Credit: G.E. Marti/JILA

The National Quantum Initiative

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

Joint Center for Quantum Information and Computer Science

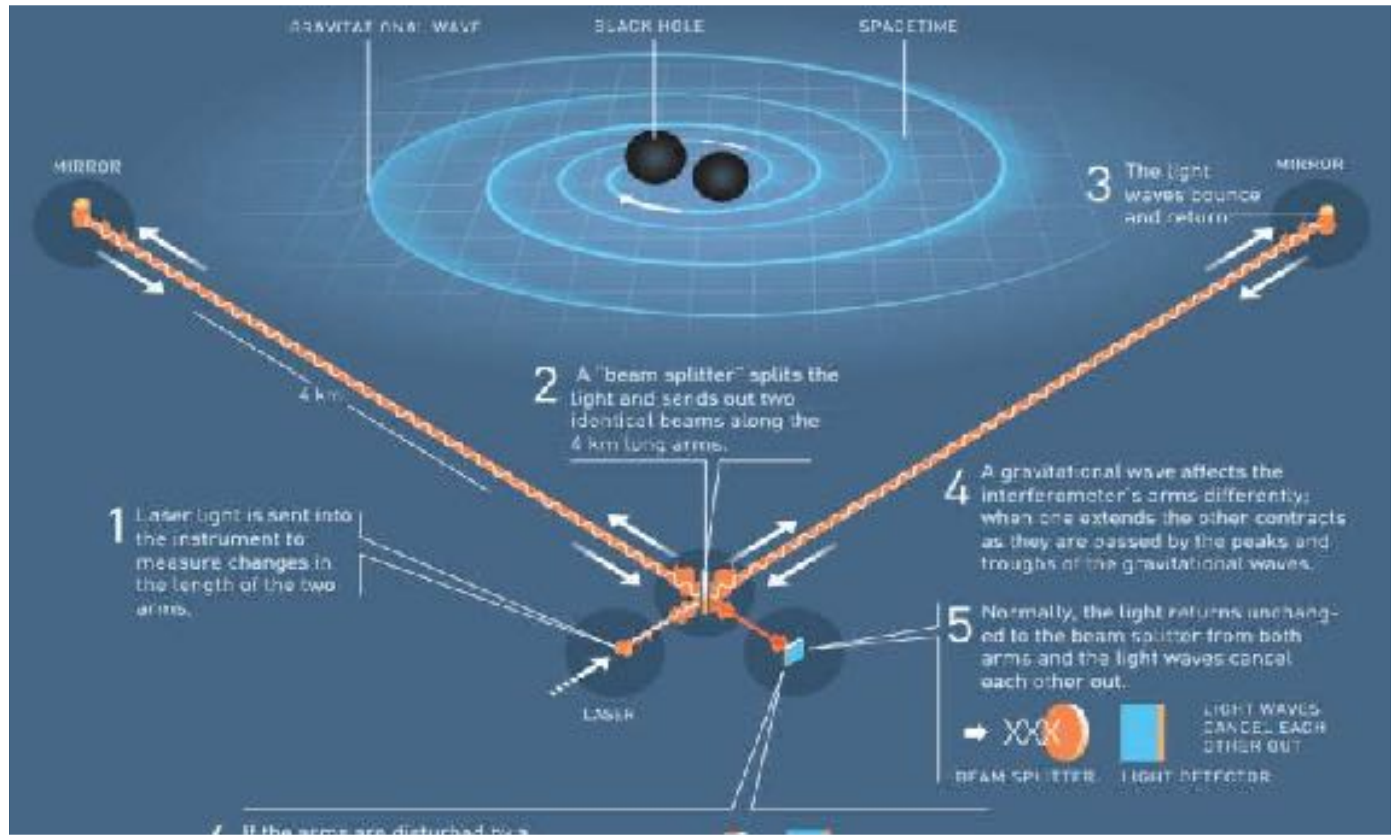
jqi

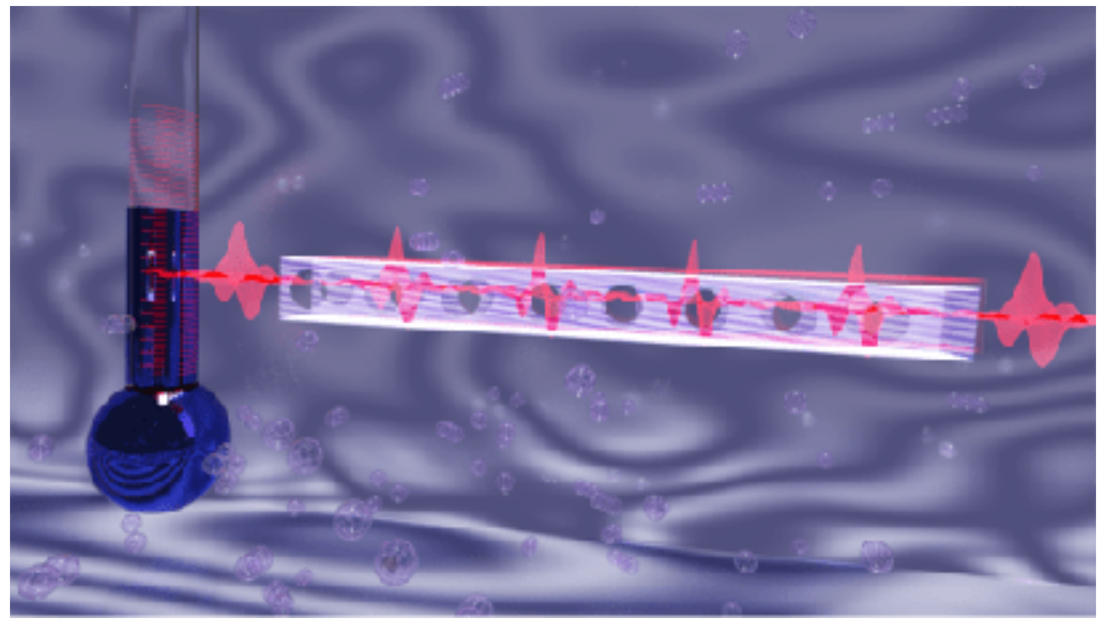
Quantum Sensing

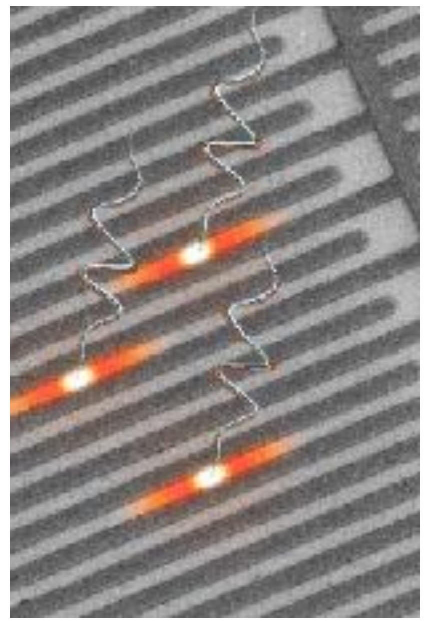
Accuracy via physical law
Concept: atoms are indistinguishable. Use this to create time standards, enables global navigation.

Concept: speed of light is constant. Use this to measure distance using a time standard.

Concept: electrons are quantized, have the same charge. Use this to calibrate electrical currents and voltages.







New worldwide approach: the Quantum SI, started May 2019

New modalities of measurement
Challenge: measuring inside the body. Use quantum behavior of individual nuclei to image magnetic resonances (MRI)

Challenge: estimating length limited by ‘shot noise’ (individual photons!). Use quantum correlations between photons to reduce this noise (LIGO v3)

