NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
U.S. DEPARTMENT OF COMMERCE

MID-ATLANTIC QUANTUM ALLIANCE

Future Technology Capability Needs:

C5ISR, Microelectronics, and Quantum Science

Albert Davydov

Material Science and Engineering Division, NIST

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MARYLAND DEFENSE FORUM

June 5-6, 2023

OVERVIEW

MID-ATLANTIC QUANTUM ALLIANCE

NIST

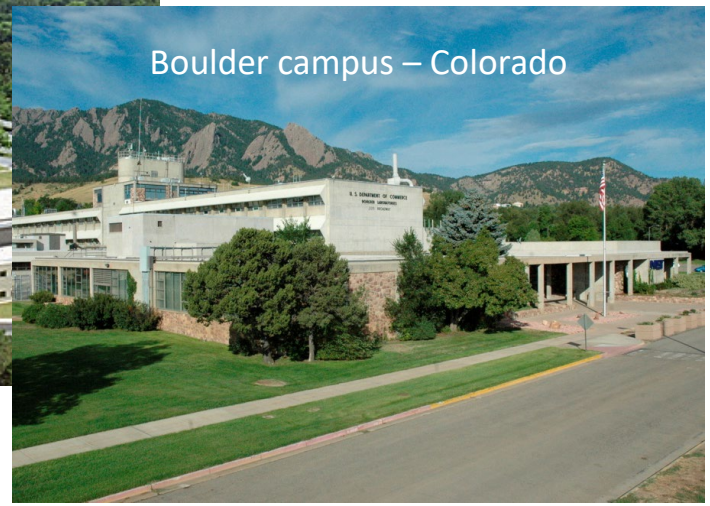
- NIST Overview
  - CHIPS and Science Act
    - Focus on Metrology Program
  - Quantum Information Science & Technology (part of NQI)
    - Network Grand Challenge
- Mid-Atlantic Quantum Alliance (MQA)
  - Reginal Hub to Accelerate Q-Technology Innovation & grow workforce

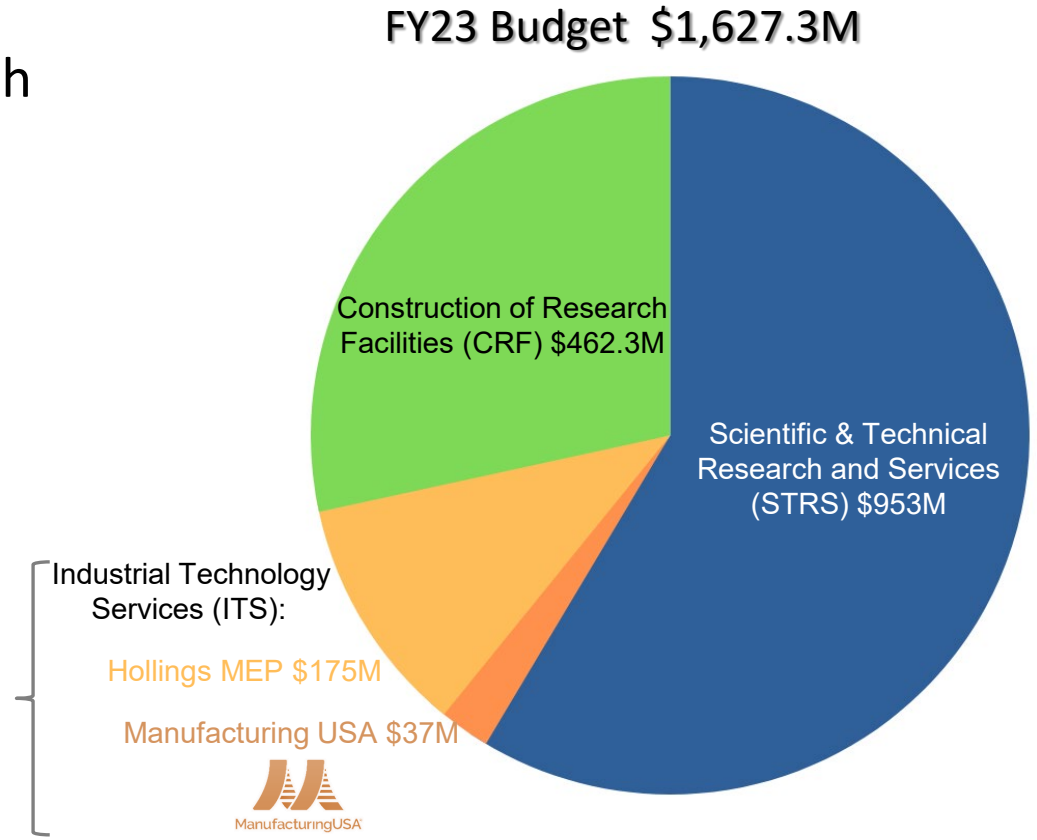
National Institute of Standards and Technology

- National Measurement Laboratory: Oldest Physical Science Lab in US (1901)

NIST Mission: To promote U.S. innovation and industrial competitiveness by advancing *measurement science, standards, and technology* in ways that enhance economic security and improve our quality of life

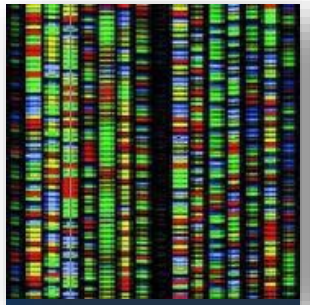
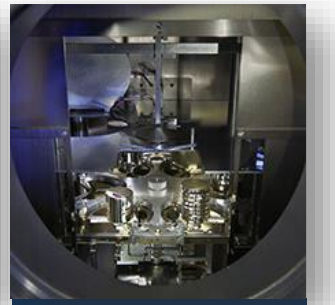
- World class facilities, national networks, international reach
- 3,400+ employees and as many associates





NIST Laboratory Programs

https://www.nist.gov/labs-major-programs



Material Measurement Laboratory	Physical Measurement Laboratory	Engineering Laboratory	Information Technology Laboratory	Communication Technology Laboratory	NIST Center for Neutron Research
Metrology Laboratories		**Technology Laboratories**			**User Facility**
Driving innovation through measurement science		Accelerating the adoption and deployment of advanced technology solutions			Providing world class, unique facilities

Unique NIST Products and Services

Million Pound-Force Deadweight Machine for calibrating force sensors

1,200 Standard Reference Material (SRM) products

100 Standard Reference Data (SRD) products

600 measurement services

Every year:

