SAND2022-11867R

Sandia QIS Program Overview

Rick Muller

Senior Manager,

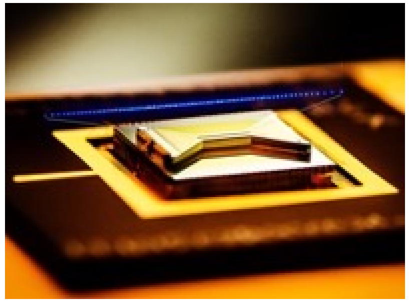
Quantum and Advanced Microsystems Group

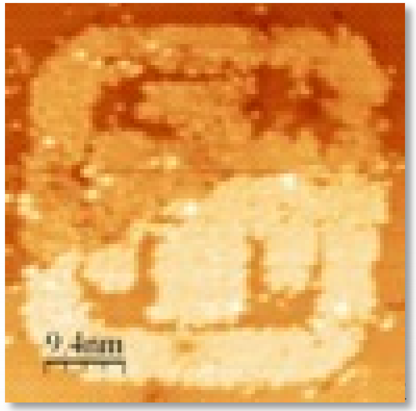
Sandia National Laboratories

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

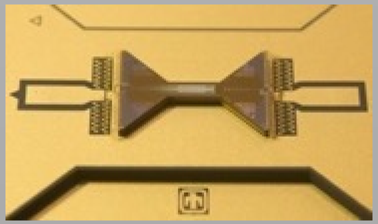
Overview of Sandia QIS Portfolio

- Sandia has a multiplatform, multiapplication 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
- The QIS program is built leveraging Sandia's strengths in microelectronics fabrication, nanotechnology, and computational modeling, and complements and strengthens Sandia's overall mission.
- Sandia is currently working to mature and explore quantum technologies under DOE and other governmental agency funding.





SANDIA'S QUANTUM CAPABILITIES



QSCOUT

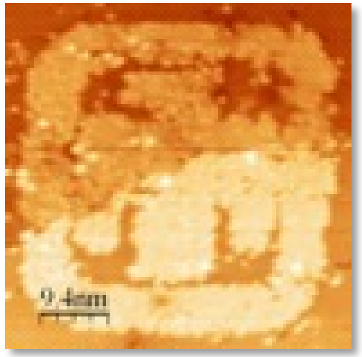
- Open trapped ion quantum testbed
- User-configurable quantum circuits, gates, pulses, programming language
- 5-11 qubits currently supported
- 3rd call for user proposals opening shortly: http://qscout.sandia.gov

QUANTUM SYSTEMS ACCELERATOR

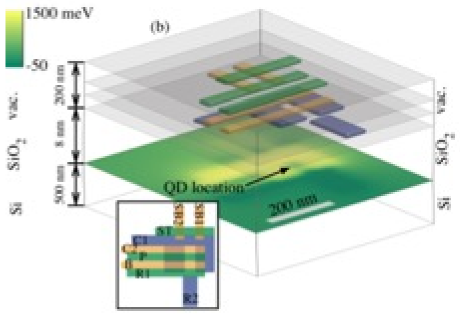
Catalyzing the Quantum Ecosystem

- NQI Hub co-lead by SNL & LBNL
- Elite team of academic, national laboratory researchers investigating superconducting, trapped ion, trapped atom, and other critical quantum technologies.