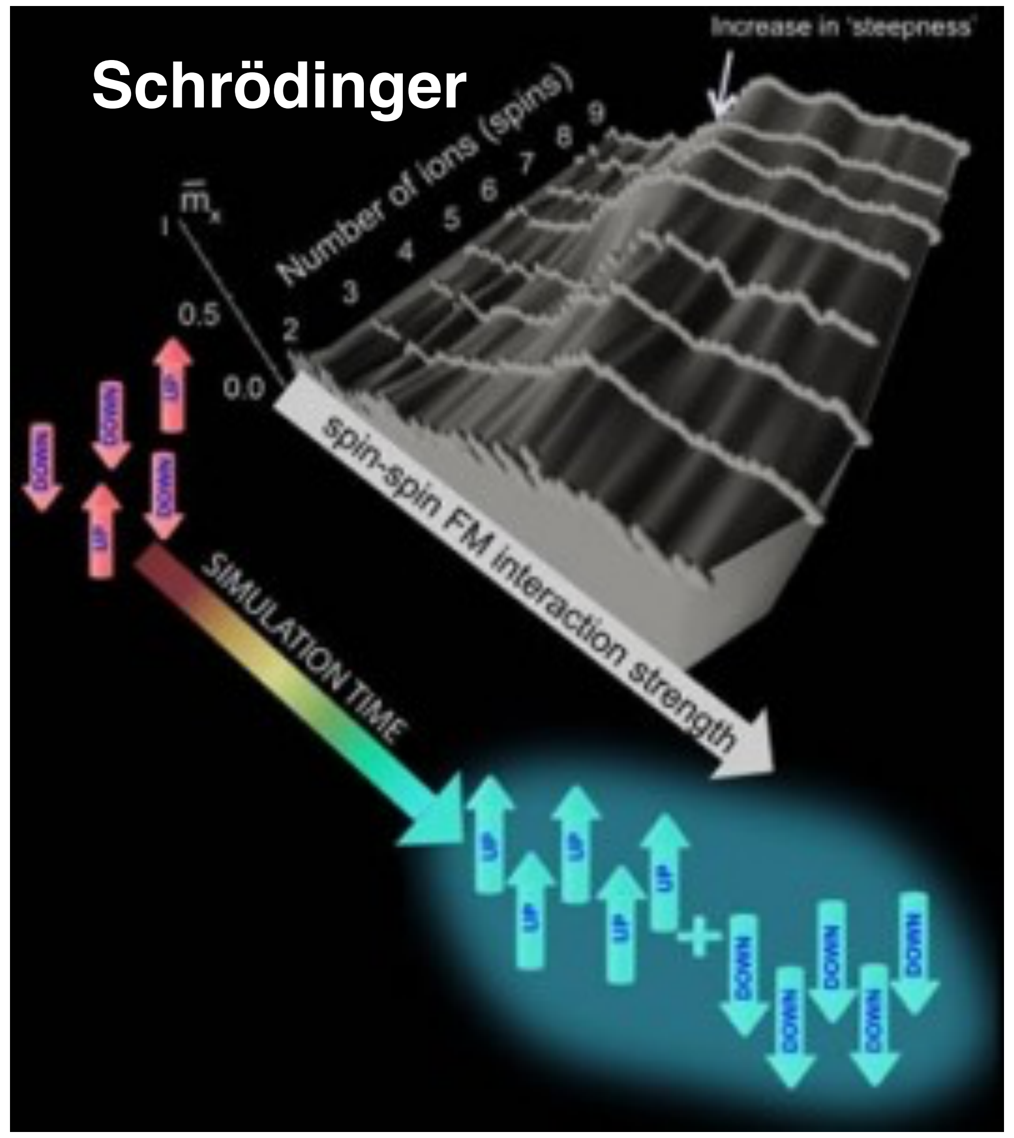
Challenge: measuring brain activity must be fast, sensitive. Use entanglement between magnetic sensors to increase bandwidth

Quantum Computing

Quantum simulation
Chemistry, biology, materials science all depend on solving quantum mechanics problems

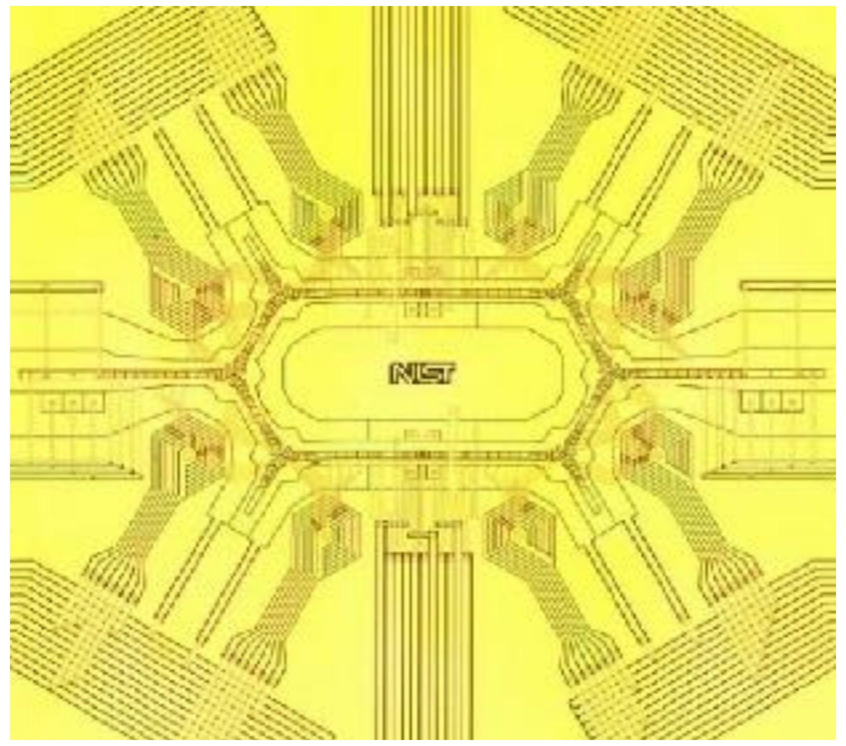
Recall: Simulating quantum mechanics is hard…