32,000 SRM units sold

13,000 calibrations and tests

800 accreditations of testing and calibrations laboratories

Calibrated Equipment is Essential

Boeing force measurements are traceable to the SI

Photo Courtesy of Boeing

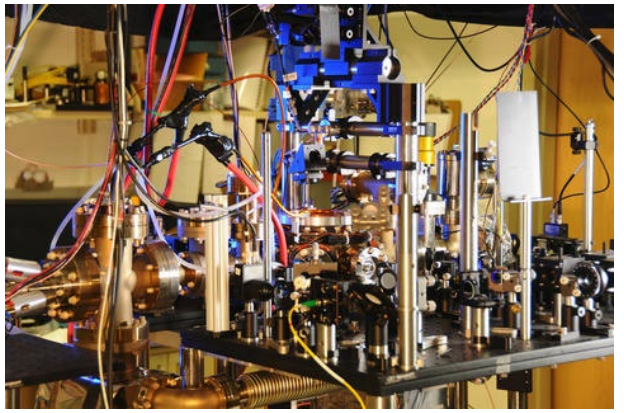
Clocks and Other Metrology Applications

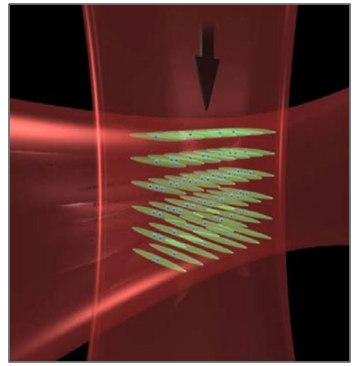
- CSAC : Chip Scale Atomic Clock

Chip-scale atomic clock

Commercialized by Symmetricom – Now MicroSemi

Cesium or Ytterbium optical lattice clock



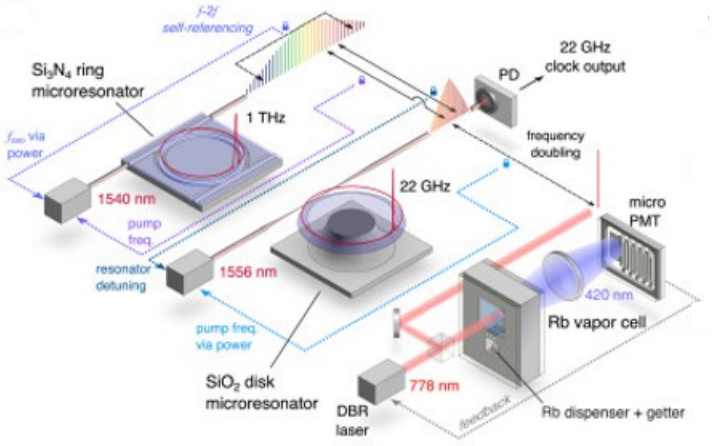


- A compact highly stable and accurate clock could enable navigation and a backup for GPS
- As clocks approach accuracy of 10^{-19}, they become environmental sensors: electric and magnetic field, gravity

DARPA Atomic Clock with Enhanced Stability (ACES):

"Develop battery-powered tactical atomic clock for PNT with laboratory-grade performance"

- **Impact:** Provide precise timing in GPS-denied environments to enable:
  - Advanced secure GPS receivers
  - Secure communications
  - Intelligence, surveillance, and reconnaissance and geo-location
  - Distributed engagement



Extramural Activities: Manufacturing USA Institutes

Manufacturing USA Semiconductor Institute(s)

CHIPS for AMERICA

Digital Manufacturing & Cybersecurity
Chicago, IL

Bio-industrial Manufacturing and Design Ecosystem
St. Paul, MN

Sustainable Manufacturing
Rochester, NY

Integrated Photonics
Albany, NY
Rochester, NY

Regenerative Manufacturing
Manchester, NH

Advanced Fibers and Textiles
Cambridge, MA

Advanced materials

Flexible Hybrid Electronics
San Jose, CA

Modular Chemical Process Intensification
New York, NY

Clean Energy Smart Manufacturing
Los Angeles, CA

Bio-pharmaceutical Manufacturing
Newark, DE

ManufacturingUSA®

Lightweight Metals
Detroit, MI

Cybersecurity
San Antonio, TX

Additive Manufacturing
Youngstown, OH
El Paso, TX

Advanced Composites
Knoxville, TN
Detroit MI

Advanced Robotics
Pittsburgh, PA

Wide Bandgap Semiconductors
Raleigh, NC

CHIPS Act at a Glance

CHIPS for America Incentives: $54.2B over 5 years

DOC R&D Office: funding, oversight, interagency coordination, collaboration

$39 billion for manufacturing

Two component programs:

1. Attract large-scale investments in advanced technologies such as leading-edge logic and memory
2. Incentivize expansion of manufacturing capacity for mature and other types of semiconductors

$11 billion for R&D

- National Semiconductor Technology Center
- National Advanced Packaging Manufacturing Program
- Manufacturing USA institute(s)
- National Institute of Standards and Technology measurement science

Workforce development

$54.2B over 5 years: together with CHIPS Initiatives from other agencies, including DOD, State, NSF and Treasury

NSTC: Public-private partnership to conduct advanced semiconductor manufacturing R&D and prototyping; invest in new technologies; expand workforce training and development opportunities

A VISION AND STRATEGY FOR THE NATIONAL SEMICONDUCTOR TECHNOLOGY CENTER
CHIPS Research and Development Office
April 25, 2023

NAPM: Federal R&D program to strengthen advanced assembly, test, and packaging (ATP) capabilities (in coordination with the NSTC)

Manufacturing USA Semiconductor Institute(s): partnership between government, industry, and academia to research *virtualization of semi-conductor machinery*; develop ATP capabilities; design and disseminate training

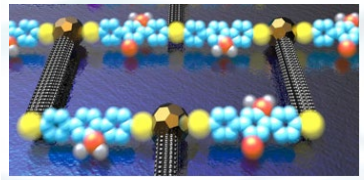
Manufacturing USA Semiconductor Institute(s)
Summary of Responses to Request for Information
June 1, 2023

Metrology R&D: NIST research program to advance measurement science, standards, material characterization, instrumentation, testing and manufacturing capabilities ($0.5B)

NIST Metrology R&D: Programmatic Focus Areas

❑ Advanced Modeling for Next-Generation Materials, Design, and Components:

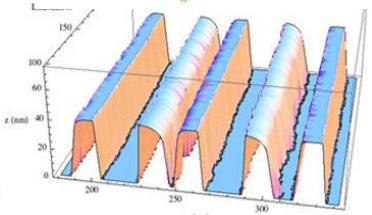
- Multi-physics models that capture thermal/chemical/physical/mechanical properties, reliability, power consumption, and other parameters.



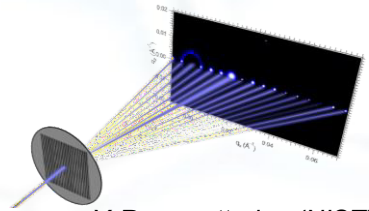
Molecular nanoelectronics

❑ Advanced Metrology for 3D Structures and Devices:

- Measurements for in-situ, rapid measurements for interfaces and sub-surface interconnects, and internal 3D structures including warpage, voids, substrate yield, stresses, adhesion, and reliability with improved throughput and resolution



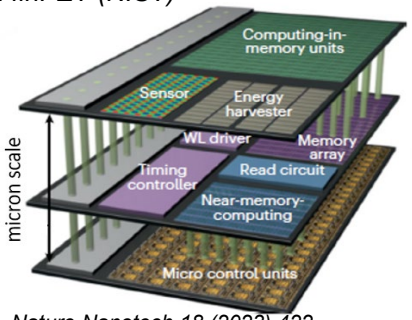
3D reconstruction of 10 nm finFET (NIST)



X-Ray scattering (NIST)

❑ Advanced Metrology for 3D Heterogeneous Integration:

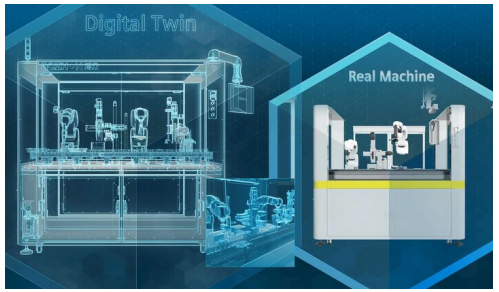
- Methods and measurements for integrating components (e.g., chiplets, system-on-chip, memory) into packages, including hybrid bonding and interfacial adhesion and bond integrity



Nature Nanotech 18 (2023) 422

❑ Advanced Modeling for Next-Generation Manufacturing Processes:

- Modeling, data analysis, and validation tools to enable efficient process development and optimization (semiconductor materials, circuits, components, and manufacturing)



❑ Advanced Measurement Services:

- SRMs, data, instruments, and calibration & measurement services; product development kits

