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JULIANE PRICE

Vocalist & Multi-Instrumentalist

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6TH ANNUAL Q4I WORKSHOP | JUNE 25-27 | ROME, NY

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WORKSHOP

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DR. MICHAEL J. HAYDUK

Deputy Director

Air Force Research Lab (AFRL) Information Directorate (RI)

Rome, NY

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MS. ELISE STEFANIK

Congresswoman (R-NY)

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MR. ANTHONY J. PICENTE JR.

Oneida County Executive

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MS. MARIANNE BUTTENSCHON

Assemblymember

NYS - 119th District

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MR. JEFF LANIGAN

Mayor

City of Rome, New York

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DR. GRETCHEN CAMPBELL

Director

National Quantum Coordination Office (NQCO)

Office of Science and Technology Policy (OSTP)

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6TH ANNUAL Q4I WORKSHOP | JUNE 25-27 | ROME, NY

The National Quantum Initiative

Quantum For International Workshop
June 25, 2024

Dr. Gretchen Campbell
Director
National Quantum Coordination Office
Office of Science and Technology Policy

quantum.gov
whitehouse.gov/ostp
@WHOSTP

Office of Science and Technology Policy

OSTP works to harness the power of science, technology, and innovation to achieve America's greatest aspirations.

National Quantum Coordination Office

- **Dr. Gretchen Campbell**, Director
- **Dr. Brad Blakestad**, Deputy Director
- **Dr. Tanner Crowder**, Senior Policy Analyst
- **Dr. Thomas Wong**, Consultant

The National Quantum Initiative (NQI) Act

To provide for a coordinated Federal program to accelerate quantum research and development for the economic and national security of the United States.

Establishes a 10-year program to advance quantum research and technology applications and workforce development. Ensures continued leadership of the United States in QIST applications by:

1. Supporting R&D, demonstration, and application of QIST
2. Improving interagency planning and coordination of Federal R&D of QIST;
3. Maximizing the effectiveness of the Federal QIST research, development, and demonstration programs;
4. Promoting collaboration among the Federal Government, Federal laboratories, industry, and universities; and
5. Promoting the development of international standards for QIST security.

Public Law 115–368
115th Congress

An Act

Dec. 21, 2018
[H.R. 6227]

To provide for a coordinated Federal program to accelerate quantum research and development for the economic and national security of the United States.

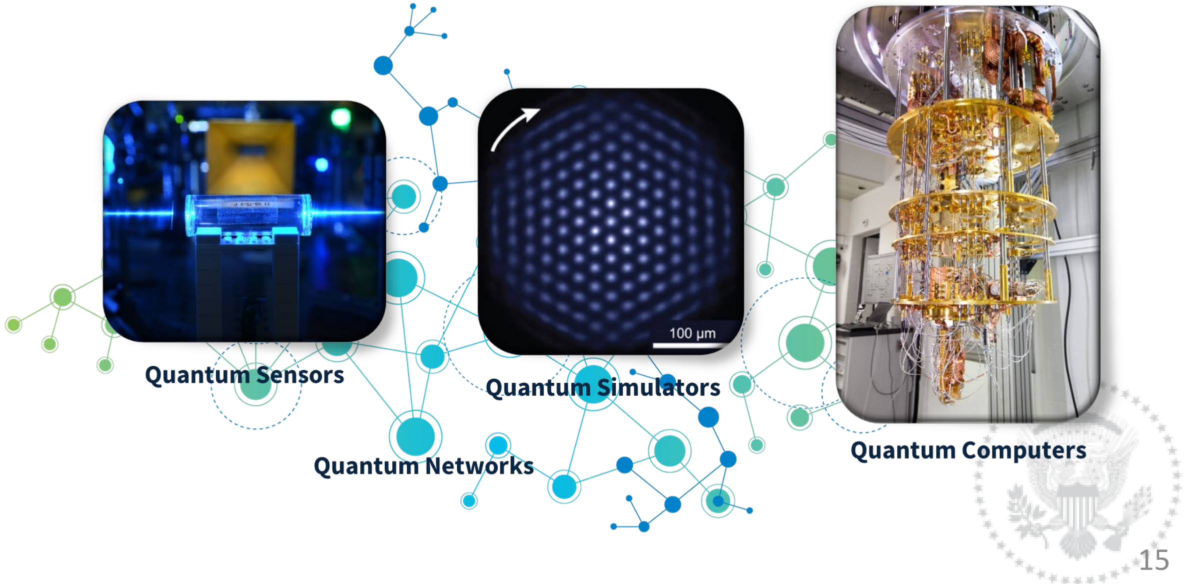
Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled,

National Quantum Initiative Act. 15 USC 8801 note.

SECTION 1. SHORT TITLE; TABLE OF CONTENTS.

(a) Short Title.—This Act may be cited as the "National Quantum Initiative Act".

(b) Table of Contents.—The table of contents of this Act is as follows:



The National Quantum Initiative

White House COORDINATING BODIES

NSTC Subcommittee on Quantum Information Science (SCQIS)*

Co-Chairs from:

NSTC Subcommittee on Economic and Security Implications of Quantum Science (ESIX)**

Co-Chairs from:

NQI Advisory Committee (NQIAC)*

- Committee composed of experts from industry, academia, and Federal labs
- Tasked with providing an independent assessment of and making recommendations for the NQI

National Quantum Coordination Office (NQCO)*

- Carries out the daily coordination activities needed by the NQI program
- Serves as the POC on Federal civilian QIST activities.
- Provides support to the subcommittees and NQIAC
- Staffed by employees on detail from NIST, DOD, DOE, and NSA.

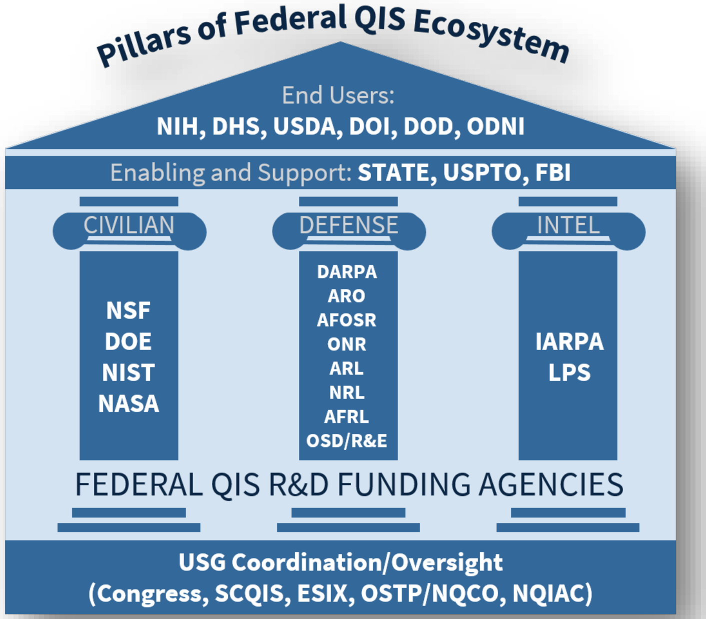
Participating Agencies

The NQI is a whole-of-government approach

* from National Quantum Initiative Act (PL 115-368) 2018
** from National Defense Authorization Act for FY'22 (PL 117-81)

Federal Agencies in the QIS Ecosystem

Technical leaders from across the interagency compose the NSTC Subcommittees working groups that develop policy recommendations and aid in coordination.



CIVILIAN
- National Science Foundation (NSF)
- Department of Energy (DOE)
- National Institute of Standards and Technology (NIST)
- National Aeronautics and Space Administration(NASA)

DEFENSE
- Defense Advanced Research Projects Agency (DARPA)
- Army Research Office (ARO)
- Air Force Office of Scientific Research (AFOSR)
- Office of Naval Research (ORN)
- Army Research Lab (ARL)
- Naval Research Lab (NRL)
- Air Force Research Lab (ARFL)
- Office of the Secretary of Defense/Research and Engineering (OSD/R&E)

INTELLIGENCE
- Intelligence Advanced Research Projects Activity (IARPA)
- Laboratory For Physical Sciences (LPS)

END USERS
- National Institutes of Health (NIH)
- Department of Homeland Security (DHS)
- United States Department of Agriculture (USDA)
- United States Geological Survey (DOI/USGS)
- Department of Defense (DOD)
- Office of the Director of National Intelligence (ODNI)

ENALBING AND SUPPORT
- Federal Bureau of Investigation (FBI)
- U.S. Patent and Trade Office (USPTO)
- Department of State (STATE)

National Science and Technology Council (NSTC) Quantum Subcommittees

Subcommittee on Quantum Information Science (SCQIS)

Co-Chaired by **OSTP**, **DOE**, **NSF**, and **NIST**

Responsibilities from the NQI Act:

1. **coordinate QIST research** / information sharing
2. establish **goals and priorities** of the NQI
3. assess and recommend Federal **infrastructure needs**
4. assess the status, development, and diversity of the U.S. QIS **workforce**
5. assess the **global outlook** for QIS R&D efforts
6. evaluate opportunities for **international cooperation** with strategic allies on R&D in QIST
7. propose a **coordinated interagency budget** for the NQI ensure the maintenance of a balanced QIS research portfolio and an appropriate level of research effort

Subcommittee on Economic and Security Implications of Quantum Science (ESIX)

Co-Chaired by **OSTP**, **DOE**, **NSA**, and **DOD**

Responsibilities from the NQI Act:

1. **track investments** of the Federal Government in QIS R&D
2. review and assess any **economic or security implications**
3. review and assess any counterintelligence **risks** or other foreign **threats**
4. recommend **goals and priorities** to address any counterintelligence risks or other foreign threats
5. assess the **export** of technology associated with QIS
6. recommend **investment strategies** in QIS that advance the economic and security interest of the United States;
7. recommend appropriate **protections** to address counterintelligence risks or other foreign threats
8. ensure Federal investments in QIS R&D **balance** scientific progress and potential economic and security implications

National Quantum Coordination Office

- Currently staffed by quantum information **scientists on detail** from NSA, NIST, DOD, and DOE (and previously NSF)
- Oversee interagency **coordination** of the NQI, ensure coordination of collaborative ventures, conduct public **outreach**, promote **access**
- Provides technical and administrative **support** to the above committees an the NQI Advisory Committee
- Serve as the **point of contact** on Federal civilian QIST activities

Quantum Legislation

NATIONAL QUANTUM INITIATIVE ACT

[Public Law 115-368]

[As Amended Through the National Defense Authorization Act (NDAA) for FY2022 (Public Law 117-81), Enacted December 27, 2021]
[As Amended Through Amendments by the CHIPS and Science Act of 2022 (Public Law 117-167), Enacted August 9, 2022]

[Note: While this publication does not represent an official version of any Federal statute, substantial efforts have been made to ensure the accuracy of its contents. The official version of Federal law is found in the United States Statutes at Large and in the United States Code. The legal effect to be given to the Statutes at Large and the United States Code is established by statute (1 U.S.C. 112, 204).]

AN ACT To provide for a coordinated Federal program to accelerate quantum research and development for the economic and national security of the United States.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled,

SECTION 1. SHORT TITLE; TABLE OF CONTENTS.

(a) Short Title.--This Act may be cited as the ``National Quantum Initiative Act''.
(b) Table of Contents.--The table of contents of this Act is as follows:

[1] As in law. NDAA 2022 did not include "Sec." when adding sections 105 and 106 to the table of contents.

Available on quantum.gov

LEGISLATION SUPPLEMENTING THE NATIONAL QUANTUM INITIATIVE ACT

Since its passage in December 2018, the National Quantum Initiative (NQI) Act (Public Law 115-368) has been amended and supplemented by various laws. In a separate document, the National Quantum Coordination Office (NQCO) has published the NQI Act with its amendments. In this document, the NQCO has collected excerpts of legislation that has supplemented the NQI Act, but that has not amended the NQI Act itself.

While this publication does not represent an official version of any Federal statute, substantial efforts have been made to ensure the accuracy of its contents. The official version of Federal law is found in the United States Statutes at Large and in the United States Code. The legal effect to be given to the Statutes at Large and the United States Code is established by statute (1 U.S.C. 112, 204).

NDAA 2019

John S. McCain National Defense Authorization Act for Fiscal Year 2019
Public Law 115-232
Enacted August 13, 2018

With amendments through the National Defense Authorization Act for Fiscal Year 2020 (Public Law 116-92), enacted December 20, 2019

SEC. 234. DEFENSE QUANTUM INFORMATION SCIENCE AND TECHNOLOGY RESEARCH AND DEVELOPMENT PROGRAM.

(a) Establishment.--The Secretary of Defense shall carry out a quantum information science and technology research and development program.
(b) Purposes.--The purposes of the program required by subsection (a) are as follows:
  (1) To ensure global superiority of the United States in quantum information science necessary for meeting national security requirements.
  (2) To coordinate all quantum information science and technology research and development within the Department of Defense and to provide for interagency cooperation and collaboration on quantum information science and technology research and development between the Department of Defense and other departments and agencies of the United States and appropriate ~~private sector entities~~private sector and international entities that are involved in quantum information science and technology research and development.
  (3) To develop and manage a portfolio of fundamental and applied quantum information science and technology and engineering research initiatives that is stable, consistent, and balanced across scientific disciplines.
  (4) To accelerate the transition and deployment of technologies and concepts derived from quantum information science and technology research and development into the Armed Forces, and to establish policies, procedures, and standards for measuring the success of such efforts.
  (5) To collect, synthesize, and disseminate critical information on quantum information science and technology research and development.

National Quantum Initiative Act

Established December 2018, amended by the

- National Defense Authorization Act (NDAA) for Fiscal Year (FY) 2022
- CHIPS and Science Act of 2022

Established

- Coordinating/oversight bodies
- NIST QIS research, standards, launch industry consortium
- NSF QIS research and education programs and Centers
- DOE QIS research programs and Centers, quantum networking program, and user access program

Supplementing Legislation

NDAAs

- FY 2019: DOD QIS program
- FY 2020: DOD QIS Centers, Coordinate efforts with broader NQI
- FY 2022: Dual-use quantum technologies

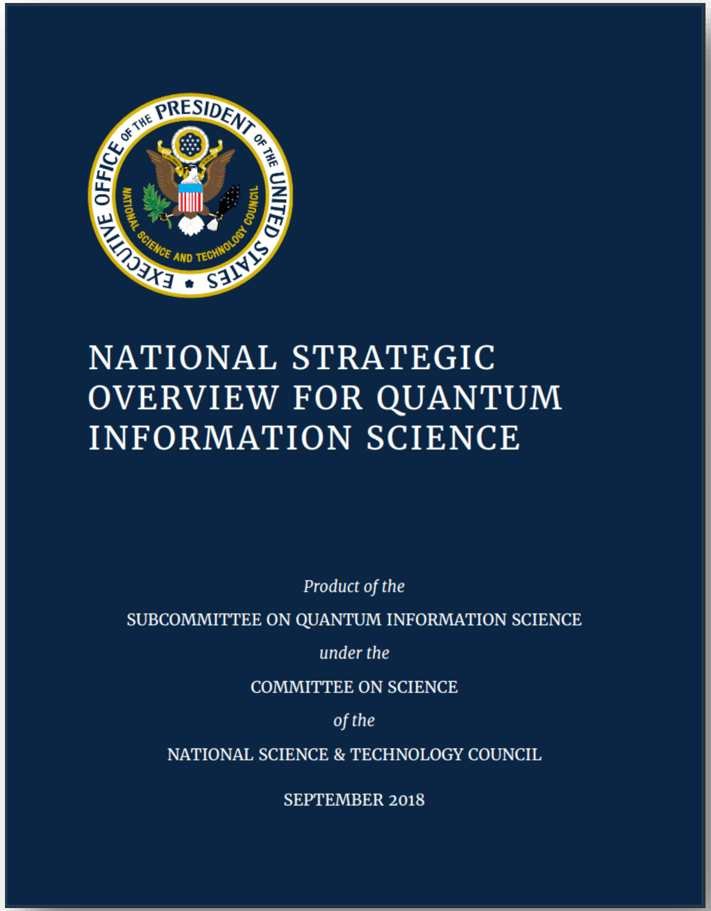
CHIPS and Science Act of 2022

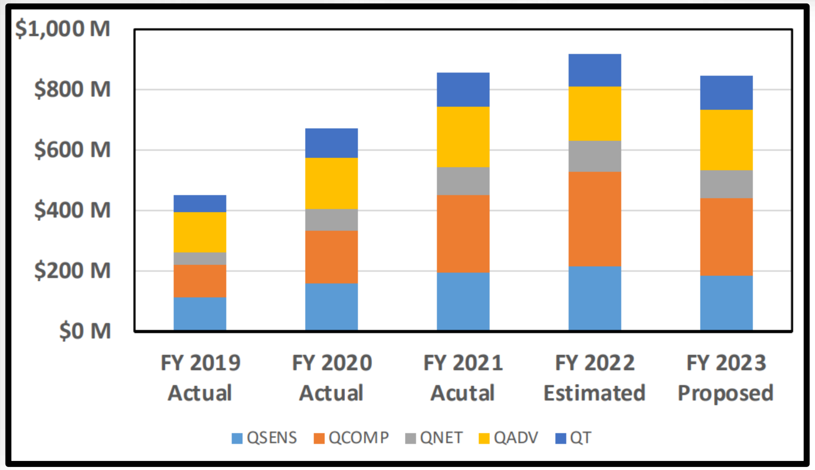
- NSF TIP directorate, key technology focus areas include QIS
- NSF quantum workforce report and education program
- Microelectronics Centers should coordinate with QIS Centers

U.S. National Strategy for QIS

Six Policy Pillars:

1. Take a **science-first** approach
2. Provide the key **infrastructure**
3. Build a quantum-capable and diverse **workforce**
4. Nurture the nascent quantum **industry**
5. Balance **economic** and **national security**
6. Continue to develop **international collaboration** and cooperation





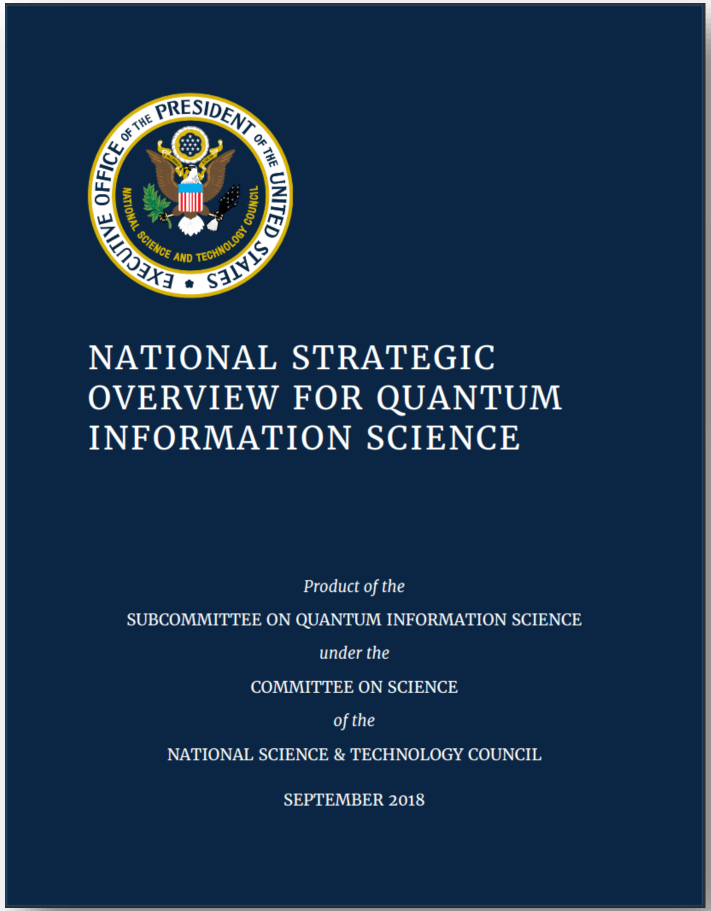
Find all our strategy documents on quantum.gov

U.S. National Strategy for QIS

Getting the science right by understanding the applications and timelines by which QIST will benefit our society, and roadblocks we must overcome to get there;

Enhancing competitiveness by accelerating technology development toward useful economic and mission applications while also protecting our national security; and

Enabling people by building the necessary talent pipeline and ensuring that this field creates new opportunities for all Americans.


NATIONAL STRATEGIC OVERVIEW FOR QUANTUM INFORMATION SCIENCE

Product of the

SUBCOMMITTEE ON QUANTUM INFORMATION SCIENCE

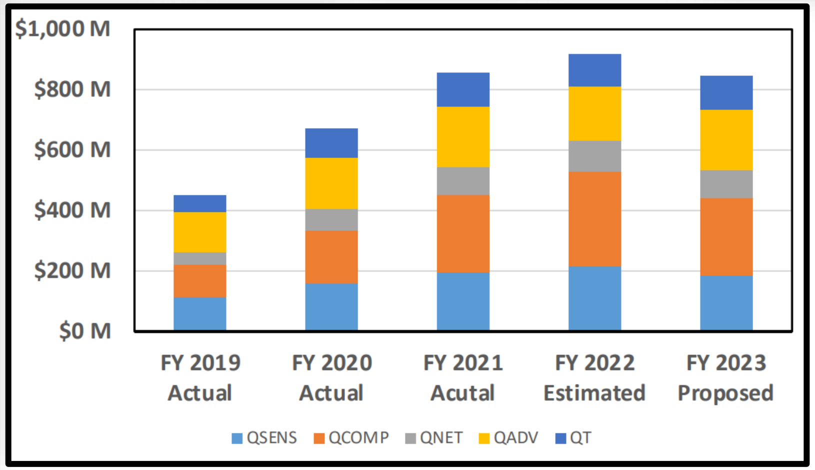
under the

COMMITTEE ON SCIENCE

of the

NATIONAL SCIENCE & TECHNOLOGY COUNCIL

SEPTEMBER 2018

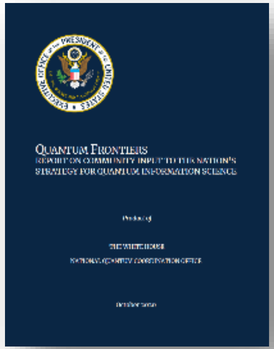


Find all our strategy documents on quantum.gov

Getting the Science Right - Augmenting the National Strategic Overview

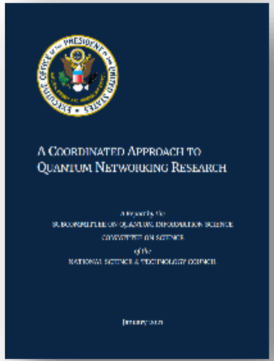
Quantum Frontiers

1. QIST to Benefit Society
2. Building Quantum Engineering
3. Materials Science for QIST
4. Quantum Mechanics using Quantum Simulations
5. QIST for Precision Measurement
6. Quantum Entanglement for New Applications
7. Quantum Errors
8. The Universe through Quantum Information



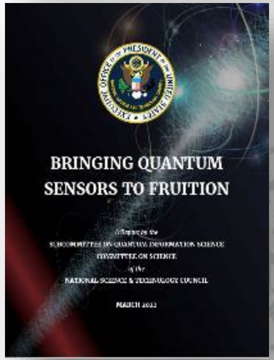
Quantum Networking

TR 1: Continue Research on Use Cases
TR 2: Prioritize Cross-Beneficial Core Components
TR 3: Improve Classical Capabilities
TR 4: Leverage "Right-Sized" Quantum Testbeds
PR 1: Increase Interagency Coordination
PR 2: Establish Timetables for R&D Infrastructure
PR 3: Facilitate International Cooperation



Quantum Sensing

1. QIST R&D leaders should partner with end-users to raise the TRL of new quantum sensors
2. Agencies using sensors should jointly test quantum prototypes with QIST R&D leaders
3. Develop broadly applicable components and subsystems
4. Streamline tech transfer and acquisition practices



Getting the Science Right: Centers

5 NSF Quantum Leap Challenge Institutes

- CIQC: Challenge Institute for Quantum Computation
- Q-SEnSE: Quantum Systems through Entangled Science and Engineering
- HQAN: Hybrid Quantum Architectures and Networks
- QuBBE: Quantum Sensing for Biophysics and Bioengineering
- RQS: Institute for Robust Quantum Simulation

5 DOE National QIS Research Centers

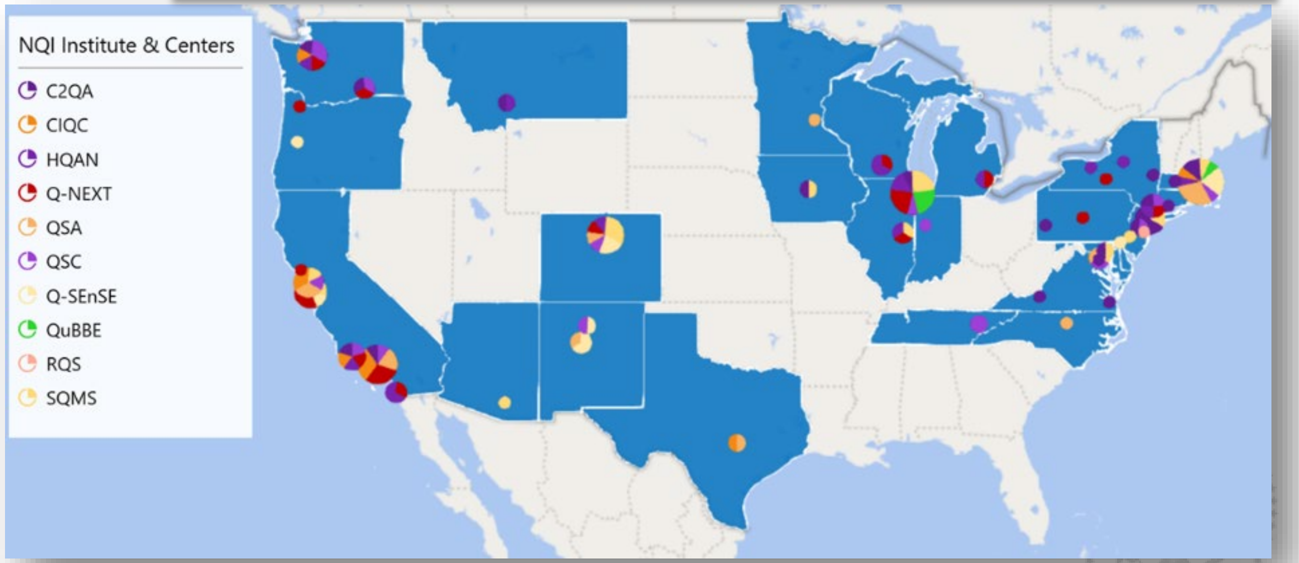
- Q-NEXT: Next Generation Quantum Science and Engineering
- C2QA: Co-design Center for Quantum Advantage
- SQMS: Superconducting Quantum Materials and Systems Center
- QSA: Quantum Systems Accelerator
- QSC: The Quantum Science Center

4 DOD/IC QIS Research Centers

- Air Force Research Laboratory
- Naval Research Laboratory
- Army Research Laboratory
- Laboratory for Physical Sciences (LPS) Qubit Collaboratory (LQC)

+ Core Research Programs

U.S. National Quantum Centers and Institutes



Getting the Science Right: Programs and Workshops

Some quantum.gov news posts

QUANTUM COMPUTING / R&D FUNDING OPPORTUNITIES

IARPA Launching New Program on Entangled Logical Qubits

(July 22, 2022) The Intelligence Advanced Research Projects Activity (IARPA) is launching a new program on Entangled Logical Qubits (ELQ). It is a four-year program scheduled to start in the ...

NSF / QUANTUM COMPUTING / R&D FUNDING OPPORTUNITIES

NSF Funds Access to Cloud-based Quantum Computing Platforms

(June 3, 2022) The National Science Foundation, in conjunction with Amazon Web Services (AWS), IBM, and Microsoft, is promoting the availability of cloud-based access to quantum-computing platforms to advance research ...

QUANTUM SENSING / R&D FUNDING OPPORTUNITIES

DOE BER Releases FOA for Quantum-Enabled Imaging and Sensing for Bioenergy

The DOE SC program in Biological and Environmental Research (BER), through its Bioimaging Research effort, announced its interest in receiving applications to advance fundamental research or use-inspired technologies of new ...

R&D FUNDING OPPORTUNITIES / WORKFORCE

AFOSR Funding Opportunities in STEM Education, Quantum Welcomed

(March 21, 2022) The Air Force Office of Scientific Research (AFOSR) has two funding opportunities involving STEM education, which could include quantum information science: STEM FOA: This announcement explicitly encourages ...

R&D FUNDING OPPORTUNITIES / WORKFORCE

LPS Supports Young Investigator Program in QIS

(March 17, 2022) The Laboratory for Physical Sciences (LPS), which hosts a National Quantum Information Science Research Center called the LPS Qubit Collaboratory (LQC), is partnering with the Air Force ...

R&D FUNDING OPPORTUNITIES / WORKFORCE

Quantum Community Networking Workshops at National Laboratories

(May 26, 2022) The Department of Energy's (DOE) Advanced Scientific Computing Research (ASCR) program is organizing two QIS community networking workshops. These are designed to increase participation of underrepresented groups ...

R&D FUNDING OPPORTUNITIES / WORKFORCE

NASA SCaN Quantum Faculty Fellowship Opportunities

NASA's Space Communications and Navigation (SCaN) program office seeks to enhance faculty professional knowledge and leadership experience by offering two 10-week summer fellowship opportunities for educators who are interested in ...

INTERNATIONAL / NSF / R&D FUNDING OPPORTUNITIES

NSF Funding for International Collaboration in Quantum

(August 18, 2022) The National Science Foundation (NSF) released a Dear Colleague Letter on July 21, 2022 on International Collaboration Supplements in Quantum Information Science and Engineering Research. With this ...

QUANTUM COMPUTING / R&D FUNDING OPPORTUNITIES

ARL and LPS release BAA on Quantum Computing in the Solid State

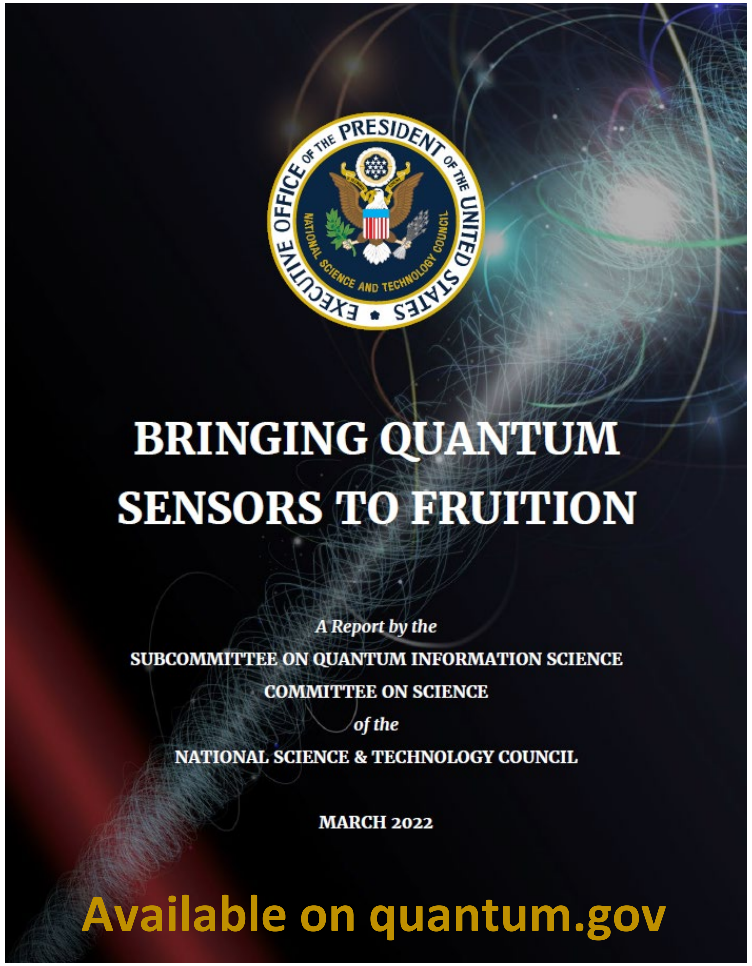
(January, 18 2022) A new Broad Agency Announcement (BAA) for the QC-S5 program, BAA # W911NF-22-S-0006 has been released. The U.S. Army Research Office (ARO), in collaboration with the Laboratory ...

INFRASTRUCTURE / R&D FUNDING OPPORTUNITIES / WORKFORCE

ExpandQISE Solicitation: Invitation to a Connections-Building Workshop

(Feb. 27, 2022) ExpandQISE Solicitation: Invitation to a connections-building workshop. The recently issued program solicitation NSF 22-561 "Expanding Capacity in Quantum Information Science and Engineering (ExpandQISE)" aims to increase research ...

Getting the Science Right:
Bringing Quantum Sensors to Fruition



Synopsis of Program:

The Quantum Sensing Challenges for Transformational Advances in Quantum Systems (QuSeC-TAQS) program supports interdisciplinary teams of three (3) or more investigators to explore highly innovative, original, and potentially transformative research on quantum sensing. The QuSeC-TAQS program supports coordinated efforts to develop and apply quantum sensor systems, with demonstrations resulting in proof of principle or field-testing of concepts and platforms that can benefit society. The QuSeC-TAQS program aligns with recommendations articulated in the strategy report, *Bringing Quantum Sensors to Fruition*, that was produced by the National Science and Technology Council Subcommittee on Quantum Information Science, under the auspices of the National Quantum Initiative.

Enhancing Competitiveness: NSM-10

National Security Memorandum 10 (NSM-10)

BRIEFING ROOM

National Security Memorandum on Promoting United States Leadership in Quantum Computing While Mitigating Risks to Vulnerable Cryptographic Systems

MAY 04, 2022 • STATEMENTS AND RELEASES

OMB Memo on Complying with NSM-10

EXECUTIVE OFFICE OF THE PRESIDENT
OFFICE OF MANAGEMENT AND BUDGET
WASHINGTON, D.C. 20503

THE DIRECTOR

November 18, 2022

M-23-02

MEMORANDUM FOR THE HEADS OF EXECUTIVE DEPARTMENTS AND AGENCIES

FROM: Shalanda D. Young, Director

SUBJECT: Migrating to Post-Quantum Cryptography

This memorandum provides direction for agencies to comply with National Security Memorandum 10 (NSM-10), *on Promoting United States Leadership in Quantum Computing While Mitigating Risk to Vulnerable Cryptographic Systems* (May 4, 2022).[1]

Sec. 1: Policy

- Quantum computers hold the **potential to drive innovations** across the American economy
- Yet alongside its potential benefits, **quantum computing also poses significant risks** to the economic and national security of the United States.
- In order to **balance** the competing opportunities and risks of quantum computers, it is the policy of the United States (1) to **maintain United States leadership** in QIS; and (2) to mitigate the threat of CRQCs through a timely and equitable **transition to PQC.**

Sec. 2: Promotion

- Pursue a **whole-of-government/society strategy to harness the economic and scientific benefits of QIS**, and the security enhancements provided by QRC.
- **R&D**: encourage transformative and fundamental scientific discoveries through investments in core QIS research programs.
- **Workforce**: foster the next generation of scientists and engineers with quantum-relevant skill sets, including those relevant to QRC.
- **Partnerships**: promote domestic partnerships and professional and academic collaborations with overseas allies and partners.

Sec. 3: Mitigating Risks to Encryption

- U.S. must prioritize the timely and **equitable transition of cryptographic systems to QRC.**
- Central to this effort will be an emphasis on **cryptographic agility**, to reduce the transition time and to allow for updates for future cryptographic standards.
- Series of deadlines for federal agencies to support the transition

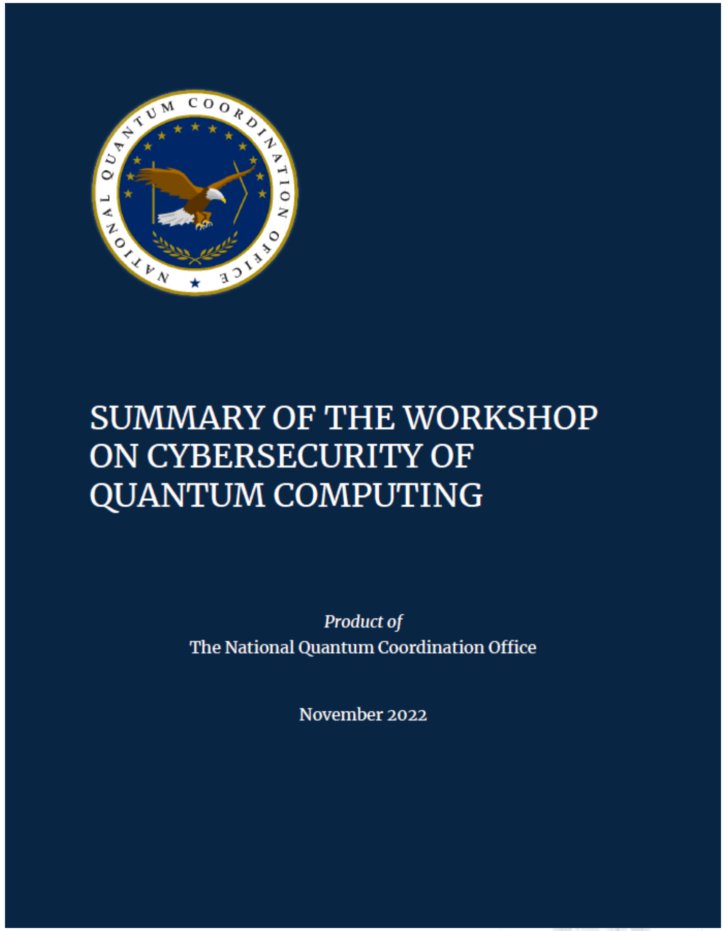
Sec. 4: Protecting U.S. Technology

- U.S. Gov must work to **safeguard relevant quantum R&D and intellectual property (IP)** and to protect relevant enabling technologies and materials.
- Agencies responsible for either promoting or protecting QIS and related technologies should **understand the security implications** of QC
- U.S. should ensure the protection of U.S.-developed quantum technologies from theft by our adversaries.