Solution: Use one system to simulate another

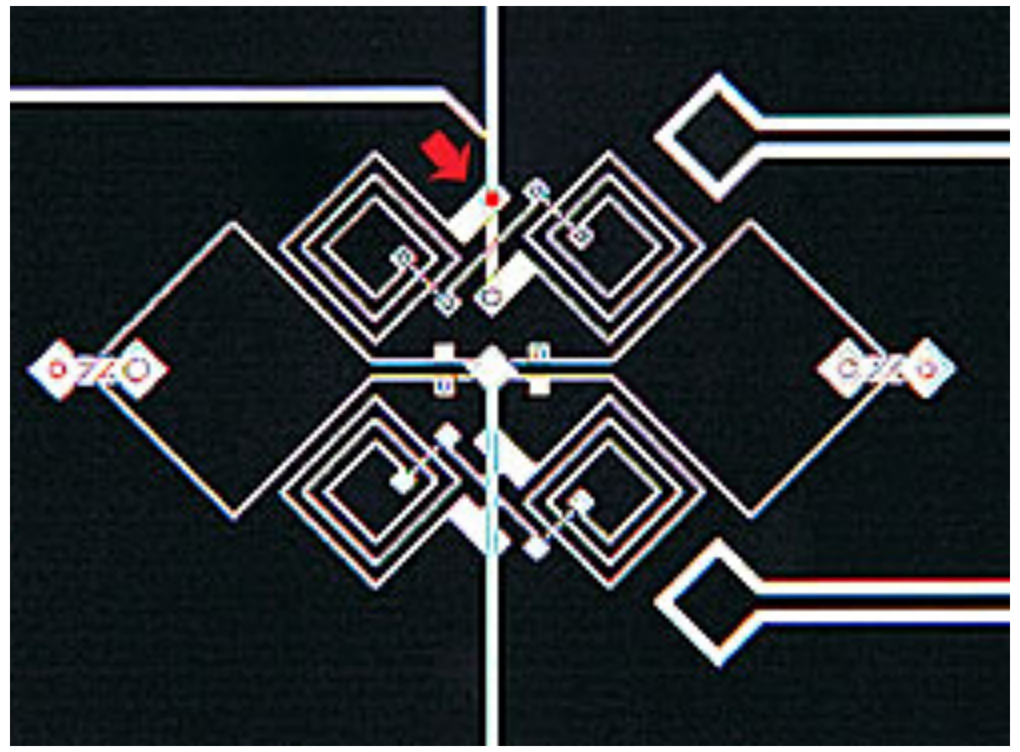


Quantum computation
Ideal case: programmable quantum computer, which is now moving from the lab to systems and engineering.