Standards Development Organizations

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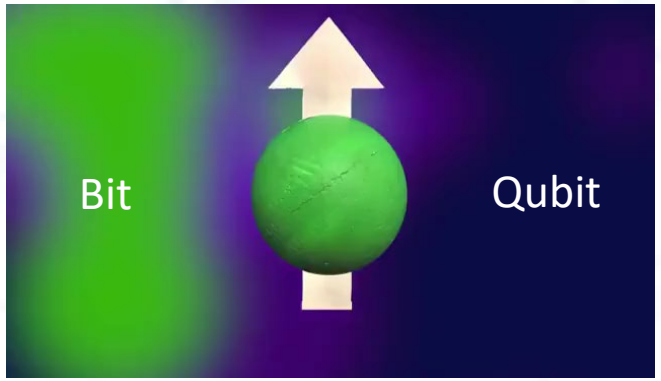
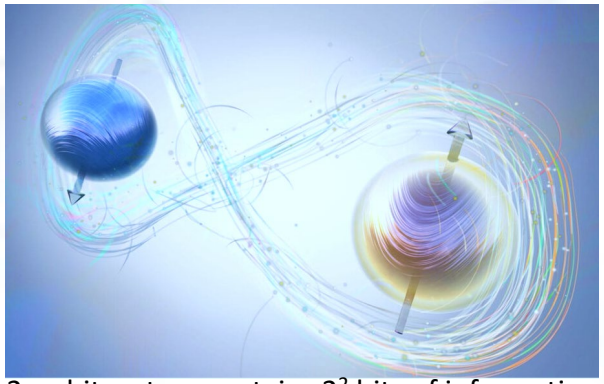
Quantum Phenomena & Quantum Revolution 2.0

Superposition

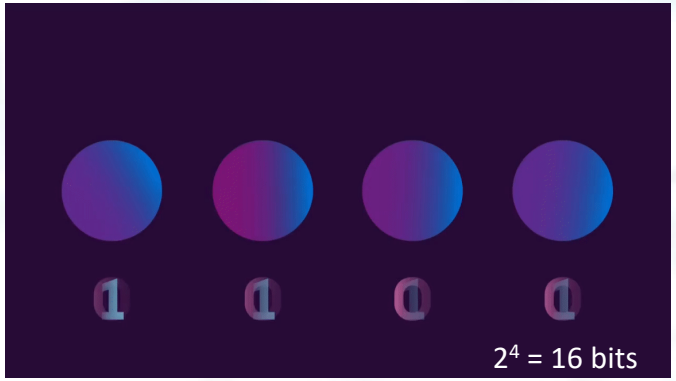


Entanglement



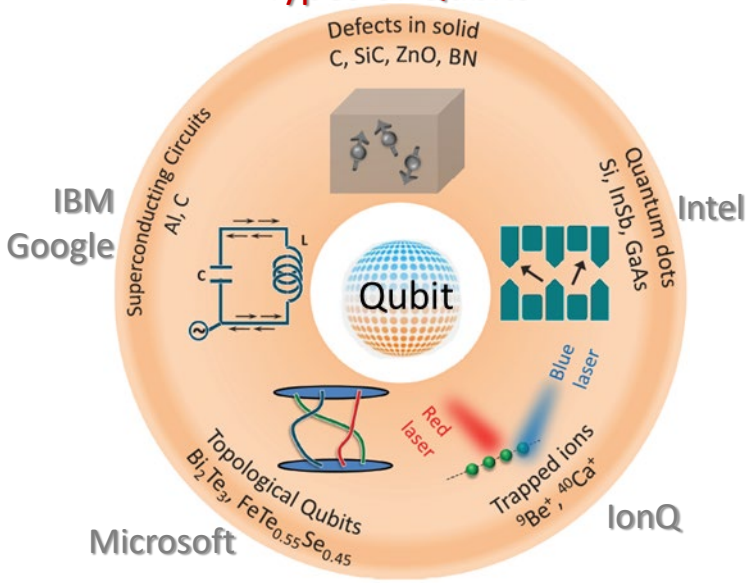
2-qubit system contains 2^2 bits of information

Entangled Qubits Operation



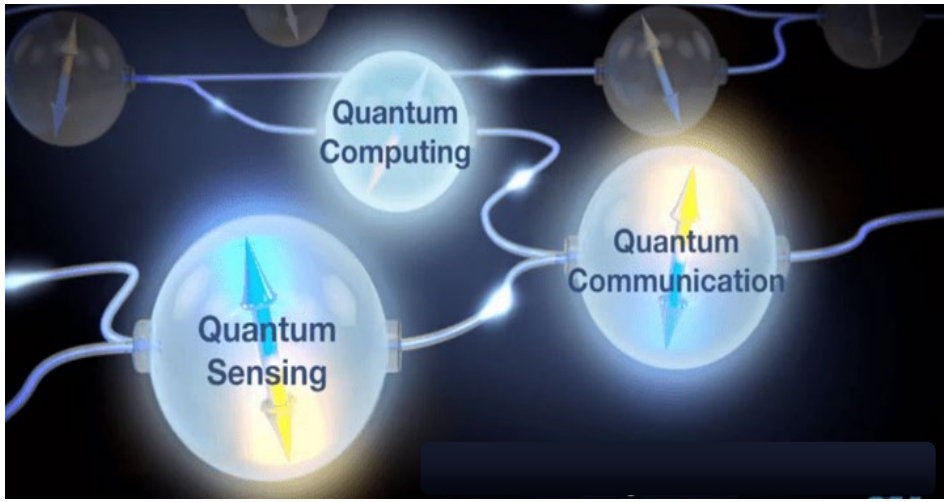
A quantum state of 300 qubits is described by 2^{300} complex numbers = $2 \cdot 10^{90}$ bits of classical information > # of particles in our Universe