Enhancing Competitiveness: Security

Workshop on Cybersecurity of Quantum Computing

- Supported by NSF & OSTP
- Brought together roughly 40 experts from the cybersecurity and quantum computing communities to explore topics such as:
  1. Protecting quantum computing intellectual property
  2. Mechanisms to ensure that quantum computers are not used for illicit purposes
  3. Opportunities for research on the cybersecurity of quantum computers
- Participants identified research areas to address challenges that included:
  - Secure large-scale control systems
  - Distributed high-performance quantum computing
  - Attack vectors on different types of quantum computers
  - Formal methods for safe and secure quantum computing systems
  - Multi-layered instrumentation framework
  - Tools for service providers to verify quantum algorithms

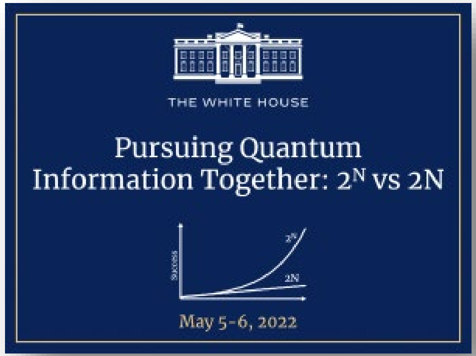

SUMMARY OF THE WORKSHOP ON CYBERSECURITY OF QUANTUM COMPUTING

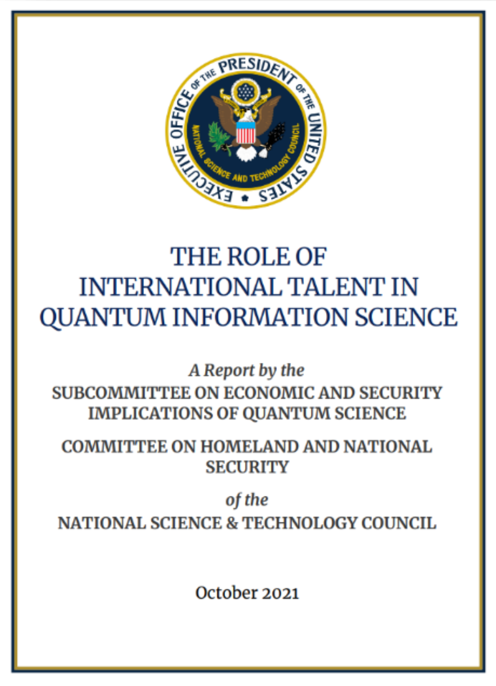
Product of
The National Quantum Coordination Office

November 2022

Enhancing Competitiveness: International Cooperation

As new technologies continue to evolve, we'll work together with our democratic partners to ensure that new advances in areas from biotechnology, to quantum computing, 5G, artificial intelligence, and more are used to lift people up, to solve problems, and advance human freedom – President Biden



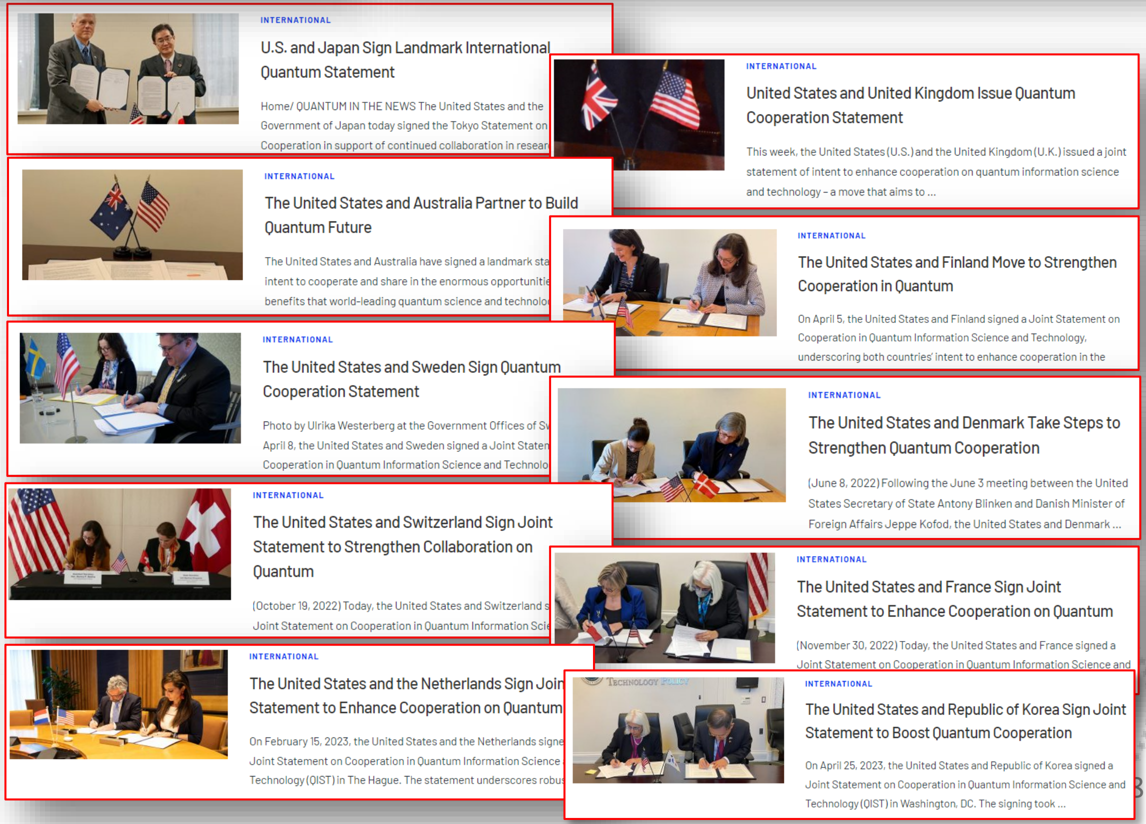


THE ROLE OF INTERNATIONAL TALENT IN QUANTUM INFORMATION SCIENCE

A Report by the
SUBCOMMITTEE ON ECONOMIC AND SECURITY IMPLICATIONS OF QUANTUM SCIENCE
COMMITTEE ON HOMELAND AND NATIONAL SECURITY
of the
NATIONAL SCIENCE & TECHNOLOGY COUNCIL

October 2021

- Good faith cooperation underpinned by shared values.
- Promoting jointly funded and cooperative QIST R&D.
- Understand trajectories in QIST.
- Enabling opportunities for global market and supply chain
- Creating regular bilateral and multilateral opportunities
- Promoting multidisciplinary research, including the exchange of people.



EntanglementExchange.org

Entanglement Exchange

The development of the next generation of scientists and engineers benefits humanity and is necessary to expand the field of quantum information science and technology. The Entanglement Exchange represents a commitment to facilitate this exchange of students, researchers, and professionals in the field.

Quantum is a global endeavor. International cooperation and collaboration through people exchanges are key to combine the expertise, ingenuity, and creativity of all people to expand humanity's fundamental understanding of quantum information and thereby accelerate the realization of new technologies for the benefit of society.

These partnerships begin with personal experiences. The Entanglement Exchange represents a beginning step in creating more opportunities to work alongside each other from joint graduate fellowships to postdoctoral opportunities to visits and sabbaticals.

This website links to Entanglement Exchange pages hosted by several countries. Each page will be maintained to help individuals looking for international research experiences, both inward and outward, to or from the respective quantum ecosystems.

- Australia
- Canada (Page 1, Page 2)
- Denmark
- Finland
- France (Under Development)
- Germany
- Japan
- Netherlands
- Republic of Korea
- Sweden
- Switzerland
- United Kingdom
- United States

NEWS

4/14/2023 - The Entanglement Exchange Celebrates World Quantum Day and Welcomes the Republic of Korea

11/30/2022 - Entanglement Exchange Links Quantum Researchers Across Twelve Nations

Entanglement Exchange Links Quantum Researchers Across Twelve Nations

New website is a portal for international exchange opportunities in quantum information science

November 30, 2022

...k, Finland, France, Germany, Japan, the ...zerland, the United Kingdom, and the ... launch the Entanglement Exchange, a ...rnational exchange opportunities for ...searchers in quantum information science

The Entanglement Exchange Celebrates World Quantum Day and Welcomes the Republic of Korea

Happy World Quantum ... Exchange!

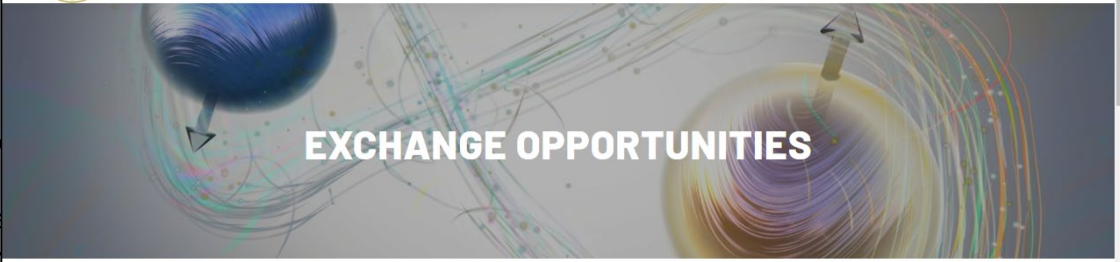
April 14, 2023

Celebrated annually on Ap... international, grassroots e... of quantum science and te... include public lectures, so... laboratory tours, and more... Exchange is engaged in thi...

An official website of the United States government Info

⟨quantum|gov⟩

HOME ABOUT STRATEGY SCIENCE COMPETITIVENESS PEOPLE NEWS NQCO Search...



As described in the 2018 National Strategic Overview for Quantum Information Science, a pillar of the U.S. national strategy for quantum information science (QIS) is advancing international collaboration. This was supplemented by a 2021 report on The Role of International Talent in Quantum Information Science, which "finds that maintaining a strong flow of international students and researchers is an essential component to developing the expert QIST workforce required to achieve U.S. QIST goals as part of an advancing global research enterprise."

Toward this goal, the U.S. is a founding member of the Entanglement Exchange, a portal for exchange opportunities in QIS with like-minded nations. As part of this exchange, below are some opportunities for U.S. persons to study and/or work abroad, as well as opportunities for international students and scholars to study and/or work in the United States.

Contents [hide]

VISA INFORMATION

For international students, scholars, and professionals in STEM disciplines looking for opportunities to gain experience in QIS in the United States, information about visas can be found from a variety of sources.

U.S. Citizenship and Immigration Services (USCIS, a component of the U.S. Department of Homeland Security) has published online information to provide an official government overview of the standards applicable for pathways for noncitizens to work in the United States in STEM fields. This guide highlights some of the most important considerations for STEM professionals who want to work in the United States, using reasonably non-technical language. USCIS STEM pathways resources

Enabling People: Federal Workforce Activities in QIS

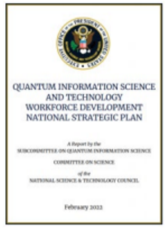
⟨quantum|gov⟩

FEDERAL WORKFORCE ACTIVITIES IN QUANTUM INFORMATION SCIENCE

OVERVIEW

The 2018 National Strategic Overview for Quantum Information Science (QIS) identifies **creating a quantum-smart workforce for tomorrow** as a key policy area. The strategy for creating this workforce is detailed in the 2022 report, Quantum Information Science and Technology (QIST) Workforce Development National Strategic Plan, and it includes four critical actions:

1. Develop and maintain an understanding of the **workforce needs** in the QIST ecosystem, with both short-term and long-term perspectives.
2. Introduce **broader audiences** to QIST through public outreach and educational materials.
3. Address QIST-specific **gaps** in professional education and training opportunities.
4. Make **careers** in QIST and related fields more accessible and equitable.

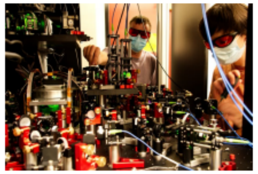
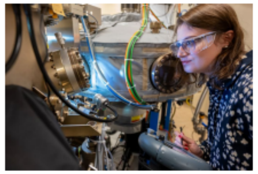
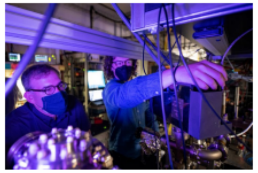
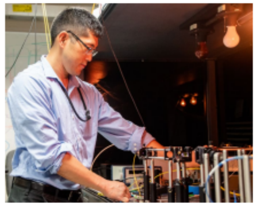

QUANTUM INFORMATION SCIENCE AND TECHNOLOGY WORKFORCE DEVELOPMENT NATIONAL STRATEGIC PLAN

One of the primary mechanisms for coordinating Federal workforce activities in QIST is through the National Science and Technology Council (NSTC) Subcommittee on Quantum Information Science (SCQIS) **Interagency Working Group on Workforce (IWG-WF)**.

This factsheet gives some examples of activities that Federal agencies have engaged in or funded in order to create a quantum-smart workforce for tomorrow. At the **K-12** level, the activities include identifying QIST concepts and integrating them into existing K-12 courses, developing and curating approachable quantum lessons and activities, providing professional development for teachers, and engaging in public outreach about QIST and QIST careers. For **undergraduate** and **graduate** students, the activities increasingly involve scholarships, fellowships, and research opportunities, while providing additional on-ramps to QIST through summer schools. For **postdoctoral** scholars and **professionals**, activities include fellowships, summer schools, research opportunities, and funding for institutions traditionally underrepresented in the Federal research portfolio.

See quantum.gov for more information



There are a number of workforce development efforts underway across all sectors. To show the breadth of activities, here is a *small sample* of efforts that agencies have engaged in or funded.

K-12

- Q-12 Education Partnership of industry, academia, and government (OSTP & NSF spearheaded)
- Workshop on nine Key Concepts for Future QIS Learners (NSF funded)
- Frameworks for including QIS topics in high school physics, computer science, math, and chemistry courses (NSF funded)
- Classroom activities (e.g., Q-12 QuanTime)
- Professional development for teachers (e.g., NSF-funded Quantum for All and QuEST)
- Videos about quantum careers (e.g., for World Quantum Day, Q-12 Careers)
- High school summer internships at Government Labs (e.g., NIST SHIP) and universities (e.g., ARO High School Apprenticeship Program)
- Summer schools (e.g., National QIS Centers, AFRL Quantum STEM Summer Camp, NSF-funded Quantum for All and QuEST)

UNDERGRADUATE

- Scholarships (e.g., DOD SMART)
- Curriculum development (e.g., NSF-funded QuSTEAM)
- Summer research (e.g., NSF REU, NIST SURF, Naval Research Enterprise Internship Program, Pathways Program, AFRL Scholars Program)
- Summer schools (e.g., LPS Qubit Collaboratory, NSF-funded STAQ Virtual School)

GRADUATE

- Fellowships (e.g., ARO/LPS Quantum Computing Research Fellowship, DOD SMART, DOD National Defense Science and Engineering Graduate Fellowship, DOE CSGF) and funding through academic Principal Investigators
- Research at National QIS Research Centers (NSF, DOE, DOD, NSA), Government Labs (e.g., NIST, NASA, LPS, DOD), National Labs (DOE), and joint research institutes (e.g., JILA, JQI, LPS, QuICS)
- Research with academic and industry partners (e.g., NSF QISE-NET)
- Workshop on Gaps in Postsecondary Quantum Education and Training (LPS)
- Summer schools (e.g., DOE LANL Summer School Fellowship, DOE QSC Center, DOE C2QA Center)

POSTDOCTORAL

- Fellowships (e.g., LQC Postdoctoral Fellowship, NRC Fellowship, ODNI IC Postdoctoral Research Fellowship)
- Summer schools (e.g., NSF/DOE QS3)

PROFESSIONAL

- Faculty fellowships (e.g., NSF QCIS-FF)
- Summer research at Government Labs (e.g., Army, Navy, and Air Force Summer Faculty Fellowships)
- Career fairs (e.g., DOE Centers QIS Career Fair)
- Funding underrepresented universities in QIST (e.g., NSF ExpandQIS, DOE ASCR-RENEW, DOD/HBCU Quantum Sensing Center)
- Summer schools (e.g., AFRL/RI Short Courses)

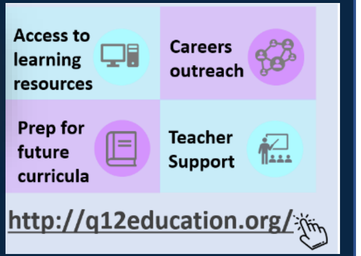
Image Credits: [Banner] J.T. Consoli, U. Maryland [Pictures Top to Bottom] R. Hahn, Fermilab; LPS; Kaufman Group, CU Boulder, QSA; Argonne National Lab; K. Houser, UC Berkeley, QSA; NASA

Available on quantum.gov

Enabling People: Inspire + Education + Experiences => Careers

INSPIRE

National Q-12 Education Partnership



- Teaching Resources
- K-12 Framework for Phys, CS, Math & Chem

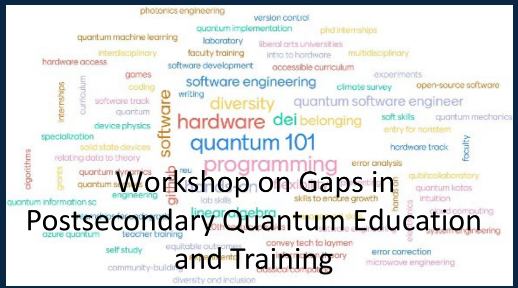
100k Views
Search:
This is quantum q12

100's of teachers

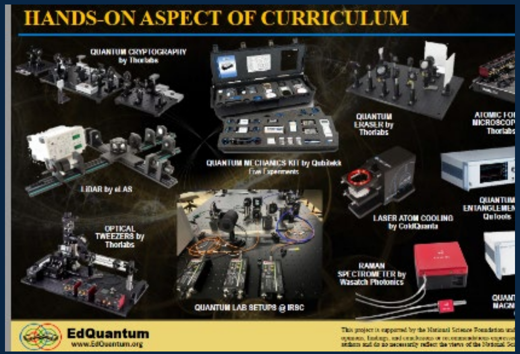
QUANTIME

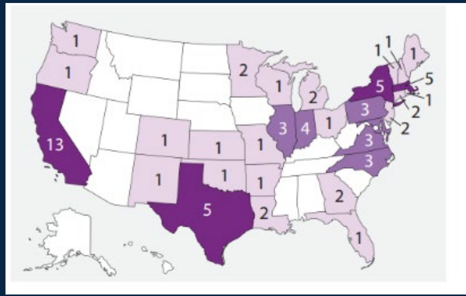
20k+ students

EDUCATION AND TRAINING



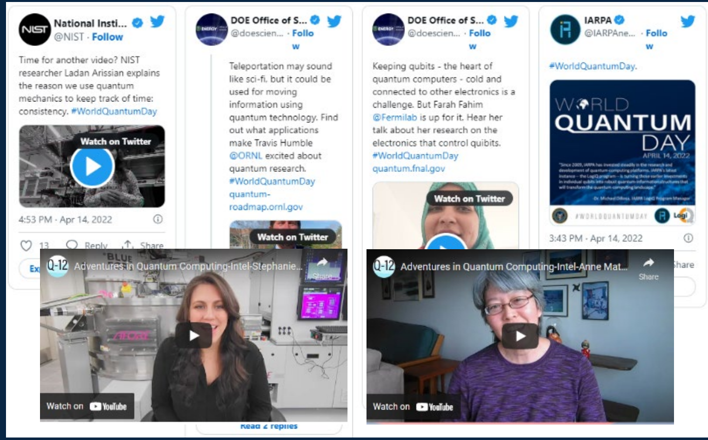
Convergent Undergraduate Education in Quantum Science, Technology, Engineering, Arts and Mathematics





Summer of Quantum
SHORT COURSE

ACCESSIBLE EXPERIENCES AND CAREERS

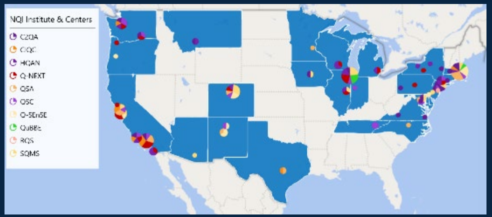


Expanding Capacity in Quantum Information Science and Engineering (ExpandQISE)

Public Outreach

ADVANCED SCIENTIFIC COMPUTING RESEARCH - REACHING A NEW ENERGY SCIENCES WORKFORCE (ASCR-RENEW)

FUNDING OPPORTUNITY ANNOUNCEMENT (FOA) NUMBER: DE-FOA-0002767



National Quantum Initiative Advisory Committee

- Established by Sec. 104 of the NQI Act
- Advises the—
  - President
  - NSTC Subcommittee on Quantum Information Science (SCQIS)
  - NSTC Subcommittee on Economic and Security Implications of Quantum Science (ESIX)
- Conducts independent assessments of the NQI, including any recommendations for improvements, through reports submitted to the President and appropriate committees of Congress

NQIAC & NQCO

NQIAC Report: Renewing the NQI


A Report of the

National Quantum Initiative Advisory Committee

June 2023

Renewing the National Quantum Initiative: Recommendations for Sustaining American Leadership in Quantum Information Science

https://www.quantum.gov/about/nqiac/

- First meeting was in December 2022
- Three Subcommittees met for six months hearing from experts across the nation
- Publish report in June 2023
- Met in November 2023 with a focus on quantum networking

Recommendations:

1. Reauthorize and appropriate the NQI Act
2. Expand research
3. Fund industry-led partnerships
4. Invest in equipment and infrastructure
5. Promote international cooperation
6. Promote and protect U.S. QIST R&D
7. Strengthen supply chains
8. Develop domestic talent
9. Attract and retain foreign talent

NQI Reauthorization

The NQI Act authorized several activities for five years, which expired on September 30, 2023

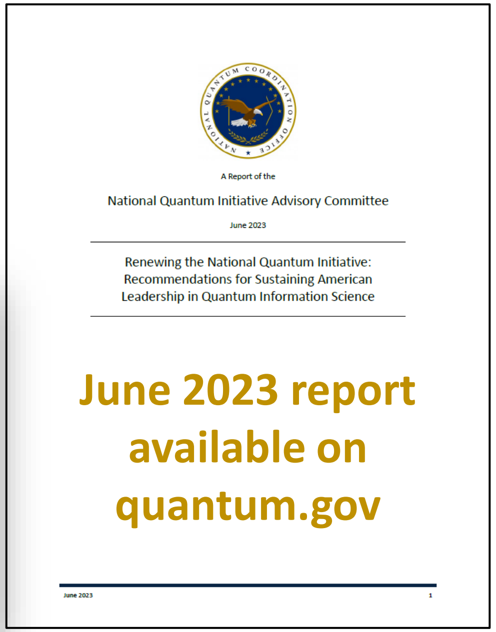
Interagency Input

1. QIS Program Day 2022

2. OSTP/NQCO coordinated an interagency process (through OMB) for recommending policies to enhance the NQI Act, which were submitted to relevant committees of Congress

Community Input

National Quantum Initiative Advisory Committee


A Report of the
National Quantum Initiative Advisory Committee
June 2023
Renewing the National Quantum Initiative: Recommendations for Sustaining American Leadership in Quantum Information Science
June 2023 1

June 2023 report available on quantum.gov

Experts representing industry (small and large), academia, and Federal laboratories

Report on Renewing the NQI: Recommendations for Sustaining American Leadership in QIS

- 3 Findings
- 4 Overarching Recommendations
- 9 Detailed Recommendations

NQI Reauthorization: House Committee on Science, Space, and Technology

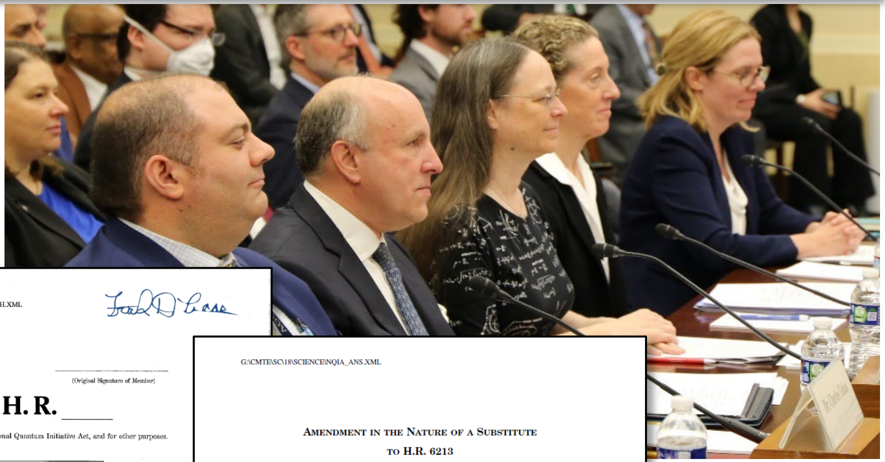
COMMITTEE ON SCIENCE, SPACE AND TECHNOLOGY
CHAIRMAN FRANK LUCAS

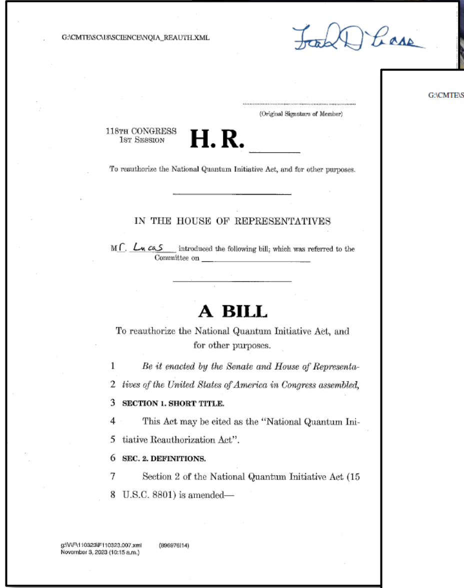
- June 7, 2023: Full hearing on *Advancing American Leadership in Quantum Technology*
  - "The purpose of this hearing is to evaluate the state of quantum research, development, and technology (RD&T) in the United States. The hearing will serve as an opportunity to **review and discuss the first five years of the National Quantum Initiative Act (NQIA)**, the economic value of quantum science and its applications, the national security importance of developing quantum capabilities, and what policies should be considered in the next five years. The hearing will help **inform legislation to reauthorize NQIA programs** that expire on September 30, 2023."
- November 3, 2023: Chairman Lucas and Ranking Member Lofgren introduced the NQI Reauthorization Act
- November 15, 2023: Full committee markup of NQI Reauthorization Act
  - Amendment in the Nature of a Substitute
  - 18 additional amendments
  - All passed by voice vote
- November 29, 2023: Passed unanimously out of committee

FULL COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
HEARING CHARTER

"Advancing American Leadership in Quantum Technology"

Wednesday, June 7, 2023
10:00 a.m.
2318 Rayburn House Office Building





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(Original Signature of Member)

118TH CONGRESS
1ST SESSION
H. R. ____

To reauthorize the National Quantum Initiative Act, and for other purposes.

IN THE HOUSE OF REPRESENTATIVES

Mr. Lucas introduced the following bill; which was referred to the Committee on ____

A BILL

To reauthorize the National Quantum Initiative Act, and for other purposes.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled,

SECTION 1. SHORT TITLE.

This Act may be cited as the "National Quantum Initiative Reauthorization Act".

SEC. 2. DEFINITIONS.

Section 2 of the National Quantum Initiative Act (15 U.S.C. 8801) is amended—

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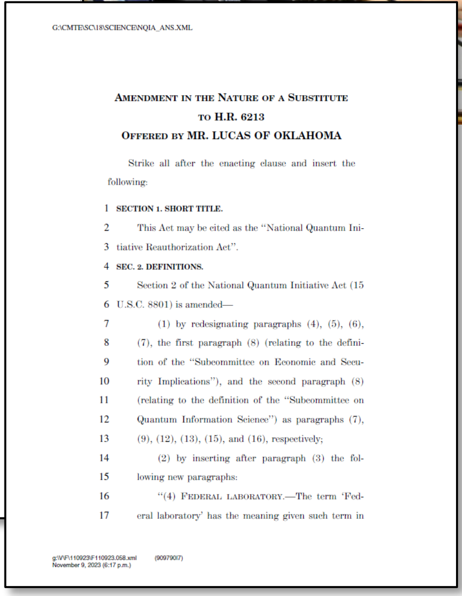
November 3, 2023 (10:15 a.m.)



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AMENDMENT IN THE NATURE OF A SUBSTITUTE
TO H.R. 6213
OFFERED BY MR. LUCAS OF OKLAHOMA

Strike all after the enacting clause and insert the following:

SECTION 1. SHORT TITLE.

This Act may be cited as the "National Quantum Initiative Reauthorization Act".

SEC. 2. DEFINITIONS.

Section 2 of the National Quantum Initiative Act (15 U.S.C. 8801) is amended—

(1) by redesignating paragraphs (4), (5), (6), (7), the first paragraph (8) (relating to the definition of the "Subcommittee on Economic and Security Implications"), and the second paragraph (8) (relating to the definition of the "Subcommittee on Quantum Information Science") as paragraphs (7), (9), (12), (13), (15), and (16), respectively;

(2) by inserting after paragraph (3) the following new paragraphs:

"(4) FEDERAL LABORATORY.—The term 'Federal laboratory' has the meaning given such term in

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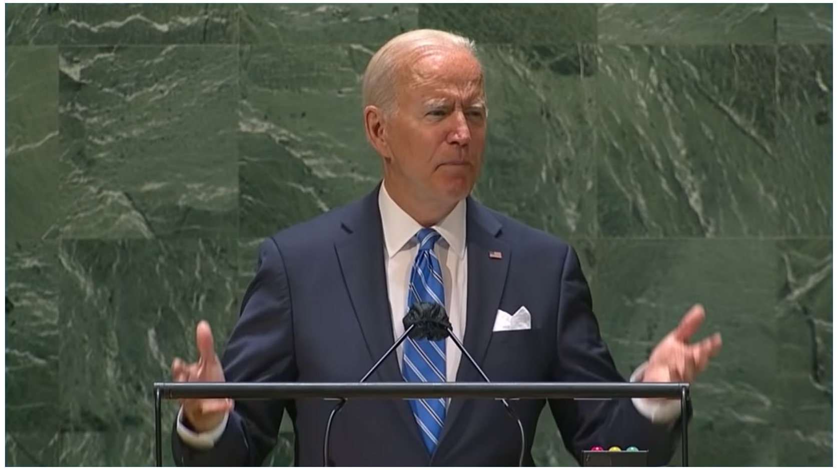
November 9, 2023 (6:17 p.m.)

Available at science.house.gov

QIS is an Administration Priority



"As new technologies continue to evolve, we'll work together with our democratic partners to ensure that new advances in areas from biotechnology, to quantum computing, 5G, artificial intelligence, and more are used to lift people up, to solve problems, and advance human freedom." – President Biden, Remarks Before the 76th Session of the United Nations General Assembly, September 21, 2021

"This increase in research and development funding is going to ensure that the United States leads the world in the industries of the future: quantum computing, to artificial intelligence, to advanced biotechnology." – President Biden, Signing of the CHIPS and Science Act, August 9, 2022

"Quantum computing has the potential to transform everything, from how we create new medicines to how we power artificial intelligence and cybersecurity. It's technology that is vital to our economy and equally important to our national security." – President Biden, Remarks on the CHIPS and Science Act, October 6, 2022

QIS is an Administration Priority

R&D Priorities for the President's FY 2025 Budget

Joint Memo from the Director of OMB and Director of OSTP

EXECUTIVE OFFICE OF THE PRESIDENT
WASHINGTON, D.C. 20503

August 17, 2023

M-23-20

MEMORANDUM FOR THE HEADS OF EXECUTIVE DEPARTMENTS AND AGENCIES

FROM: SHALANDA D. YOUNG
DIRECTOR
OFFICE OF MANAGEMENT AND BUDGET

ARATI PRABHAKAR
DIRECTOR
OFFICE OF SCIENCE AND TECHNOLOGY POLICY

SUBJECT: Multi-Agency Research and Development Priorities for the FY 2025 Budget

Lead the world in maintaining global security and stability in the face of immense geopolitical changes and evolving risks. [...]

- Advance critical and emerging technology areas, such as microelectronics, biotechnology, quantum information science, advanced materials, high performance computing, and nuclear energy.

Office of Science and Technology Policy

www.whitehouse.gov/ostp
www.ostp.gov

www.quantum.gov
@WHOSTP

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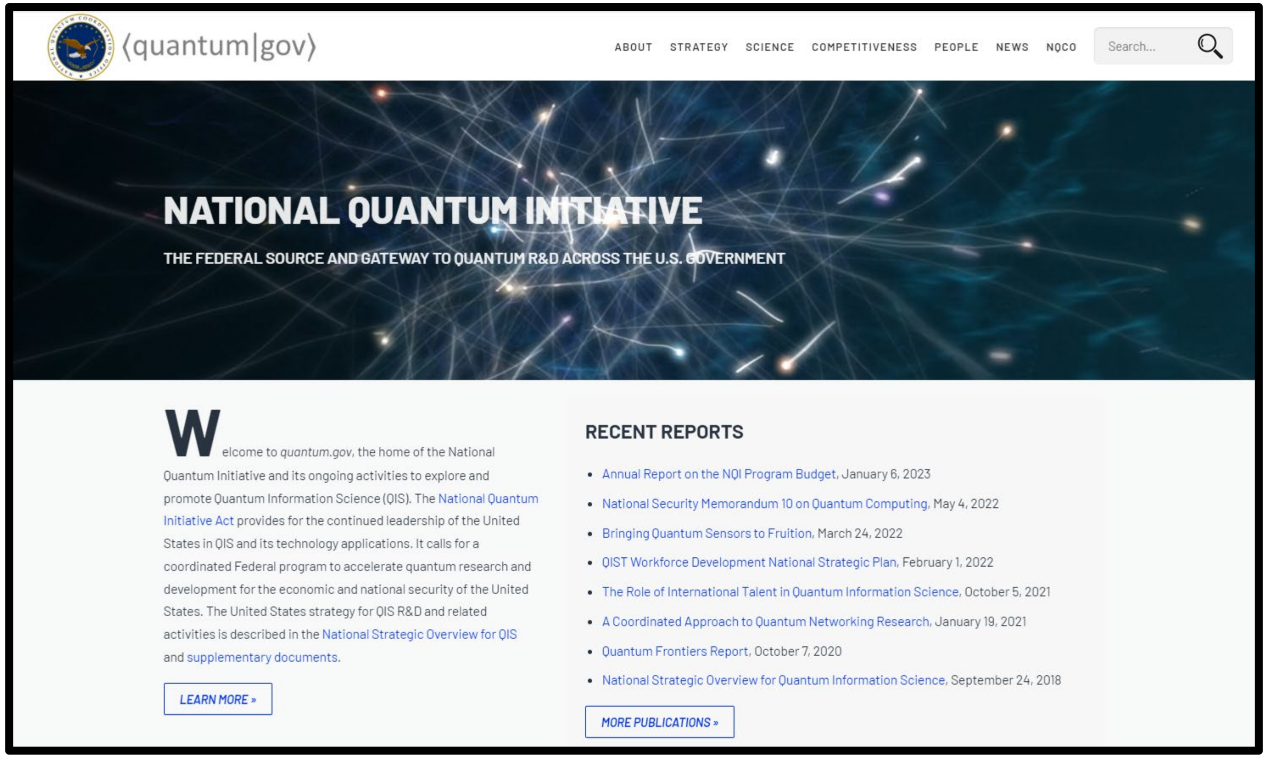

Learn more about all Departments and Agencies working in QIS at https://www.quantum.gov

SCQIS
Co-Chairs:
Denise Caldwell, NSF
Harriet Kung, DOE
James Kushmerick, NIST
Gretchen Campbell, OSTP
Executive Secretary:
Alexander Cronin, NSF

ESIX
Co-Chairs:
Barry Barker, NSA
John Burke, DOD
Harriet Kung, DOE
Gretchen Campbell, OSTP
Executive Secretary:
Corey Stambaugh, NIST

National Quantum Coordination Office (OSTP)
Gretchen Campbell– Director of NQCO and AD for QIS at OSTP
Brad Blakestad– Deputy Director for NQCO
Tanner Crowder – Senior Policy Advisor
Thomas Wong – Quantum Liaison

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Q4I
6TH ANNUAL
QUANTUM
FOR
INTERNATIONAL
WORKSHOP
25-27 JUNE 2024
ROME, NEW YORK
INNOVARE
ADVANCEMENT CENTER
AFRL
GRIFFISS
INSTITUTE

DR. ALLAN BRACKER

Research Chemist

U.S. Naval Research Lab (NRL)

INNOVARE ADVANCEMENT CENTER

AFRL

GRIFFISS INSTITUTE

Q4I

6TH ANNUAL Q4I WORKSHOP | JUNE 25-27 | ROME, NY

U.S. NAVAL RESEARCH LABORATORY

Office of Naval Research Science & Technology

Magnetometry based on defects in isotopically pure silicon carbide

Allan Bracker, Ignas Lekavicius, S. Carter, S. White[2], D. Pennachio[1], A. Yeats[1], J. Hajzus[3], A. Purdy[1], T. Reinecke[1] , E. Glaser[1], and R. Myers-Ward[1]

[1]US Naval Research Laboratory, Washington, DC 20375, USA

[2]NRC Research Associate at the US Naval Research Laboratory, Washington, DC 20375, USA

[3]ASEE Research Associate at the US Naval Research Laboratory, Washington, DC 20375, USA

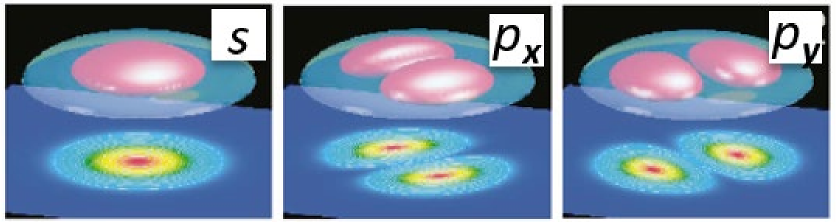
[+]Current affiliation: Laboratory for Physical Sciences, College Park, MD, 20740, USA

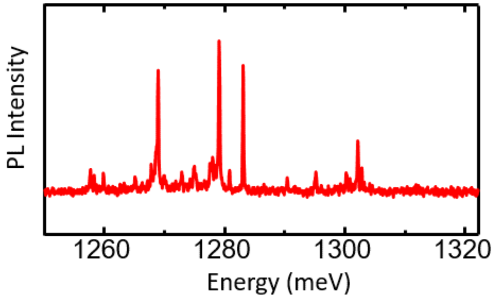
Quantum systems in semiconductors

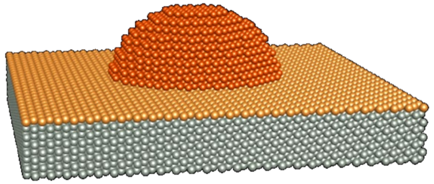
1. Crystal defects
2. Epitaxial quantum dots
3. Colloidal nanocrystals
4. Defects in 2D materials.

"Artificial atoms"

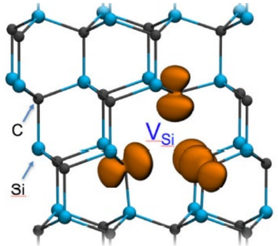
- Confine electrons in the material.
- Discrete orbital energy levels.
- Light emission and absorption, optical coherent control.



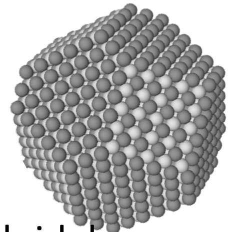




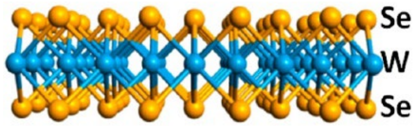
InGaAs quantum dot



SiC silicon vacancy



Colloidal nanocrystals



2D materials: WSe_2, BN, etc.

Advantages

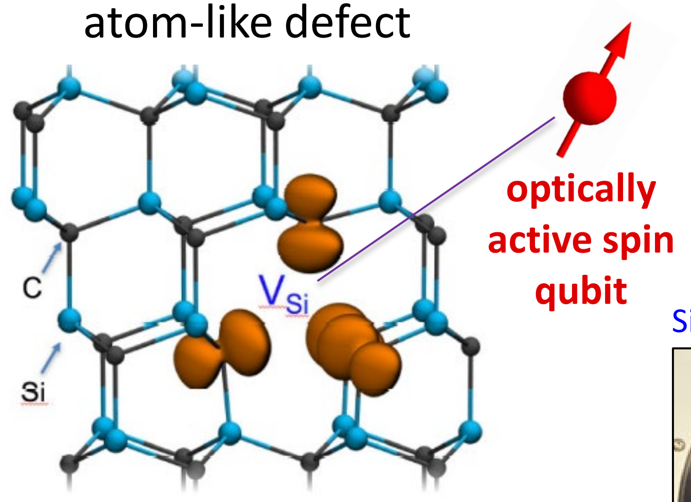
- Small size & low power.
- Leverage semiconductor industry, potential for integration.
- Quantum state "engineering" through growth/fabrication.

Challenges

- Loss of quantum coherence to environment.
- Inhomogeneity: hard to make them identical.

Silicon Carbide for quantum S&T

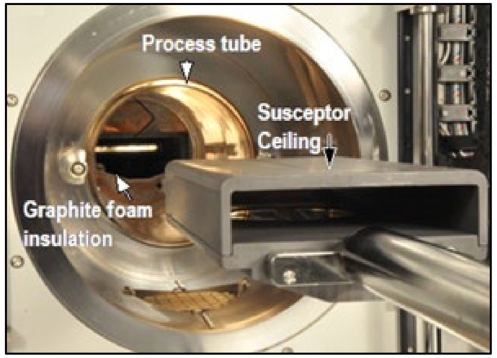
Silicon Vacancy
atom-like defect



SiC quantum-relevant research activities at NRL

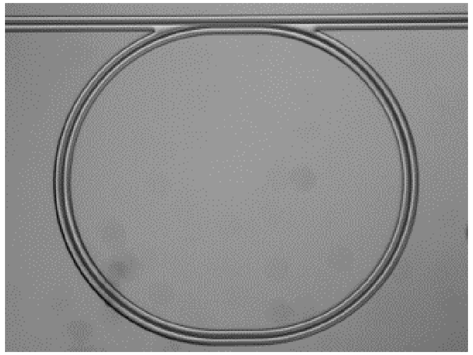
- Growth of isotopically-pure SiC
- Device fabrication: electronic, photonic, acoustic
- Sensing, spin control, quantum optics
- Theory & Modelling

SiC growth reactor



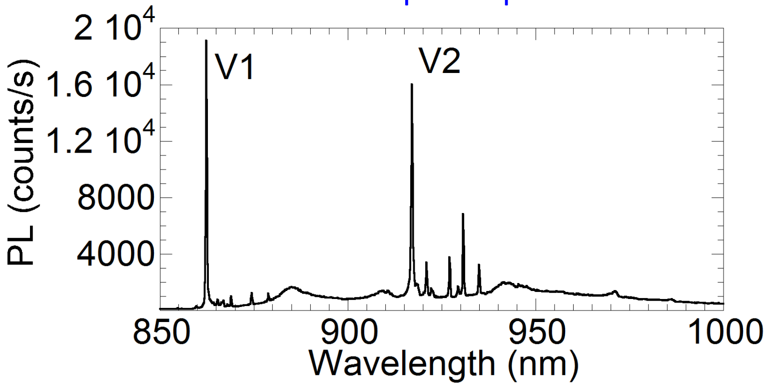
Code 6880

Ring resonator waveguide



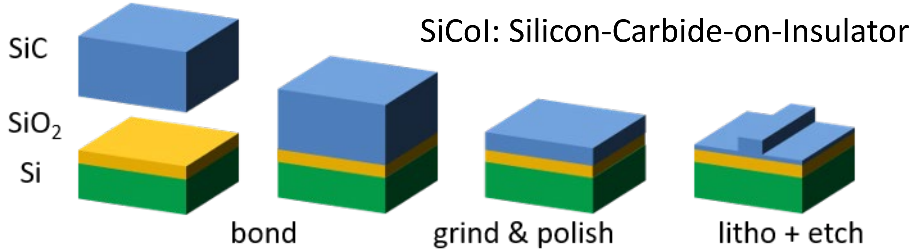
Code 5613

Atom-like optical spectrum



Advantages

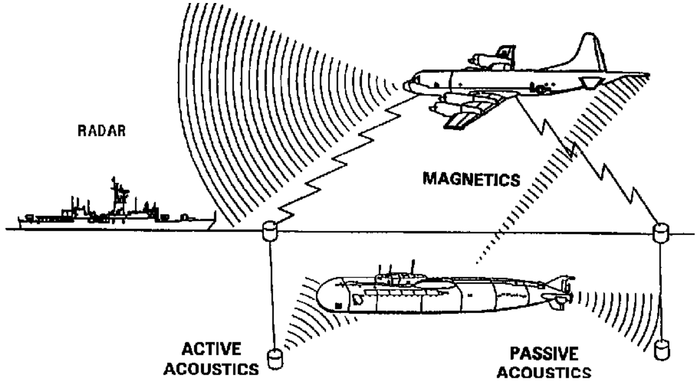
- Wafer scale growth & advanced fab
- Membrane-substrates for photonic integration
- Optical nonlinearity
- Doping / electrical control



Navy interest in magnetic sensing

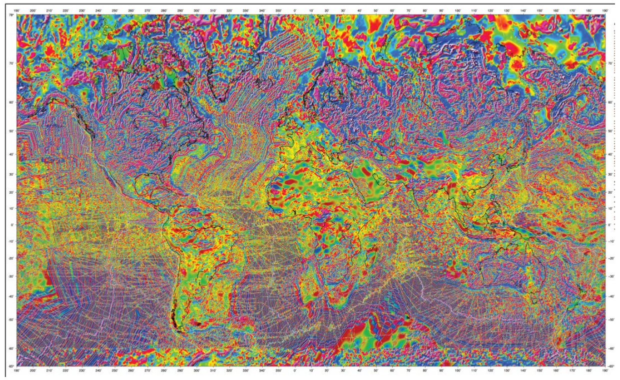
Magnetic Anomaly Detection (MAD)

Magnetic fields from submarines, unexploded ordnance, underground anomalies, and vehicles



Magnetic Navigation (MagNav)

Earth's magnetic anomaly field can be used for navigation



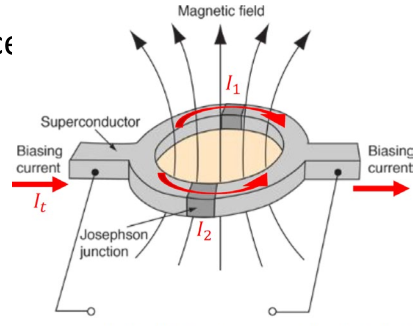
Quantum for magnetometry

State-of-the-art magnetometers are quantum.