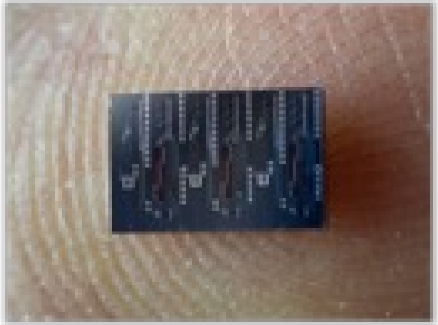
Advanced Fabrication



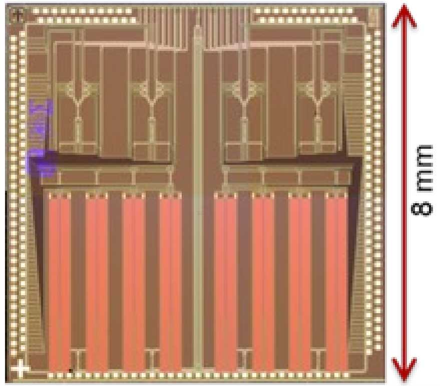
Device Modeling



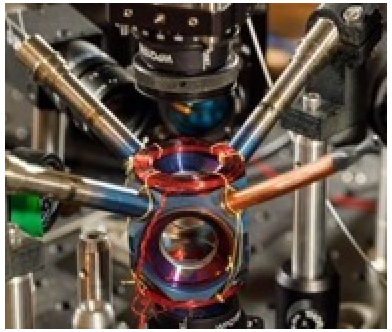
Chip-scale quantum transceiver



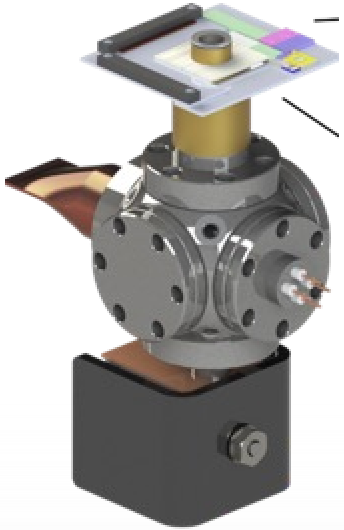
PIC for Atom Interferometer



Passively pumped vacuum package for atoms



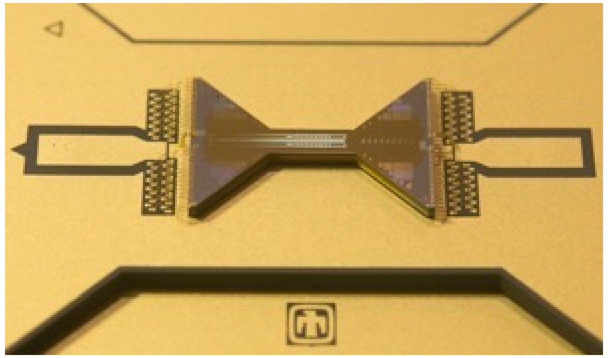
Integrated photonics and trapping ion clock



Quantum Scientific Computing Open User Testbed

PI: Susan Clark

- DOE/ASCR quantum testbed to understand promise of quantum computing platforms for DOE science problems
- Low-level access provided by QSCOUT is not available in existing commercial systems and enables researchers to study the behavior of quantum hardware
- Access to high-fidelity quantum operations
  - Qubit coherence time ≈ 14s
  - Parallel single qubit gates on all qubits, target fidelity 99.5%
  - Serial two-qubit gates between any pair of qubits, target fidelity 98%
- Jaqal Quantum Assembly Language offers low-level access, control of gate scheduling and execution, and extensible native gates.
- QSCOUT serving users:
  - 5 projects for first round (2021), 5 projects for second (2022)

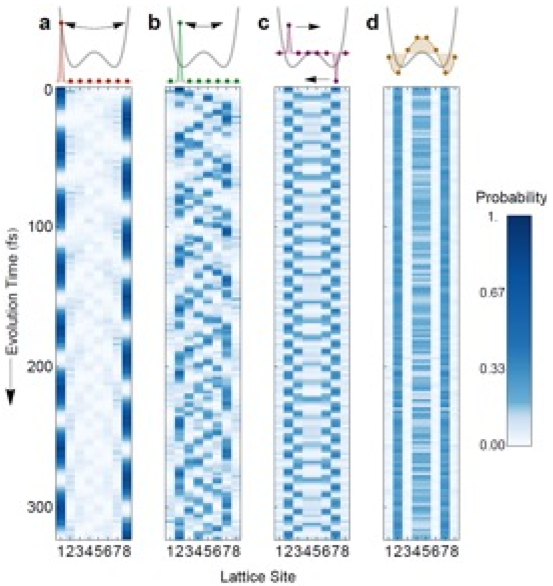


Peregrine Trap

QSCOUT round one scientific output includes problems in quantum chemistry, error mitigation, benchmarking, and simulation