Types of Qubits



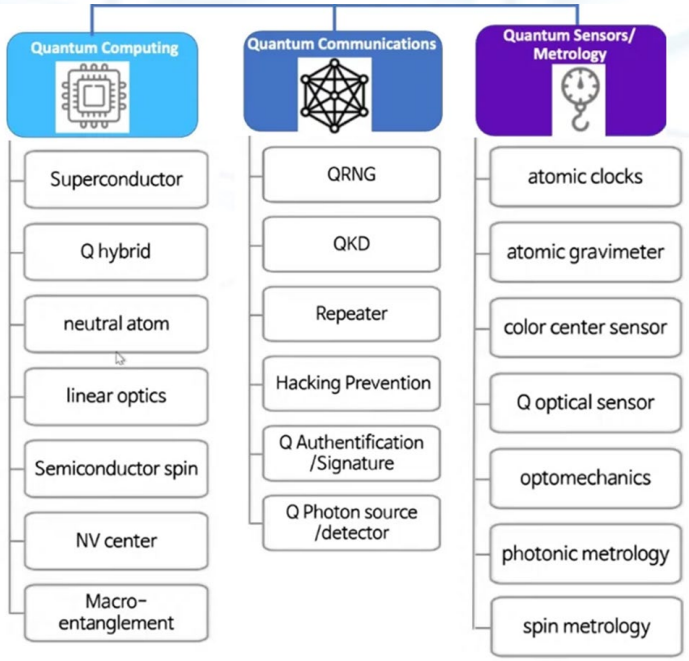
Superconducting Qubits Q-Computer

Quantum Technology Applications



Quantum Technology Applications

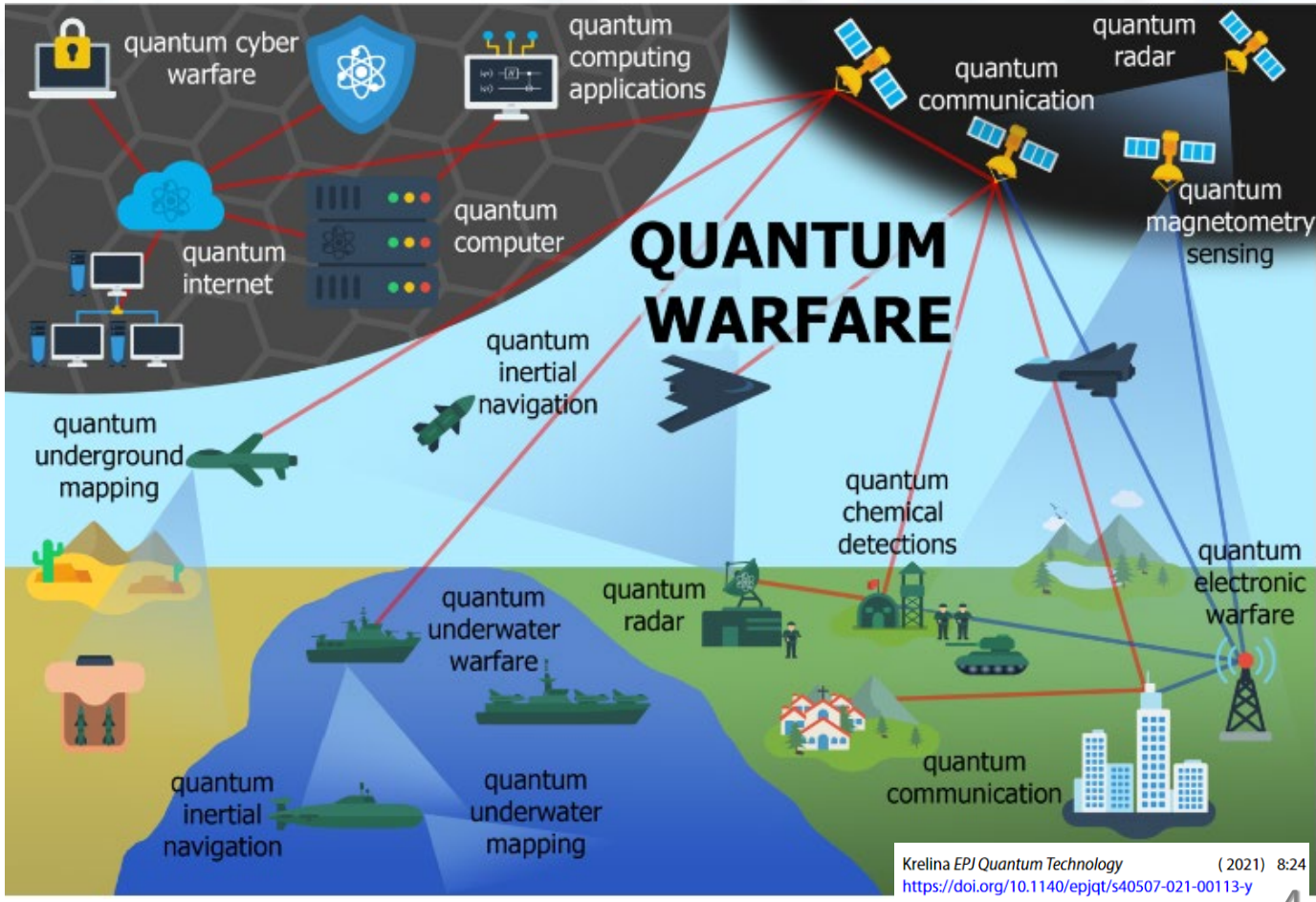
Quantum Technology Elements



EXAMPLE APPLICATIONS FOR QUANTUM TECHNOLOGY -- *Not Exhaustive* --

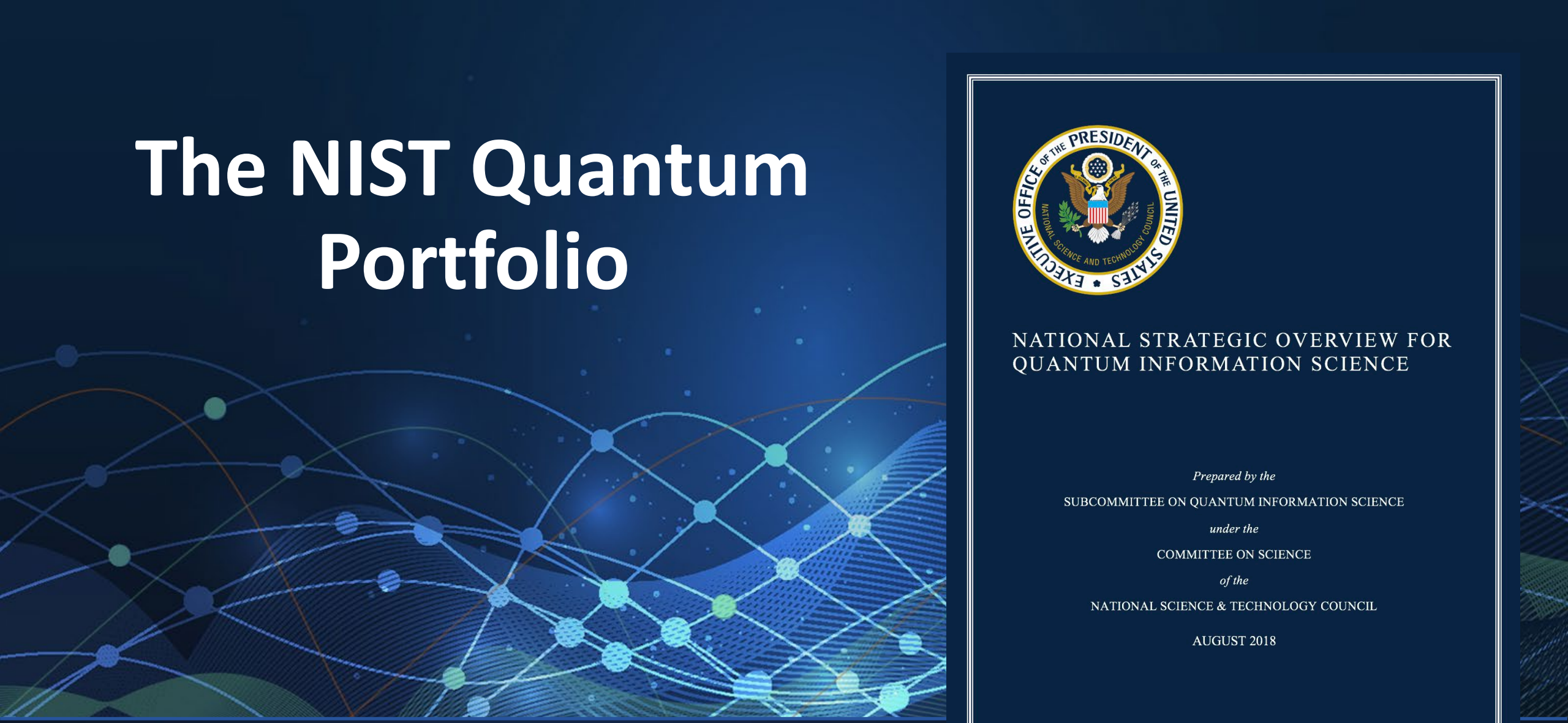
END MARKETS	Sensing/Metrology	Communication	Computing
Telecom	Clocks for synchronization	Cryptography	Network optimization
Medicine	Improved brain imaging	Protecting patient data long-term	Drug discovery
Oil & Gas	Through-ground imaging	Protecting critical infrastructure	Drilling location analysis; oil distribution logistics
Finance	Clocks for trade timestamping	Secure transactions	Portfolio management
Transportation	GPS-aided navigation; quantum LiDAR	Cryptography for connected vehicles	Battery material simulation; traffic optimization

Dual-Use Technology



Krelina *EPJ Quantum Technology* (2021) 8:24
https://doi.org/10.1140/epjqt/s40507-021-00113-y

The NIST Quantum Portfolio



NATIONAL STRATEGIC OVERVIEW FOR QUANTUM INFORMATION SCIENCE

Prepared by the

SUBCOMMITTEE ON QUANTUM INFORMATION SCIENCE

under the

COMMITTEE ON SCIENCE

of the

NATIONAL SCIENCE & TECHNOLOGY COUNCIL

AUGUST 2018

National Institute of Standards and Technology
U.S. Department of Commerce

NIST and the NQI (SEC. 201)