SQUIDs

(superconducting quantum interference devices)

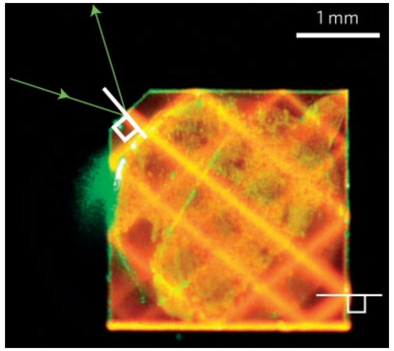
- Very sensitive < 1 pT/Hz½
- Liquid helium
- Big, bulky
- Limited dynamic range



Adapted from: "http://hyperphysics.phy-astr.gsu.edu/hbase/Solids/Squid.html"

Defects in solid state

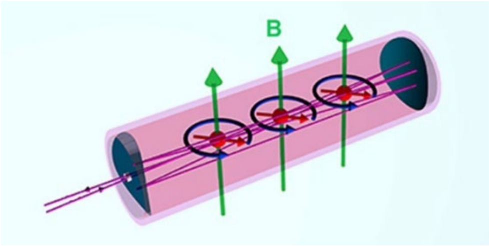
- High dynamic range
- Room temperature
- Lowest SWaP
- Natural vector magnetometer
- Relative ease of integration
- Demonstrated sensitivity ~ 1 pT/Hz½



Diamond

Atomic vapor

- Very sensitive < 1 pT/Hz½
- Cryogen free
- Challenging integration

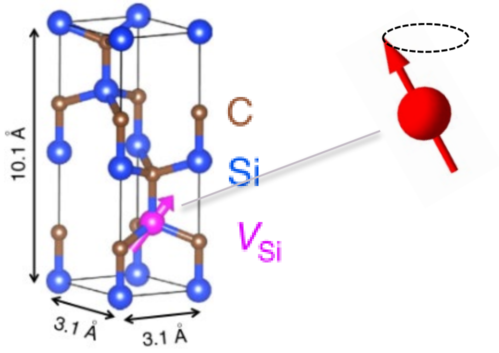


Challenge in SiC: Achieving higher sensitivity

Exploit quantum superposition

Quantum superposition

$$|\varphi\rangle = a|\uparrow\rangle + b|\downarrow\rangle$$



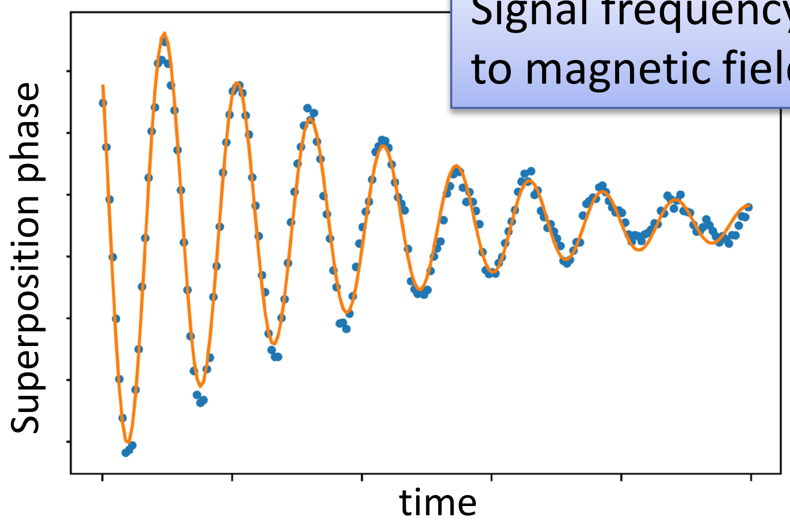
Superposition coherence is very sensitive to the environment

→ Quantum computing is difficult

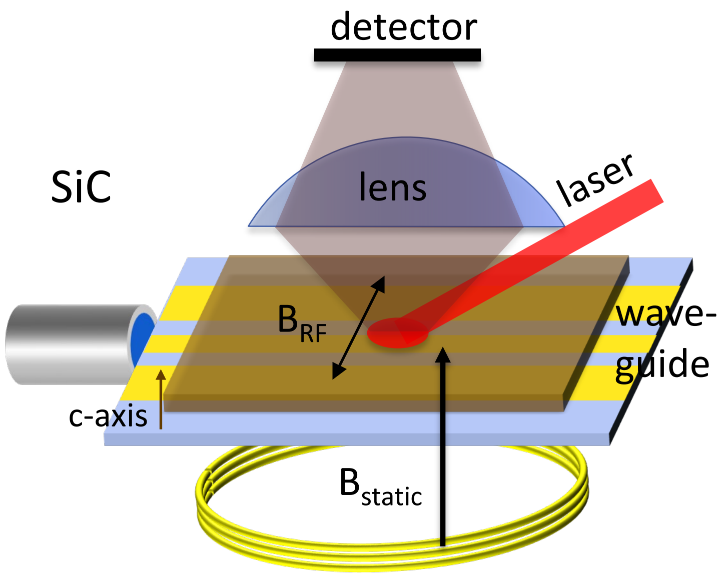
→ Quantum sensing is *comparatively* easy

Measurement: Optically-detected magnetic resonance

- Laser initializes spins
- RF magnetic field B_{RF} manipulates the spins
- Readout with spin-dependent photoluminescence



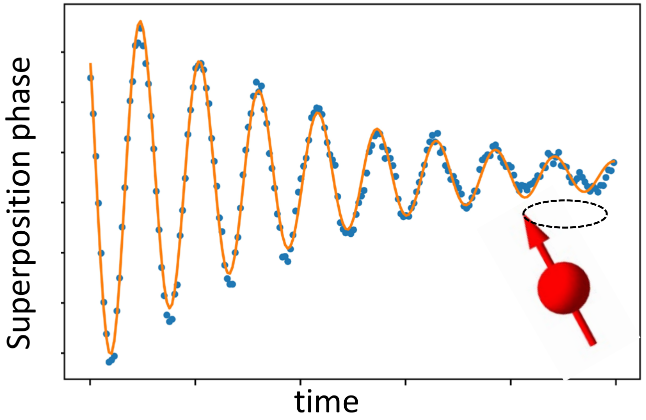
Signal frequency relates to magnetic field.



Preserving quantum coherence

Higher quantum coherence translates to greater sensitivity

→ Reduce sources of noise and inhomogeneity that limit coherence

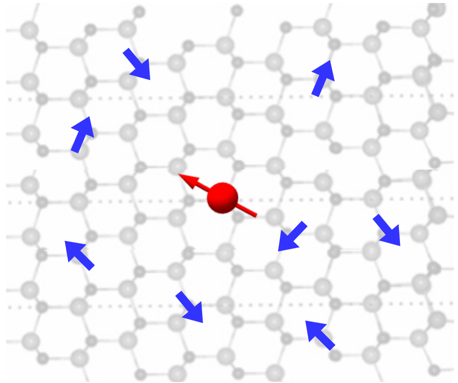


Noisy environment

- Nuclear spins in lattice **
- Phonons (crystal vibration)
- Other defects or electrons nearby

Ensemble inhomogeneity

- Crystal environment: strain, electric, magnetic
- Measurement: optical power, RF power, bias field

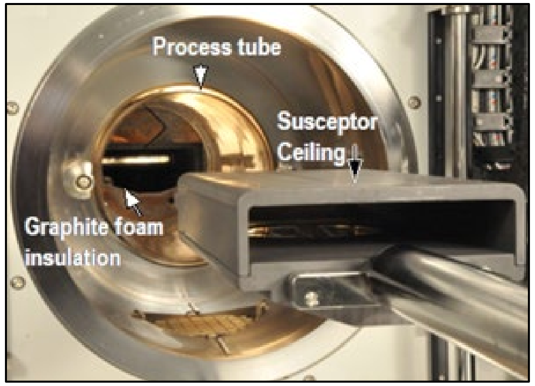


**Natural abundance of spin-containing isotopes in SiC:

^{29}Si: 4.7% and ^{13}C: 1.1%

Isotopically Pure SiC crystal growth at NRL

SiC growth reactor



Code 6880

- Isotopically pure silane gas synthesized with solid Si by Chemistry Division
- Grow isotopically purified 4H-SiC on n-doped substrates (Electronics S&T Division) Reduce ^{29}Si: 4.7% → **0.01%**, ^{13}C: 1.1% → **0.15%**

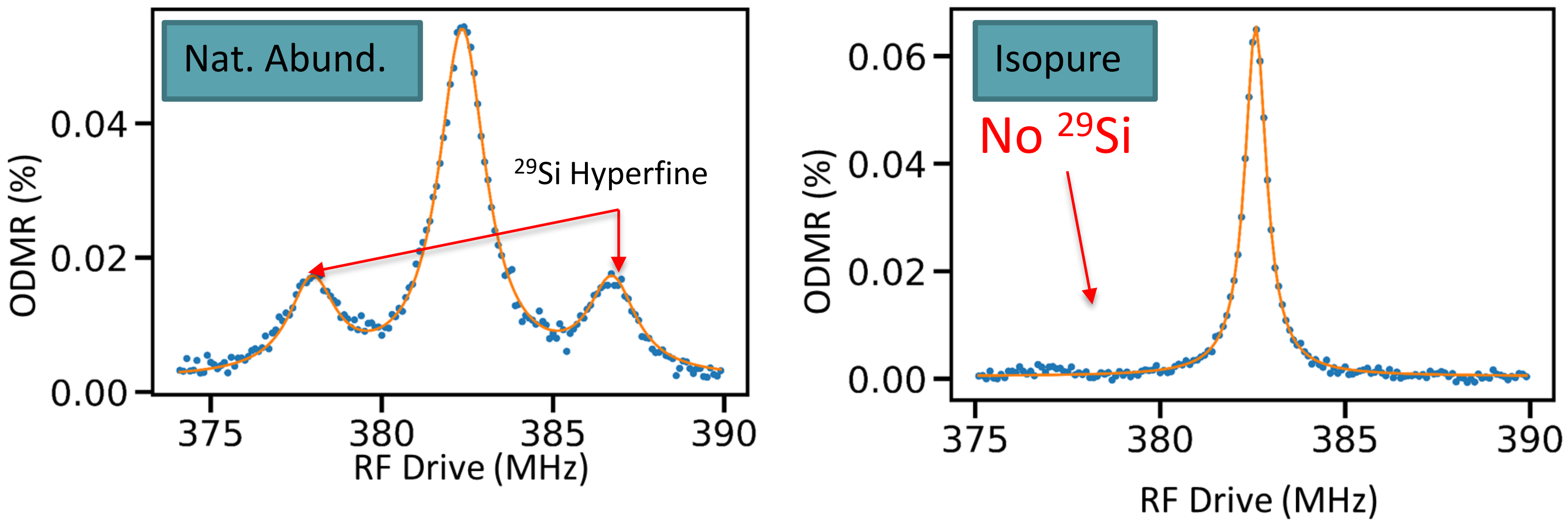
Electron irradiation creates Si-V defects

e^- irradiation, dose = $\{1 \times 10^{17}, 3 \times 10^{17}, 1 \times 10^{18}, 3 \times 10^{18}\}$ cm^{-2}

Epitaxial growth(~20um)

4H-SiC, commercial n-doped (~500um)

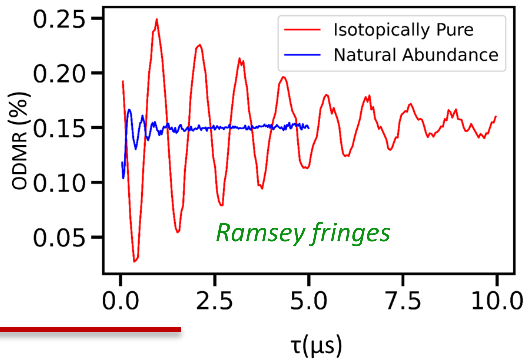
SiC Si-Vacancy: Optically-Detected Magnetic Resonance spectra



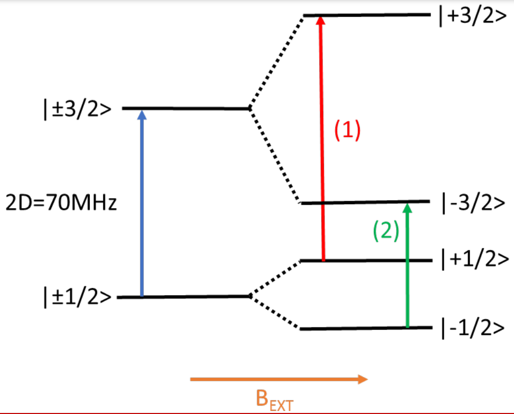
Improvements in spin coherence

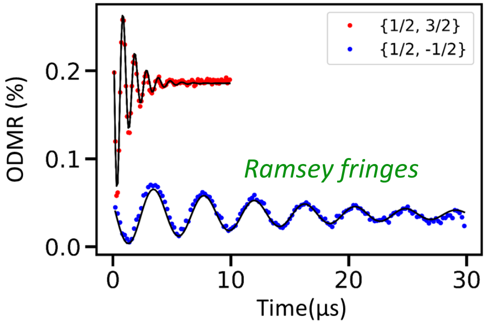
1. Iso-pure SiC: **~10x increase** in coherence time (removes nuclear spin effects).

T_2^*: 0.4 μs → 5.7 μs
T_2: 4.5 μs → 35 μs

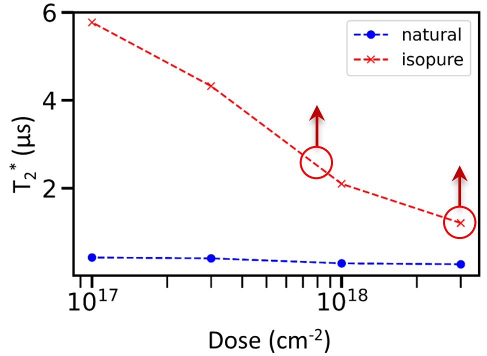


2. Judicious choice of quantum state transitions: **~10x increase** (remove influence of electric field and strain).





3. Thermal annealing at 600°C: **~50% increase.** (Reduces inhomogeneous strain from implantation damage).



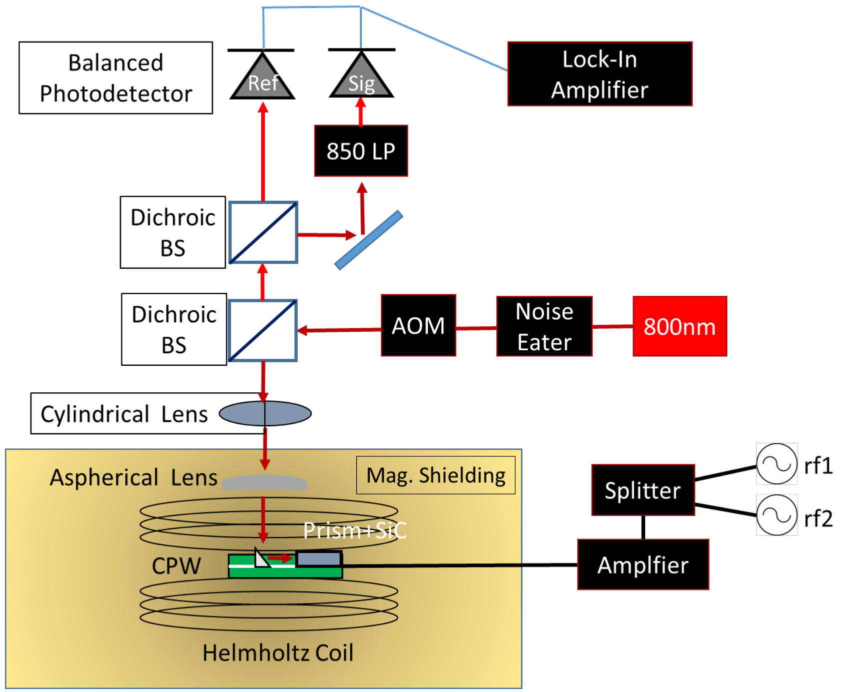
PRXQuantum.3.010343

Magnetometry with SiC spins

>10x improvement in DC magnetic sensitivity

Optically-detected magnetic resonance

- Laser spin initialization & optical detection
- Helmholtz coil for bias field $\vec{B}$
- Coplanar waveguide couples RF to SiC
- Modulated RF source with Lock-in detection



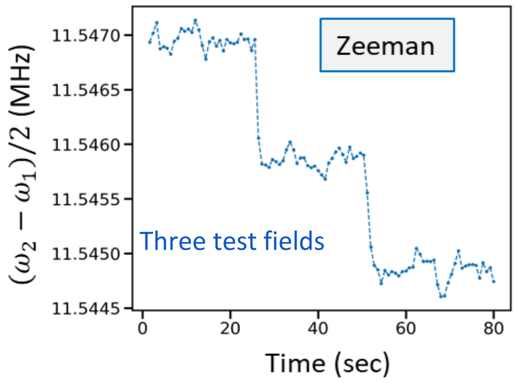
Detect DC magnetic field

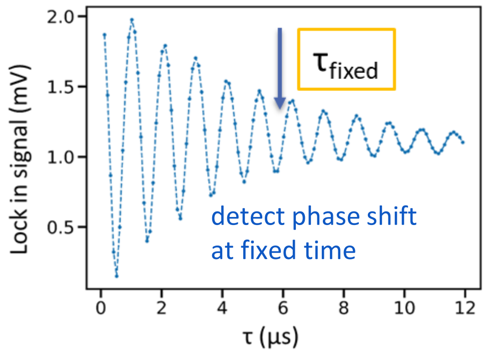
Frequency domain measurement

- 4nT/√Hz sensitivity
- Calculated shot noise limit **2 nT/√Hz**

Time domain measurement

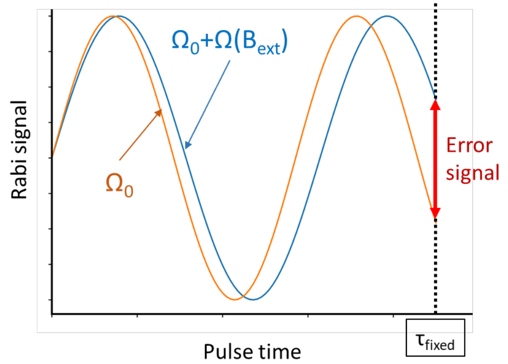
- 4.7nT/√Hz sensitivity
- Calculated shot noise limit **200 pT/√Hz**





Detect AC magnetic field

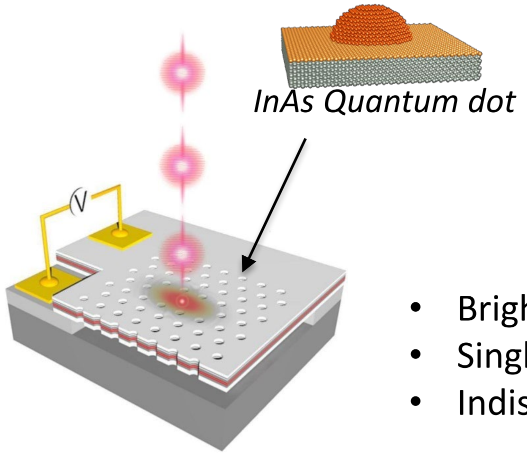
Sensitivity for 13 MHz, 101 MHz and 965 MHz detection is **16, 17 and 25 nT/√Hz.**
(Widely tunable compared to diamond)

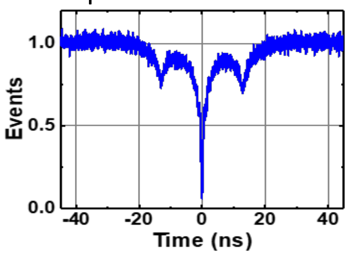


PhysRevApplied.19.044086

NRL semiconductor quantum research

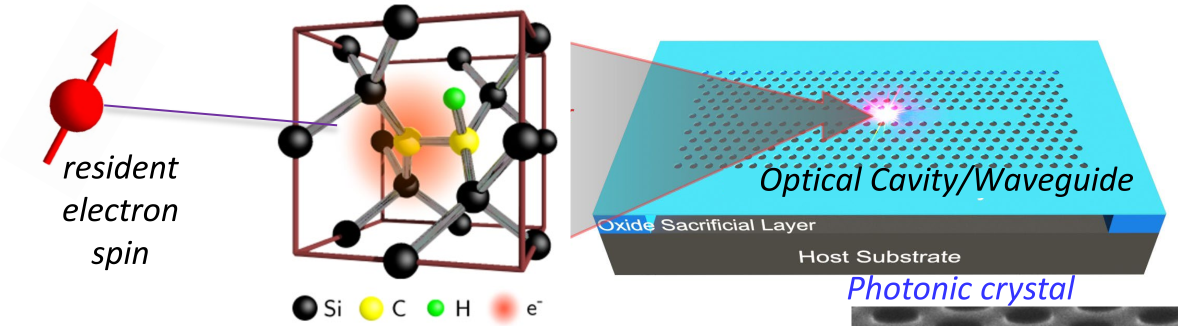
Wavelength-tunable Single Photon Source



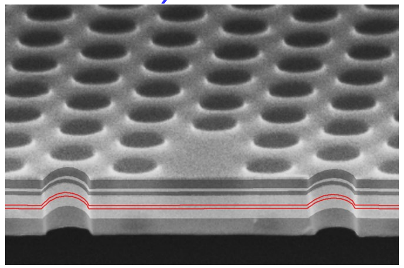


- Brightness
- Single photon purity
- Indistinguishability

Spin-photon interface in SiC, Si

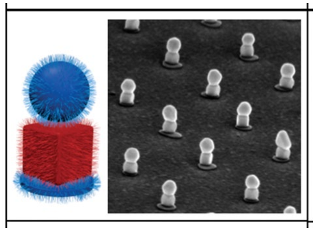


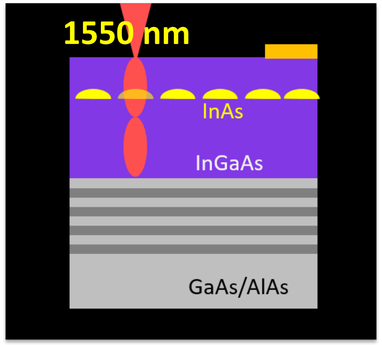
Photonic crystal



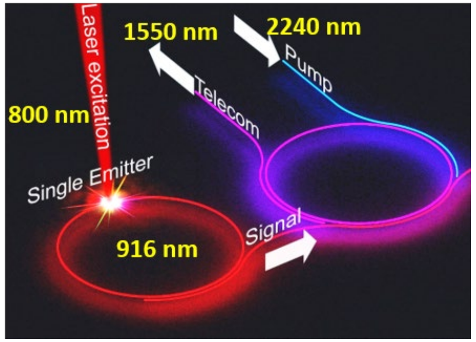
Telecommunication Wavelength SPS

Direct growth of quantum dots & nanocrystals



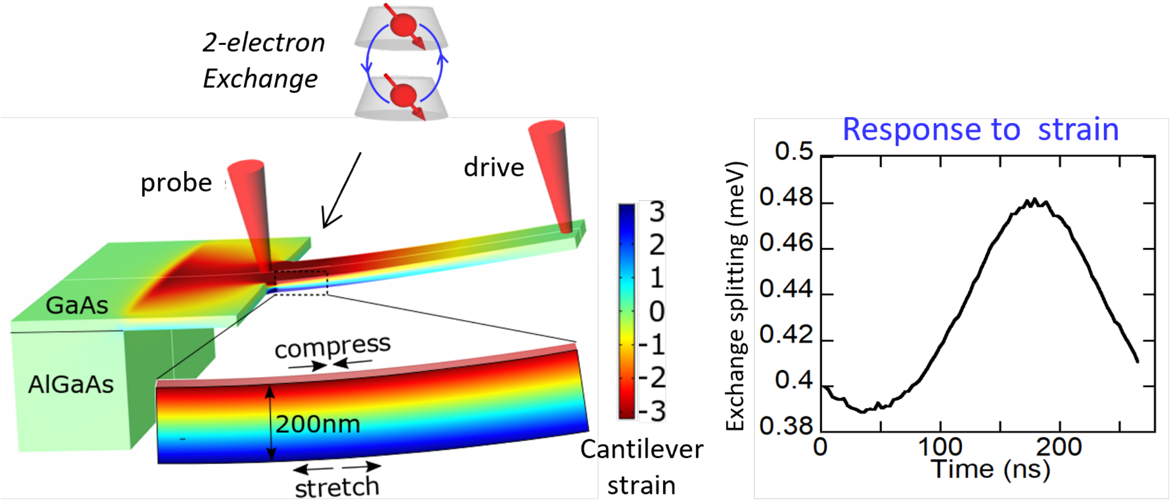


Frequency conversion in SiC

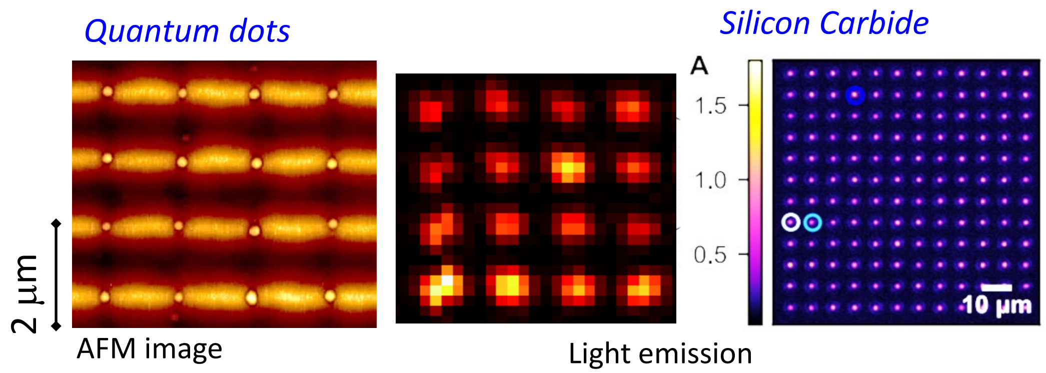


NRL semiconductor quantum research

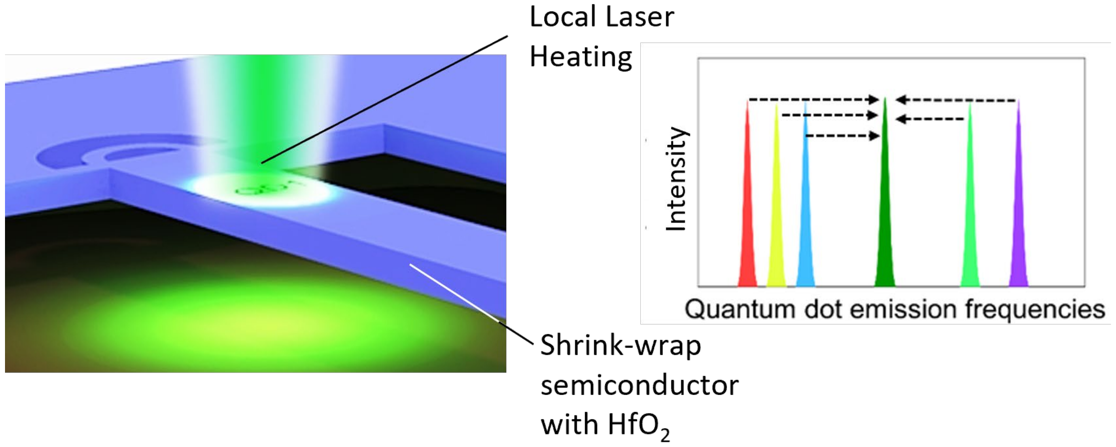
Sensing strain with quantum dot molecule



Site-control of single photon emitters



Energy fine-tuning for integration / homogeneity



SiC quantum team

Ignas Lekavicius

Rachael Myers-Ward

Sam Carter (currently at LPS)

Sam White (NRC Postdoc)

Daniel Pennachio

Andrew Yeats

Jenifer Hajzus (ISEE Postdoc)

Andrew Purdy

D. Kurt Gaskill (currently at UMd)

Thomas Reinecke

Evan Glaser

Supported by US Office of Naval Research

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DR. FREDRIK FATEMI

Senior Research Scientist for Quantum Sciences

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DR. KATHY-ANNE SODERBERG

Senior Scientist for Quantum Science and Technology

Air Force Research Lab (AFRL) Information Directorate (RI)

Rome, NY

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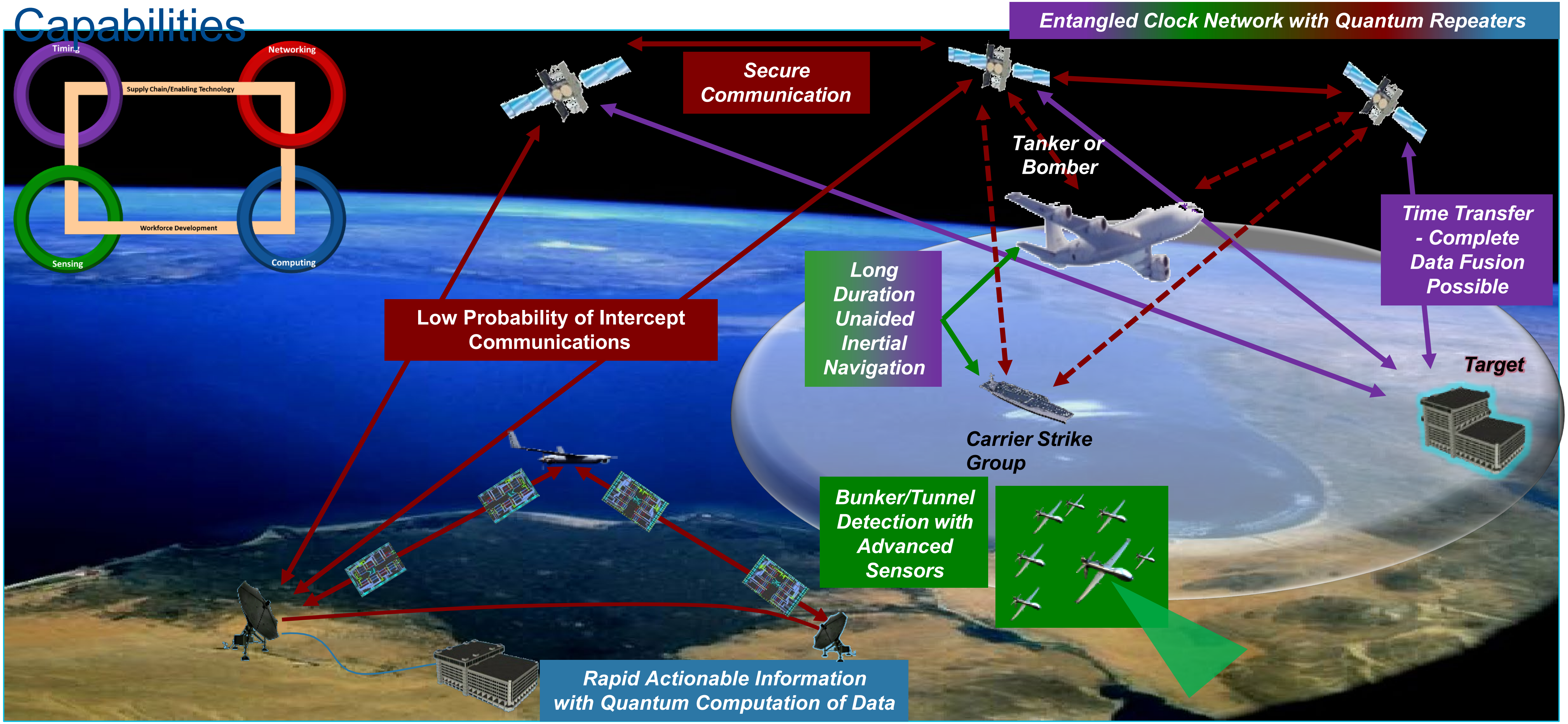
AFRL

AFRL QUANTUM INFORMATION SCIENCE

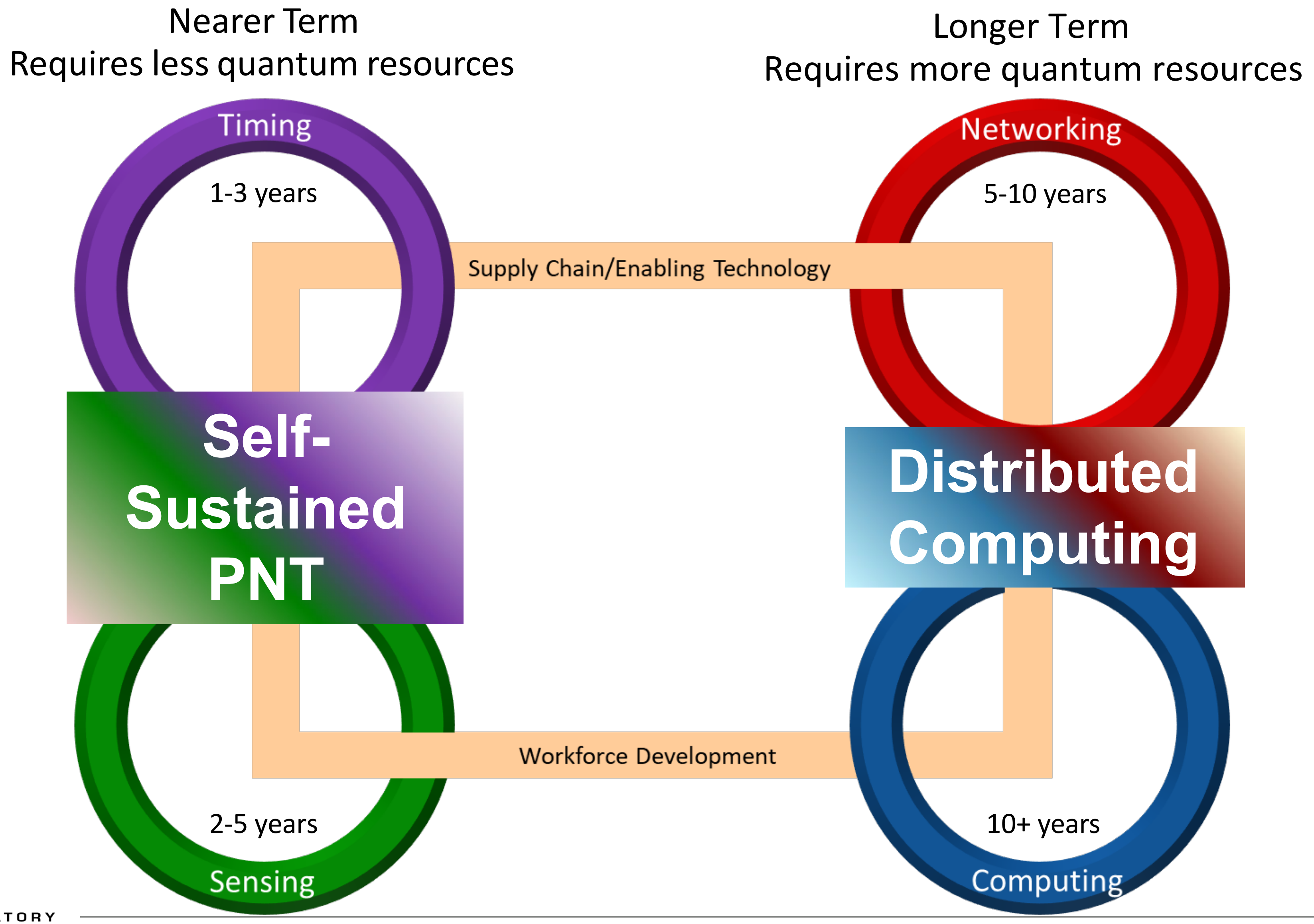
AI R F O RCE RESEARCH L ABO RA T O R Y JUNE 2024

Dr. Kathy-Anne Soderberg
Senior Scientist for Quantum Science and Technology
Air Force Research Laboratory

Quantum – Enabled Department of the Air Force (DAF) Capabilities



Quantum Technologies and DAF Needs



Quantum Information Science around AFRL

RD (Directed Energy): Satellite-based Quantum Networking (DeLange, Lafler, Lanning; NM)

RI (Information): Quantum Computing, Communication, and Networking (Hucul, LaHaye, Sheridan, A.M. Smith, Z. Smith, Wessing; NY)

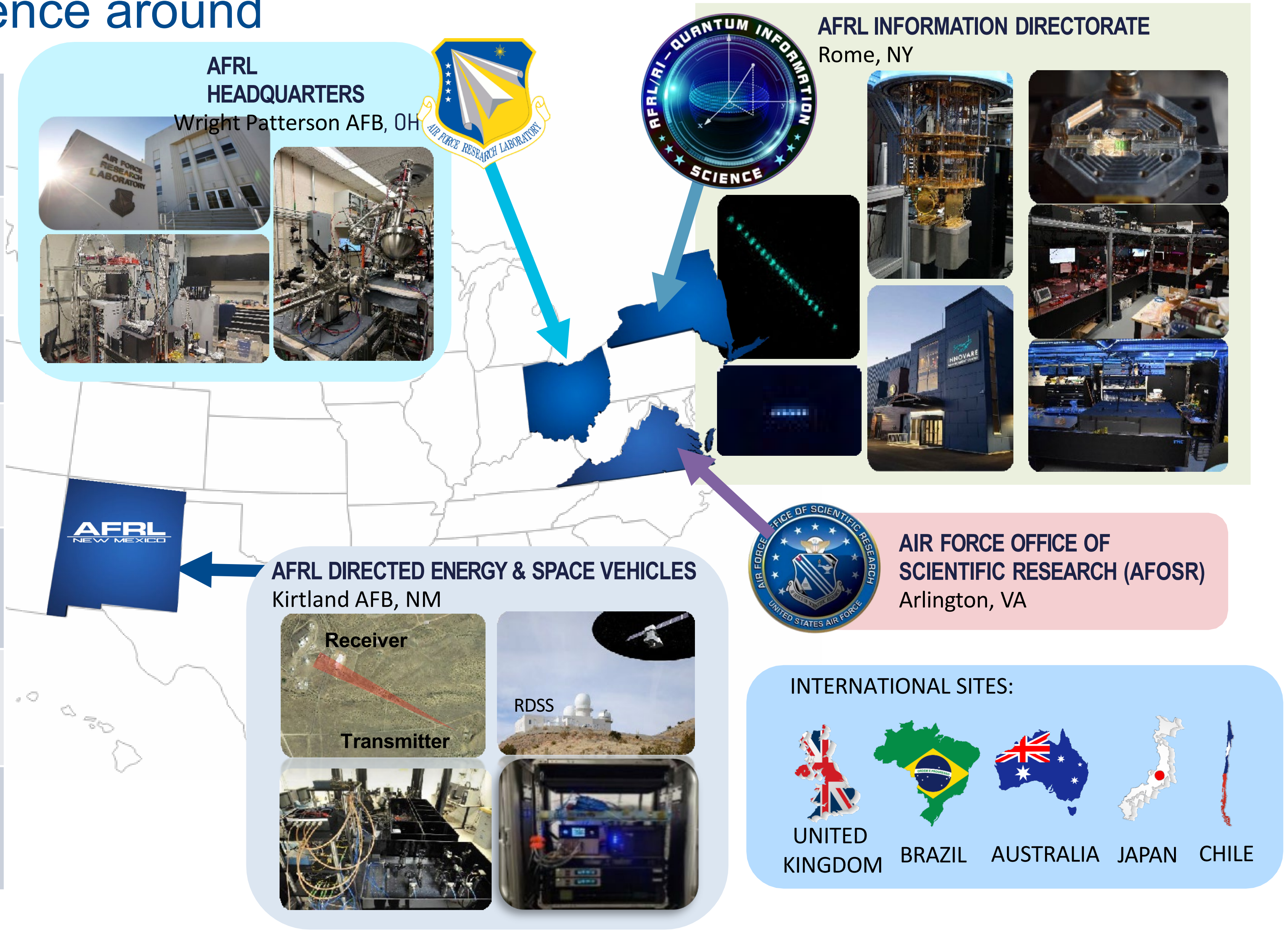
RY (Sensors): Quantum emitters, Device fabrication (Hendrickson, Usechak; OH)