INDIANA UNIVERSITY BLOOMINGTON

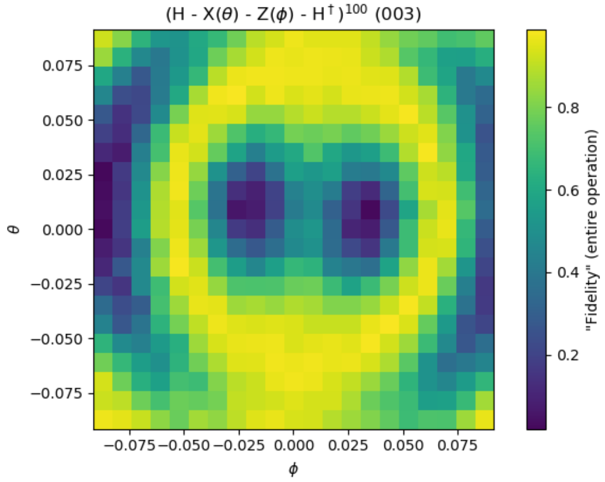
Quantum Computation of Hydrogen Bond Dynamics and Vibrational Spectra, arXiv: 2204.08571, *submitted (Nature)*



Philip Richerme
Debadrita Saha
Sam Norrell
Jeremy Smith
Amr Sabry
Srinivasan Iyengar

OAK RIDGE National Laboratory

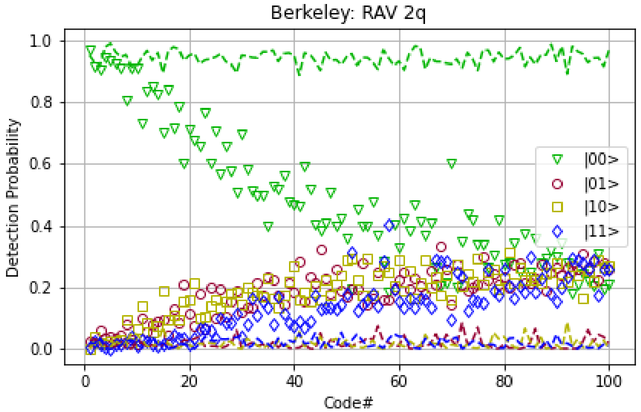
Characterizing and mitigating coherent errors in a trapped ion quantum processor using hidden inverses, *in preparation (PRX Quantum)*



Swarnadeep Majumder
Titus Morris
Raphael Pooser

Berkeley UNIVERSITY OF CALIFORNIA

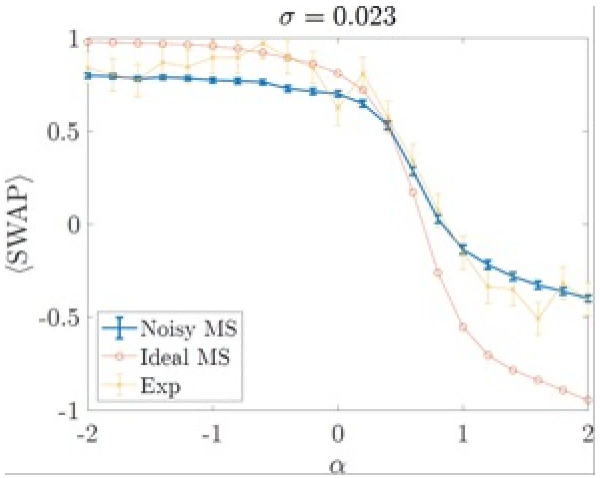
Efficient verification of continuously-parameterized quantum gates, *in preparation (PRA)*