1 Basic and Applied QIST R&D

Continue and expand basic and applied **R&D**, including **measurement and standards** infrastructure necessary to advance commercial development of quantum applications

2 Workforce

Use the existing programs of the NIST, in collaboration with other Federal departments and agencies, as appropriate, *to **train scientists*** in quantum information science and technology (QIST)

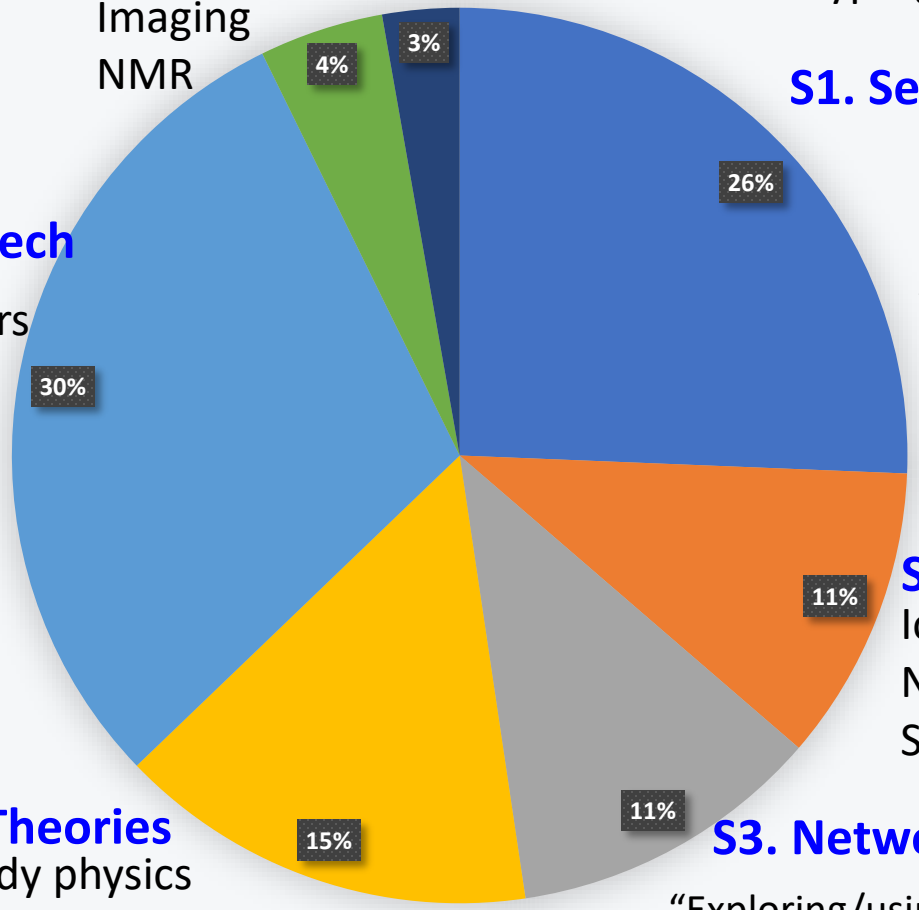
3 Collaborate and Work with Others

Establish or *expand* collaborative ventures or **consortia** with other public or private sector entities, including industry, universities, and Federal laboratories for the purpose of advancing the field of quantum information science and engineering;

4 From Contracts to OTA

Enter into such contracts, including cooperative research and development arrangements, grants and cooperative agreements, or *other transactions*, in furtherance of the purposes of this Act

NIST QIS allocations by National Strategic Program Area (FY21)



T3. Risk Mitigation (PQC)
Quantum resistant cryptography

T2. Applications
Imaging
NMR

S1. Sensing
NV centers
Rydberg systems
Atomic vapor cells
Clocks
NIST on a Chip

T1. Supporting Tech
Sources & detectors
Frequency combs
Microscopy
Spectroscopy

S2. Computing
Ion traps
Neuromorphic / quantum fusion
Simulation

S4. Devices/Theories
Many-body physics

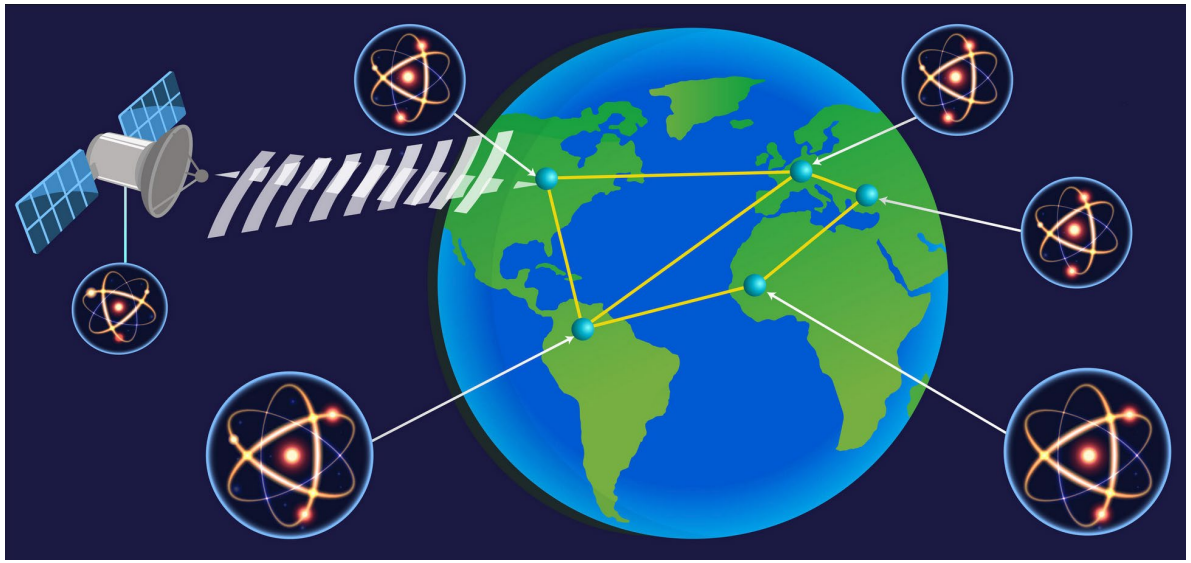
S3. Networking Quantum Network Grand Challenge

"Exploring/using coherent or entangled multi-party quantum states, distributed at distances, for new IT applications and fundamental science"

The Quantum Network Grand Challenge (QNGC)

Quantum networks will offer the ability to distribute/share quantum information securely among quantum computers, quantum sensors and related devices at regional and national distances

DC-Area U.S. Government Agencies Established the Washington Metropolitan Quantum Network Research Consortium, or **DC-Qnet** (June 2022)