RV (Space Vehicles): Position, Navigation, Timing (Elgin, Gregoire, Kasch, Kryzweski, Metcalf, Squires, Olson; NM)

RX (Materials and Manufacturing): Solid-State Quantum Defects, Materials, and Supply Chain (Bedford, Bissell, Dass, Pachter, Slocum; OH)

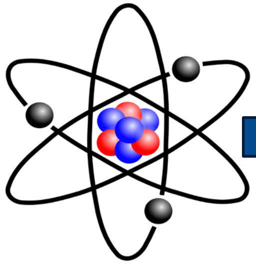
AFOSR: 6.1 Basic Research funding in QIS (Metcalfe, Tabakov; DC, Lyke SOARD; Richards AOARD; Dudley EOARD)

Quantum Senior Scientist (ST): Soderberg; NY
Quantum Senior Advisor for Strategic Partnerships: Hayduk; NY

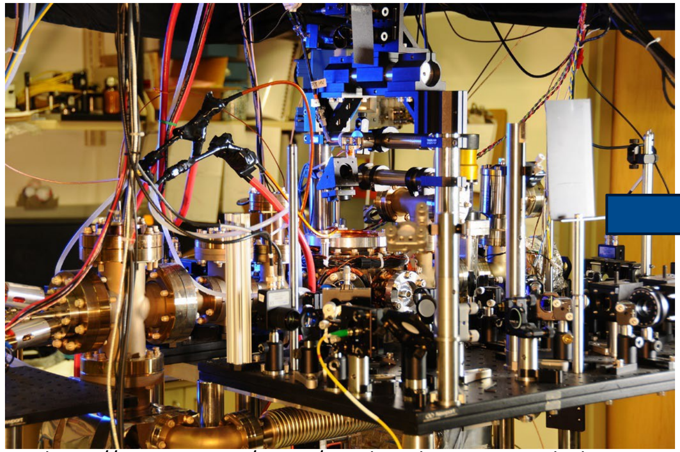


Across the spectrum of fundamental to applied research

Cold atom

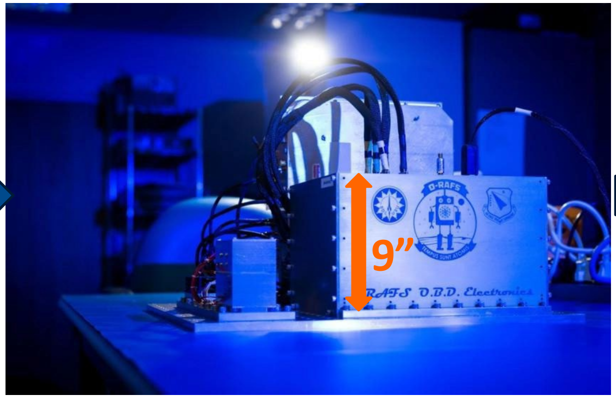


Cold atom optical atomic clock



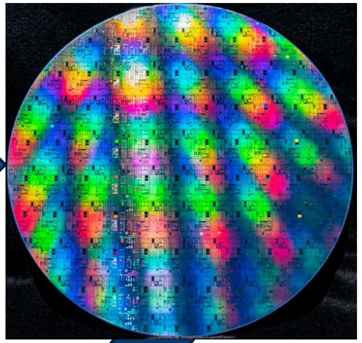
https://www.nist.gov/image/ytterbiumlatticeatomicclockjpg

Low-SWaP cold atom optical atomic clock



AFRL Optical Rubidium Atomic Frequency Standard

Towards portable atomic clocks…

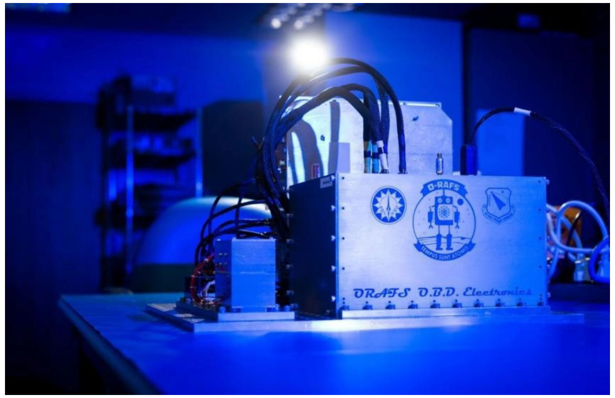


Understanding atomic physics… …to creating research grade atomic clocks… …to developing portable atomic clocks… …to exploring the future…

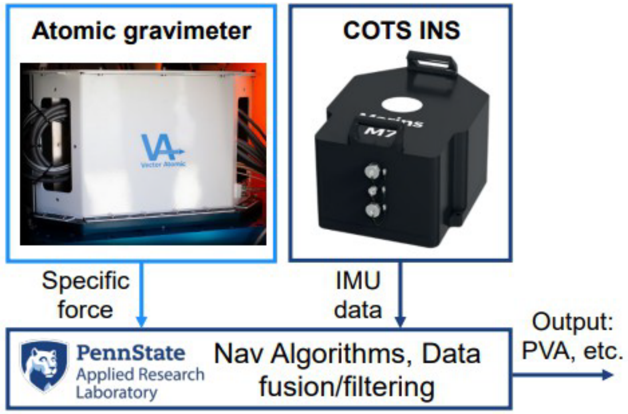
Demonstration of Quantum Sensors, Quantum Clocks and Critical Components at Rim of the Pacific (RIMPAC) 2022 Exercises

Among the first US field tests of advanced optical atomic clocks, cold-atom technology, quantum gravimeters, optical frequency combs, and other quantum-supporting technologies.

Image of the HMNZS Aotearoa while underway at RIMPAC. The ONR custom shipping container used to support the various experiments is visible on the deck.

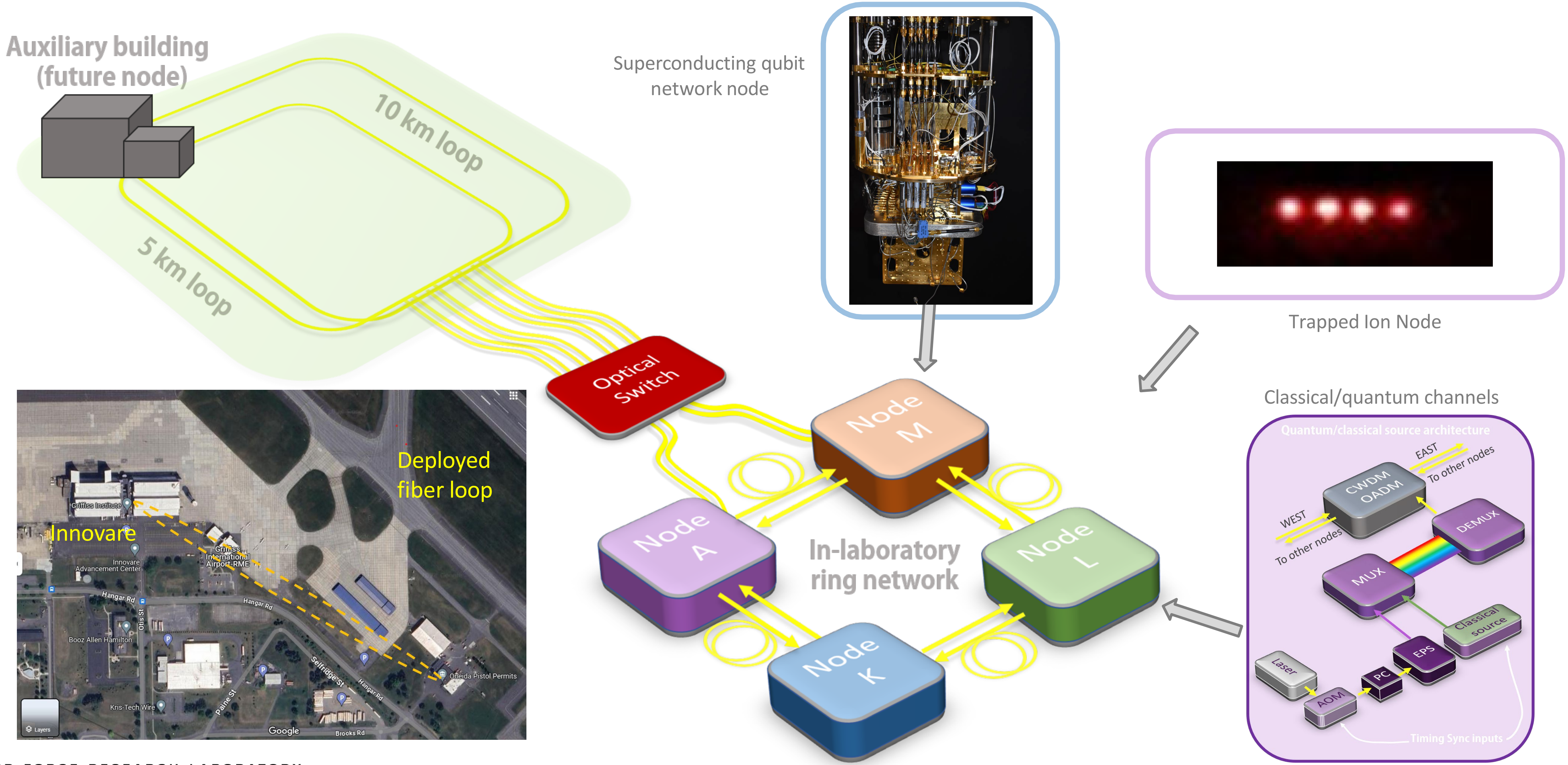


Air Force Research Laboratory's Optical Rubidium Atomic Frequency Standard, or ORAFS, is an advanced optical clock design built on existing vapor cell and laser technologies.



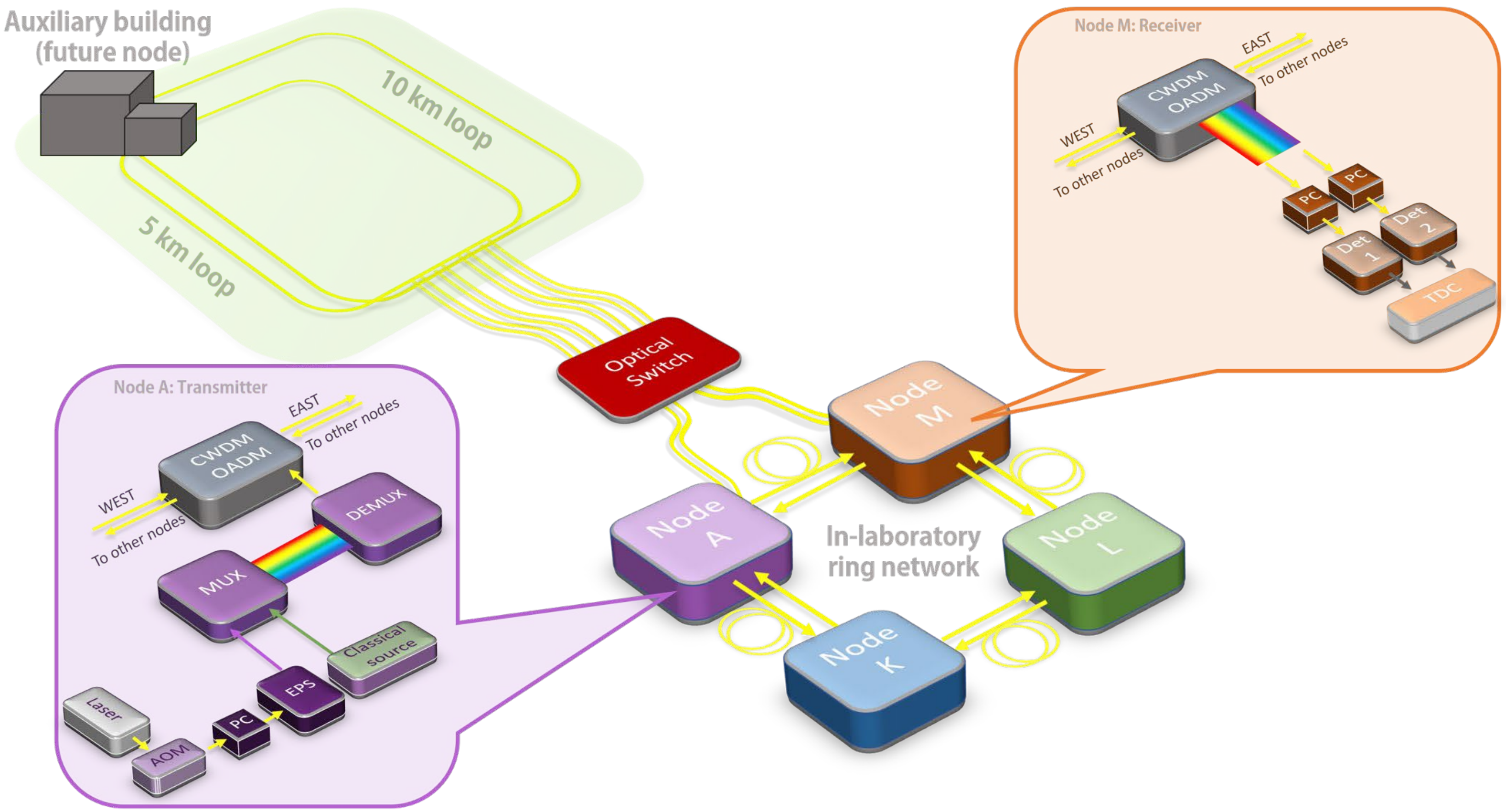
Block diagram and images of the atomic gravimeter and commercial off-the-shelf INS system used during the RIMPAC event.

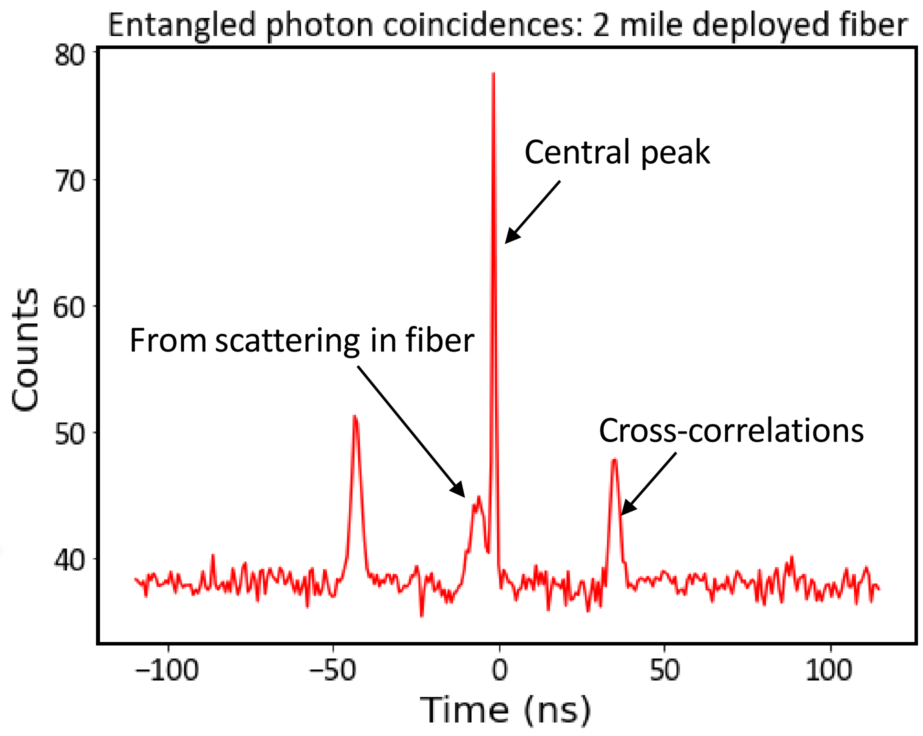
AFRL Quantum Networking Distributed Testbed: Classical and Quantum Interfaces



Entangled photons sent through deployed fiber

- Quantum photonic integrated circuit (QPIC) entangled photon sourced designed by RITQ and fabricated by AIM Photonics
- Entangled photon output routed through indoor ring network and sent through 5 km outdoor loop





- Polarization and frequency-entangled photons (correlated pair) at 1530 nm and 1570 nm
- Coincidence peak demonstrates the quantum correlation between the entangled photon pair survives transport through the network

Connecting with AFRL: Non-Traditional Pathways to Partner and Engage

K-12 STEM, INTERNSHIPS, VISITING FACULTY

- K-12 STEM Camps and Activities
- Internships
- Visiting Faculty Program
  - Information Institute

SMALL BUSINESS

- Small Business Innovation Research (SBIR)
- Small Business Technology Transfer (STTR)

AGREEMENTS

- Cooperative Research and Development
- Information Transfer
- Material Transfer
- Educational Partnership
- Patent License
- Commercial Test

INNOVATION FACILITIES

- Innovare Advancement Center
- Quantum Labs
- Electronics Labs
- Collaboration Workspaces

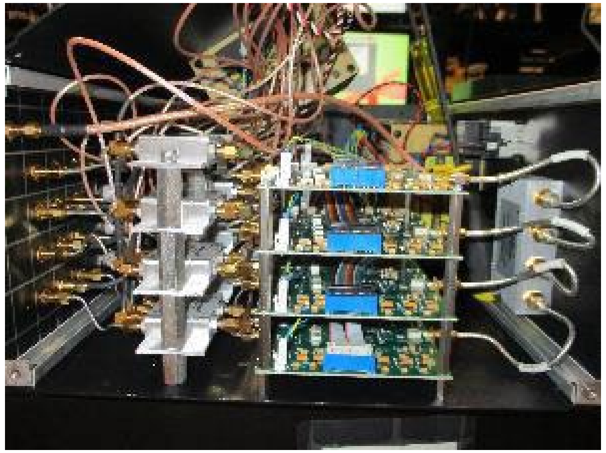
"Accelerate Innovation and Embrace the Power of Collective Learning." – *AFRL Commanders Intent*

See Q4I talks on Day 3 (27 Jun) !

For more info visit innovare.org and afresearchlab.com

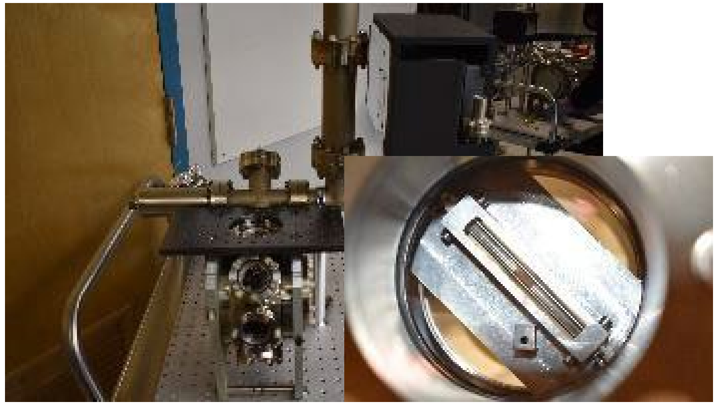
Connecting with AFRL: Some examples of what our students and interns work on

Design, build, and test electronics



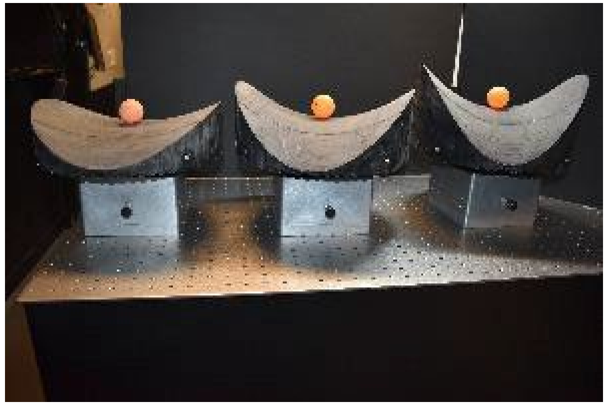
Coop (undergrad) student (6 months)

Design and build vacuum chamber; operate experiments



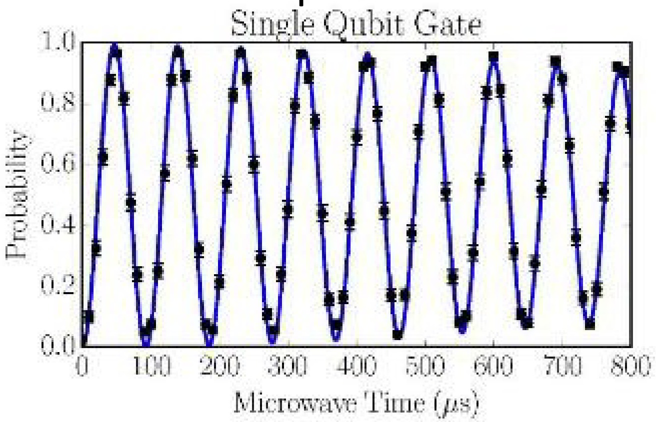
Returning (almost graduate) student (1 year)

Design, build, and test lab demos



Summer (undergrad) student (2-3 months)

Run experiments



Coop (undergrad) student (6 months)

Investigate quantum algorithms

Information loss and run time from practical application of quantum data compression

Saahil Patel,[1,*] Benjamin Collis,[1,2] William Duong,[3] Daniel Koch,[1,2] Massimiliano Cutugno,[1] Laura Wessing,[1] and Paul Alsing[1]
[1]*Air Force Research Laboratory, Rome,*
[2]*Griffiss Institute, Rome, NY*
[3]*Rochester Institute of Technology, Roches*
(Dated: March 23, 2022)

Demonstrating NISQ era challenges in algorithm design on IBM's 20 qubit quantum computer EP

Cite as: AIP Advances **10**, 095101 (2020); https://doi.org/10.1063/5.0015526
Submitted: 28 May 2020 • Accepted: 07 August 2020 • Published Online: 01 September 2020

Daniel Koch, Brett Martin, Saahil Patel, et al.

Summer (undergrad) students (2-3 months) plus continuing work during school year and/or joining our team for an additional year

See Q4I talks on Day 3 (27 Jun) !

QUESTIONS?

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DR. JOE ALTEPETER

Program Manager
Microsystems Technology Office
Defense Advanced Research Projects Agency (DARPA)

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Preventing Strategic Surprise from Quantum Computers

Joe Altepeter, Ph.D.
Program Manager, Microsystems Technology Office

June 2024

Why are quantum computers strategically important?

Economic Opportunity

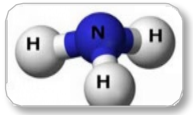
- It has been **credibly hypothesized** – but not proven – that quantum computers would have a **transformational impact** on many industries.
- **Examples:** Machine learning, quantum chemistry, materials discovery, molecular simulation, many-body physics, classification, nonlinear dynamics, supply chain optimization, drug discovery, battery catalysis, genomic analysis, fluid dynamics, protein structure prediction, solving systems of linear and nonlinear equations.

Pharmaceuticals
($145B Market)

Image Recognition
($109B Market)

Battery Catalysis
($141B Market)

Machine Learning
($97B Market)



Nitrogen Fixation
($85B Market)

Encryption
($146B Market)

Sources: Shutterstock

Security Threat

- **NIST analysis of the threat:**
  "If large-scale quantum computers are ever built, they will be able to break many of the public-key cryptosystems currently in use. This would ***seriously compromise*** *the confidentiality and integrity of digital communications on the Internet and elsewhere."*
- **NIST on the timeline for cryptographically relevant quantum computers:**
  "Some engineers even predict that ***within the next twenty or so years*** *sufficiently large quantum computers will be built to break essentially all public key schemes currently in use."*

[Quotes from: *https://csrc.nist.gov/projects/post-quantum-cryptography]*

Source: Shutterstock

Utility-scale quantum computers have the potential for significant economic disruption

Potential applications of quantum computing: The hype

Boston Consulting Group's proposed list of quantum computing applications

Optimization and simulation dominate

BCG Estimates a potential value creation of $10B - $100B each

Sparse matrix math

4 Types of computational problems and how quantum computing addresses them

Simulation
Quantum-system simulation
Precisely and efficiently simulate the dynamics of a quantum system

Optimization
Efficient routing
Map absolute routing optimizations vs. relative best guesses (conducted currently)

Machine learning
Principal component analysis
Process data sets to reduce noise and simplify computations exponentially faster

Cryptography
The RSA problem
Decrypt trapdoor RSA encrypted messages via prime factorization

100+ Use cases[1]

Simulation:
- Pharma: drug discovery — $40 billion to $80 billion
- Aerospace: computational fluid dynamics — $10 billion to $20 billion
- Chemistry: catalyst design — $20 billion to $50 billion
- Energy: solar conversion — $10 billion to $30 billion
- Finance: market simulation (used in derivatives pricing) — $20 billion to $35 billion

Optimization:
- Logistics: network optimization — $50 billion to $100 billion
- Insurance: risk management — $10 billion to $20 billion
- Finance: portfolio optimization — $20 billion to $50 billion
- Aerospace: route optimization — $20 billion to $50 billion

Machine learning:
- Automotive: autonomous-vehicle AI algorithm design — Up to $10 billion
- Finance: money laundering and fraud prevention — $20 billion to $30 billion
- Tech: generative, foundation, and horizontal AI — $50 billion to $100 billion

Cryptography:
- Government: encryption and decryption (related to secure communications and cybersecurity)
- Corporate: encryption (related to secure communications and cybersecurity)

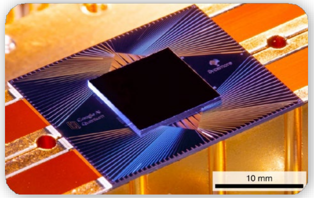
Machine learning applications will impact most, if not all, industries

Source: Boston Consulting Group

Companies have compiled long lists of potential applications without a clear path to realization

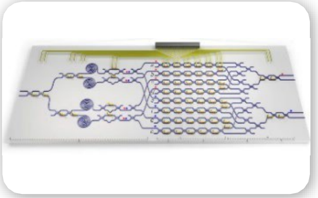
Quantitatively predicting the utility of a quantum computer

superconducting



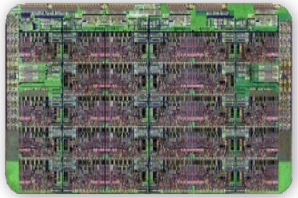
Nature 574, 505-510 (2019)

photonic



Nature Photon 12, 534–539 (2018)

classical



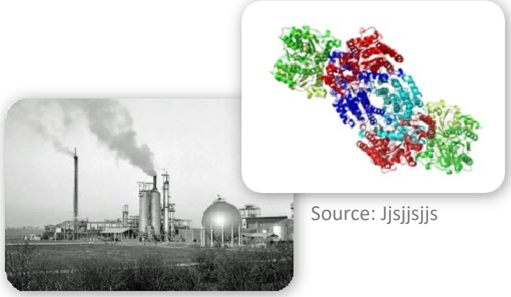
Source: Fritzchens Fritz

Technical Area 1
Creating Benchmarks

Quantify Application Impact ⇄ Parametrize Scope ⇄ Define Benchmark ⇄ Algorithm Concept ⇄ Optimize Algorithm ⇄ Map Algorithm to Hardware ⇄ Define Hardware Thresholds

Technical Area 2
Predicting Benchmark Performance

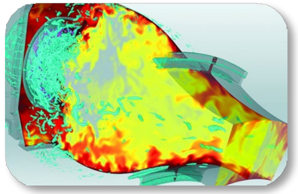
material and molecular simulation



Source: Jjsjjsjjs

Source: Robin Webster

fluid dynamics

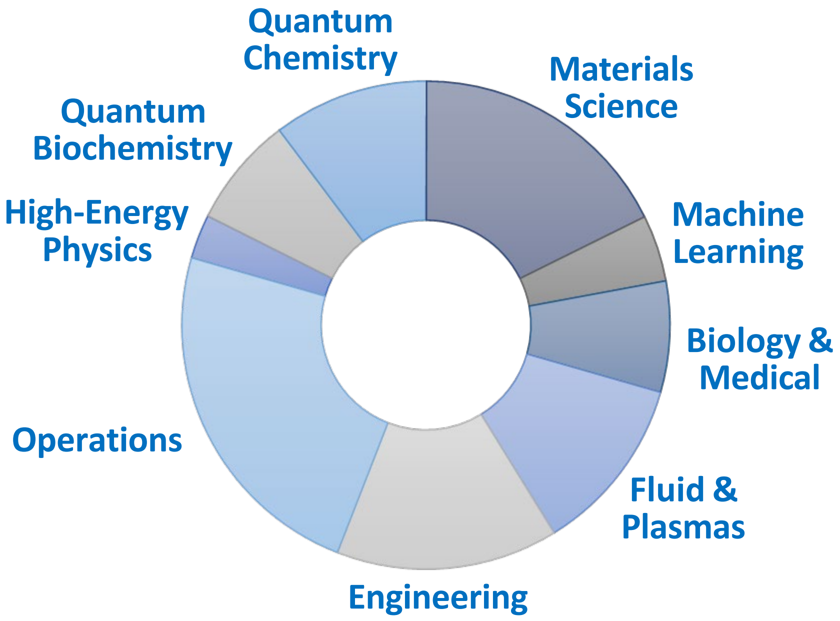


Source: Argonne National Lab

What did we learn in Phase 1 of the Quantum Benchmarking program?

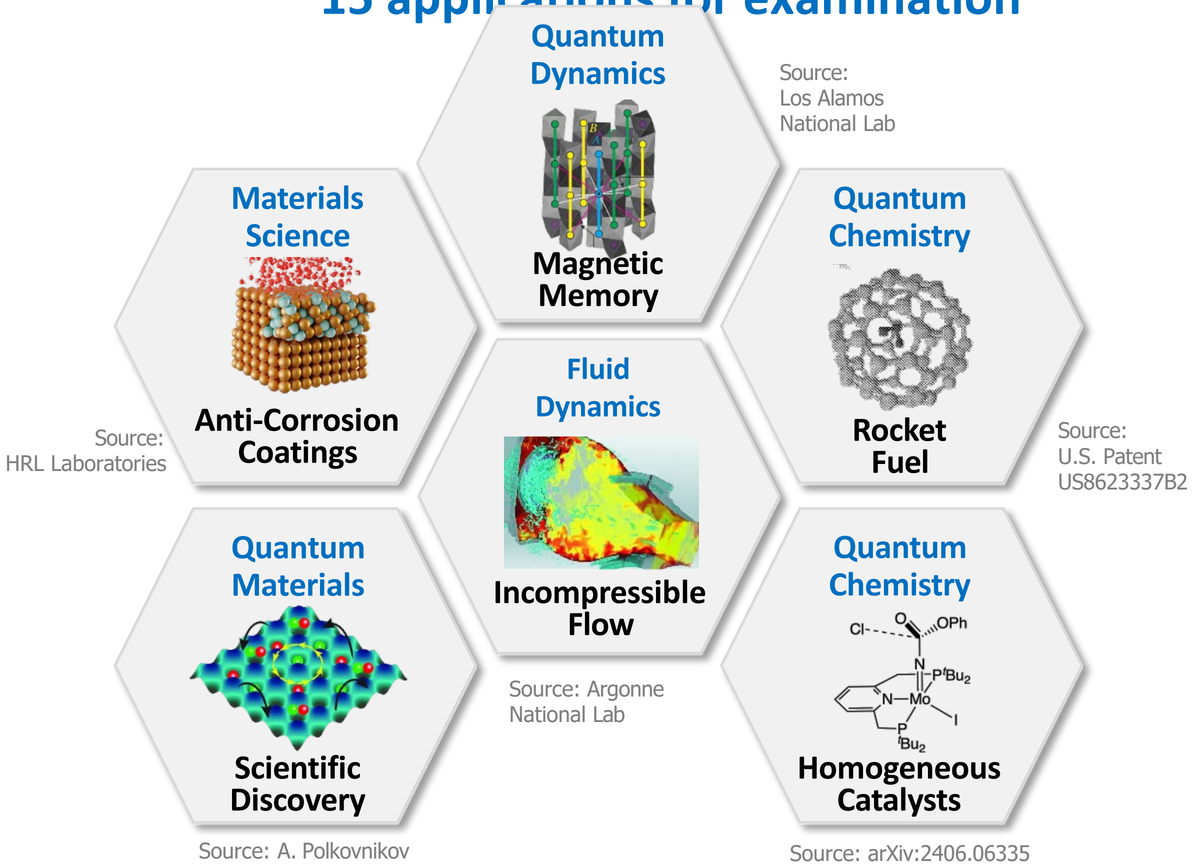
Applications summary

More than 200 applications were documented by DARPA's Quantum Benchmarking Program in 2022-2023



Staff Experts (50 FTE total)	61	Industry	35	Government
	83	University	8	Nonprofit

Using available resources, DARPA has prioritized ~15 applications for examination



Examining quantum utility for a few key problem classes, but many more remain

Guidelines for a good quantum application

Clearly defined use-cases with classical and quantum interfaces described

Subject matter experts define the application parameters

Application specification

Concrete utility estimation from existing workflows and potential value expansion

Comparison to state-of-the-art classical approaches and limitations

Value of computation

Quantum algorithms mapped to application, with clear classical hardware needs

Compiled resources for logical and physical qubits

Hardware requirements

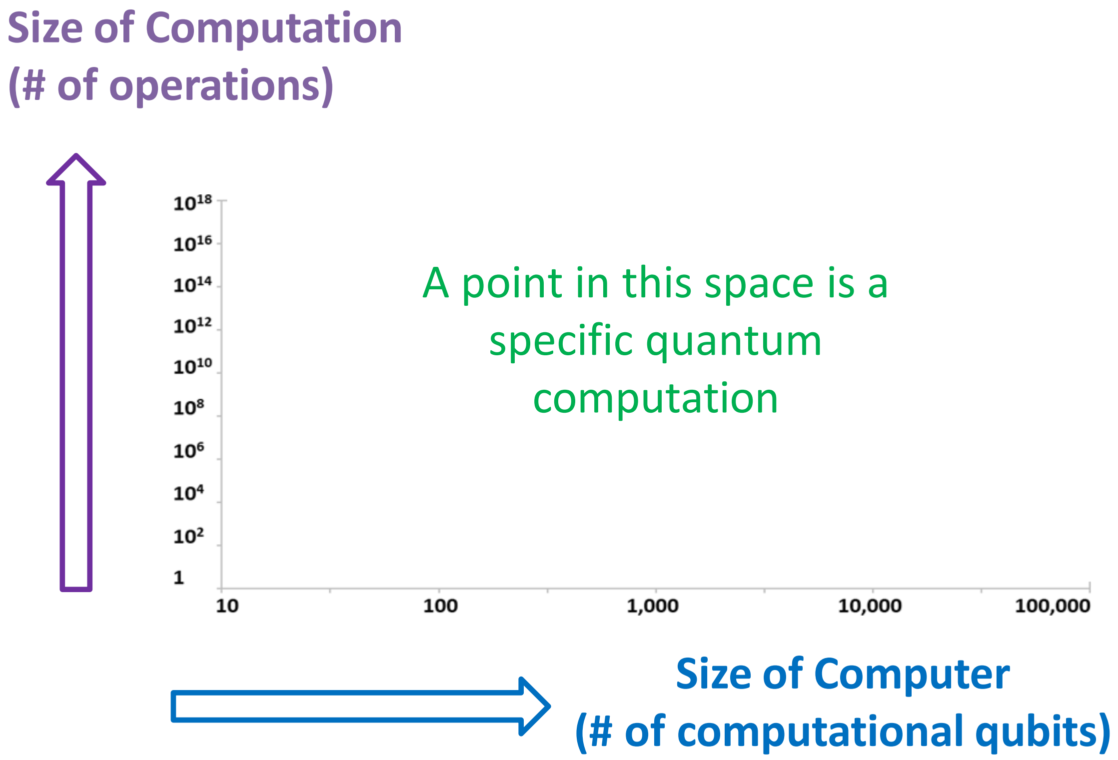
The space of possible quantum computations

Size of Quantum Computer

- Units: **Number of computational quantum bits, or "qubits"**
- In other words:
    - # of "logical qubits", for a fault-tolerant computer
    - # of "physical qubits", for a non-fault-tolerant computer

Size of Quantum Computation

- Units: **Number of quantum operations (i.e., quantum gates) in the computation**
- Cannot be larger than [1 / (gate error rate)]
- Equal to: (# of computational qubits) * (circuit depth)



Quantum computers are limited by the size of the computer and the size of the computation

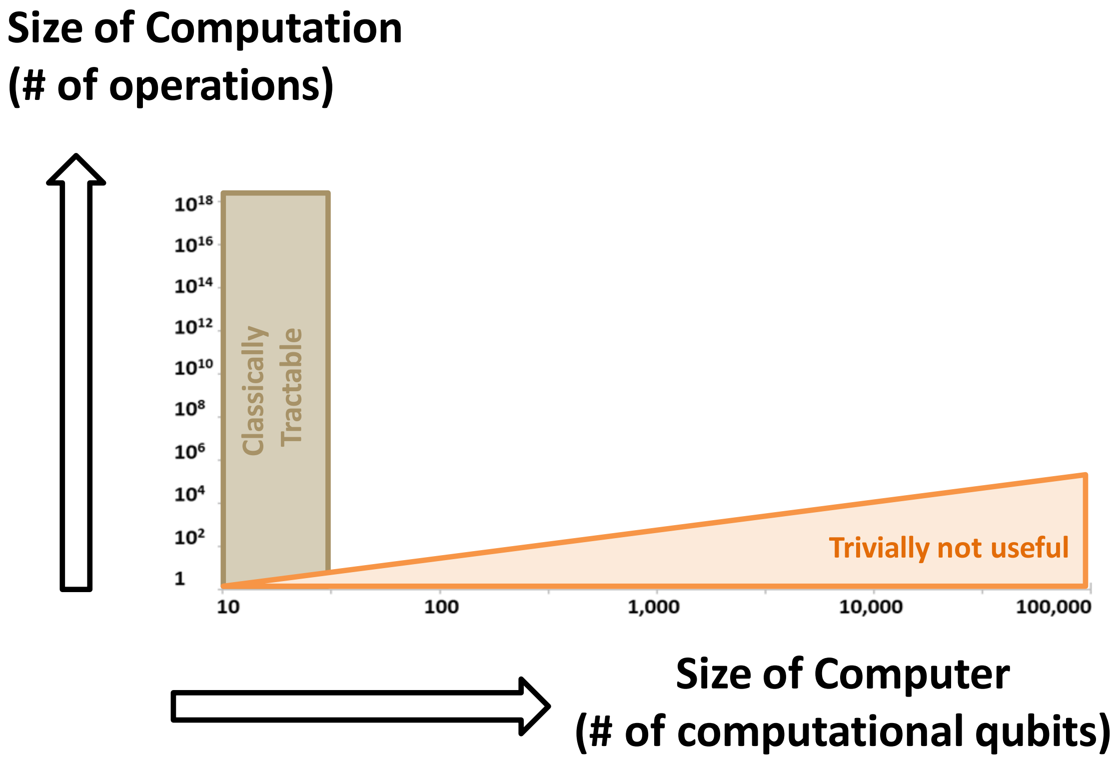
The space of possible quantum computations

Trivially Useless Regime

- When (# of gates) << (# of qubits), most qubits are never used; when (# of gates) ≈ (# of qubits), large-scale entanglement is not possible
- A high-error computer might be stuck in this regime

Classically Tractable Regime

- Small quantum systems can be efficiently simulated on classical computers
- The limit of classical tractability is thought to be between 50-70 qubits, depending on assumptions



Some quantum computations are clearly not useful

The space of possible quantum computations

Noisy Intermediate Scale (NISQ) Regime

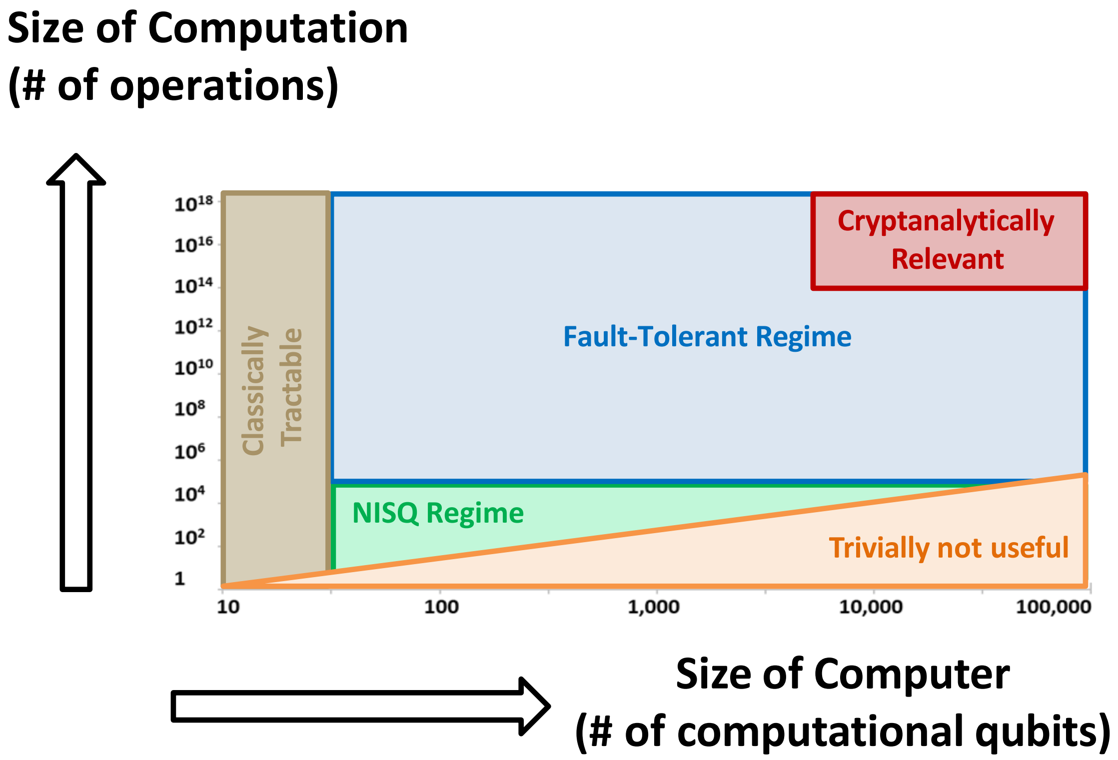
- Physical qubit error rates are thought to be limited to 10^{-3} to 10^{-5}
- This limits the number of useful gates to ~10^3 to ~10^5

Fault Tolerant Regime

- Fault tolerance has never been experimentally demonstrated
- Huge systems engineering challenge → 100-10,000 physical qubits per logical qubit needed for fault tolerance

Cryptanalytically Relevant Regime

- Published journal articles show that a quantum computer of this size can break RSA-2048 encryption [see Gidney-Ekera arXiv:1905.09749v3 (2021)]



The boundary between NISQ and Fault Tolerance is unclear and device-dependent

How is this plot relevant for Applications?