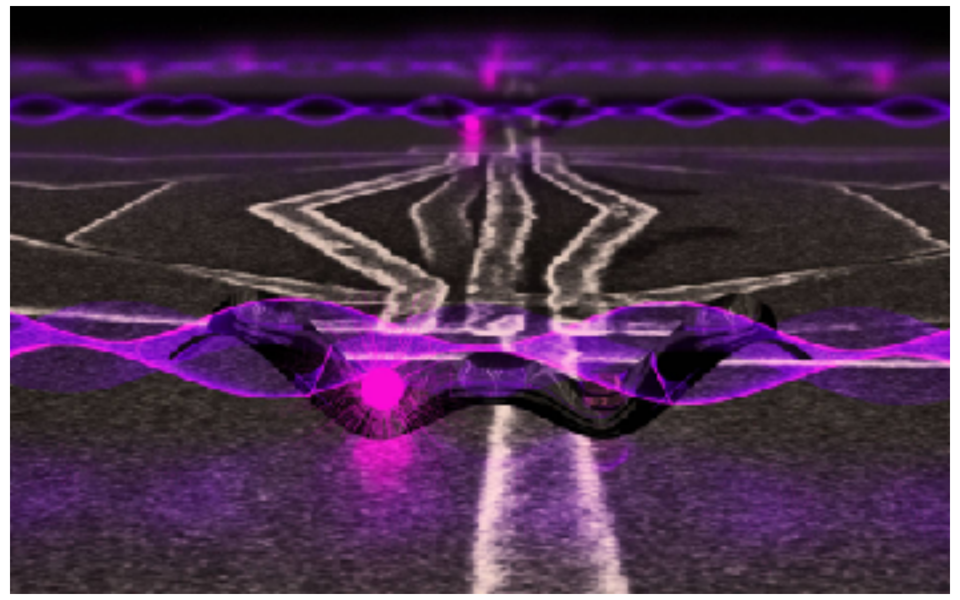
Atomic qubits

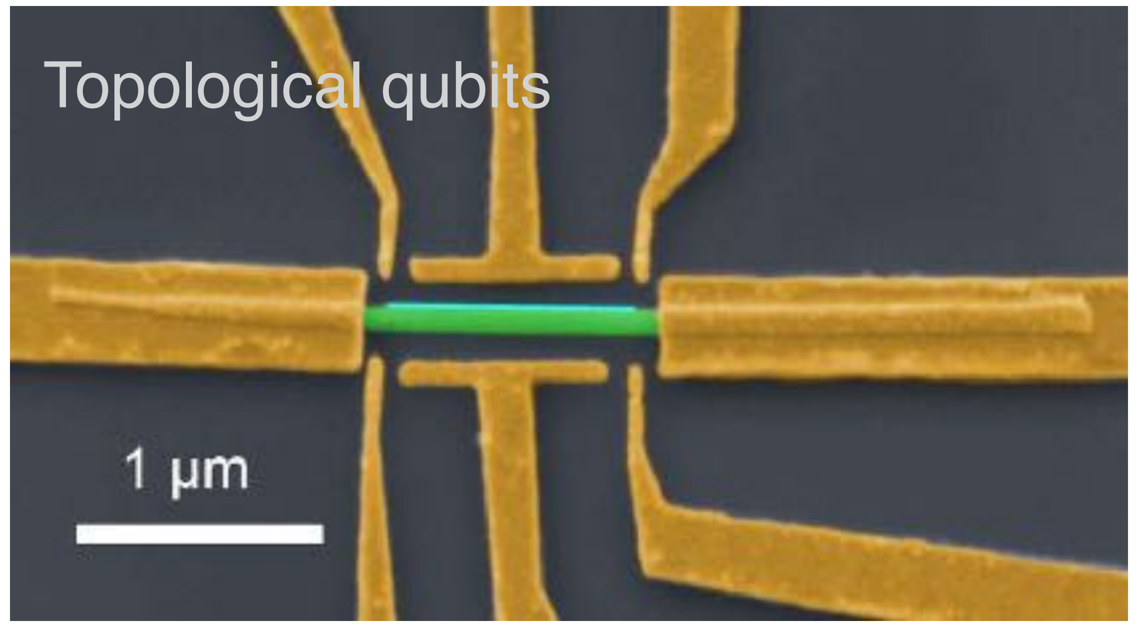


Superconducting qubits



Semiconductor spins





Quantum ~~Communication~~ Networking

Quantum communication
Quantum key distribution, and tons of enabling technology:
Sources, detectors, fibers, transducers, low-loss elements, improved engineering, new networking protocols and procedures

Quantum repeaters drive small-scale (5 qubit-ish) device growth, enable modular architectures.

Quantum internet of things
Internetworked sensors enable new measurement modalities and capabilities.

Many technological steps such as optical phase synchronization between distant clocks are goals in their own right.

Space-based systems can play critical roles in both comms and sensing.