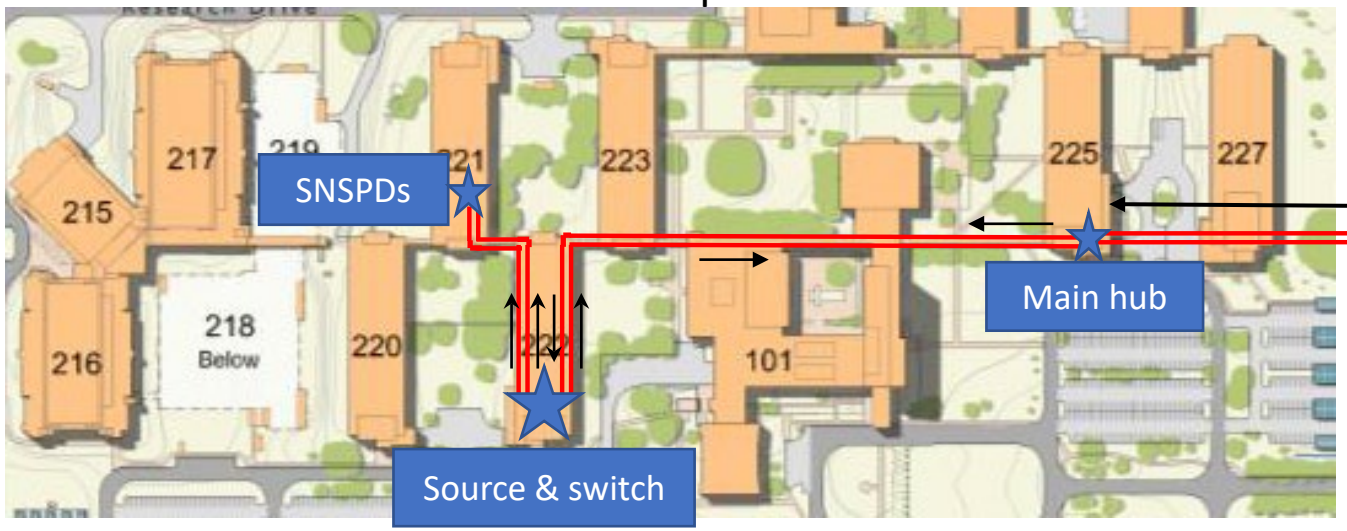
A superconducting qubit in North America; an atom in Africa – how to entangle?

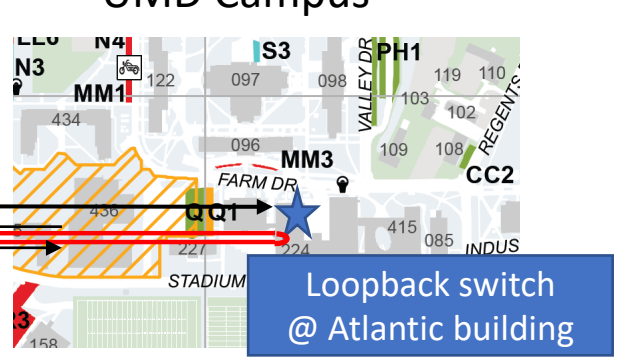
National Institute of Standards and Technology
U.S. Department of Commerce

What makes DC-QNet Consortium Unique in the USA?

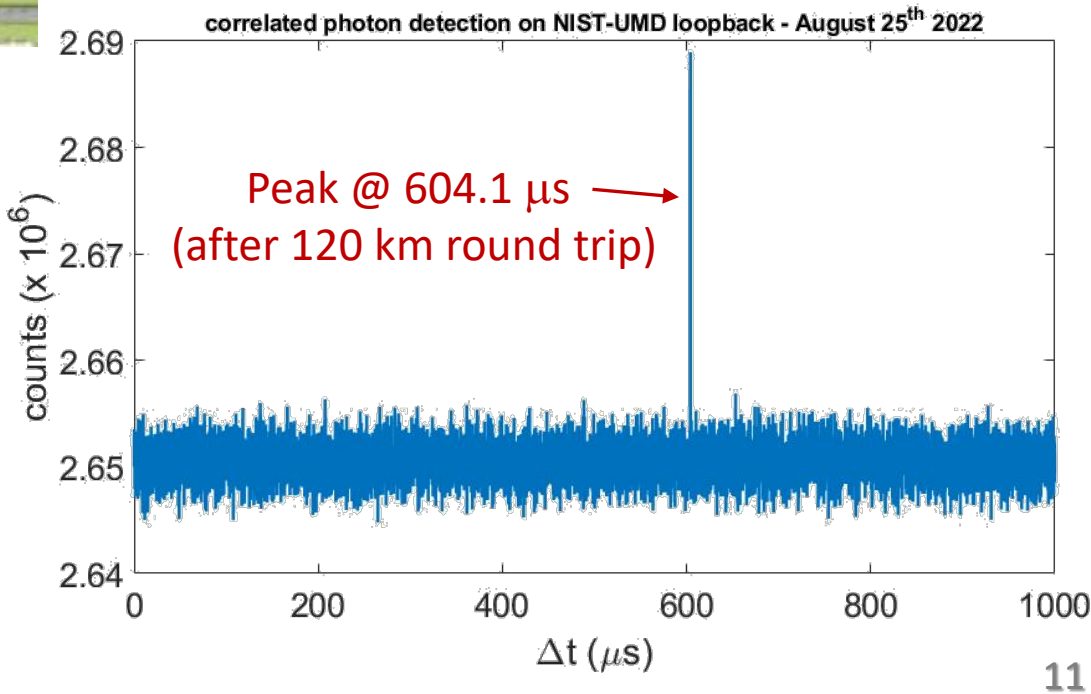
- By keeping only Federal employees in certain areas, we can pursue pre-decisional activities and CUI
- Being in DC makes it easy for policy makers/funding organizations to visit and see the technology as it gets created and applications get developed
- Having the best time-keeping expertise may be a prerequisite for quality quantum networking
- Providing a platform for the military to test its special quantum network requirements
- A focus on metrology in support of QN will be crucial

Correlated Photon Detection on NIST-UMD DC-QNet





- Photon pairs from an SPDC source were generated at NIST
- One photon was kept within NIST and sent from Bldg. 222 to Bldg. 221
- Its partner photon was sent to UMD and looped back to NIST for coincidence detection



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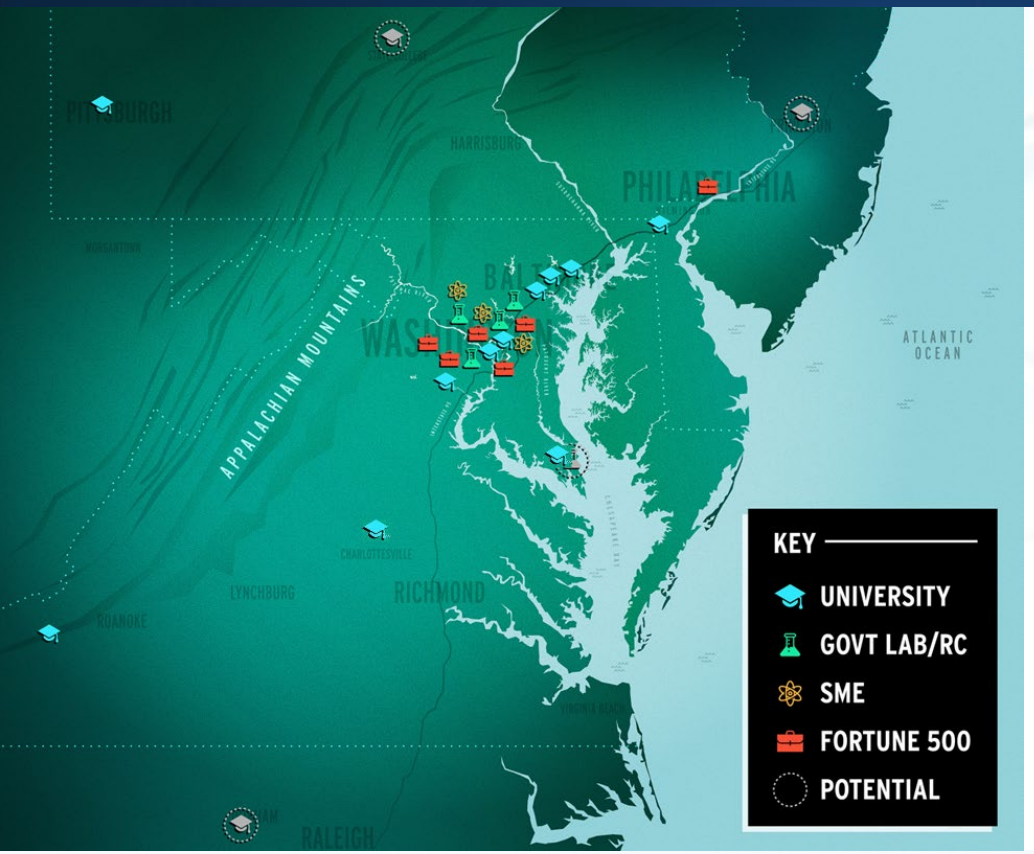
MID-ATLANTIC QUANTUM ALLIANCE