Ryan Shaffer
Hang Ren
Emiliia Dyrenkova
Hartmut Haffner

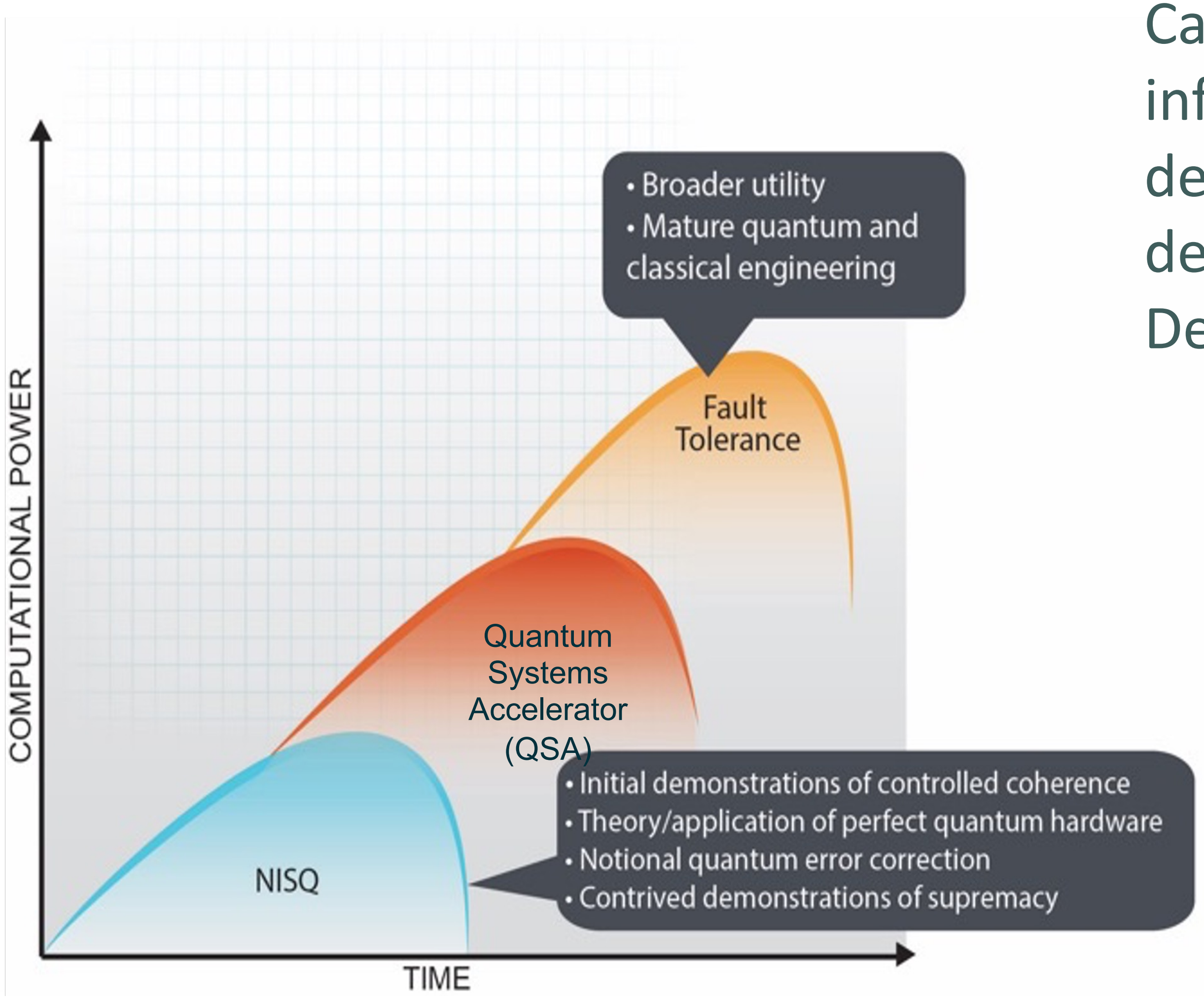
THE UNIVERSITY OF NEW MEXICO

Digital simulation of non-stoquastic Hamiltonians



Tameem Albash
Namitha Pradeep
Milad Marvian
Elizabeth Crosson

Scientific Foundations for Quantum Computation

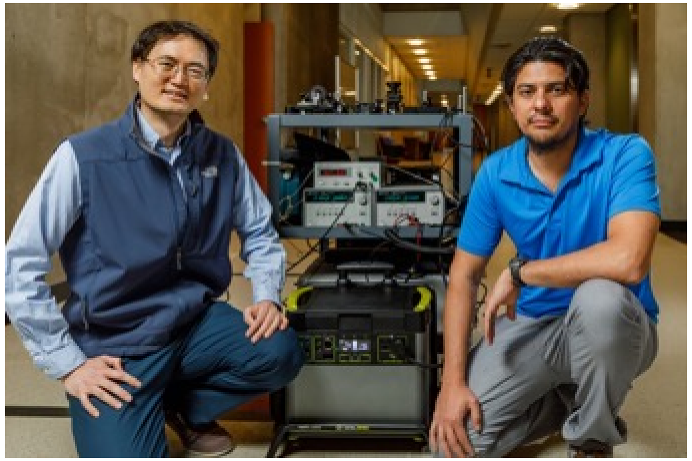


Catalyze national leadership in quantum information science to co-design algorithms, devices, and engineering solutions needed to deliver certified quantum advantage in Department of Energy scientific applications.