Quantum^2 cloud computing
Distributed quantum computing:
• quantum error correction (inside data center)

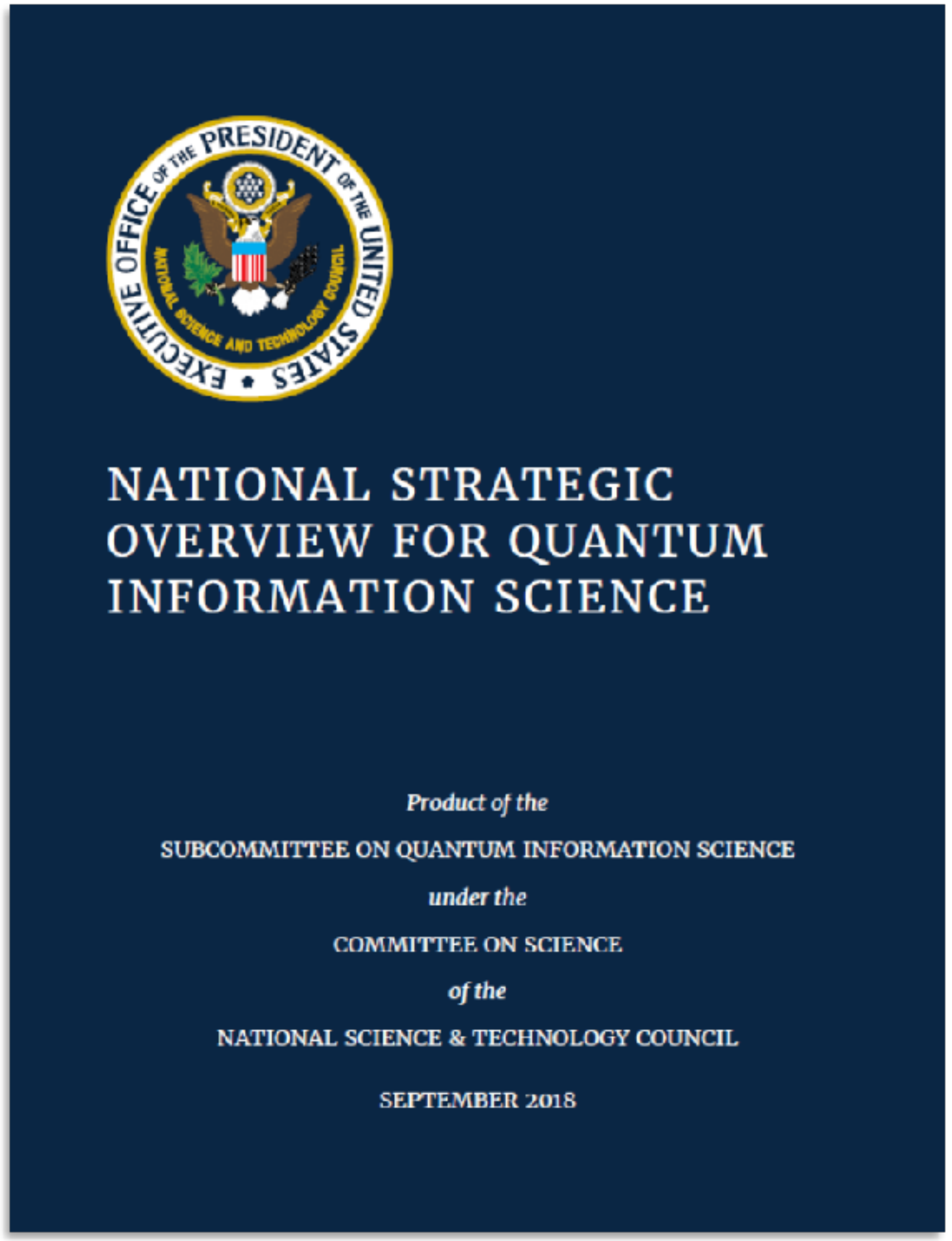
• interactive proofs (MIP*=RE ☺)

• homomorphic computing

And more???

What is the USG Policy?

- Focus on a science-first approach that aims to identify and solve Grand Challenges: problems whose solutions enable transformative scientific and industrial progress;
- Build a quantum-smart and diverse workforce to meet the needs of a growing field;
- Encourage industry engagement, providing appropriate mechanisms for public-private partnerships;
- Provide the key infrastructure and support needed to realize the scientific and technological opportunities;
- Drive economic growth;
- Maintain national security; and
- Continue to develop international collaboration and cooperation.