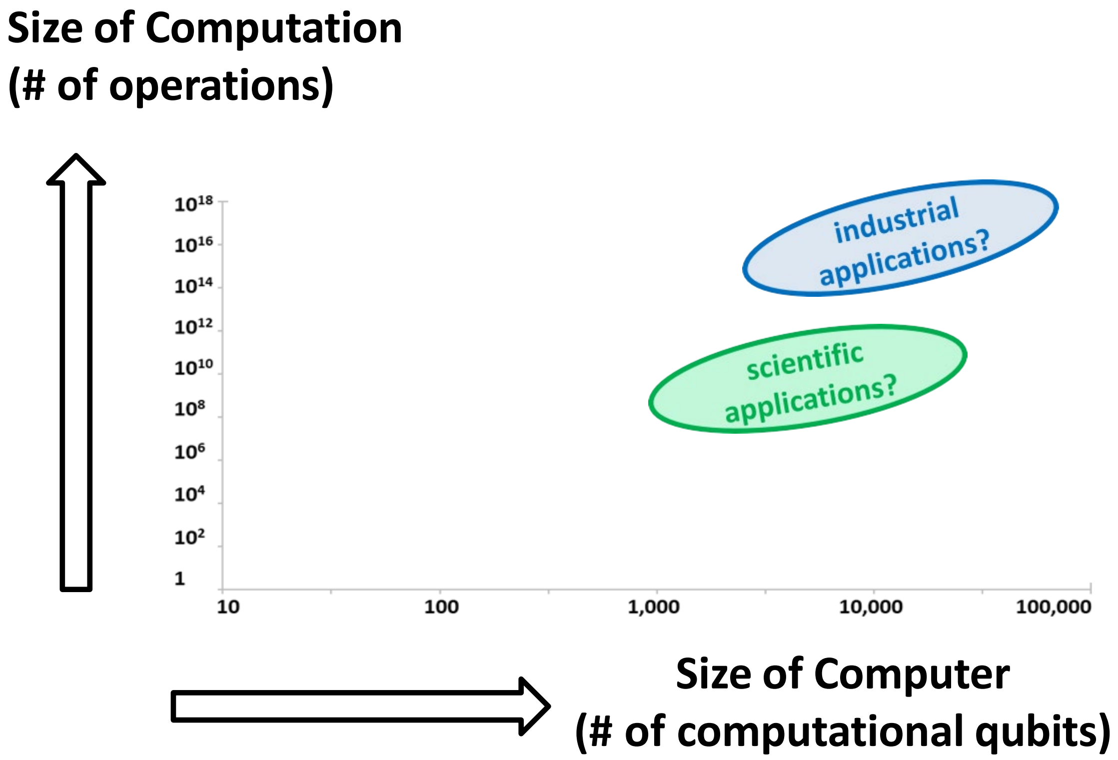
- A quantum circuit that solves a specific application problem can be added to the plot as a single point

Application-related challenges:

- Identify useful candidate application problems
- Identify fair comparisons to state of the art classical solutions
- Define success in a way that allows other novel hardware paradigms to compete against quantum solutions
- Define utility → what is the impact of solving the application?

On hybrid quantum-classical algorithms

- Note that essentially all potentially useful quantum algorithms, in both the NISQ and fault-tolerant regimes, use quantum computers as a specialized co-processor for a classical system



Discovering new applications for quantum computers puts points on the plot

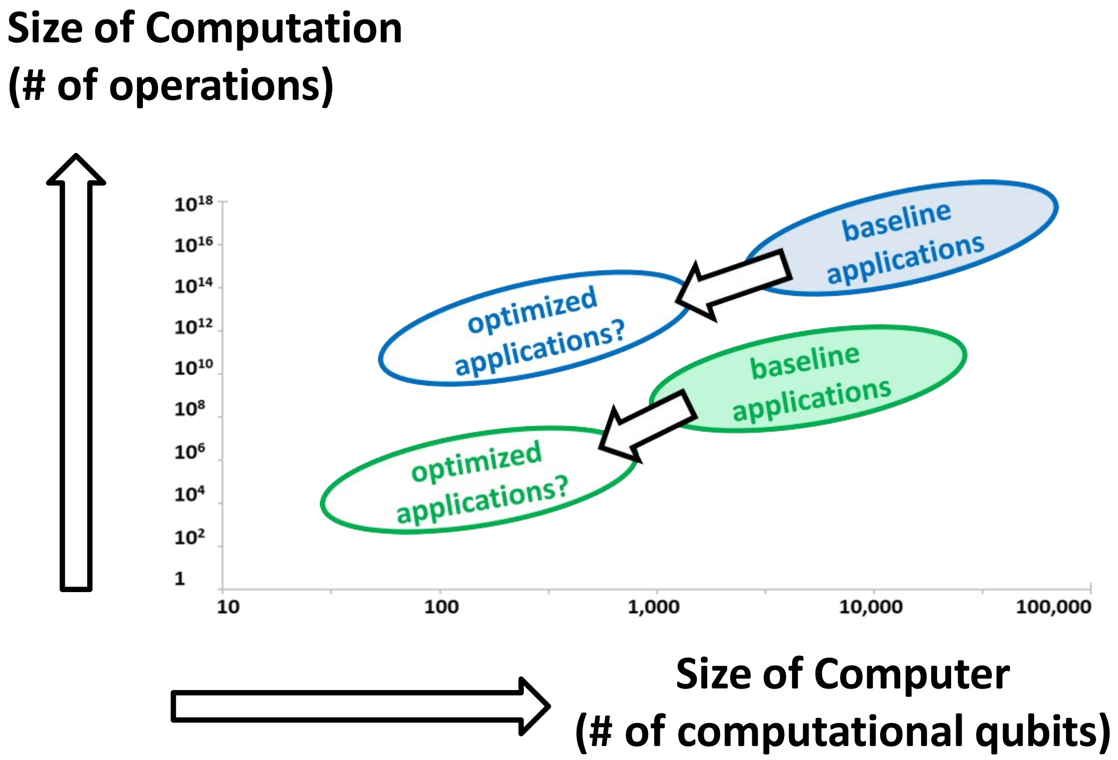
Algorithms

How is this plot relevant for Algorithms?

- For a given application, different candidate algorithms show up as different points on the plots, corresponding to different quantum circuits

Algorithm-related challenges:

- Decrease the quantum resources need to solve a given problem through algorithmic optimization
- Examples:
    - General algorithmic compilers
    - Hardware-specific optimization
    - Application-specific optimization



Optimizing algorithms moves existing points down and to the left

Hardware

How is this plot relevant for Hardware?

- A given hardware system is represented by a boundary

Non-fault-tolerant systems are rectangles

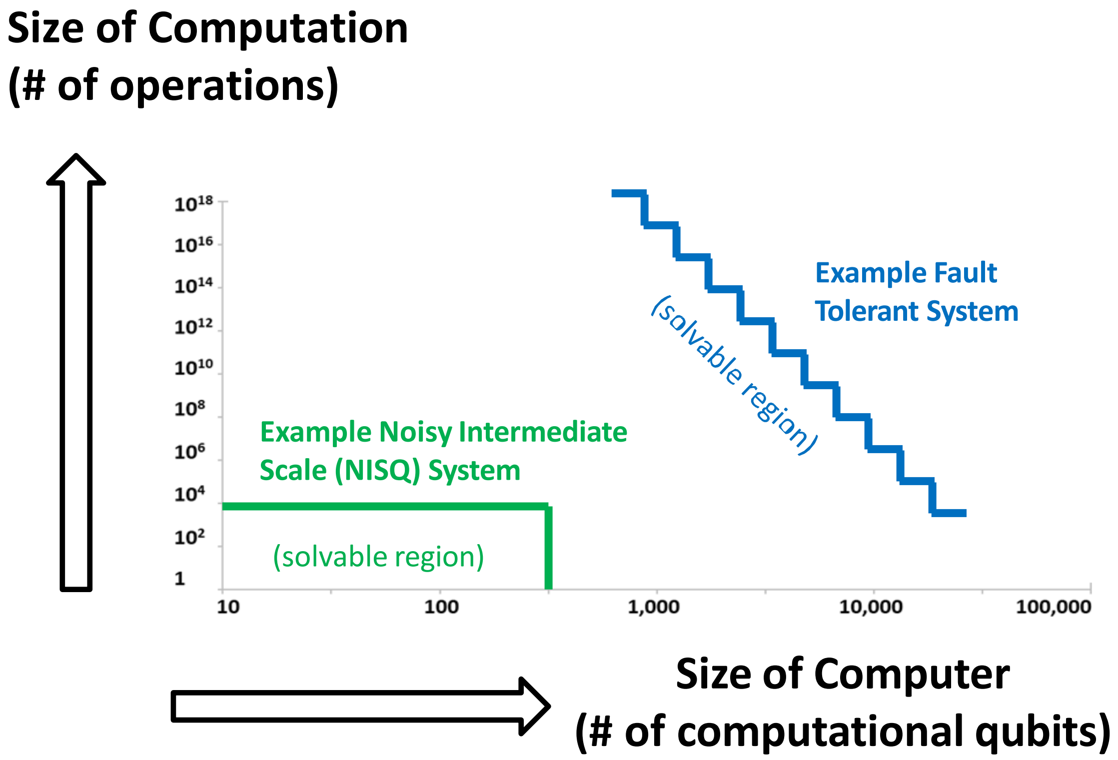
- They can solve any point inside the rectangle

Fault-tolerant systems are staircases

- They can solve any system down and to the left of the staircase
- Increasing the number of physical qubits per logical qubits decreases both gate error probability and number of usable logical qubits → this creates a staircase shape

Hardware-related challenges:

- Create hardware that can solve larger, more complex, longer computations



Creating bigger, better quantum computers moves hardware boundaries up and to the right

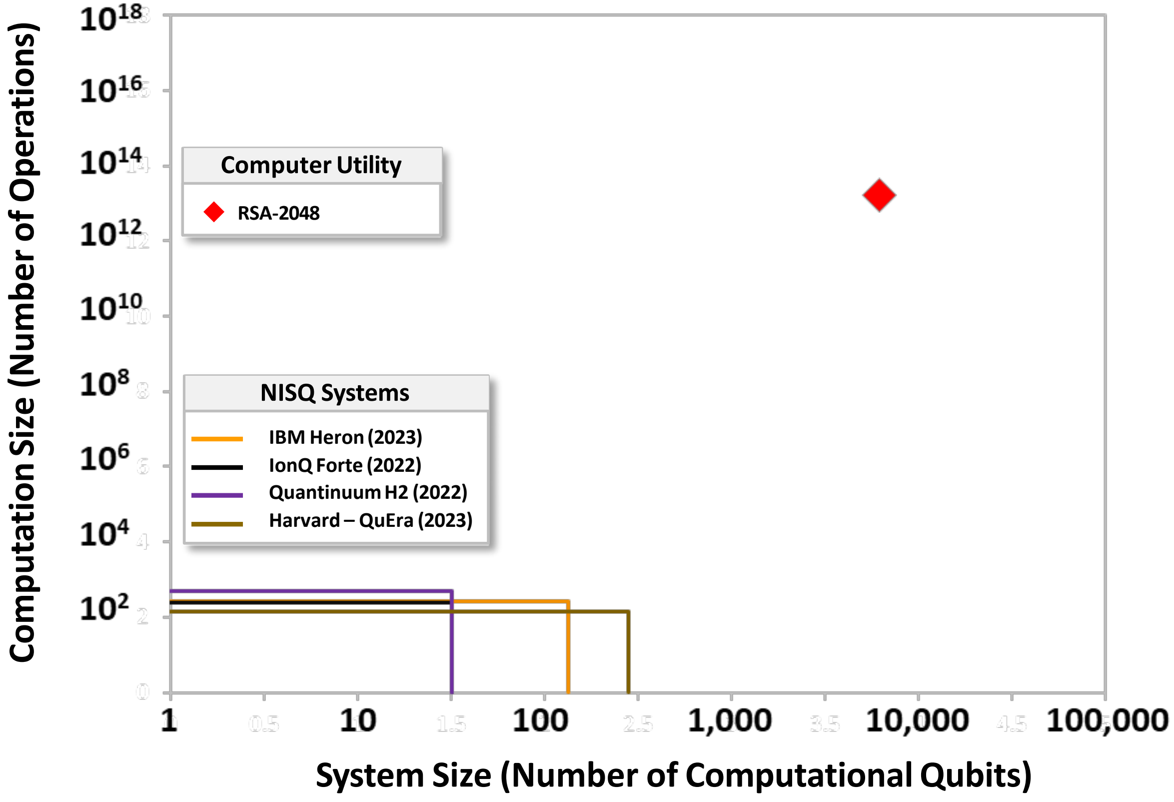
For reference → Existing hardware demonstrations

NISQ systems

- Noisy-intermediate-scale-quantum (NISQ) computers appear as rectangles; the upper right corner represents the largest computation that can be done
- Current generation systems have <1,000 qubits and $<10^4$ computational volume

Where do known algorithms lie on this plot?

- The well-known Gidney-Ekera estimate for factoring RSA-2048 is the red dot that requires around 6,000 logical qubits and a computational volume of 10^{13}



Current quantum computers are far too small and noisy to be relevant for factoring

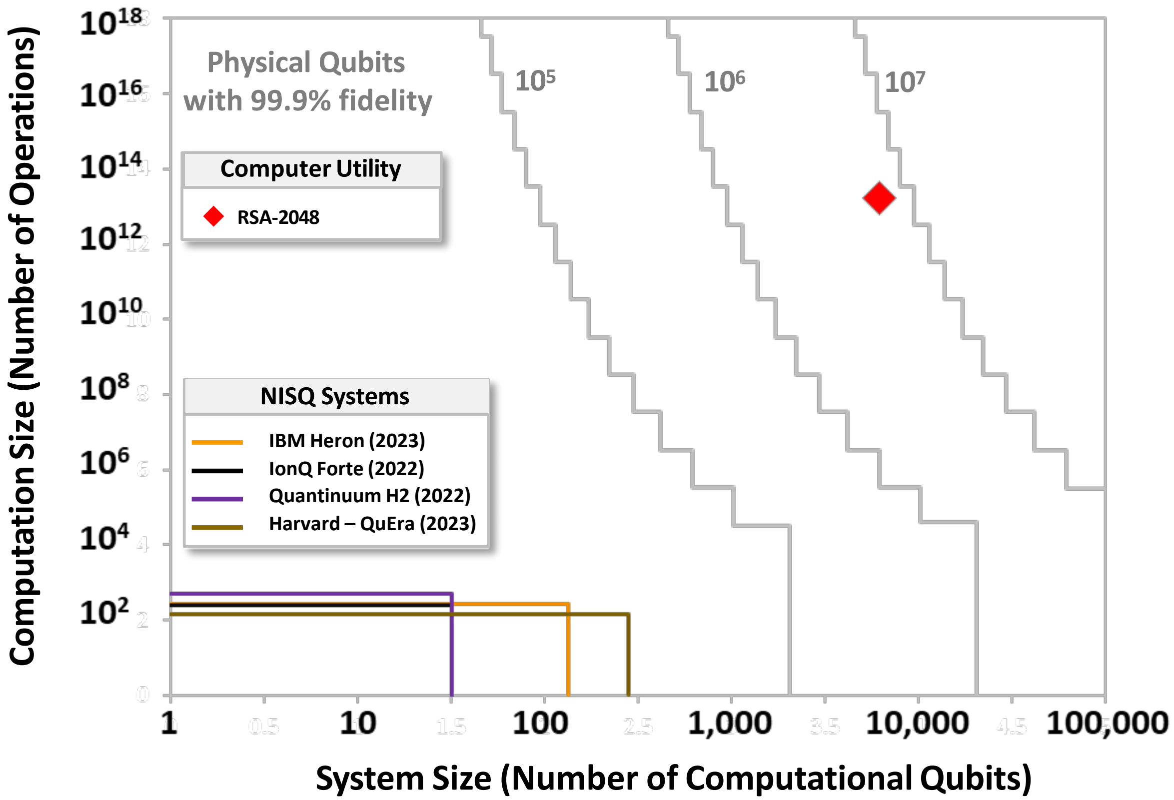
Plotting generic fault tolerant machines in this space

Fault-tolerant systems

- Idealized reference systems are shown for different numbers of physical qubits, a physical error rate of 0.1% and a code threshold rate of 1%
- A system with 10^7 physical qubits would be sufficient to factor RSA-2048

Are these staircases realistic?

- Specific hardware implementations will have **many** engineering challenges, and may or may not be reconfigurable for different code distances. However, in principle, these show the space of solvable problems.



Systems large enough to be cryptanalytically relevant require fault-tolerant operation

Quantum Benchmarking

Key Question

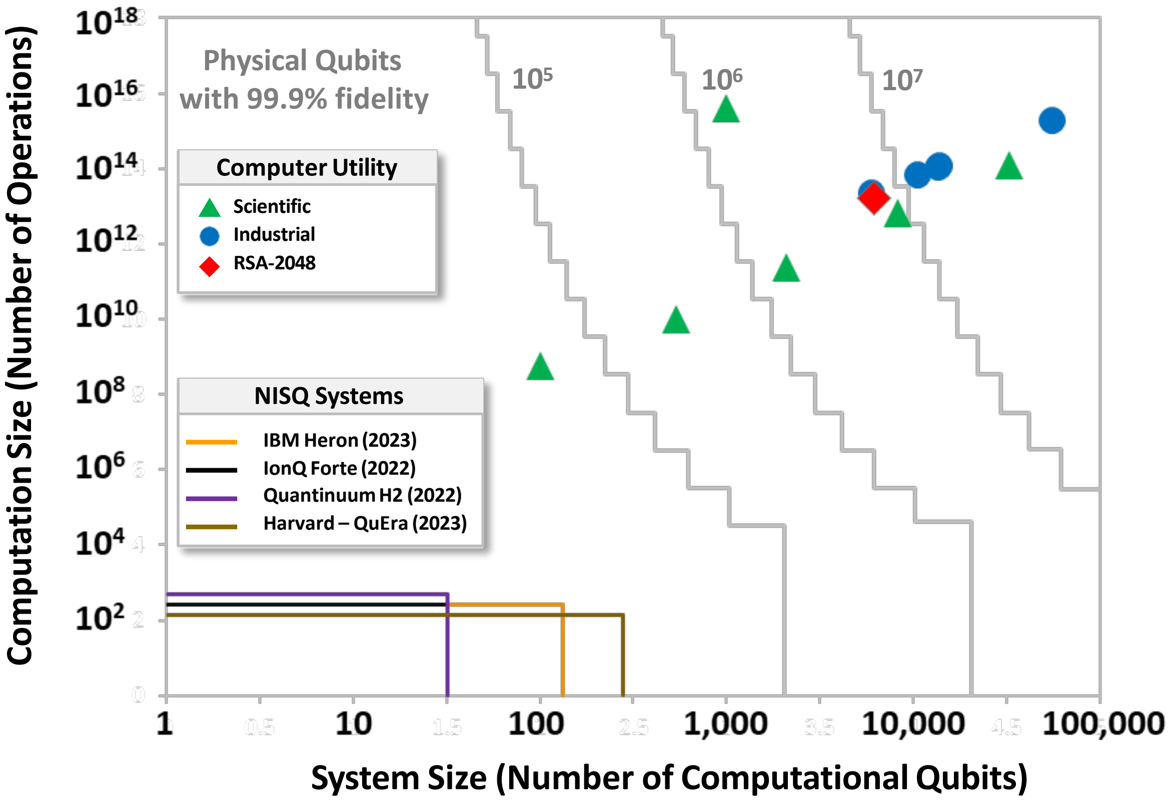
- What is the long-term utility of quantum computers?

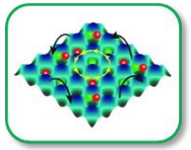
Approach

- Create hardware-agnostic, application-focused benchmarks for transformational computational problems
- Estimate the hardware resources – at both the logical and physical level – needed to execute benchmarks

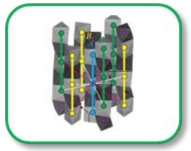
Results/Plans

- Evaluated ~200 candidate applications for economic value, testability, and quantum amenability
- Identified the following candidate application instances in the sub-Shor regime; Phase 2 will refine and expand this list

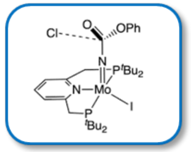




Fermi-Hubbard Simulations



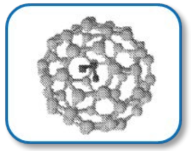
MAGLAB



Homogeneous Catalysts

FeMoco

Mg-based Anti-Corrosion Coatings



Cyclic Ozone

Identify and benchmark quantum computing applications with clear economic value

Potential resource reductions

Optimization	Applicable Application Instances	Estimated Resource Reduction
Use first quantization encoding instead of second quantization	Cyclic Ozone, Ru MACHO, FeMoco, Mg2+ Slab Small/Large	Ref. [1] shows that selected applications can achieve a 100x reduction in qubit count and 10x reduction in T-count.
Advanced factorizations in second quantization	Cyclic Ozone, Ru MACHO, FeMoco, Mg2+ Slab Small/Large	More efficient factorizations in second quantization exist than the dual-plane-wave basis used in the initial estimates shown in figure on slide 17, including: sparse [2], single [3] and double [4] factorization, and tensor hypercontraction [5]. These could provide a factor of 10x reduction in T-count.
Bravyi-Kitaev (or other) encoding instead of Jordan-Wigner	Fermi-Hubbard	Ref. [6] shows an exponential decrease in circuit depth at the expense of increased constant factor overhead. For large systems of ~50 spin orbitals, they showed a ~2-4x improvement in gate count, with less improvement for smaller systems.
Trotter Order Optimization	MAGLAB	Current approach uses a second order Trotter approximation. It has been shown in Ref. [7] that going to fourth (or higher) order is beneficial and can reduce gate counts by 10-100x.
Tightened Trotter Convergence Bounds	MAGLAB	Estimates in figure on slide 17 use general Trotter-error bounds, which give guaranteed performance but are not tight. Incorporating known symmetries of the problem and using tighter bounds should reduce gate depth by 10-100x [8].
Algebraic Optimization	All	Symmetries and other algebraic properties of specific Hamiltonians can be exploited to reduce gate counts using techniques such as fast-forwarding [9]. At best these can produce exponentially reduced circuit depths. We do not incorporate these optimizations into our error bars as they are highly problem dependent.

References

1. Y. Su, *et al*., "Fault-Tolerant Quantum Simulations of Chemistry in First Quantization," PRX Quantum, vol. 2, p. 040332, 2021.
2. D. W. Berry, *et al*., "Qubitization of Arbitrary Basis Quantum Chemistry Leveraging Sparsity and Low Rank Factorization," Quantum, vol. 3, p. 208, 2019.
3. M. Motta, *et al*., "Low rank representations for quantum simulation of electronic structure," npj Quantum Inf., vol. 7, p. 83, 2021.
4. V. v. Burg, *et al*., "Quantum computing enhanced computational catalysis," Phys. Rev. Research, vol. 3, p. 033055, 2021.
5. J. Lee, *et al*., "Even More Efficient Quantum Computations of Chemistry Through Tensor Hypercontraction," PRX Quantum, vol. 2, p. 030305, 2021.
6. A. Tranter, *et al*., "A Comparison of the Bravyi–Kitaev and Jordan–Wigner Transformations for the Quantum Simulation of Quantum Chemistry," J. Chem. Theory Comput., vol. 14, p. 5617, 2018.
7. N. J. Pearson, "Thesis: Simulating Many-Body Quantum Systems:," Diss. ETH No. 27032, Zurich, 2020.
8. A. M. Childs, *et al*., "A Theory of Trotter Error," Phys. Rev. X, vol. 11, p. 011020, 2021.
9. S. Gu, *et al*., "Fast-forwarding quantum evolution," Quantum, vol. 2021, p. 577, 2021.

Quantum Benchmarking

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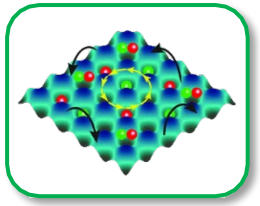
Fermi-Hubbard Simulations

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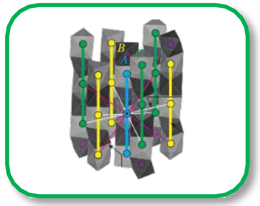
MAGLAB

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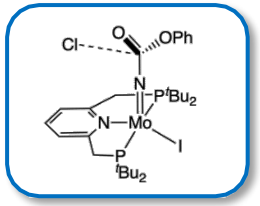
Homogeneous Catalysts

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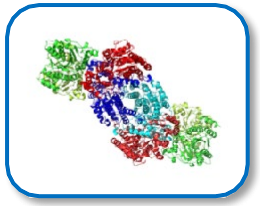
FeMoco

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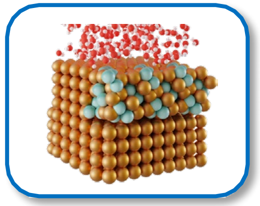
Mg-based Anti-Corrosion Coatings

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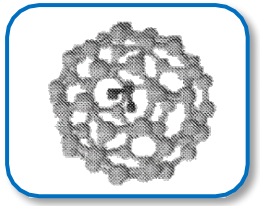
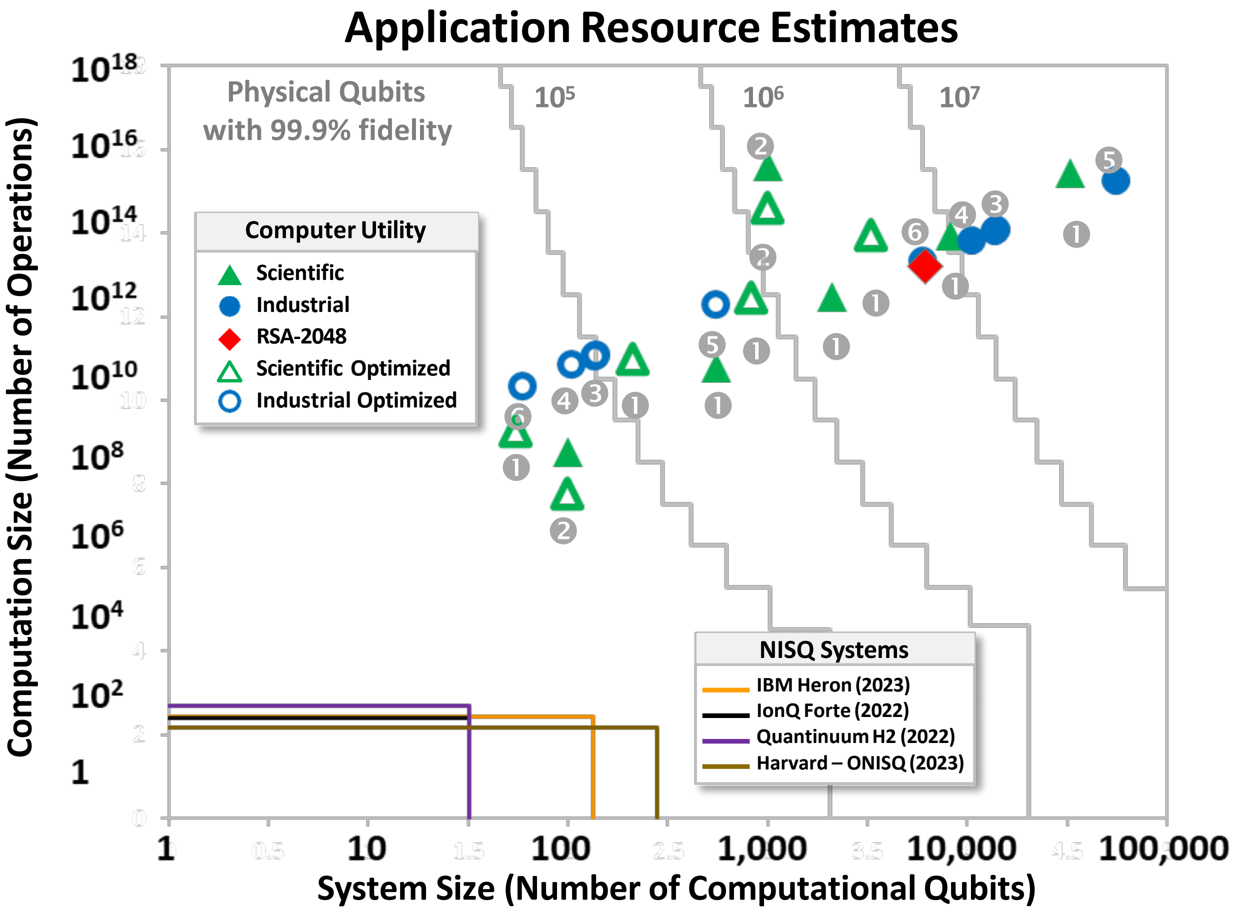

Cyclic Ozone



Preliminary conclusion → Large-scale quantum computers will likely enable solutions to high-value scientific and industrial problems

Where did we go in Phase 2 of the Quantum Benchmarking program?

Phase 2 results - Pessimistic

~20 use cases developed

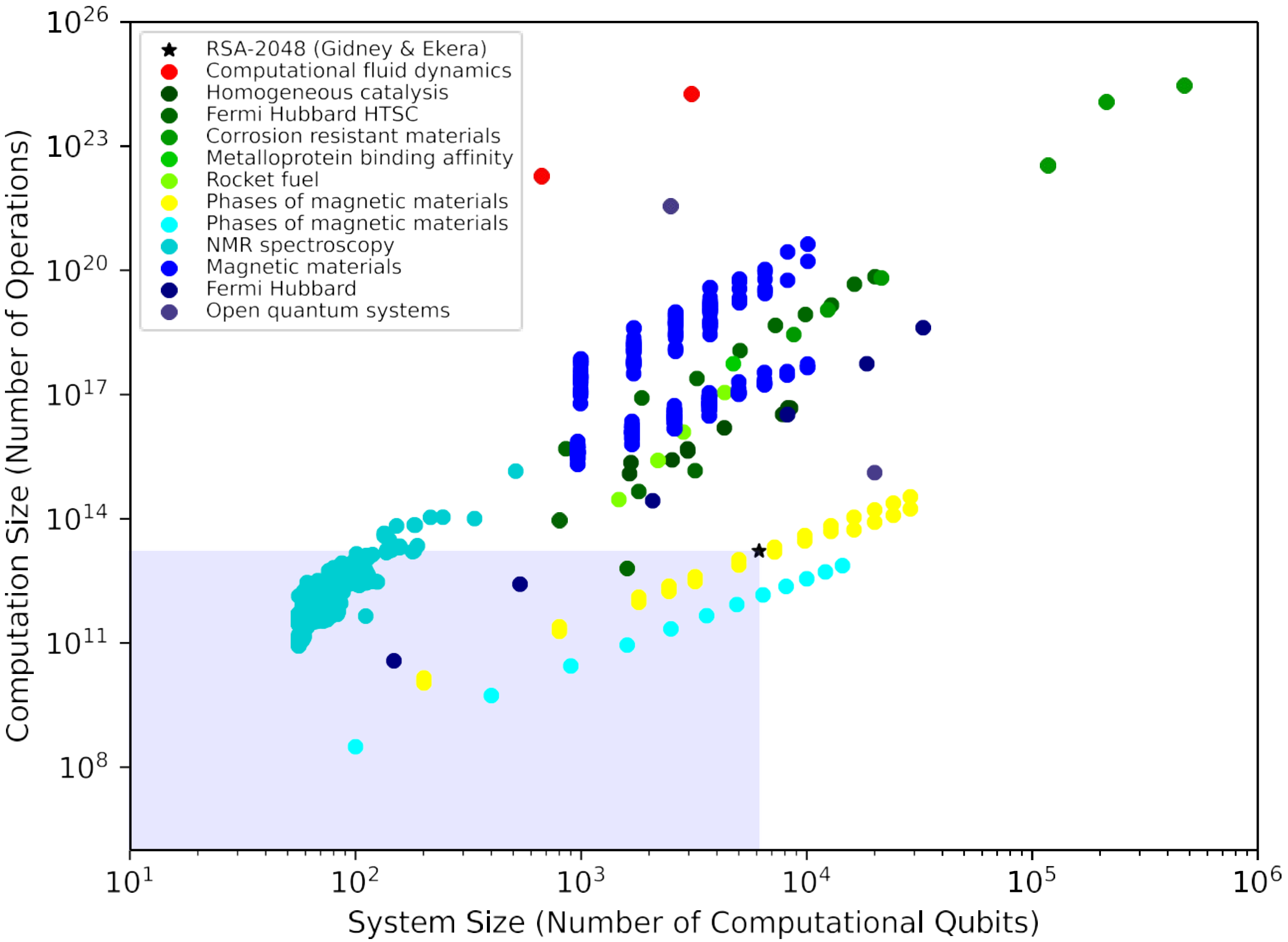
- 8 application-focused publications on the arXiv this week and next
- 2 focused on tools for resource estimation
- ~10 more use cases under active development

Tools for estimating required resources

- Automated tools for estimates of utility-scale hardware
- Algorithmic refinements and compilation methods

Quantum utility estimates

- Phase 2 focuses on applications with clear utility
- The remainder of Phase 2 will focus on mapping economic utility estimates to quantum benchmarking metrics



The last six months have significantly increased the number of potential applications

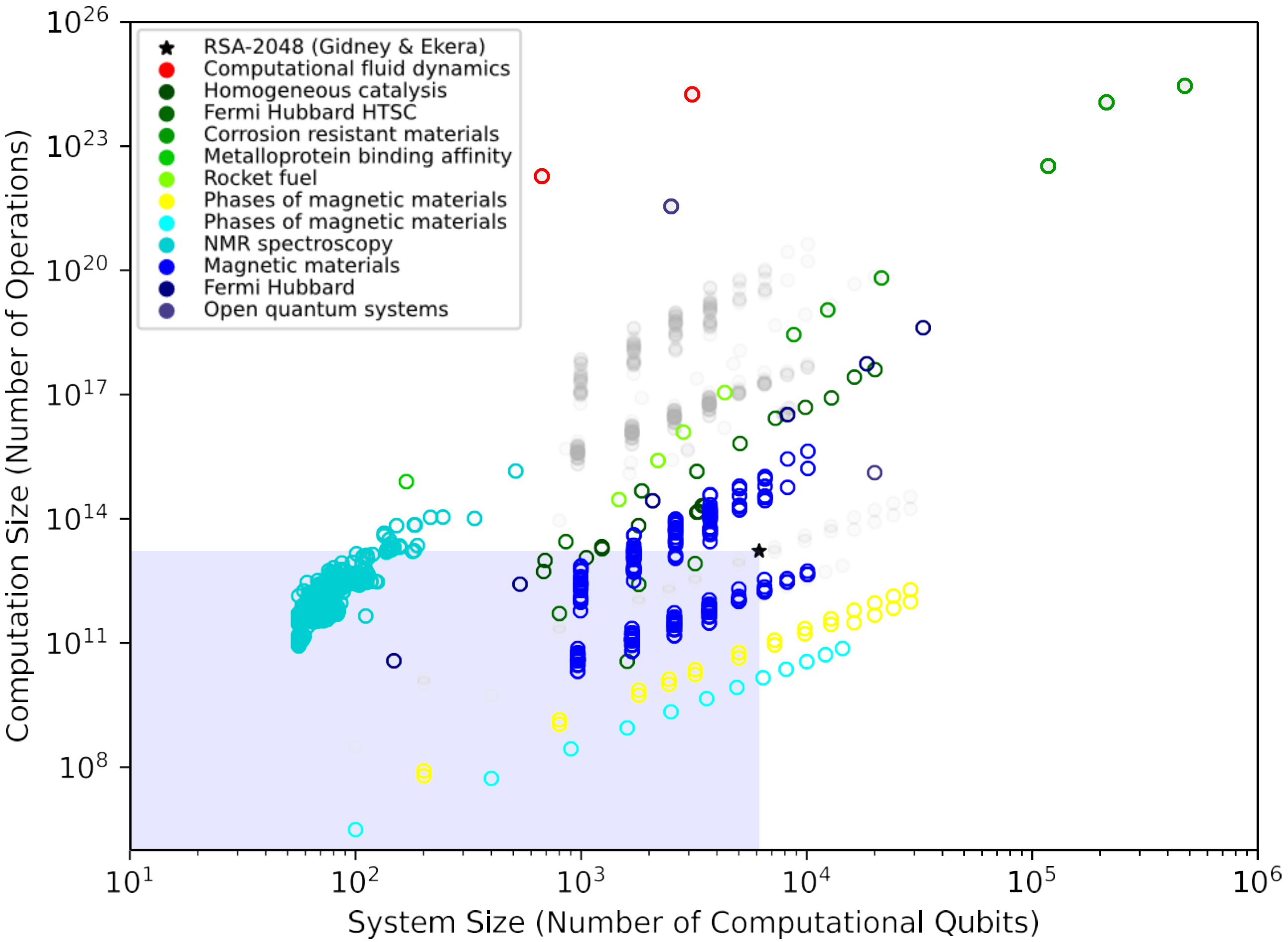
Phase 2 results - Optimistic

Open circles show expected optimizations

- Latest algorithmic advances are shown
- Includes improved bounds on error tolerances and algorithmic requirements

Not considered: future algorithm improvements

- Further resource reductions can also happen through new algorithm development, but are not considered here



Applying known algorithmic advances may have a big impact

Resource reductions for ground state energy estimation

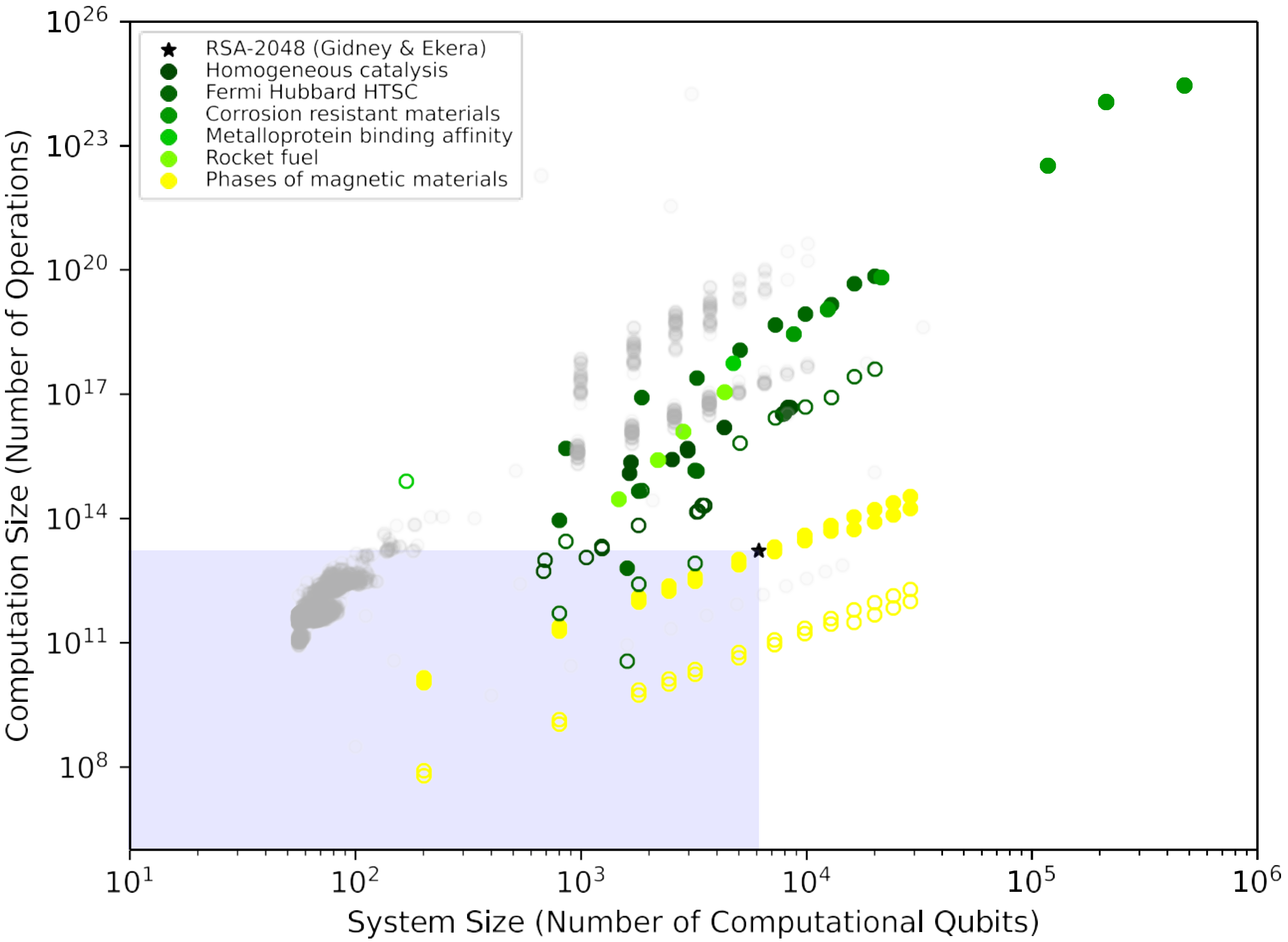
What optimizations did we assume for ground state energy problems?

