of Jaqal programs within classical computing loop possible
  - Expect to have ≈ 100h of execution time available per user
  - First stage experiments for about 4 months

- Later stages will
  - Add more qubits
  - Improve fidelities
  - Improved classical control
  - Partial measurement and sympathetic cooling

QSCOUT Team and QIS Ion Trapping at Sandia

Trap design & experimentation
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Susan Clark
Craig Hogle
Daniel Lobser
Melissa Revelle
Dan Stick
Christopher Yale

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John Rembetski
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Theory
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Setso Metodi
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Timothy Proctor
Kenny Rudinger
Antonio Russo
Brandon Ruzic
Kevin Young

QSCOUT

Visit qscout.sandia.gov for more info
QSCOUT inquiries –
email qscout@sandia.gov

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