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

on quantum.gov

The National Quantum Initiative

Signed Dec 21, 2018

11 years of sustained effort

DOE: new centers working with the labs, new programs

NSF: new academic centers

NIST: industrial consortium, expand core programs

Coordination: NSTC subcommittee on QIS combined with a National Coordination Office and an external Advisory committee

Enabling the

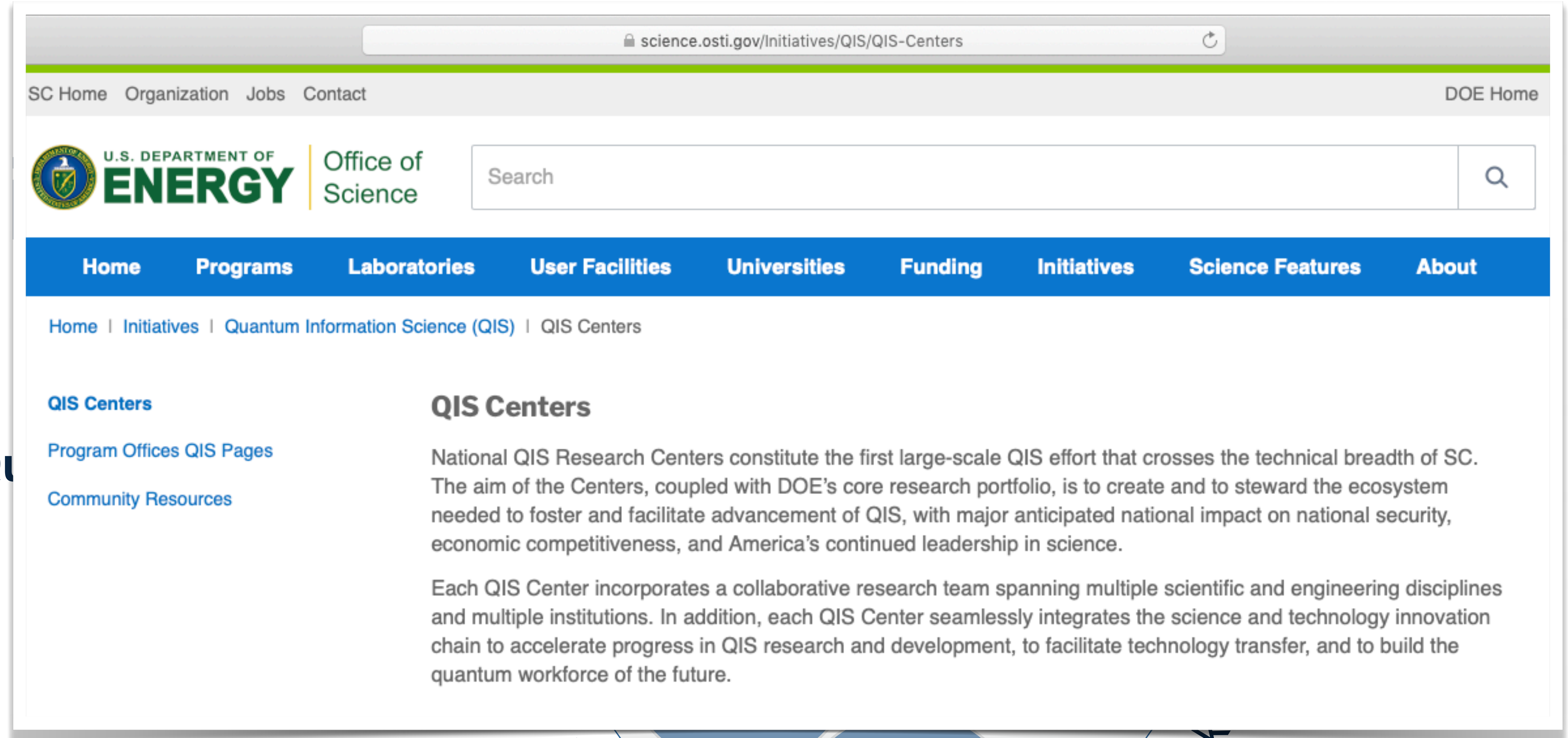
Lessons learned with JQI and Qu

Physical co-location

Dedicated infrastructure

Long-term focus

Information and talent flow



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Home | Initiatives | Quantum Information Science (QIS) | QIS Centers

QIS Centers

Program Offices QIS Pages

Community Resources

QIS Centers

National QIS Research Centers constitute the first large-scale QIS effort that crosses the technical breadth of SC. The aim of the Centers, coupled with DOE's core research portfolio, is to create and to steward the ecosystem needed to foster and facilitate advancement of QIS, with major anticipated national impact on national security, economic competitiveness, and America's continued leadership in science.