Volunteer-based organization to connect partners with quantum expertise and capabilities in the region to accelerate technology innovation and transition and to grow the workforce (established in 2020)

MQA: Forum of Quantum Organizations



200+ Volunteers in 16 Workgroups from 41 Current Members:

Amazon Web Services; Aspen Quantum Consulting; Booz Allen Hamilton; Bowie State University; CCDC Army Research Laboratory; George Mason University; Georgetown University; Harrisburg University; IonQ; IBM; Johns Hopkins University; Johns Hopkins University Applied Physics Laboratory; LeSchack Integrations; Lockheed Martin; The MITRE Corporation; Morgan State University; NASA Goddard Space Flight Facility; National Institute of Standards & Technology (NIST); Noblis; Northrop Grumman; Pittsburgh Quantum Institute; Potomac Quantum Innovation Center; Protiviti; Psirch; QI Solutions; Quantinuum; Quantum Optics – Jena; Quaxys; Qubit by Qubit; Qrypt; Riverlane, St. Mary's College of Maryland; The Coding School; United States Naval Academy; University of Delaware; University of Maryland, Baltimore County; University of Maryland, College Park; University of Virginia; Virginia Tech; Zebraket

Goal - engage in intra-regional dialog and collective action to:

Accelerate Quantum Innovation in the Region

- Promoting interdisciplinary, applied and translational research, commercialization efforts & impact outcomes
- Encouraging quantum RDT&E collaboration & networking
- Enabling dialog with potential end-users & customers
- Improving the visibility and accessibility of the region's world-leading quantum expertise and technology
- Identifying regional research infrastructure needs and opportunities

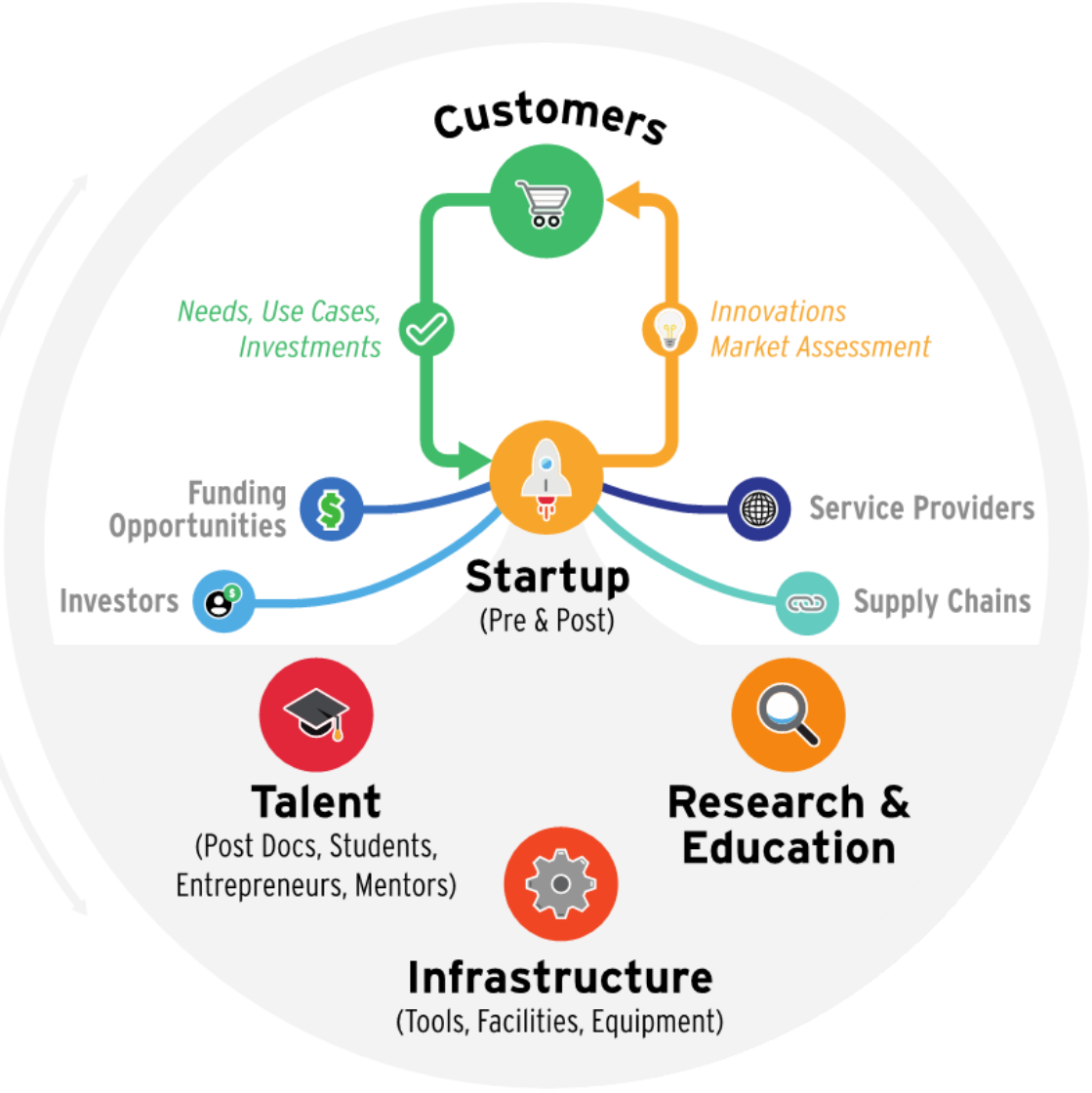
Build the Quantum Workforce

- Facilitating curriculum sharing & access to unique equipment, labs, and expertise
- Creating shared experiential learning programs
- Elevating diversity, equity & inclusion
- Connecting/amplifying public and K-12 education campaigns

Quantum Startup Foundry (established in 2021)

MID-ATLANTIC QUANTUM ALLIANCE

Ecosystem



Access to **customers** (*TraQtion Program*)

Assistance with SBIR/STTR (pre-*TraQtion Program*)

Connections to targeted investors and non-dilutive funding opportunities

Regulatory **guidance** (*export controls*)

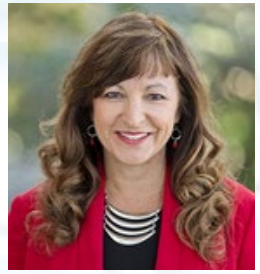
Access to **talent** & **IP**

Marketing opportunities through public educational campaigns

Office / Lab space (*MAX GigaPop internet*)

*A*ccess to **specialized quantum equipment & facilities**

International Soft Landing



Julie Lenzer
Chief Innovation Officer
jlenzer@umd.edu

New 350K sf development at the main entrance of campus to become the home of quantum