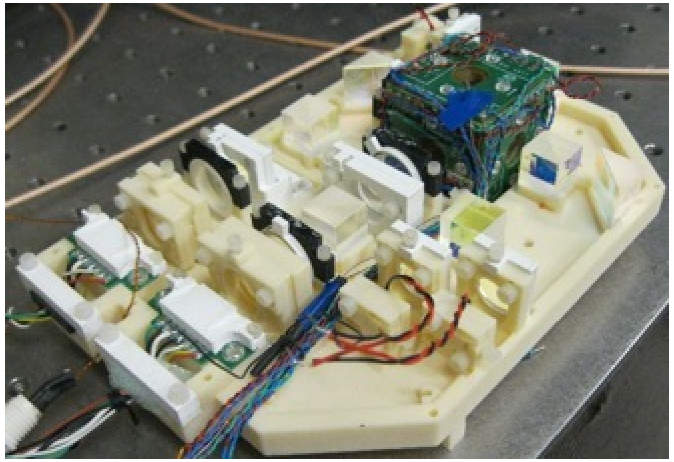
7

Quantum Sensing

P. Schwindt & A. Borna: **MEG with optically pumped magnetometers**
[Borna, Amir, et al. *Plos one* 15.1 (2020)]

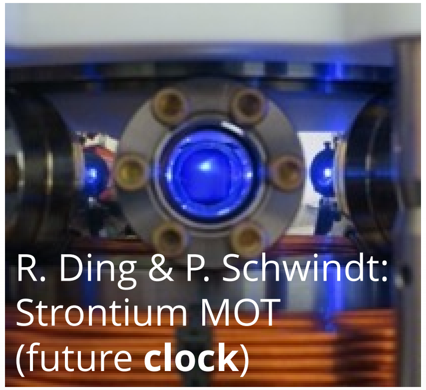


R. Ding, J. Lee, A. Orozco, & J. Christensen: how to operate cold-atom **inertial sensors in dynamic environments**

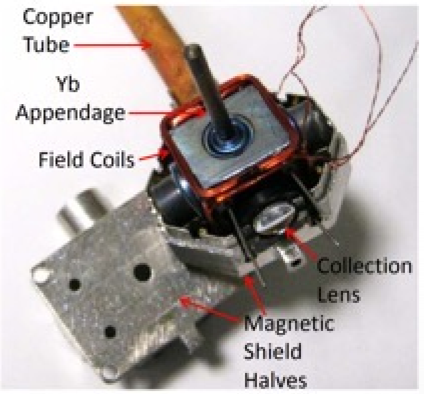


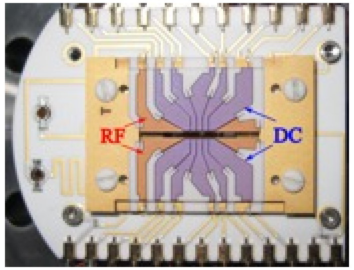
J. Dhombridge, N. Claussen, P. Schwindt: **RF magnetometer** with 0.6 liter volume for **VLF frequency ~ 20 kHz**
Dhombridge et al., submitted to PRA 2022.