For molecular chemistry

- 1-norm reduction via tensor decomposition[1]
- Improved error bounds, pre- and post-processing[2]
- 1st quantization for problems without active spaces[3]
- Tensor-Hypercontraction[4]
- Block Invariant Symmetry Shift[5]

For Fermi Hubbard/spin systems

- Replace Hamiltonian simulation with walk operator[6]



1. arXiv: 2403.03502 (2024)
2. arXiv: 2310.18410 (2024), 2404.18878 (2024), PRXQ 3, 040305 (2022), PRXQ 8, 041015 (2018), PRXQ 2, 030305 (2021)
3. PRXQ 2, 040332 (2021)
4. PRXQ 2, 030305 (2021)
5. J. Chem. Th. Comput. 19, 8201 (2023)
6. Nature 4, 22 (2018)

Many small utility-scale systems within sub-Shor region. Large utility-scale instances require further algorithm development.

Resource reductions for quantum dynamics

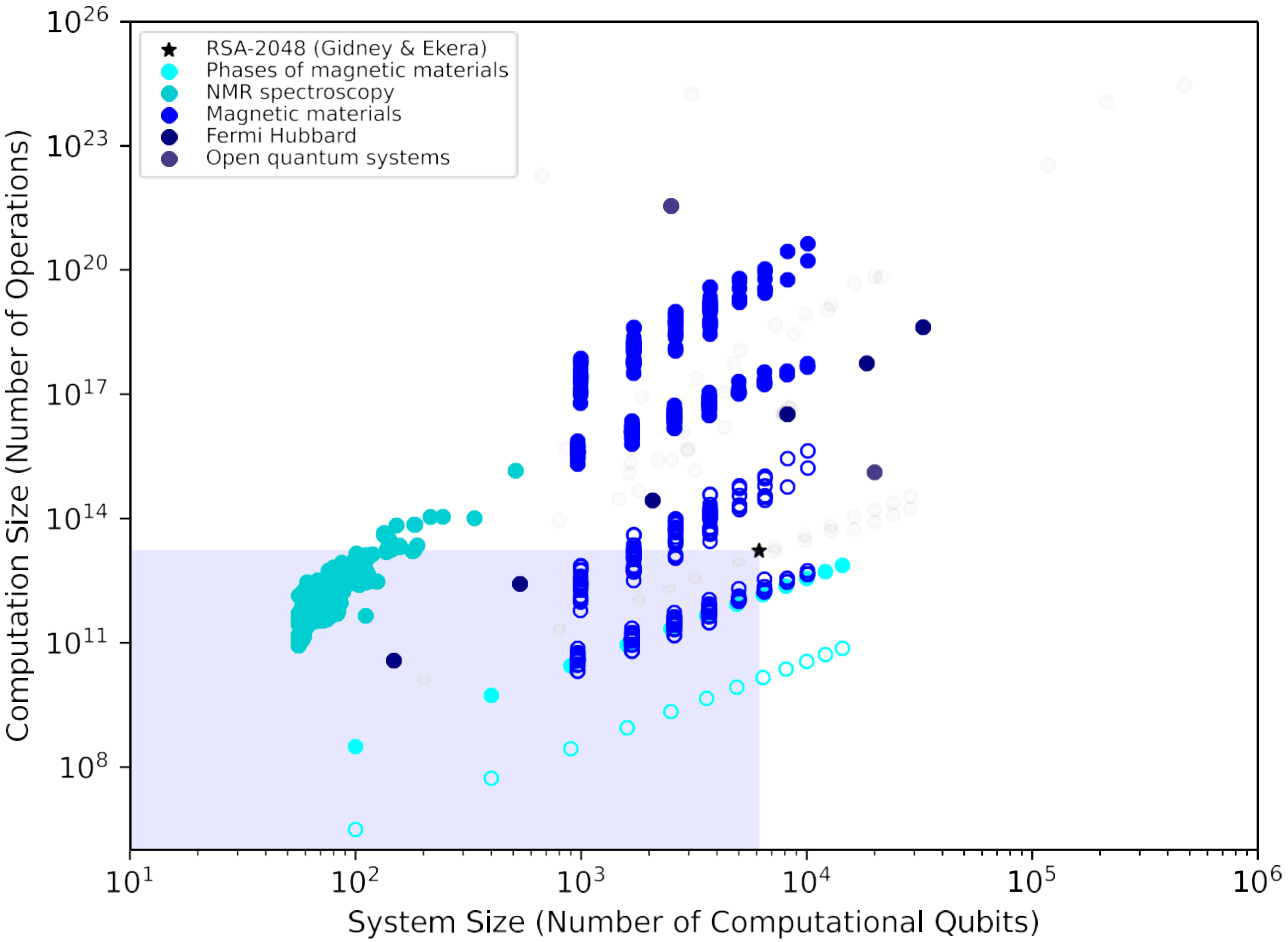
What optimizations did we assume for quantum dynamics problems?

Spin System Optimizations

- Analytic Trotter bounds are loose. Utilizing empirical bounds can reduce resource costs by orders of magnitude.[1]
- Application has very strict error tolerances. If these can be relaxed, resources can be lowered by a factor proportional to the error tolerance.[1]

Fermi-Hubbard Optimizations

- Improved mapping of fermions to qubits.[2]



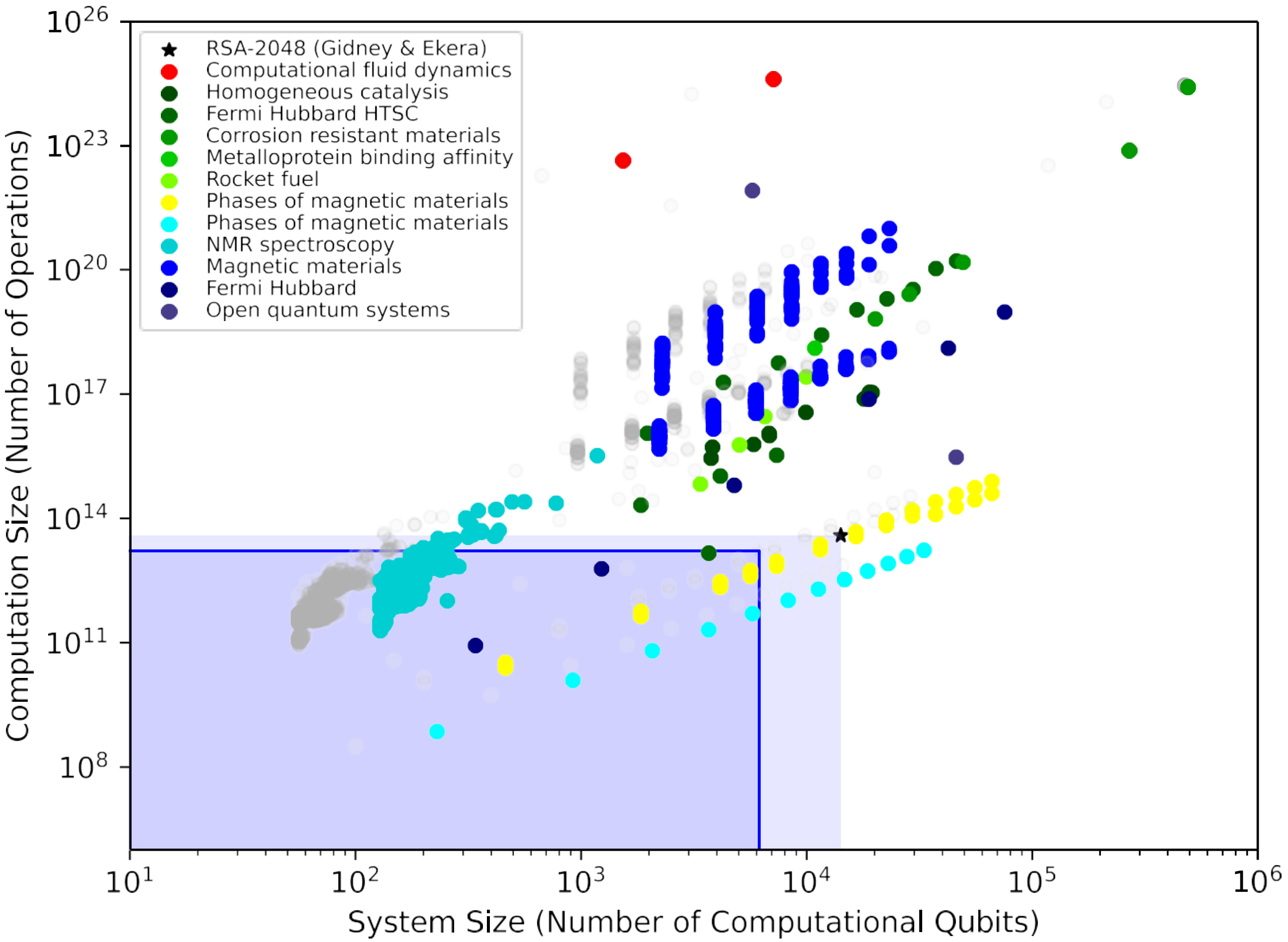
Qubit count is nearly optimal for spin systems, but future work may enable further T-count reduction.

1. PNAS 115, 9456 (2018)
2. J. Chem. Th. Comp. 14, 5617 (2018)

Architectural overhead and physical resource estimation

So far we've been talking about abstract logical architectures.

Any assumptions about real hardware push points to the right.

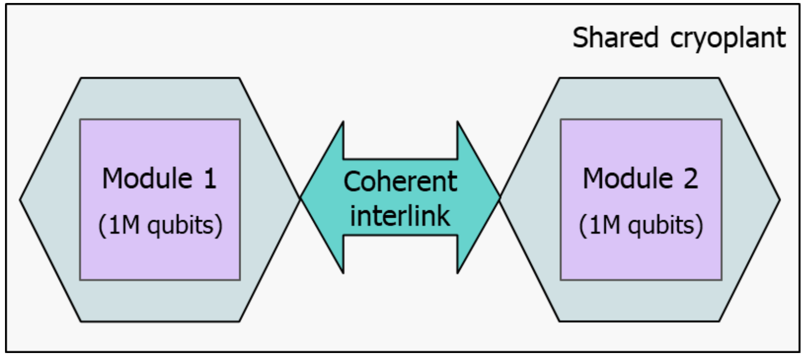


Architectural constraints shift all points (and sub-Shor region) up and to the right.

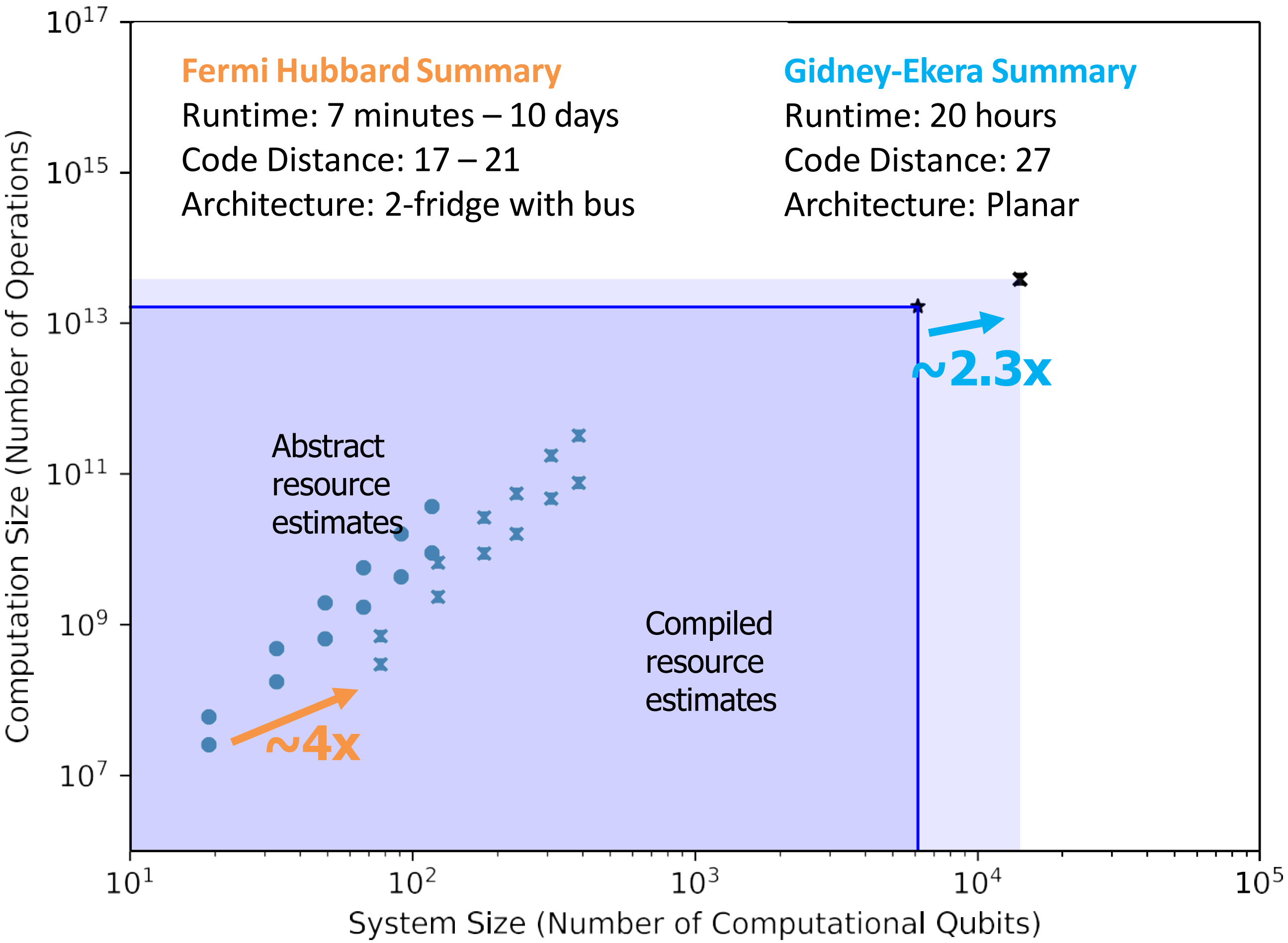
TA2 automated compilation tools

Automated compilation for small problems

- Run on small-scale Fermi-Hubbard instances
- Provide estimates of architectural overheads
- Provide detailed physical resource estimates (runtime, power consumption, etc.)



Two-fridge architecture with coherent interconnect used for Rigetti physical resource estimates



TA2 compilers automate physical resource estimates

Future work in Phase 2 and beyond

QB Phase 2

Connect utility to computer capabilities

Predict future performance of systems

Guide application development

Finalize Benchmarks

$/T-gate for each application, including lower and upper bounds

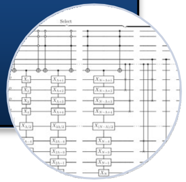
Connect utility to benchmark score

Robust Utility Estimates

Continue to develop and implement known algorithmic optimizations

Improve performance bounds of existing applications

Optimized Algorithms



Post-QB Work

Quantum algorithm development and optimization

Automated tools to speed up application development

Quantum architecture co-design

New applications

Post-QB Opportunities

Underexplored Systems for Utility-Scale Quantum Computing (US2QC)

The US2QC program in one slide

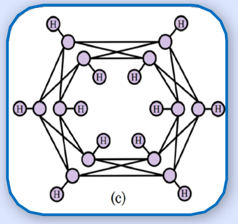
US2QC Motivation:

Quantum computing is strategically important

Source: U.S. Government

Technical assumptions have made us vulnerable to surprise

Source: Niel de Beaudrap



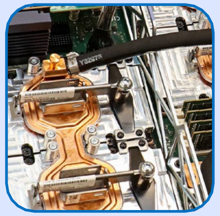
Viable paths defy those assumptions

Source: PsiQuantum

US2QC Goal:

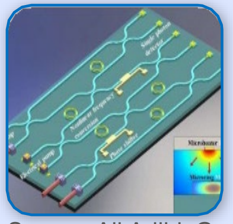
Reduce the danger of strategic surprise from underexplored quantum computing systems

US2QC Approach:



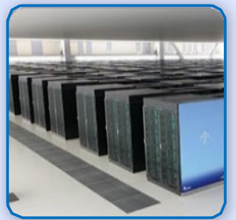
Evaluate designs for utility-scale quantum computers

Source: ORNL



Demonstrate enabling components and subsystems

Source: Ali Adibi, Ga Tech

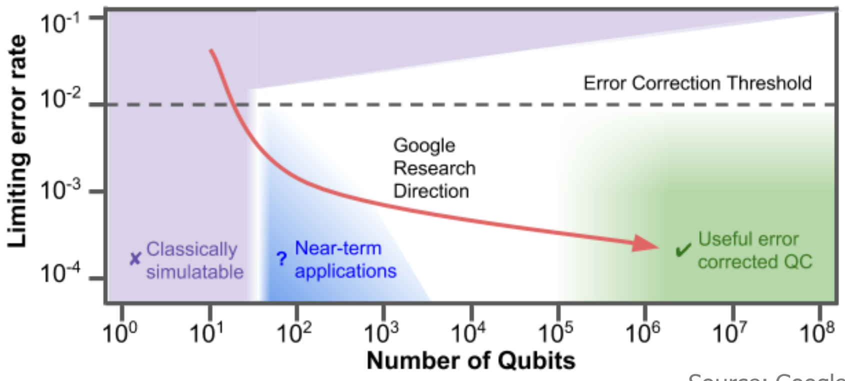


Construct a prototype fault-tolerant quantum computer

Source: Fujitsu

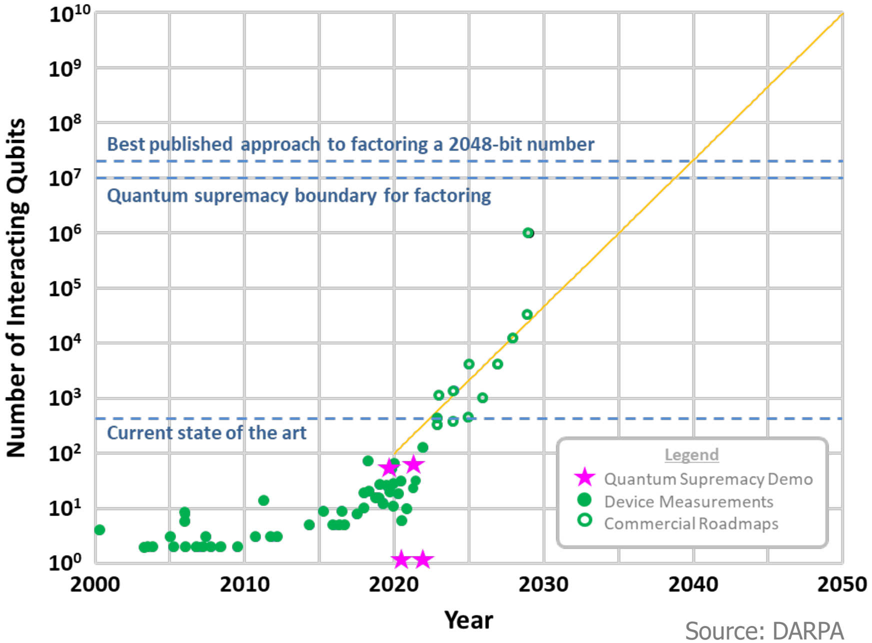
Technical assumptions have made us vulnerable to strategic surprise

Google Quantum Computing Planned Research Trajectory



Source: Google

Commercial Quantum Computer Roadmaps over Time



Source: DARPA

Assumption → Logical Qubits are made of Physical Qubits

- Conventional wisdom dictates that error-correction only works with physical qubits
- Superconducting and ion-trap companies are incrementally improving physical qubits

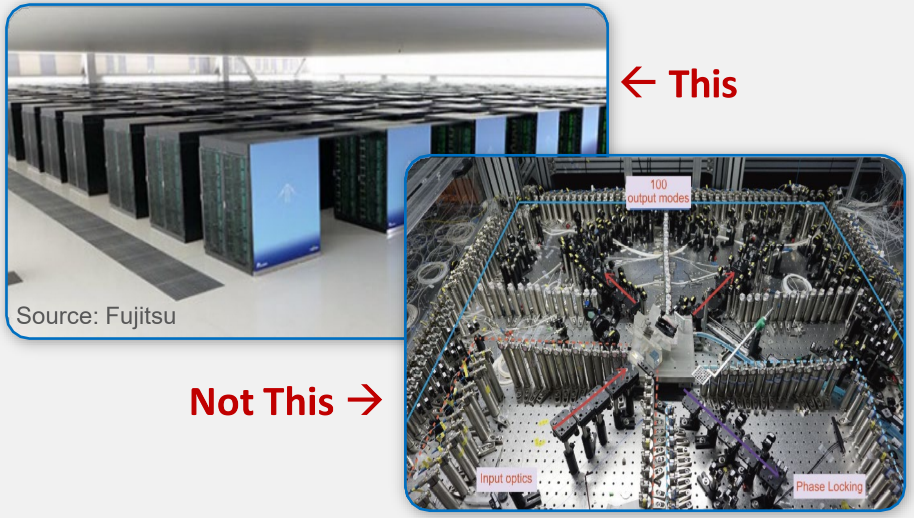
Assumption → Qubit Number, Fidelity are the Key Metrics

- This model supports an initial goal of “quantum supremacy”
- NISQ progress may not be directly relevant to Utility-Scale performance

These assumptions ignore quantum computing paradigms that are invalid in the noisy intermediate-scale (NISQ) regime

Critical concepts for the US2QC program

Utility-Scale Quantum Computer (USQC)



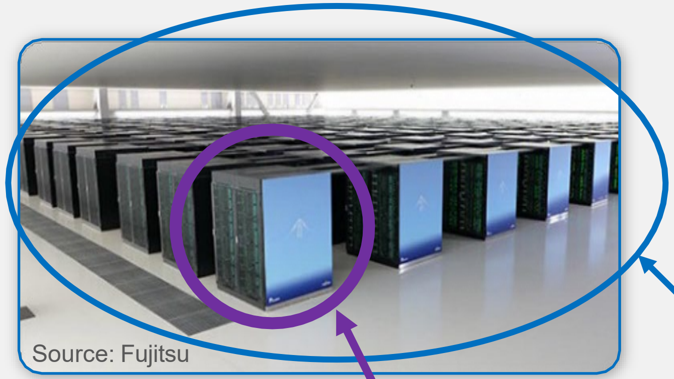
← This

Not This →

Source: Science

A fault-tolerant quantum computer whose value exceeds its construction cost

Fault-Tolerant Prototype (FTP)



Utility-scale system

Fault-tolerant prototype

A small fault-tolerant quantum computer that demonstrates that the utility-scale design is viable

US2QC will build Fault-Tolerant Prototypes and use them to validate designs for a Utility-Scale Quantum Computer

Program structure, part 1 → Architecture R&D

Utility-Scale Concept Review | Fault-Tolerant Prototype Requirements Review | Utility-Scale System Requirements Review

Architecture R&D

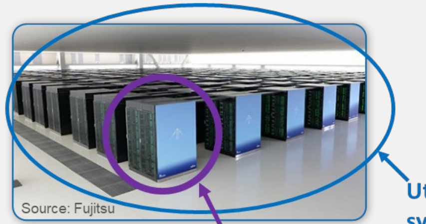
Utility-Scale Concept → ● → **Fault-Tolerant Prototype Design** → ● → **Utility-Scale System Design** → ●

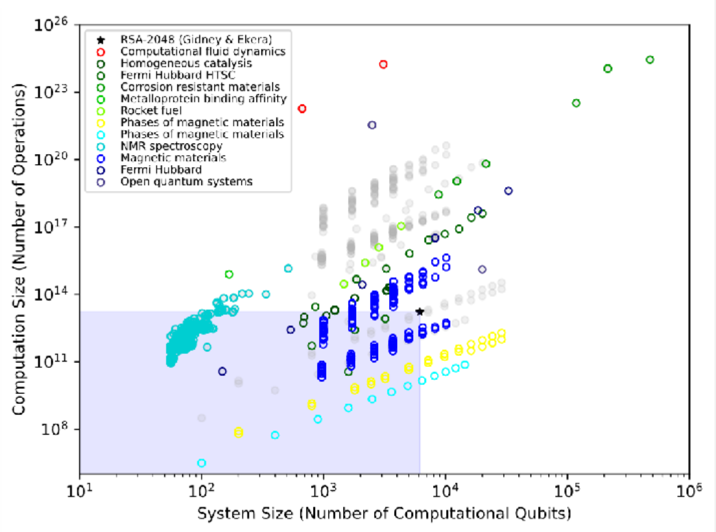
Establishes that the concept is viable

Sets Fault-Tolerant Prototype component requirements

Sets Utility-Scale System component requirements

High-Level Metrics

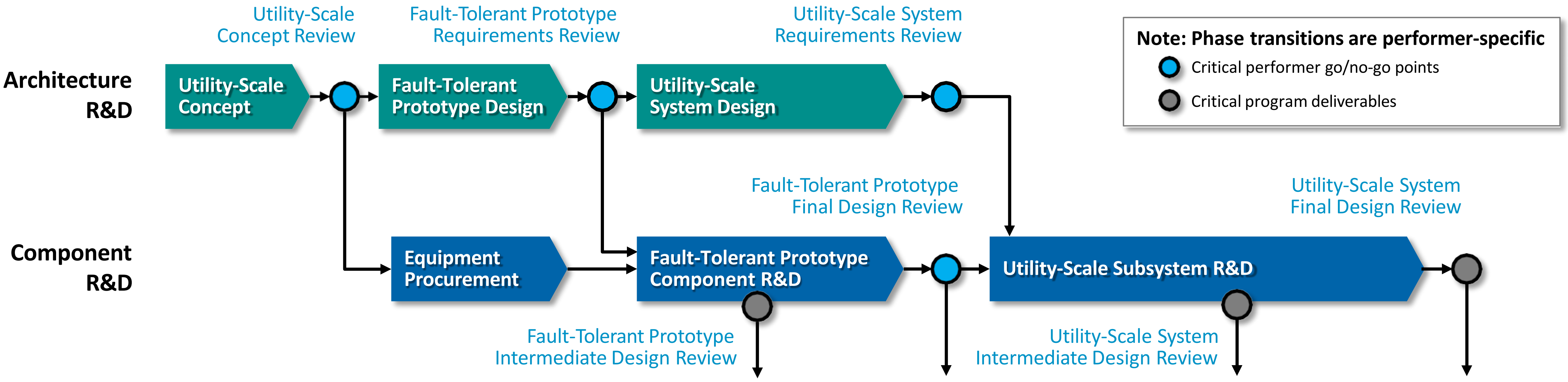




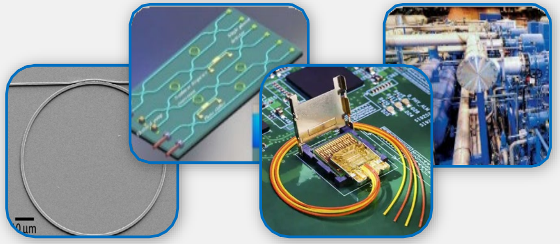
High-Level Utility-Scale System (USQC) Requirements Derived from Applications Results

US2QC will build Fault-Tolerant Prototypes and use them to validate designs for a Utility-Scale Quantum Computer

Program structure, part 2 → Component R&D



Paradigm-Specific Metrics



Sources: Optica, Ali Adibi, Jeffrey Tseng, CERN

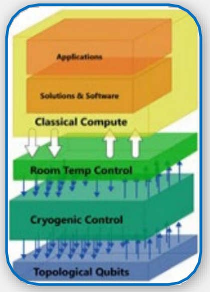
Examples for discrete photonics:

- Integrated switch bandwidth, insertion loss
- Waveguide/fiber-coupling loss
- Source efficiency, purity, net heating
- Detector efficiency, dark counts, speed
- Component size/integrated density
- Component yield
- Decoder speed
- I/O bandwidth
- Cryosystem mean time between failures

T&E Strategy

← Evaluate hardware designs

And quantum architectures →

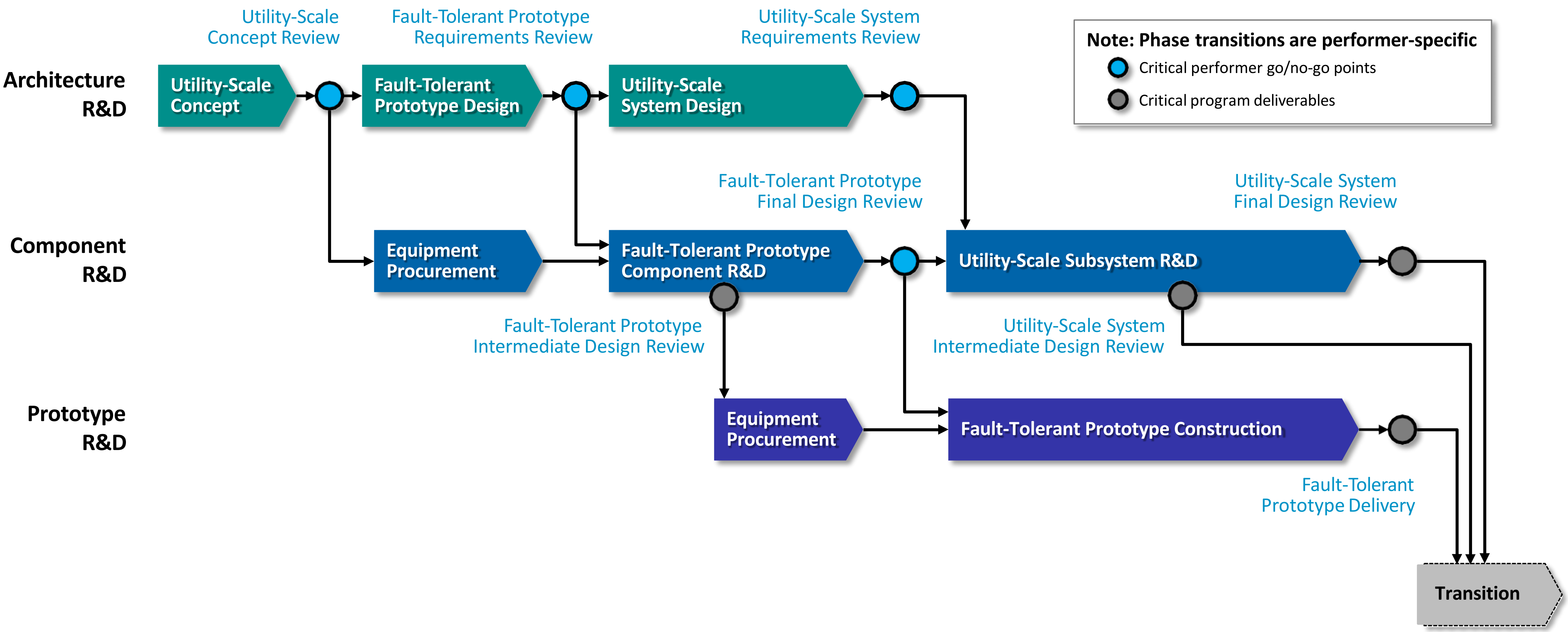


Sources: Xanadu, Microsoft

- Independent verification & validation
- Don't slow performers down
- Build U.S. Government expertise
- Real-time
- Support U.S Government missions

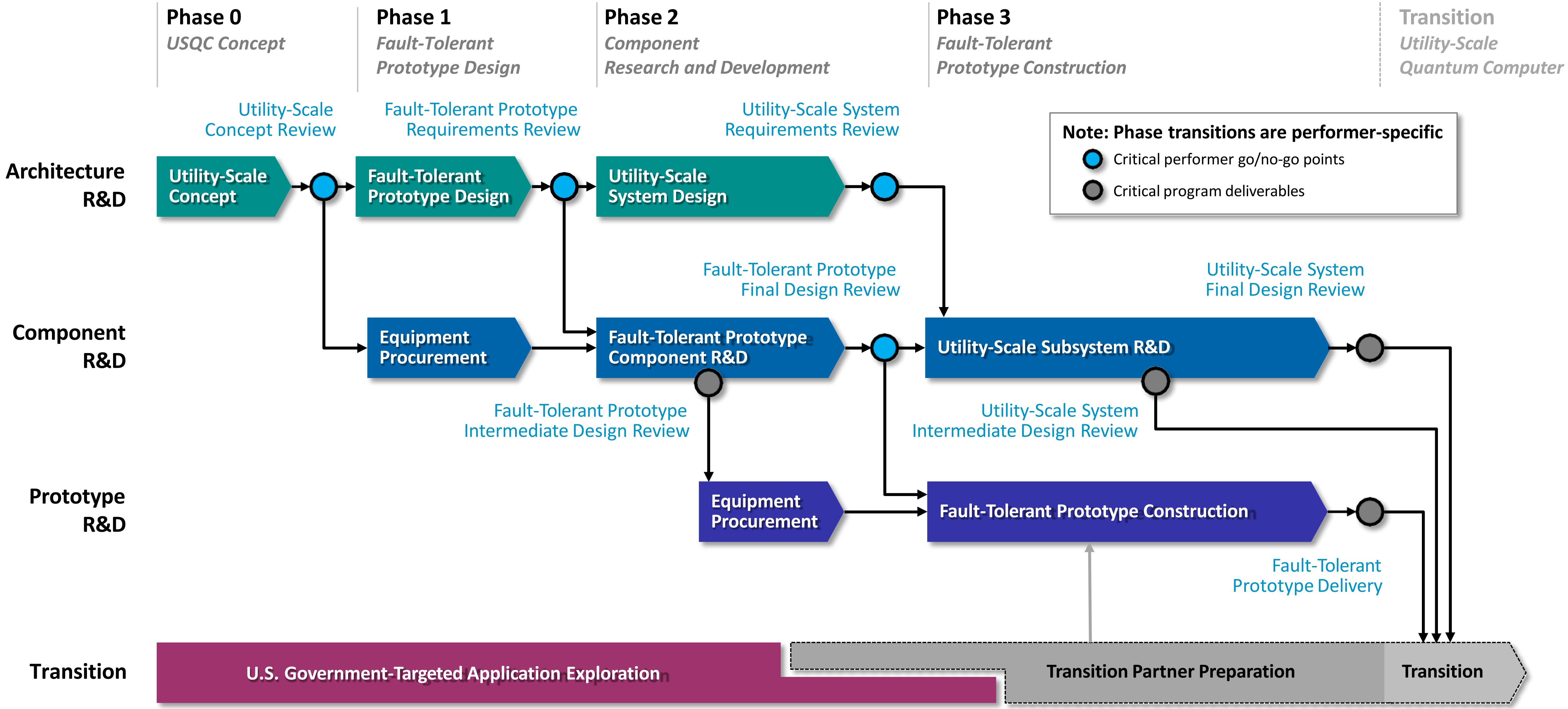
Advanced Fault-Tolerant Prototype and Utility-Scale System designs can't be completed without component R&D

Program structure, part 3 → Prototype R&D



A successful Fault-Tolerant Prototype should allow construction to begin on a Utility-Scale Quantum Computer immediately

Complete program structure with phases



Test and Evaluation (T&E) approach

The T&E team is exploring key questions such as:

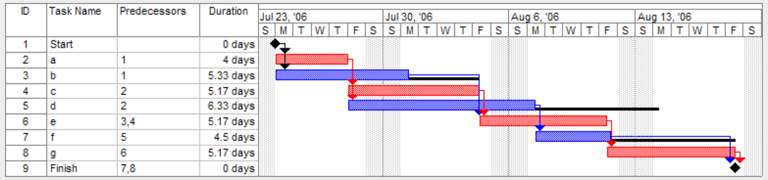
- How sound is the quantum approach?
- Can a utility-scale quantum computer be built?
- Can this organization build the quantum computer?
- Can this quantum computer be used effectively?

T&E comprises two general categories:

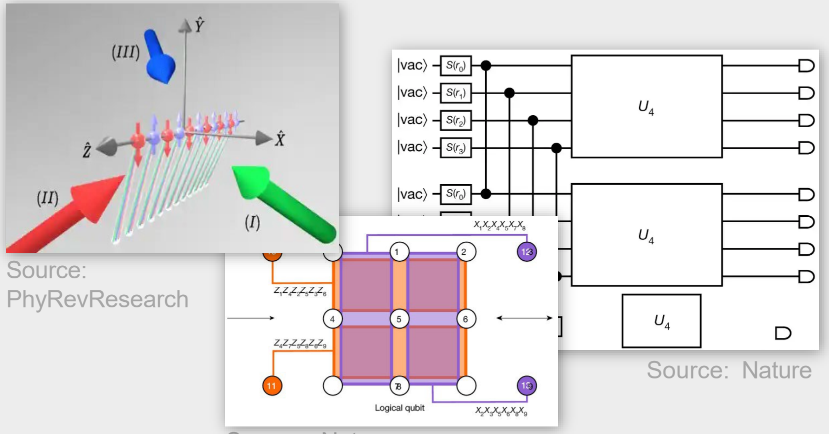
Broad System Evaluation

Source: Shutterstock

Source: Autodesk



Deep, Targeted Analysis



Source: PhyRevResearch

Source: Nature

Source: Nature

T&E System Evaluation Methodology

Roots (3)

USQC Physical Decomposition

- What is a high-level description of a Utility Scale Quantum Computer?
- What are all the components and sub-systems and how do they fit together?
- What happens at the interfaces of those components and sub-systems?

USQC Functional Decomposition

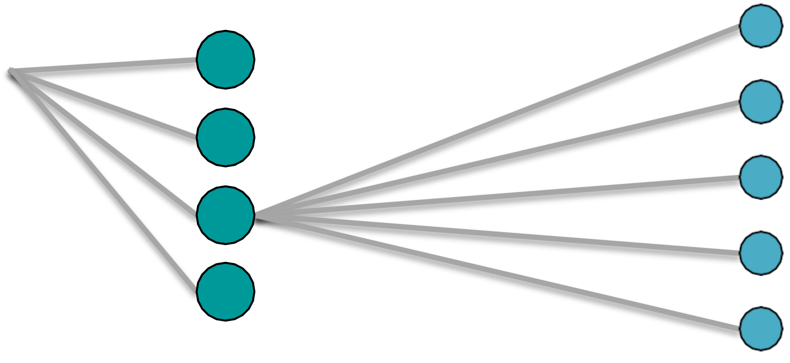
- How does the proposed USQC actually work?
- How is it intended to be used?
- What are its intended modes of operation and user interfaces?