Quantum Ecosystem Vision

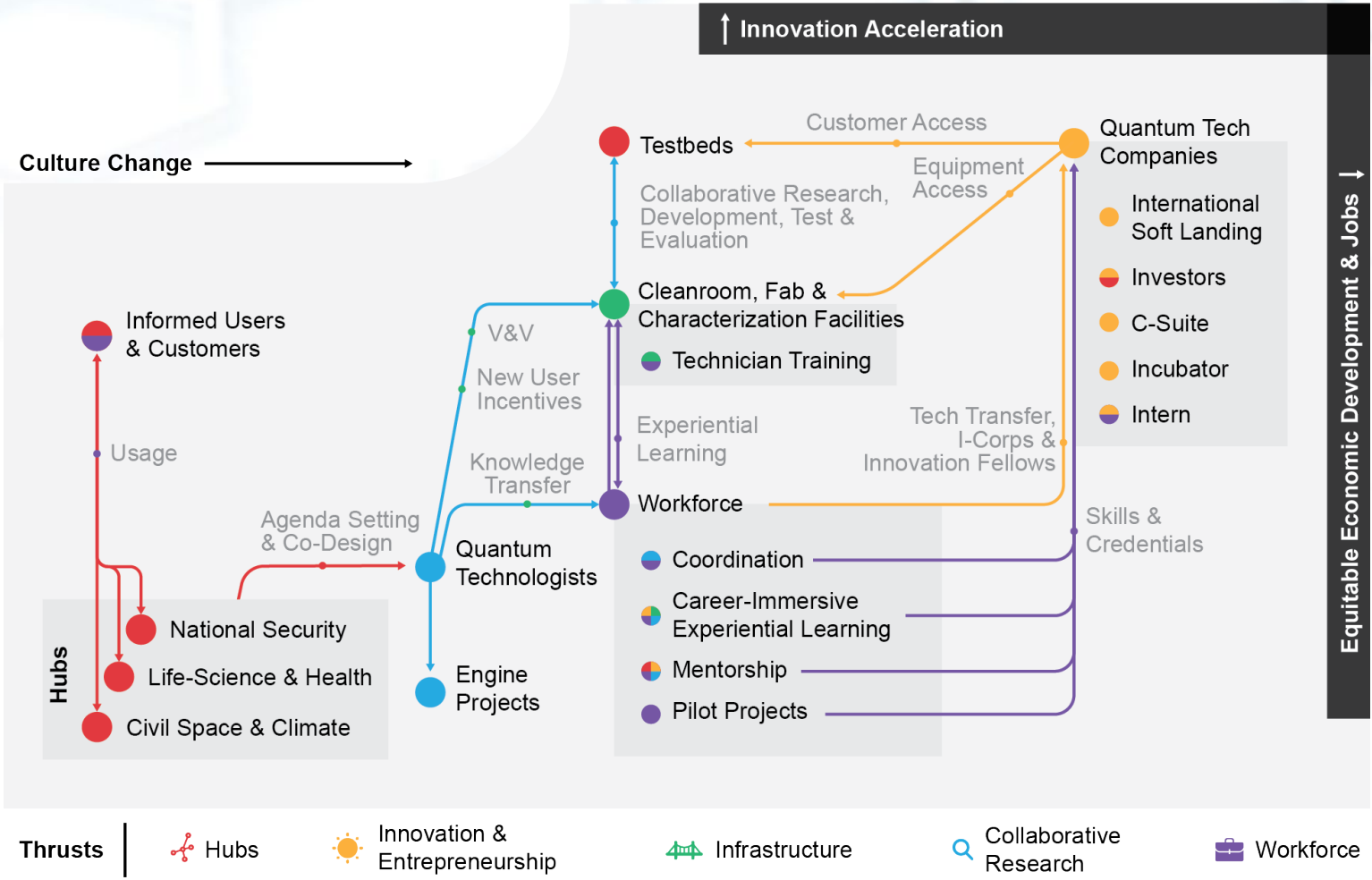
POTOMAC QUANTUM INNOVATION CENTER powered by CONNECTED DMV

MID-ATLANTIC QUANTUM ALLIANCE

Strategic blueprint for ***inclusive*** **economic, workforce and technology development** in Quantum Capital Region proposed to *NSF Engines Program ($160M/10 year) & will pursue through other channels if needed*

80+ Partners, e.g.

- Fed, State, Local Government
- Industry
- HBCUs/MSIs
- Community Colleges
- D&I and Accessibility Orgs
- Incubators & Innovation Enablers



Summary and Leadership Team

MID-ATLANTIC QUANTUM ALLIANCE

Invest in the Capital of Quantum

- Work with 400+ quantum experts
- Recruit quantum workforce from world-leading programs
- Access and/or co-invest in unique enabling infrastructure
- Leverage region's economic development incentives
- Co-locate with early-adopting customers

Steve Rolston
Founding Director & MQA Curriculum Workgroup Lead

John Sawyer
Executive Director & International Engagement Workgroup Co-Lead

Joan Hoffmann
MQA Diversity & Inclusion Team Co-Lead & Sensors Workgroup Lead

Leon Tune
MQA Strategic Communications Team Co-Lead

Charles Robinson
MQA Diversity & Inclusion Team Co-Lead & Crypto Workgroup Co-Lead

Denis Mandich
MQA Crypto Workgroup Lead

Patrick Vora
MQA Materials Workgroup Co-Lead

Albert Davydov
MQA Materials Workgroup Co-Lead

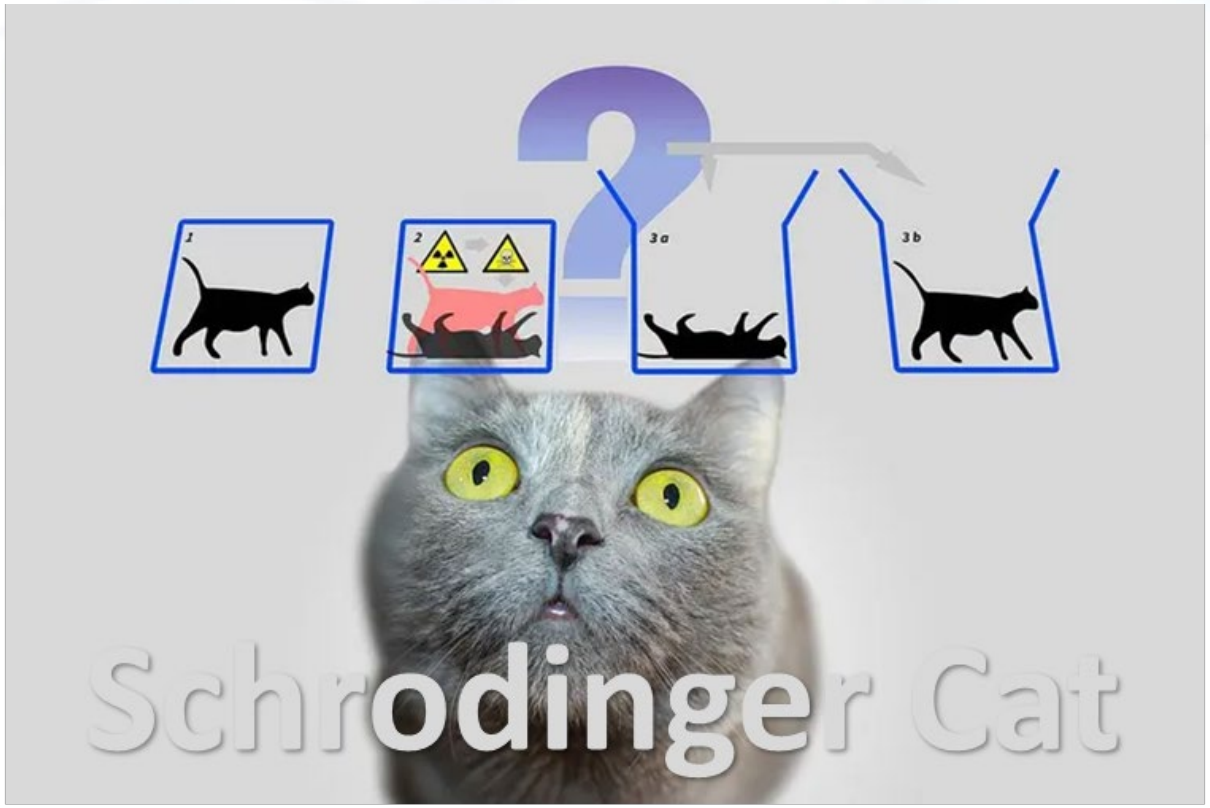
Brian Kirby
MQA Networking Workgroup Lead

Chris LeSchack
Co-Lead, International Engagement Task Force

Question? Contact MQA's Executive Director, John Sawyer (jsawyer2@umd.edu)

https://mqa.umd.edu/

Thank you for your attention!



Follow-up Questions? davydov.@nist.gov