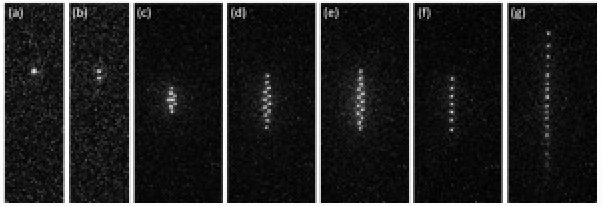
D. Thrasher & YY Jau: **Microwave Atomic Clock**



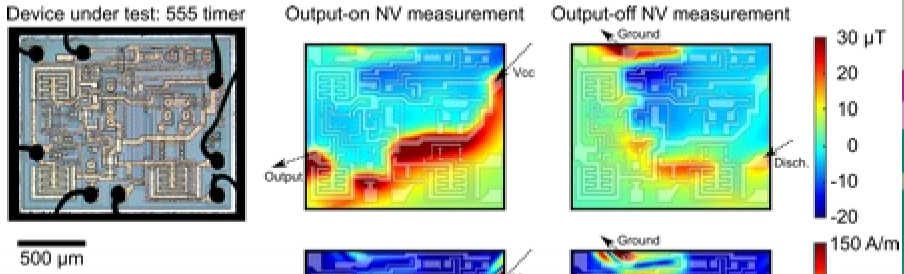
R. Ding & P. Schwindt: Strontium MOT (future **clock**)