Performer Processes

- What processes, plans, and products does this team have in place?
- How have they leveraged those (or different) processes, plans, products, in the past to come to their current USQC concept?
- How will the team's processes, plans, products change or be leveraged in the future to burn down all the risks and actually be ready to start USQC construction?

Branches (16)

Leaves (50)



Example Branch
Components and Subsystems

Example Leaf
System description of the USQC including a graphic depiction of the components and subsystems

System Evaluation → Provide a broad evaluation of the completeness and quality of concepts

System Evaluation Example

Performer Processes

Prototypes/Generations
- 1.1.1 Definition of USQC
- 1.1.2 Prototypes Planned
- 1.1.3 Form of FTP

Design Processes
- 1.2.1 Design Process/Practices
- 1.2.2 Technical/Management Teams

Critical Technologies/Risks
- 1.3.1 Component/Subsystem Risks
- 1.3.2 Technical Risks/Mitigation
- 1.3.3 Program/Design Risks

R&D Plan
- 1.4.1 Critical Technology Dev Plan
- 1.4.2 Program Timelines
- 1.4.3 Program Costs
- 1.4.4 Business Case

Trade Studies
- 1.5.1 Trade Study Plan
- 1.5.2 Tradeoffs/Decision Factors
- 1.5.3 Trade Study Methodology

Supply Chain Analysis
- 1.6.1 Initial Analyses
- 1.6.2 Production Capabilities
- 1.6.3 3rd-Party Partnerships

Physical Decomposition

Components & Subsystems
- 2.1.1 USQC System Description
- 2.1.2 Plan to Develop Description
- 2.1.3 USQC Parameters

Physical Quantum Layer
- 2.2.1 Fundamental Physics/Devices
- 2.2.2 Physical Qubits/USQC
- 2.2.3 Map Qubits to Components
- 2.2.4 Quantum Ops/Errors/Times

Classical Computing Layer
- 2.3.1 Classical Components/Subsys
- 2.3.2 Information Flow
- 2.3.3 Process/Mem Resources

Interfaces & Connectivity
- 2.4.1 Internal/External Interfaces
- 2.4.2 Key Interface Attributes

Noise Models
- 2.5.1 Sources/Individual Impacts
- 2.5.2 Collective Performance Impact

Functional Decomposition

Logical Layer
- 3.1.1 Logical Qubits/Ops Created
- 3.1.2 Error Models
- 3.1.3 Qubits/Rates/Depth/Runtime
- 3.1.4 Logical Qubit Connectivity
- 3.1.5 Logical Ops Execution Model

Modes of Operation
- 3.2.1 Quantum Circuit to Devices
- 3.2.2 Modes of Operation
- 3.2.3 Calibration Process
- 3.2.4 System Runtime Model

Applications
- 3.3.1 High-Level US Applications
- 3.3.2 Cost-Benefit Estimates
- 3.3.3 Quantitative Suitability for USQC

Algorithms
- 3.4.1 Algorithms Needed for Apps
- 3.4.2 Algorithm Inputs & Outputs
- 3.4.3 Quantum/Classical Interaction

Software
- 3.5.1 Full Software Stack
- 3.5.2 Software to Develop USQC
- 3.5.3 Processing Needs

Criteria
- Greatly Exceeds
- Exceeds
- Meets
- Partially Meets
- Does not Meet

Distribution Statement 'A' (Approved for Public Release, Distribution Unlimited)

Test and Evaluation (T&E) team

DARPA has assembled a robust set of quantum computing and engineering experts to help understand and evaluate the US2QC quantum computer concepts

National Aeronautics and Space Administration (NASA)

Strengths
- Broad, deep quantum expertise
- Classical High Performance Computing

Air Force Research Laboratory (AFRL)

Strengths
- Systems engineering
- Broad quantum expertise

Johns Hopkins Applied Physics Laboratory (JHU-APL)

Strengths
- Quantum error correction
- Systems engineering

Oak Ridge National Laboratory (ORNL)

Strengths
- Classical supercomputing
- Ions / Photons

Los Alamos National Laboratory (LANL)

Strengths
- Applications
- Quantum algorithms

Applied Research Laboratory for Intelligence and Security

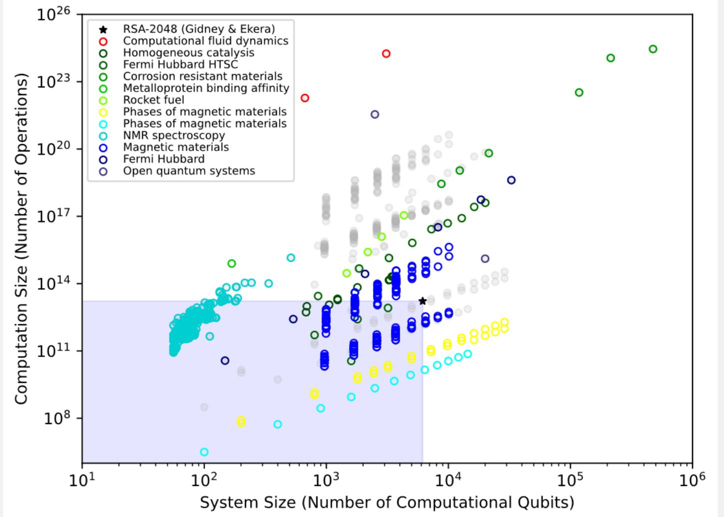
Strengths
- Data security expertise
- Access to academics

Metrics and milestones

Deliverable	Timing	Purpose (See backup slides for detailed review requirements)
USQC Concept Review	Phase 0	• Confirm feasibility of the performer's USQC concept • Confirm the design concept is consistent with US2QC goals • Review system conceptual baseline and initial system level specifications
FTP System Requirements Review	Phase 1	• Confirm that key FTP system performance metrics have been completely and properly identified • Confirm all FTP components and sub-systems initial specification targets • Confirm the FTP system concept is consistent with the US2QC goals
FTP System Intermediate Design Review	Phase 2	• Update FTP System baseline and component targets since the FTP Requirements Review • Review the key FTP system performance metrics • Provide a schedule and risk update, as well updates to targets based on experimental results
USQC Requirements Review		• Update the USQC baseline design, and confirm USQC concept is consistent with 10-year time limit • Confirm that key USQC system performance metrics have been completely and properly identified • Confirm initial specifications targets for all components and sub-systems of the USQC
FTP System Final Design Review		• Provide a final update of the FTP System design prior to entering Phase 3 system build • Identify the current component and sub-system performance; link to system's key performance metrics • Provide a schedule and risk update for the Phase 3 system build
USQC Intermediate Design Review	Phase 3	• Update USQC System baseline; provide schedule and risk update • Review key USQC system performance metrics • Identify experimental progress on component and sub-system specs; update targets and changes
USQC Final Design Review		• Provide a final update of the USQC System design to enable the execution of a USQC acquisition program • Review the key USQC system performance metrics; provide schedule and risk update • Identify the current component and sub-system performance including the FTP sub-system
USQC ROM Cost & Milestone Plan		• Provide ROM Cost and Milestone plan for transition partner execution; details will be provided in invitation to submit to Phase 3
Deliver Fault-Tolerant Prototype		• Deliver physical FTP to Govt site for independent verification and validation of all key system performance metrics; delivery must occur in time for realistic specified test plan to be executed

Paradigm-Specific Performance Specifications (Example abridged list for a discrete photonics paradigm below)				
Pump power, lambda	Pump BW, rep rate	Photon indistinguishability, purity	Switch power, speed	Loss per component
Yield per component	Min bend radius	Detector efficiency, dark counts, reset	Multi-pair probability	Sources per RSG
Circuit depth per photon	RSG state fidelity	Waveguide phase stability with temp	Local classical latency	Temp gradient on chip

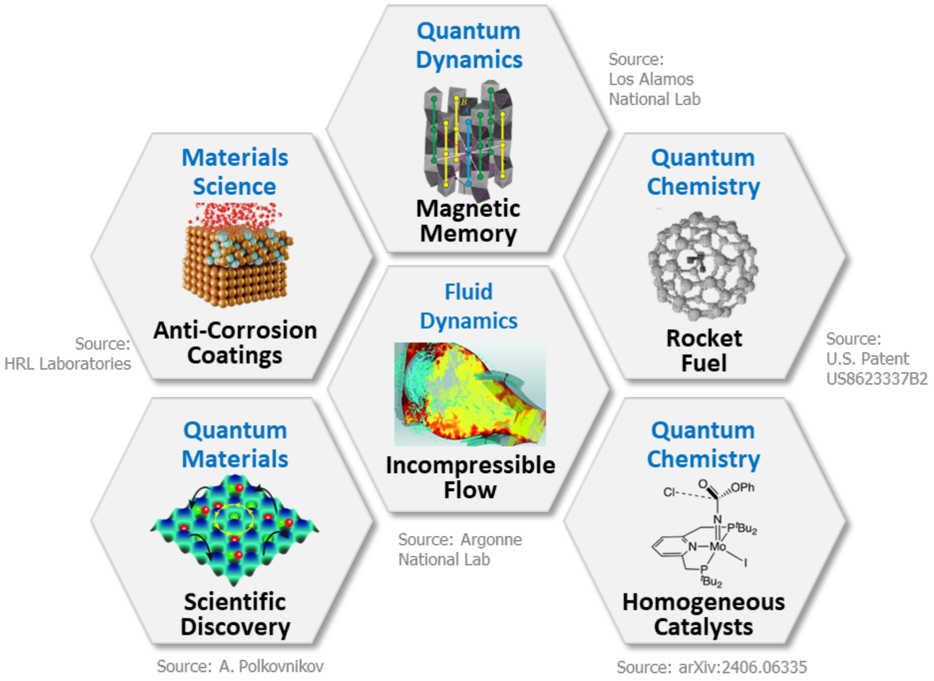
High-Level Utility-Scale System (USQC) Requirements Derived from Applications Results



Generic Performance Specifications
Area/Volume of system components and total system
Wall power requirement (for all systems)
Classical computing power required in steady state (in GFlops)
Cooling power at specified temperatures, in specified volumes
Required configuration and connectivity within and between quantum and classical sub-systems
Input/Output requirements for key systems
Space/time tradeoffs between total system size, gate depth, logical qubit number, etc.
Expected calibration time
Expected purchase price

If we succeed, what difference will it make?

Source: Shutterstock



National Security Impact

Reduce Strategic Surprise

Economic Impact

Reveal First Utility-Scale Quantum Computers

www.darpa.mil

6TH ANNUAL

QUANTUM FOR INTERNATIONAL

WORKSHOP

25-27 JUNE 2024

ROME, NEW YORK

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DR. KEVIN GEISS

Director

Air Force Office of Scientific Research (AFOSR)

Air Force Research Lab (AFRL)

Arlington, VA

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Q4I KEYNOTE ADDRESS

AFRL
AFOSR AIR FORCE OFFICE OF SCIENTIFIC RESEARCH

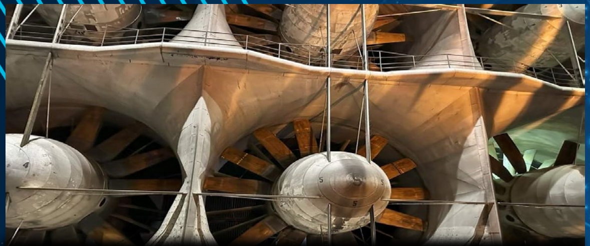
DR. KEVIN T. GEISS, SES
DIRECTOR, AFRL/AFOSR
25 JUNE 2024

One AFRL, One Fight

AFRL Reimagines Warfighter Capability for America's Air, Space & Cyberspace Advantage

Air Force Research Laboratory (AFRL) Enterprise At-a-Glance


AEROSPACE SYSTEMS (RQ)


AFWERX (RG)


BASIC RESEARCH (AFOSR)

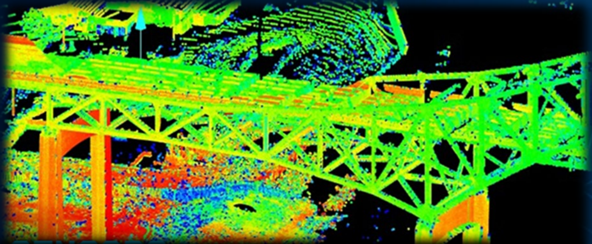

DIRECTED ENERGY (RD)


HUMAN PERFORMANCE (711th)


INFORMATION (RI)


MATERIALS & MANUFACTURING (RX)


MUNITIONS (RW)


SENSORS (RY)


INTEGRATED CAPABILITIES (RS)


SPACE VEHICLES (RV)

**Functional Directorates not pictured*

Balanced Near, Mid, Far-Term Investments

NEAR		MID		FAR

Ready to Go!
6.4+

Advanced Tech Development
6.3

Applied Research
6.2

Basic Research
6.1

OPERATIONAL DEVELOPMENT/ EXPERIMENTATION

- Research, development, test and evaluation
- Strategic development planning experimentation
- Small business innovation research program

Experimentation

~20%

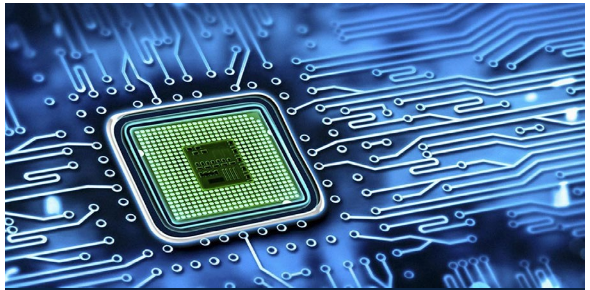
ADVANCED TECHNOLOGY DEVELOPMENT

Capabilities Concepts

The development and integration of hardware for field experiments and tests

From Application to Capability

~25%



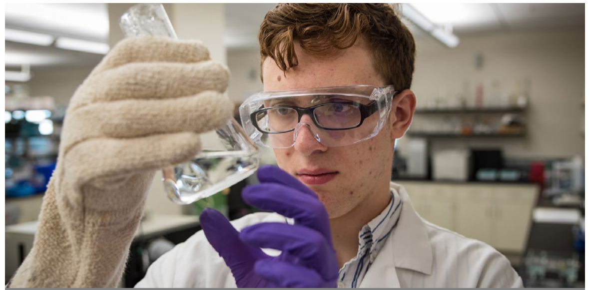
APPLIED RESEARCH

Technologies

Appling knowledge or understanding to determine the means by which a recognized and specific need may be met

Science to Application

~40%



BASIC RESEARCH

Science Knowledge

Greater knowledge or understanding fundamental aspects

Observable facts

Without specific applications toward processes or products

New Science

~15%

AFRL

AFRL/AFOSR Mission & Span of Influence

AFOSR's Mission is to Discover, Shape, Champion, and Transition High Risk Basic Research to profoundly impact the future Air and Space Force

Core Mission - With a broad, long-term perspective, we identify areas for investment and collaboration to advance the Department of the Air Force's (DAF) research and development enterprise across the full spectrum of air, space, and cyber operations. We build bridges to the world's most prestigious universities and talented researchers to enhance partnerships and provide revolutionary science and technology discoveries to the Warfighter.

Span of Influence - 60+ World-class Subject Matter Experts manage 1,600+ grants at over 300 leading academic institutions across 50 states and 65 countries, 150 industry-based contracts, and more than 230 internal AFRL research efforts.

Inherent in our mission, we strive to strengthen and shape the Science and Engineering talent pipeline through targeted outreach, research, internships, and fellowship programs to include a focus on Historically Black Colleges and Universities and Minority Serving Institutions. Fund DAF's K-12 STEM Outreach at 30+ bases supporting 500+ competitions!

DAF Link to Academia

Global Footprint and Reach

STEM Outreach Impact

Who We Are

A small organization with a big mission …

to Discover, Shape, Champion and Transition High Risk Basic Research to profoundly impact the future Air and Space Force

Scientists & Engineers and Business Professionals

- Active-duty Air & Space Force
- All-service veterans
- Renowned academics
- Passionate civil servants

A global network of talent

We partner, grow and discover with a global network of the greatest scientific minds in the world, pulling them into our ecosystem, launching career trajectories, and strengthening their contributions to national defense.

We are the Basic Research Arm of the Department of the Air Force and AFRL

Why We Do What We Do

"BASIC RESEARCH LEADS TO NEW KNOWLEDGE. IT PROVIDES THE SCIENTIFIC CAPITAL. IT CREATES THE FUND FROM WHICH THE PRACTICAL APPLICATIONS OF KNOWLEDGE MUST BE DRAWN.

NEW PRODUCTS AND NEW PROCESSES DO NOT APPEAR FULL-GROWN. THEY ARE FOUNDED ON NEW PRINCIPLES AND NEW CONCEPTIONS, WHICH IN TURN ARE PAINSTAKINGLY DEVELOPED BY RESEARCH IN THE PUREST REALMS OF SCIENCE."

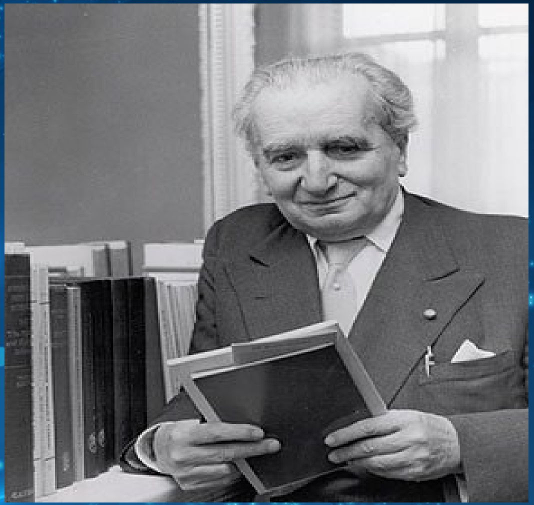
— *SCIENCE, THE ENDLESS FRONTIER*

Our Job is to Discover the Basic Research that will Protect the Future Department of the Air Force!

Historical Context for Basic Research

General Henry H. "Hap" Arnold (1886 -1950)

"The technical genius which could find answers was not cooped up in military or civilian bureaucracy but was to be found in universities and in the people at large." [1]



Dr. Theodore von Kármán (1881-1963)

"The scientist describes what is; the engineer creates what never was." [2]

1. Henry H. Arnold, "The Wind and Beyond: Theodore von Karman, Pioneer in Aviation and Pathfinder in Science". Book by Theodore von Karman, p. 268, 1967.
2. Theodore von Kármán, Biographical Memoirs of Fellows of the Royal Society (1980), 26, 110.

Why does the Department of the Air Force invest in Basic Research?

World Wars I and II made it obvious the perils of decades of neglect of aeronautical related R&D – *U.S. pilots during World War I, for the most part, flew second-hand European aircraft during the war*

"The first essential of air power is preeminence in research"
– Gen. Hap Arnold

General "Hap" Arnold, head of Air Forces

First Army Air Forces Scientific Advisory Group, 1944

"…clear beyond all doubt that scientific research is absolutely essential to National Security"
– Vannevar Bush, Director of Office for Scientific Research and Development, *Science the Endless Frontier*, 1945

AFRL/AFOSR: Over 70 Years of Basic Research

In recognition of the significant role of basic research for the Air Force, the Air Force Office of Scientific Research (AFOSR) was created in October 1951

Original AFOSR location in downtown Baltimore, MD

The AFRL/AFOSR mission ***then*** still persists ***today*** – discover, shape, champion, and transition high risk basic research to profoundly impact the future Air Force and Space Force

AFRL/AFOSR Basic Research Portfolio Areas

Engineering and Complex Systems

- Dynamic Materials and Interactions
- GHz-THz Electronics and Materials
- Energy, Combustion, and Non-Equilibrium Thermodynamics
- Unsteady Aerodynamics and Turbulent Flows
- High-Speed Aerodynamics
- Low Density Materials
- Multiscale Structural Mechanics and Prognosis
- Space Propulsion and Power
- Agile Science of Test and Evaluation (T&E)

Information and Networks

- Computational Cognition and Machine Intelligence
- Computational Mathematics
- Dynamics and Control
- Dynamic Data and Information Processing
- **Information Assurance and Cybersecurity**
- Optimization and Discrete Mathematics
- Science of Information, Computation, Learning, and Fusion
- Trust and Influence
- Complex Networks
- Cognitive and Computational Neurosciences

Physical Sciences

- **Materials with Extreme Properties**
- **Atomic and Molecular Physics**
- Electromagnetics
- Laser and Optical Physics
- **Optoelectronics and Photonics**
- Plasma and Electro-Energetic Physics
- **Quantum Information Sciences**
- Remote Sensing
- Space Physics
- Ultrashort Pulse Laser-Matter Interactions
- **Condensed Matter Physics**

Chemistry and Biological Sciences

- Biophysics
- Human Performance and Biosystems
- Mechanics of Multifunctional Materials and Microsystems
- **Molecular Dynamics and Theoretical Chemistry**
- Natural Materials, Systems, and Extremophiles
- Organic Materials Chemistry
- Space Biosciences

International Office

- Asian Office of Aerospace R&D Tokyo
- European Office of Aerospace R&D London
- Southern Office of Aerospace R&D Santiago
- North America - Arlington

**** Multiple AFOSR portfolios contribute to QIS***

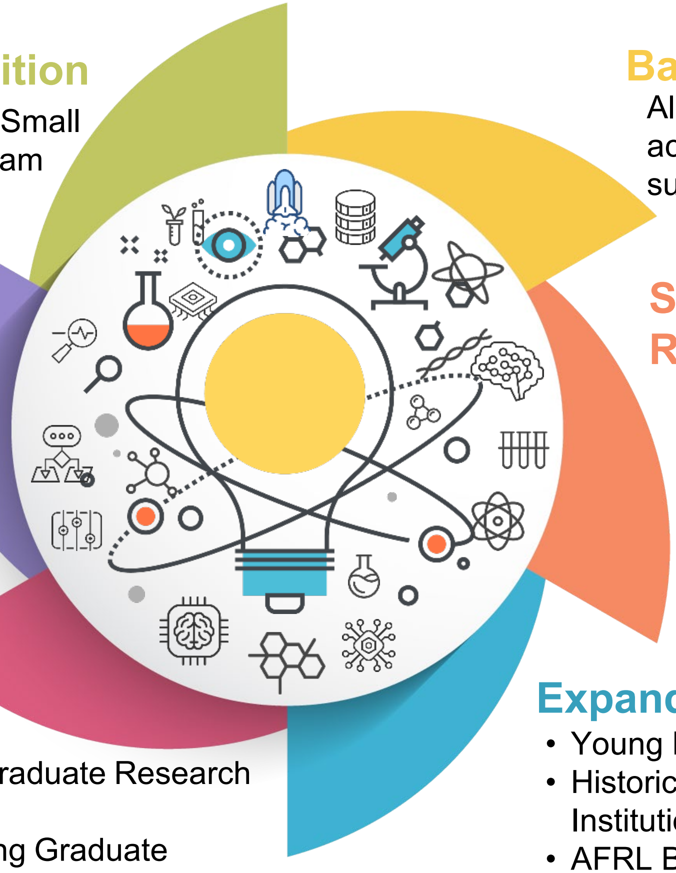
How We Accomplish Our Mission

Technology Transition

- Small Business Innovation Research (SBIR)/Small Business Technology Transfer (STTR) Program
- Partnerships for Transition

Basic Research Traditional Grants

All qualified, responsible organizational applicants from academia, the non-profit sector, and industry are eligible to submit research proposals.



Strengthening Academic Research Capabilities

- Multidisciplinary University Research Initiative (MURI) Program
- Defense University Research Instrumentation Program (DURIP)
- Presidential Early Career Award for Scientists and Engineers (PECASE)

Strengthening Air & Space Force Research Capabilities

- US Air Force Academy Program
- Summer Faculty Fellowship Program (SFFP)/Science & Technology Fellowship Program (STFP)

Workforce Development

- Awards to Stimulate and Support Undergraduate Research Experiences (ASSURE)
- National Defense Science and Engineering Graduate Fellowship Program (NDSEG)
- Pre K-12 STEM

Expanding Air & Space Force Academic Reach

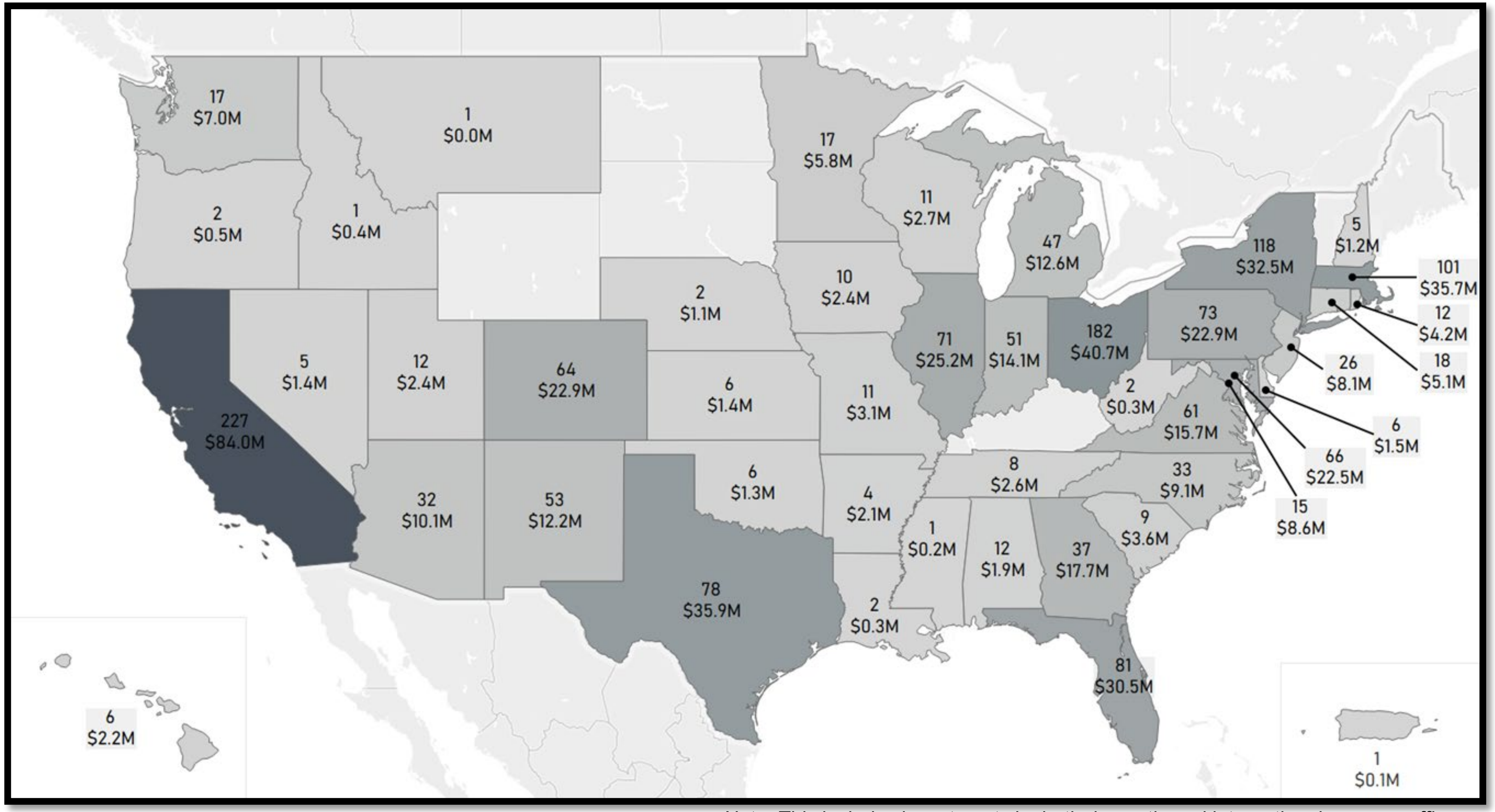
- Young Investigator Program (YIP)
- Historically Black Colleges & Universities/Minority Serving Institutions (HBCU/MSI) Program
- AFRL Basic Research National Science Portals (NSPs)

Diversified investment strategy for maximum discovery potential

Achieving Local, National, and Global Partnerships

FY23 AFRL/AFOSR Domestic Investments in Basic Science

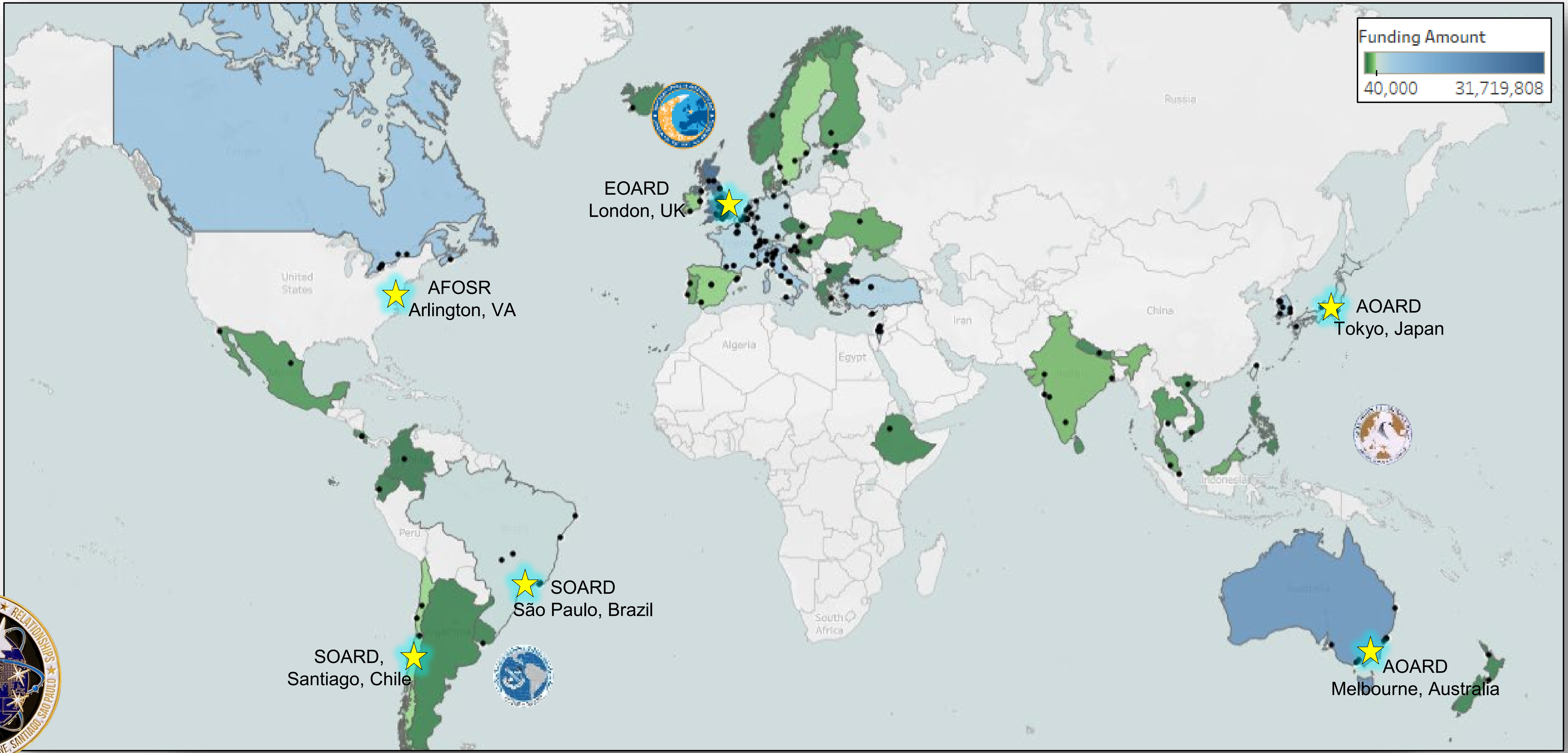
AFRL/AFOSR supported 1603 domestic investments in FY23 at 246 universities and small businesses across 45 states.

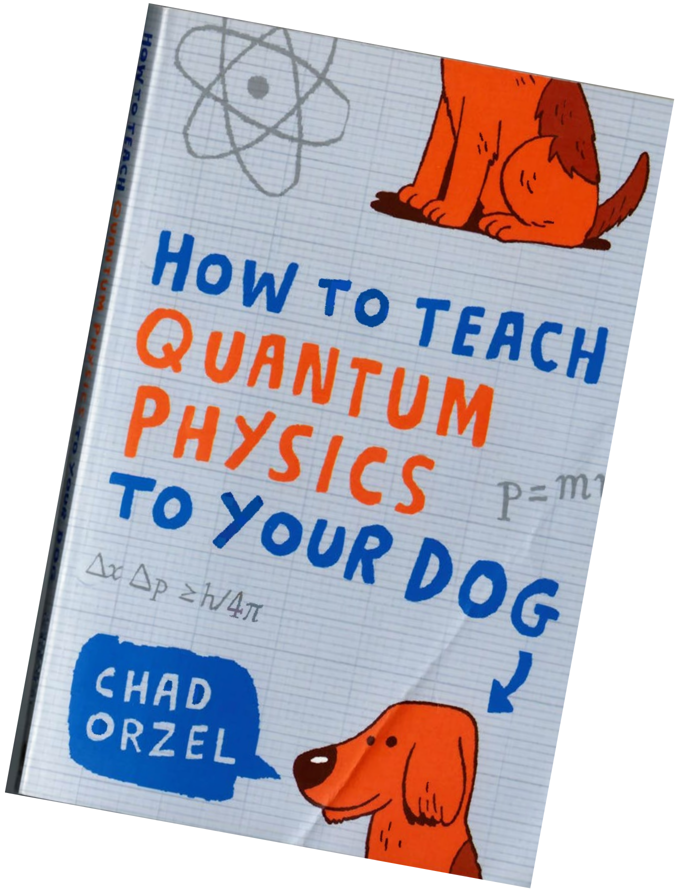


Note: This includes investments by both domestic and international program officers.

FY23 AFRL/AFOSR International Investments in Basic Science

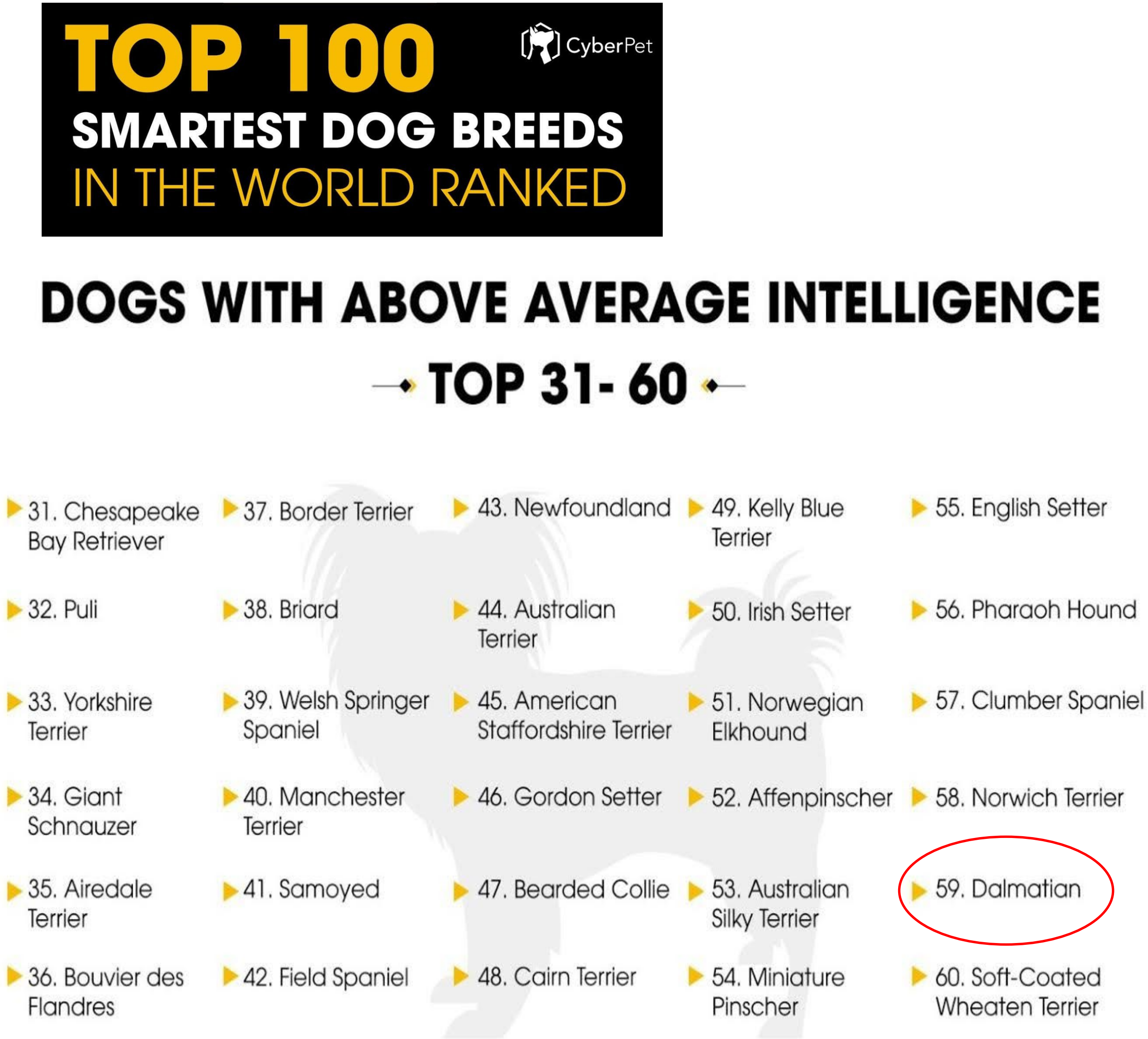
AFRL/AFOSR supported over 460 investments in FY23 across 49 countries and 6 continents.





*

* Reference to this book does not imply Government endorsement of the book, its author, or content



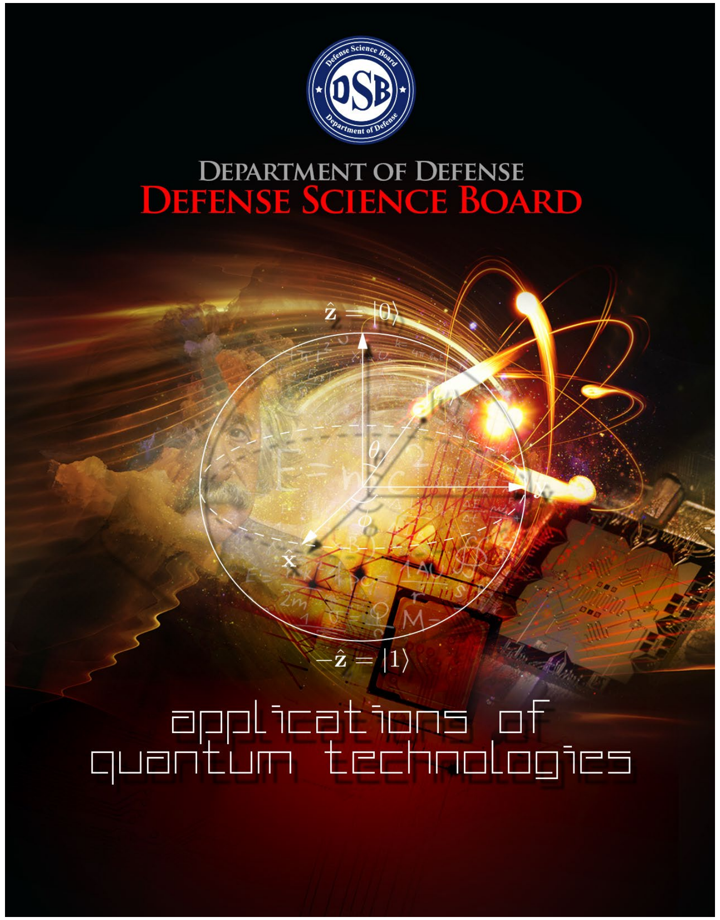
https://www.cyberpet.com/wp-content/uploads/2020/04/Smartest-Dog-Breeds.jpg

Why does USAF/USSF/DoD care about Quantum Information Science?

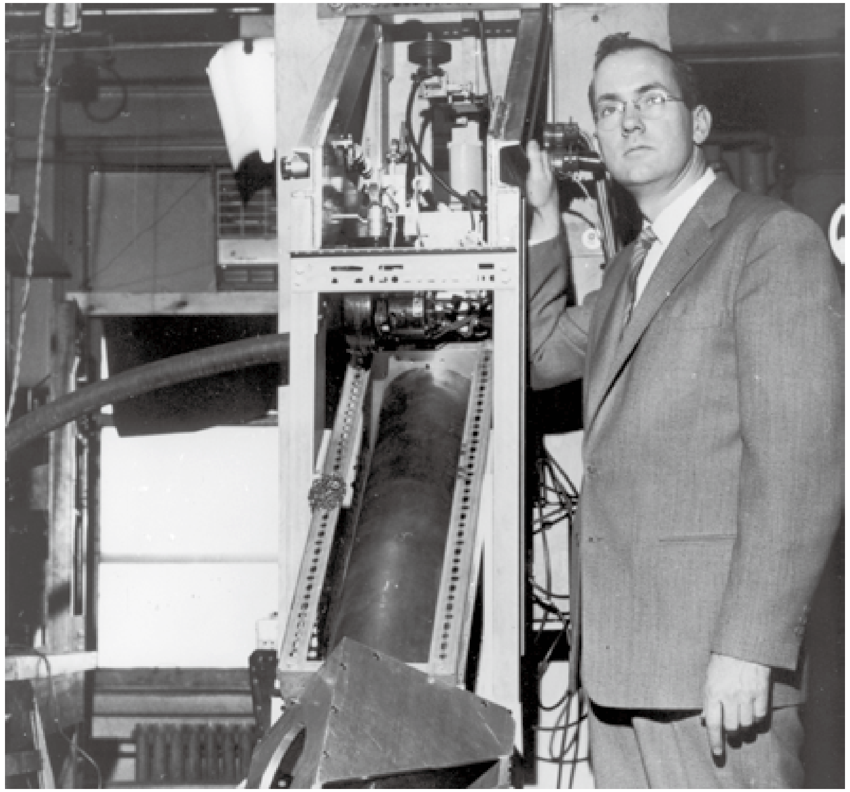
- Seen impact of atomic clocks in GPS for navigation

- *At the core, the promise and impacts of quantum science and technology are about the collection, generation, processing, and communication of information.*

- Three technology areas with critical value to DoD
  - **Quantum Sensing** (*e.g.*, timing and positioning, magnetometry, gravimeters, *etc.*)
  - **Quantum Computing** (*e.g.*, cryptography, signal processing, simulation, *etc.*)
  - **Entanglement Distribution** (*e.g.*, teleportation, distributed computing, *etc.*)



Nobel Prize Winning Research



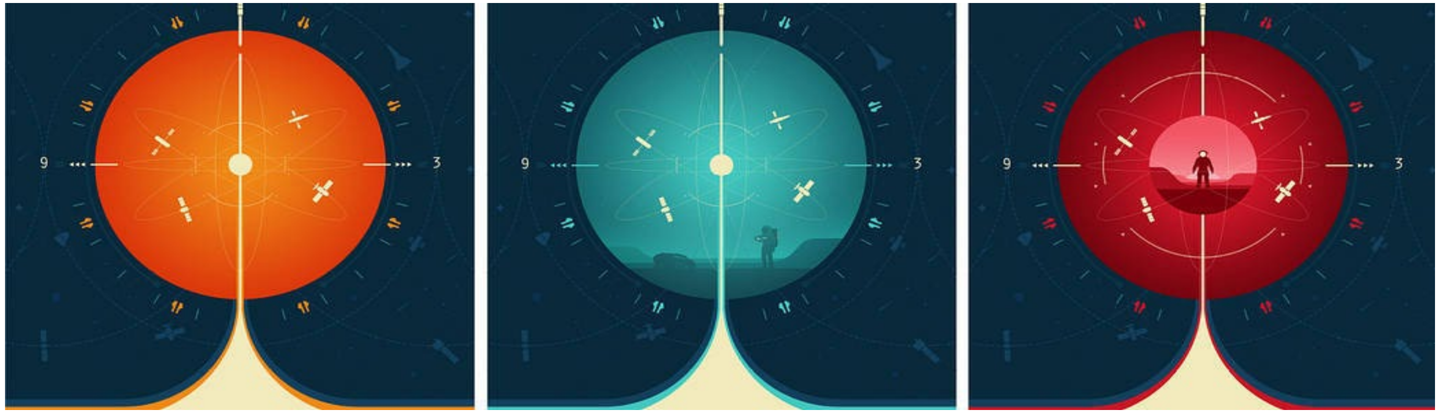
Dr. Charles Townes, Columbia University

Microwave Amplification by Stimulated Emission of Radiation (MASER) (1953)

Basic Research leads to first MASER in 1954, supported by AFRL/AFOSR as part of Joint Services Electronics Program

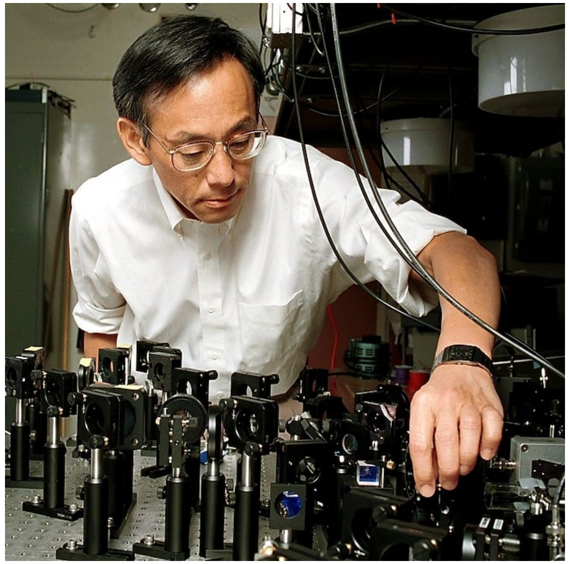
- Led to explosion of **laser-related breakthroughs** (many that were AFRL/AFOSR-supported), including **atomic clocks integral to GPS satellite operations**

1964 **Nobel Prize in Physics,** shared with Nicolay Basov and Aleksandr Prokhorov



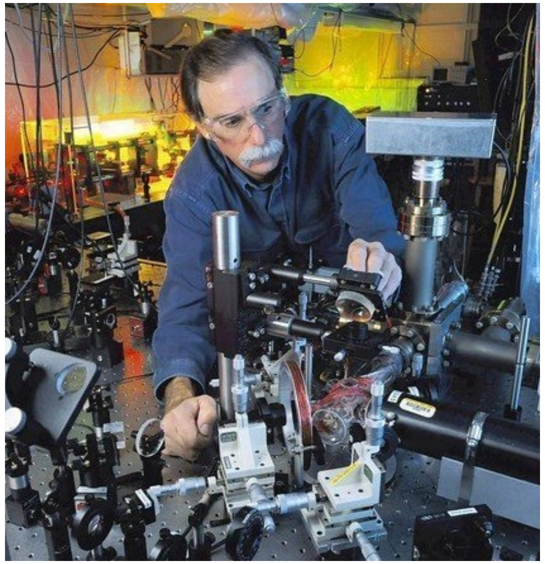
Nobel Prize Winning Research

Dr. Steven Chu, Stanford University
Laser Cooling (1988)



Research into **cooling and trapping of atoms with laser light**

- Led to a **1000-fold increase in atomic clock accuracy**
- 1997 **Nobel Prize in Physics**, shared with Claude Cohen-Tannoudji and William Philips



Dr. David Wineland, University of Colorado Boulder and NIST
Single Ion Manipulation (1982**)**

"for ground-breaking experimental methods that enable measuring and manipulation of individual quantum systems"

- Demonstrated **first quantum logic gate with two qubits**
- 2012 **Nobel Prize in Physics**, shared with Serge Haroche

Quantum Photonics at Oxford & ORCA Computing *as of 29 May 2024*

Professor Ian Walmsley
- *Oxford University*
  - *AFOSR Grants 2009-12, 2012-15*
- *ORCA Computing*
  - *Grant 2021-24*

2nd Oxford Grant
1 Sep 2012

7 PAPERS

"Enhancing multiphoton rates with quantum memories," Phys. Rev. Lett., 2013 (152)

ORCA Computing founded 28 Oct 2019, "ORCA" stems from the "Off-Resonance Cascaded Absorption" memory

"ORCA Computing provides UK MoD with first quantum computer", June 2022

GXC

ORCA Computing acquires Austin, Texas-based Integrated Photonics Division of GXC, Jan 2024

(276) *"Single-photon-level quantum memory at Room Temperature," Phys. Rev. Lett, 2011*

Fundamental Research — Fundamental Research — TRANSITION — Technology Advancement

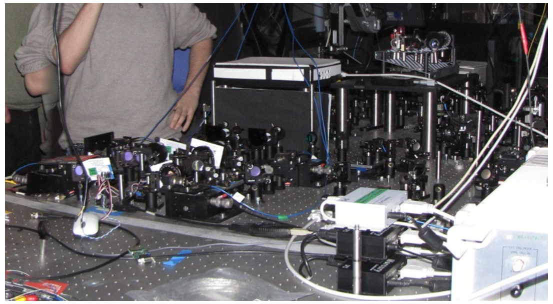
1st Oxford Grant
1 Apr 2009

15 PAPERS

Science

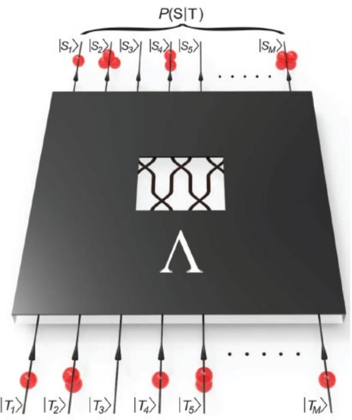
"Entangling Macroscopic Diamonds at Room Temperature," (2011) (417)

1st Contact
June 2008



Science (940)

"Boson sampling on a photonic chip" (2013)



Optics Letters *31 October 2022*

Zeeman optical pumping of ^{87}Rb atoms in a hollow-core photonic crystal fiber

AFOSR Grant awarded Sept 2021 to ORCA Computing with goal to improve performance and robustness of quantum memories.

CITATIONS as of 2023 per Google Scholar

2008 — 2012 — 2016 — 2020 — 2024

AIR FORCE RESEARCH LABORATORY

"Changing the world one photon at a time"

Quantum Photonics at University of Bristol *as of 29 May 2024*

Quantum Photonics Beyond Conventional Computing

- *Professor Jeremy O'Brien*
- *Bristol University*
- *AFOSR grant, 2012-15*

PSiQuantum, founded 28 Jun 2016 in Palo Alto, California by Bristol's O'Brien & Mark Thompson and Imperial College's Pete Shadbolt and Terry Rudolph

Quantum Computing Startup Raises $215 Million for Faster Device, Bloomberg, 6 April 2020

PsiQuantum Closes $450 Million Funding Round to Build the World's First Commercially Viable Quantum Computer, Business Wire 27 July 2021

QUANTUM NEWS
Australia raises eyebrows by splashing A$1bn into US quantum-computing start-up PsiQuantum
Physics World 7 May 2024

Dec 2010 Interest in photonic quantum computing from Air Force and visits Bristol group

AFRL/RI

EOARD

Fundamental Research — TRANSITION — Technology Advancement

NEW TECH

Grant 2012-15, "Quantum photonics beyond Conventional computing"

7 PAPERS

1128 CITATIONS as of 2024

Science — *Paper of note 14 August 2015*

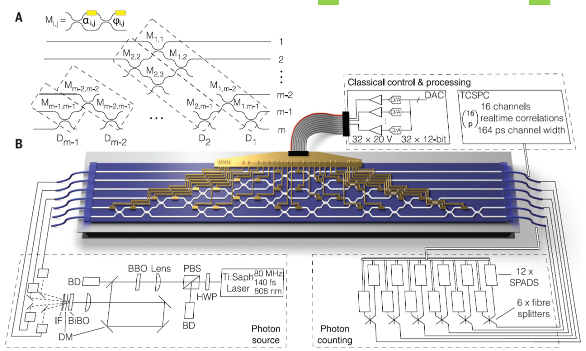
Universal linear optics

"We programmed this system to implement heralded quantum logic and entangling gates, boson sampling with verification tests, and six-dimensional complex Hadamards," said the University. "We implemented 100 Haar random unitaries with an average fidelity of 0.999 ± 0.001. Our system can implement any linear optical protocol." Electronics Weekly, 10 Aug 2015

Senator Schumer announces $25 million for GlobalFoundries and PsiQuantum to develop the next generation of quantum computers at Rome Air Force Research Lab & Malta, 7 April 2022

PsiQuantum will Partner with DARPA to Accelerate Path to Build the World's First Utility-Scale Quantum Computer, 31 Jan 2023

March 2011 Prof O'Brien visits AFRL/RI Rome, NY

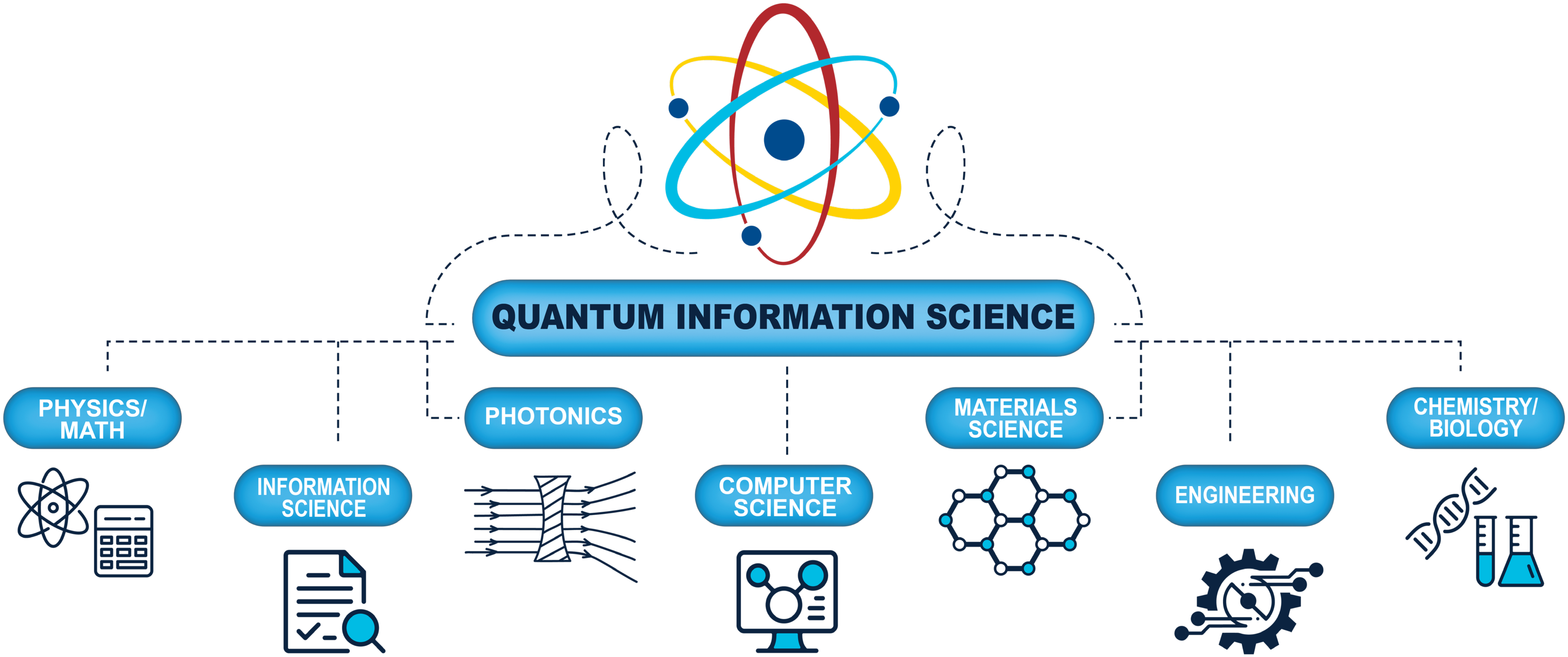


Connections to US Air Force

O'Brien visits AFLR/RI, Rome AFB, March 2011
AFOSR director visits Bristol, Jun 2011
AFRL/RI researchers visit Bristol, Sep 2011

CY 2011 | 2012 | 2016 | 2020 | 2024

QIS INHERENTLY MULTIDISCIPLINARY:



QIS Multidisciplinary University Research Initiatives (MURIs)

Quantum Computing and Networking

1995 AFOSR *Optical Switching*
1996 ARO *Photonic Band Engineering*
1999 *ARO *Manipulating Quantum Information*
2001 *AFOSR *Superconductor-based Quantum Computing*
2003 ARO *Photonic Quantum Information Systems*
2004 *AFOSR *Nanophotonics and Plasmon Optics for Networks, Sources and Sensors*
2006 *AFOSR *Silicon-based Lasers and Nanophotonics*
2007 AFOSR *Quantum Simulations of Condensed Matter Systems using Ultra-Cold Atomic Gases*
2009 ARO *Integrated Quantum Circuits*
AFOSR *Complex Nonperiodic Nanophotonics*
2010 AFOSR *Superconducting Semiconductors*
2011 *AFOSR *Quantum Memories and Light-Matter Interfaces*
AFOSR *Integrated Hybrid Nanophotonics*
2012 AFOSR *Quantum Metaphotonics and Metamaterials*
2013 ONR *Free Space Optical Quantum Key Distribution*
ARO *Non-Equilibrium Many-Body Dynamics*
AFOSR *New Quantum Phases of Matter*
AFOSR *Optimal Measurements for Scalable Quantum Technologies*
2014 *AFOSR/ARO/LPS, *Quantum Transduction*
AFOSR *Control of Light Propagation through Metasurfaces*
2015 ARO *New Regimes in Quantum Optics*
AFOSR *Semantics and Structures for Higher-level Quantum Programming Languages*
2016 ARO/AFOSR *Modular Quantum Systems*
AFOSR *Quantum Many-Body Physics with Photons*
*AFOSR *Attojoule Nanooptoelectronics*
2017 AFOSR *Foundations of Interactive Protocols for Quantum Computation and Communications*
ARO *Anyons in 2D materials and cold Atomic gases*
2018 ARO *Integrated Quantum Sensing and Control for High Fidelity Qubit Operations*
2019 AFOSR *Dissipation Engineering in Open Quantum Systems*
AFOSR *Quantum Holography*
2020 ARO *Mathematical Intelligence: Machines with More Fundamental Capabilities*
AFOSR *Weyl Fermion Optoelectronics*
2021 ARO *Quantum Network Science*
AFOSR *Quantum Random Access Memory*
AFOSR *Non-Hermitian Programmable Materials at Exceptional Points*
AFOSR/ARO *Interfacial Engineering of Superconductors*

Colored by area: Quantum Computing (black), Networking (orange), Timing (green) and Sensing (blue).
Year denotes start date of program with a typical 5 year duration per program. An asterisk denotes multiple awards for the topic.

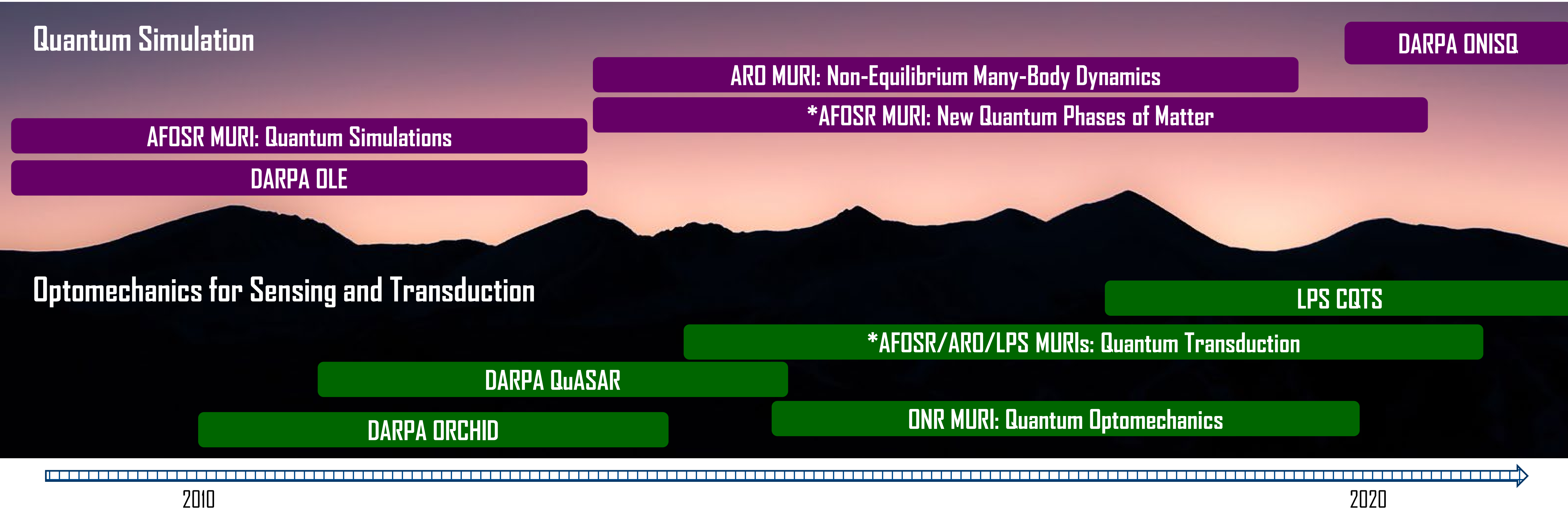
1990 1995 2000 2005 2010 2015 2020 2025

Quantum Timing and Sensing

2021 ONR *Molecular Qubits for Synthetic Electronics*
2020 ARO *Quantum State Engineering for Enhanced Metrology*
*AFOSR *Full Quantum State Control at Single Molecule Levels*
2019 ARO *Reactive and non-Reactive Scattering from Targeted Molecular Quantum States*
2018 ARO *Novel solid- state materials and color centers for quantum science and engineering*
2015: ARO *Exploiting Nitrogen Vacancy Diamonds for Manipulation of Biological Transduction*
ONR *Quantum Optomechanics*
2014 ARO, *Ultracold Molecular Ion Reactions*
2012 ARO *Quantized Chemical Reactions of Ultracold Molecules*
2011 ARO *Qubit Enabled Imaging, Sensing & Metrology*
ARO *Quantum Stochastics and Control*
2010 ARO *Atomtronics*
2009 *AFOSR *Ultracold Molecules*
2006 ONR *Detection and Sensing Below the Shot Noise*
2005 ARO *Quantum Imaging*
ONR *Magnetic Detection Science and Technology*
2002 *ONR *Optical Clocks*
2000 *ARO *Atom Optics*
1992 ARO *Coherent Control of Wavefunctions*

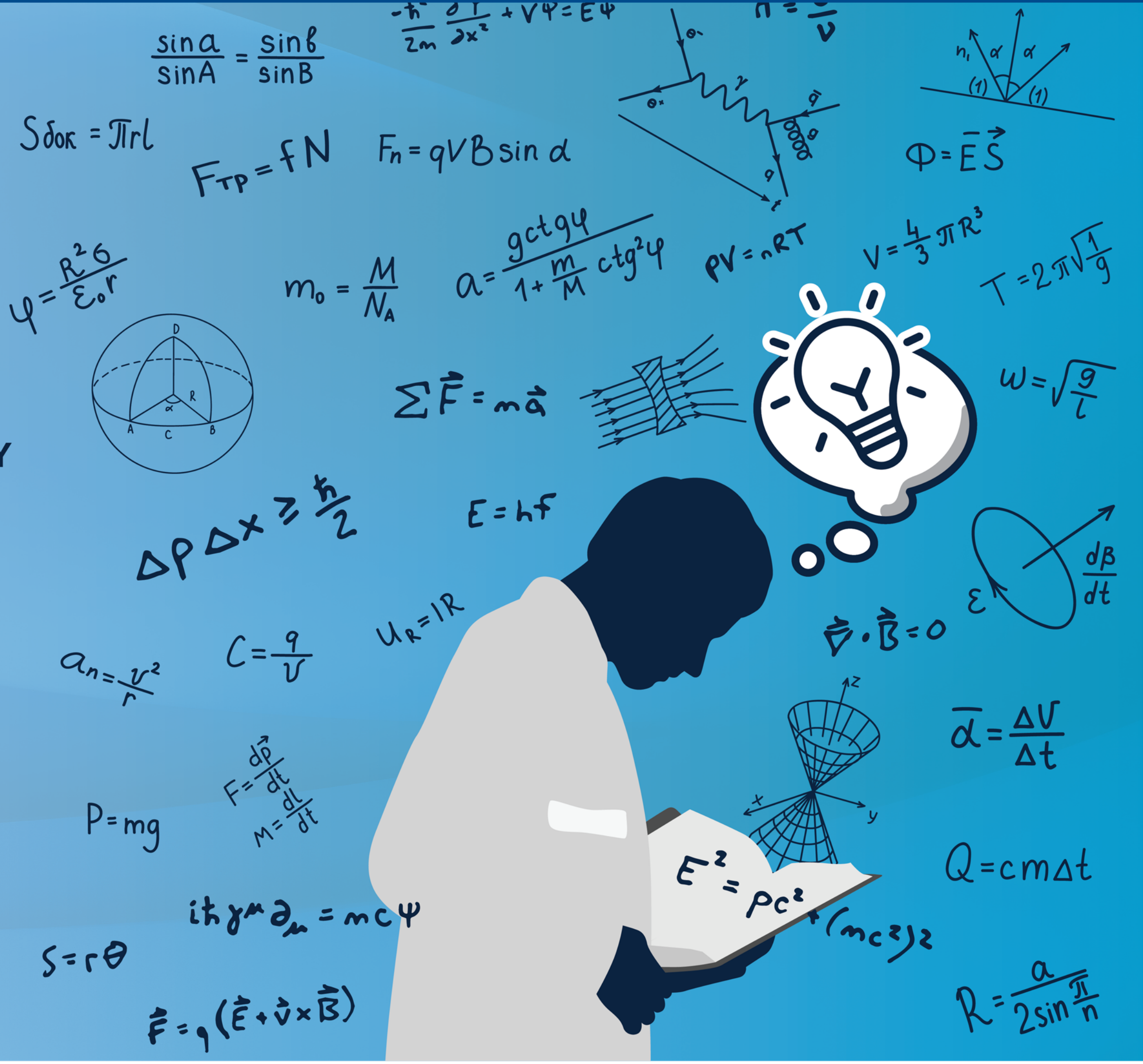
Sustained Long-Term Research and Development

- Continuous support of creative ideas
- Engage with academic community to shape focused efforts
- Continuously evolve and spawn new areas
- Partner for larger impact



OPPORTUNITIES AHEAD...

- ATOMIC PHYSICS, PHOTONICS, ENGINEERING
  - NEW QUANTUM RESOURCES: ENHANCED QUANTUM CONTROL
- COMPUTER SCIENCE, INFORMATION SCIENCE, MATHEMATICS
  - QUANTUM PROGRAMMING: LANGUAGES AND ALGORITHMS
- QUANTUM “CHECK” – E.G., CERTIFICATION OF QUANTUM INFORMATION PROCESSING DEVICES AND SYSTEMS; ESTABLISH RELIABILITY OF QUANTUM SYSTEMS; BRIDGE GAP BETWEEN THEORY AND EXPERIMENT
- MATERIALS SCIENCE, PHOTONICS, ENGINEERING
  - QUANTUM MATERIALS: "SMART" DESIGN FROM FIRST PRINCIPLES
  - QUANTUM COMPONENTS: DEVICES FOR QUANTUM S&T SUCH AS REPEATERS, MEMORIES, TRANSDUCERS, AND INTEGRATED PHOTONICS
- CONDENSED MATTER PHYSICS, CHEMISTRY, BIOLOGY, ECONOMICS, FINANCE, ETC.
  - APPLICATIONS OF QIS



WHAT WILL BE REQUIRED?

STEADY CLIMB WITH **SUSTAINED, LONG-TERM R&D**

Innovation

— There's not always a classical analogy —

ENABLING COMPONENTS

LASERS | ELECTRONICS | CONTROL SYSTEMS

HOLISTIC APPROACH

Partnerships

GOVERNMENT | ACADEMIA
INDUSTRY – NATIONALLY & INTERNATIONALLY

WORKFORCE

Beyond "STEM pipeline" model

Applications

Cast a wide net & find a common language

FY24 AFRL Basic Research National Science Portal (NSP)

- The Department of the Air Force (DAF) faces unprecedented scientific and technological challenges that require better leveraging of the nation's defense ecosystem to develop innovative solutions. The National Science Portal provides the strategic opportunity to:
  1. Accelerate science and engineering areas critical to the future DAF.
  2. Build defense research capacity in Historically Black Colleges and Universities (HBCU) and Minority Serving Institutions (MSI).
- This funding opportunity announcement (FOA) aims to diversify the research landscape and support scientific breakthroughs that enhance the technological supremacy of the Air Force and Space Force.
- FOA posted on Grants.gov (FOAAFRLAFOSR20240008 or search "National Science Portal")
  - **Proposals due – 26 July**, Notifications of award – 3 September

Technical Topic 1: Leveraging Quantum Computing to Explore Computational Challenges

AFOSR Program Officers

Dr. Gregg Abate, Unsteady Aerodynamics and Turbulent Flows
Dr. Fariba Fahroo, Computational Mathematics
Dr. Bennett Ibey, Natural Materials and Systems
Dr. Arje Nachman, Electromagnetics
Dr. Andrew Stickrath, Ultrashort Pulse Laser-Matter Interactions
Dr. Jennifer Talley, Space Biosciences
support: Dr. Grace Metcalfe, Quantum Information Science

NSP Topic: Leveraging Quantum Computing to Explore Computational Challenges

Objective: This topic seeks to explore the viability of novel quantum algorithms relevant for the DoD and DAF and build QIS research capabilities in technical disciplines outside the usual framework of QIS. Technical sub-areas of interest include

Drs. Gregg Abate & Fariba Fahroo →

(a) plasma and turbulent flow problems, wall-bounded turbulent flows, fluid-structure interaction, and/or turbulent combustion;

Dr. Bennett Ibey →

(b) biomolecular-based material design (e.g., protein, DNA, and RNA);

Drs. Arje Nachman & Andrew Stickrath →

(c) innovative computational approaches to improving upon or bypassing Density Functional Theory (DFT) (e.g., determination of accurate exchange-correlation functionals from electron density for input into DFT calculations, non-adiabatic quantum mechanics, etc.);

(d) biochemical processes design (e.g., catalyst efficiency or selectivity);

(e) and novel neural network representations (e.g., non-binary output units).

Dr. Jennifer Talley →

posers do not have to address multiple topic sub-areas within a submission.

NSP Topic: Leveraging Quantum Computing to Explore Computational Challenges

Research Concentration Areas: Suggested research areas include, but are not limited to:

1. Appropriate translation of classical computational challenges into algorithms that can be processed by quantum computers with a computational speedup. Both purely quantum and hybrid quantum-classical algorithms are of interest.
2. Assessment of the trade-off between the computational cost and the speed and accuracy of the quantum or hybrid algorithm relative to state-of-the art classical computational approaches
3. No-go theorems or proofs of computational gains of quantum computers for the proposed computational challenge.

- Projects should be supported by but not led by QIS experts.
- While proposed efforts can include employing quantum cloud computers, proposed budgets should not include access to quantum cloud computing costs. Purely theoretical proposals are acceptable.

▶▶▶ CONNECT WITH AFOSR

SCAN THE QR CODE FOR LINKS TO OUR SOCIALS, WEBSITE, AND GRANT OPPORTUNITIES!

CONNECT WITH AFRL: **AFResearchLab**

CAREERS

AFRL .af.mil

GRANTS

Questions?

Back-Up Slides

Strategic Partnerships are Vital to Basic Research Success

It is the teaming of diverse areas of science that enables the next generation of technology advancements.

Department of Defense

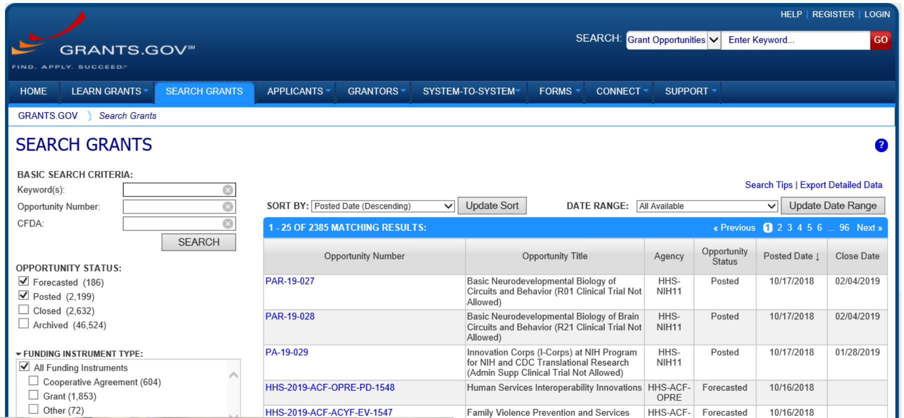
Academia

Other Gov't Offices

How to Work with Us

Review Broad Agency Announcements

- Researchers should visit www.grants.gov – the official source for finding and applying to Federal grants
- Find opportunities that match interests. Search by:
    - Keyword
    - Eligibility
    - Category
    - Agency etc.
- Study and keep current with BAAs
- Attend program reviews to understand the directions and needs of program

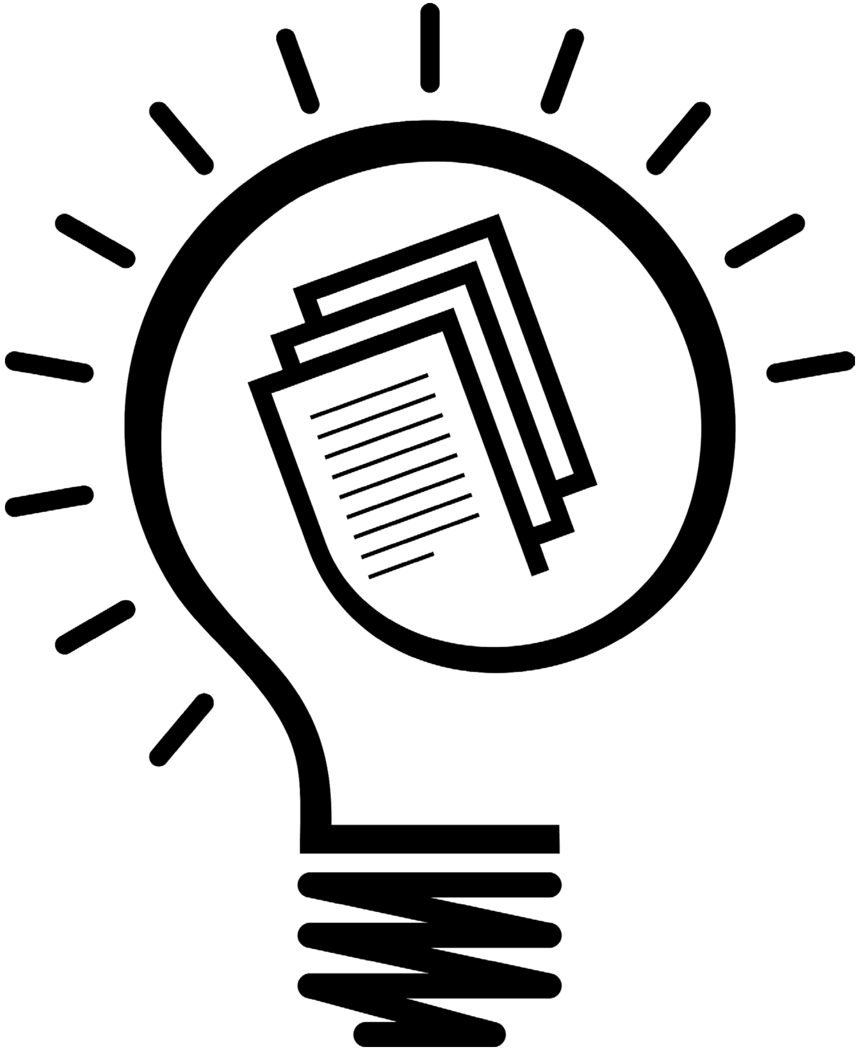


Distribution A. Approved for public release: distribution unlimited (AFRLAFRL-2024-3261 17 June 2024.

How to Work with Us
Scope and Draft Idea Statement

- Statement doesn't have to be all-inclusive, but should address the unique value proposition of the research

- Statement needs to be specific enough that it catches the interest of the Program Officer



How to Work with Us
Connect with a Program Officer

- At this point, some Program Officers will want a specifically formatted white paper

- Others will want to have a conversation
    - In person
    - Over the phone
    - Via email

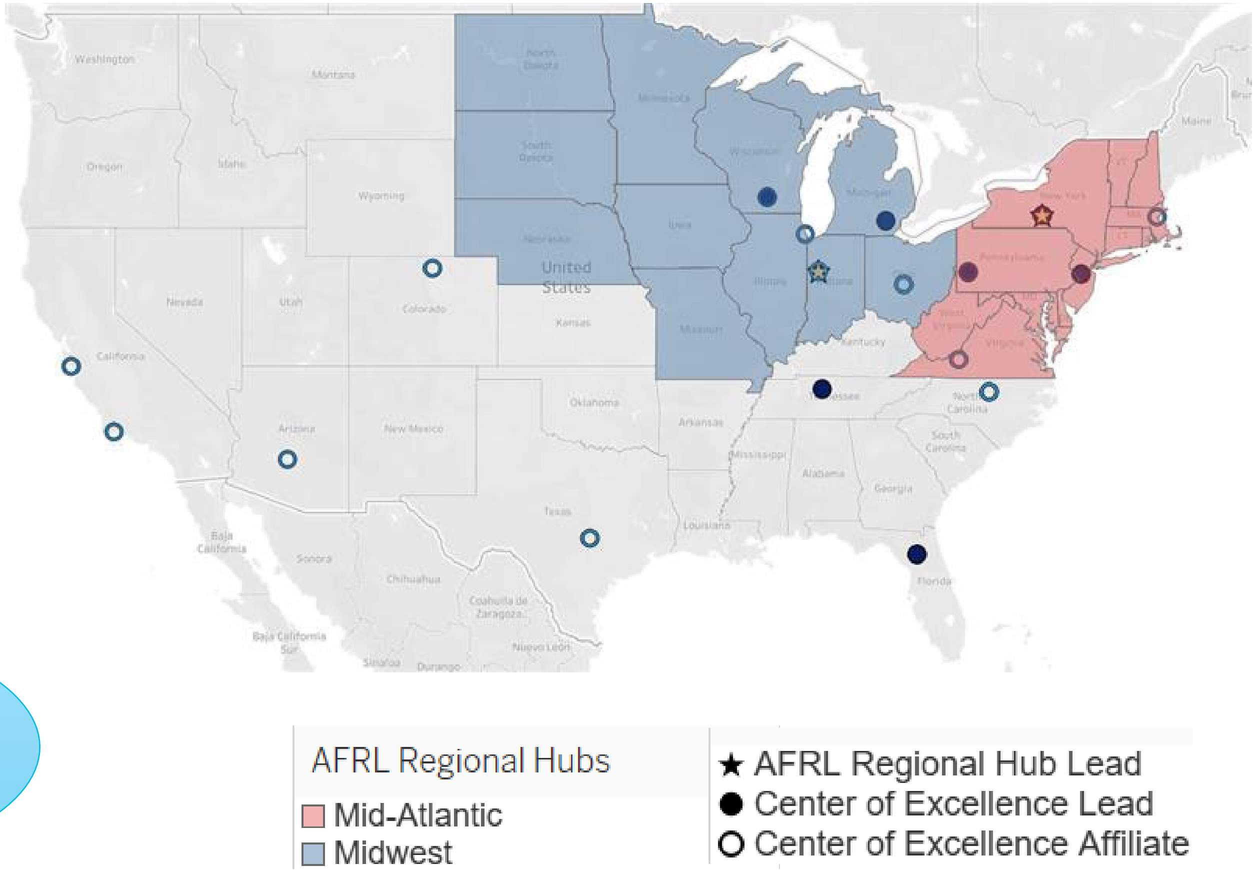
- If the idea seems promising, a Program Officer will initiate an ongoing dialogue setting expectations and explaining the process for full proposal submission.

How to Work with Us
Determine the Correct Funding Mechanism

- There are many different mechanisms for universities to obtain basic research grant funding:
  - Traditional grants
  - University Research Initiatives (i.e. Multidisciplinary University Research Initiative (MURI), Defense University Research Instrumentation Program (DURIP)
  - Special Programs (i.e. HBCU/MSI, Young Investigator Program (YIP), Presidential Early Career Awards for Scientists and Engineers (PECASE))
- Traditional grants can be awarded year-round from the general Broad Agency Announcement
- Other opportunities have specific deadlines

AFRL Partnership Opportunities

- Centers of Excellence (CoEs)
- AFRL Regional Hubs
- Educational Partnership Agreements (EPAs)
- Cooperative Research and Development Agreements (CRADAs)
- Academic Partnership Engagement Experiment (APEX)



Competitive Proposal Development!

APEX focuses specifically on growing the Department of the Air Force's technological defense capabilities in partnership with academia. This is the first of its kind in the country that is working across the country to connect small businesses and academia.

AFRL Internship/Fellowship Opportunities

- AFRL Summer Faculty Fellowship Program (SFFP)
- AFRL Science and Technology Fellowship Program (SFTP)
- AFRL Scholars Program
- SMART Scholarship-For-Service
- National Defense Science and Engineering Graduate Fellowship Program (NDSEG)
- AFRL/NSF Designing Materials to Revolutionize and Engineer our Future (DMREF)
- AFRL Minority Leaders-Research Collaboration Program (ML-RCP)

"Being able to network with students and other employees at AFRL was a great experience."

\- Nolan Herbort
University of Texas El Paso
(ML-RCP 2022 Summer Intern)

Major General Heather Pringle (former AFRL Commander) and AFRL leadership attended the ML-RCP Summer Interns' Poster Session in August 2022.

Q4I

6TH ANNUAL

QUANTUM FOR INTERNATIONAL

WORKSHOP

25-27 JUNE 2024

ROME, NEW YORK

INNOVARE ADVANCEMENT CENTER

AFRL

GRIFFISS INSTITUTE