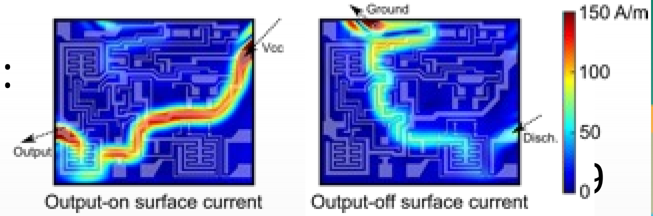






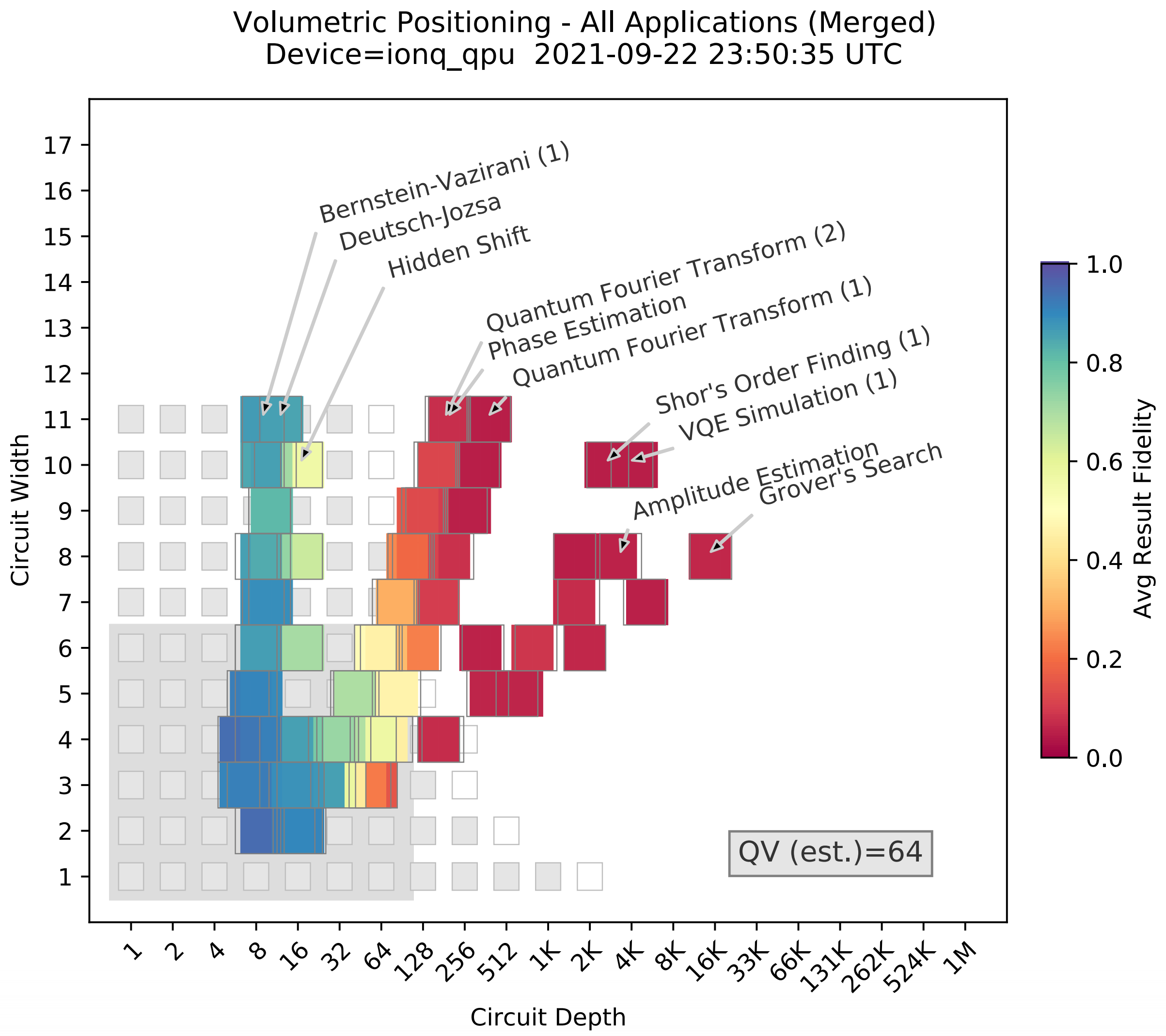
J. Schultz & P. Schwindt: **$^{171}Yb^{+}$clock**





Pauli Kehayias: **NV magnetic imaging**

QPerformance: Application Oriented Benchmarks



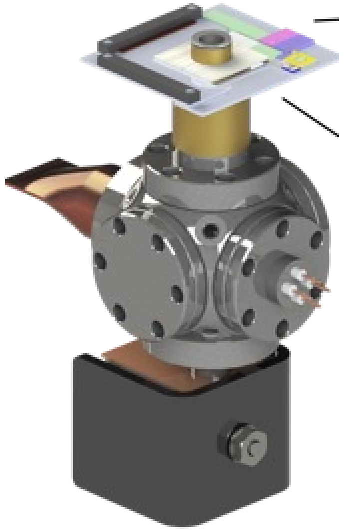
Lubinski *et al*, *Application-Oriented Performance Benchmarks for Quantum Computing*. arXiv:2110.03137

- The QPL collaborated with a team from the Quantum Economic Development Consortium (QED-C) to create and deploy the first application-oriented benchmarking suite for quantum computers.
- The final suite leveraged volumetric benchmarking framework. We (and the QED-C) used it to explore performance of current hardware.
- QPL also had key contributions to experimental programs, including a cover of Nature.

Where are we going?

- Sandia QIS Vision: Serve the nation as the premiere national laboratory for quantum research ranging from fundamental science to advanced prototypes to ensure US dominance in future quantum applications.
- More specifically, Sandia will develop, prototype, and *integrate* functioning quantum devices and algorithms that provide transformative advances in information *sensing*, *processing*, and *communication* in support of Sandia's mission and customer needs.
- Institutionalize Quantum at Sandia: Quantum enhanced technologies will likely impact a very wide array of applications, including potential mission needs:
  - Properties of matter in extreme environments
  - Material properties and aging
  - Improved physical simulation capabilities
  - More secure command and control communications
  - Enhanced sensing capabilities (e.g. for navigation)

TICTOC explores novel approaches for integrated quantum devices



Applications to quantum materials