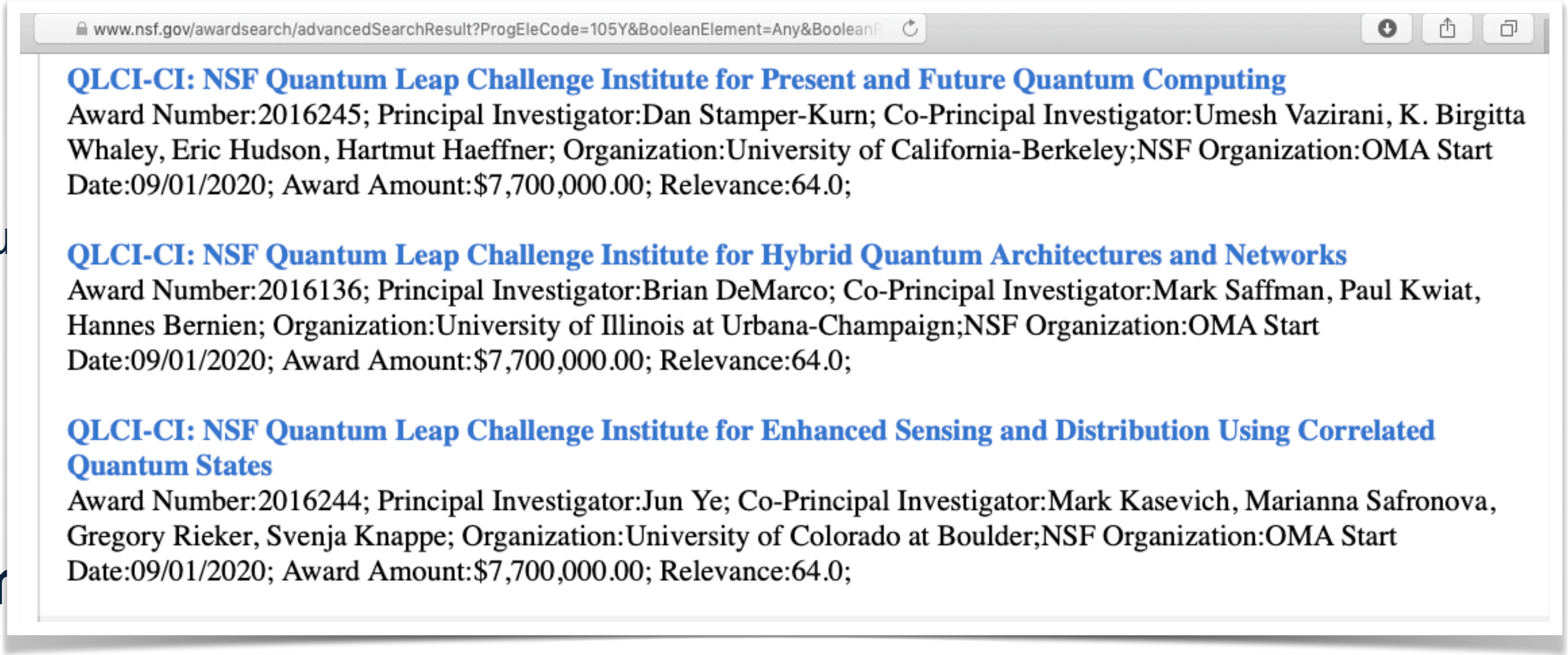
Each QIS Center incorporates a collaborative research team spanning multiple scientific and engineering disciplines and multiple institutions. In addition, each QIS Center seamlessly integrates the science and technology innovation chain to accelerate progress in QIS research and development, to facilitate technology transfer, and to build the quantum workforce of the future.

In addition:

Novel tech transfer experiments

Regular interface with OEM commu

Skills training and transfer



www.nsf.gov/awardsearch/advancedSearchResult?ProgEleCode=105Y&BooleanElement=Any&BooleanR

QLCI-CI: NSF Quantum Leap Challenge Institute for Present and Future Quantum Computing

Award Number:2016245; Principal Investigator:Dan Stamper-Kurn; Co-Principal Investigator:Umesh Vazirani, K. Birgitta Whaley, Eric Hudson, Hartmut Haeffner; Organization:University of California-Berkeley;NSF Organization:OMA Start Date:09/01/2020; Award Amount:$7,700,000.00; Relevance:64.0;

QLCI-CI: NSF Quantum Leap Challenge Institute for Hybrid Quantum Architectures and Networks

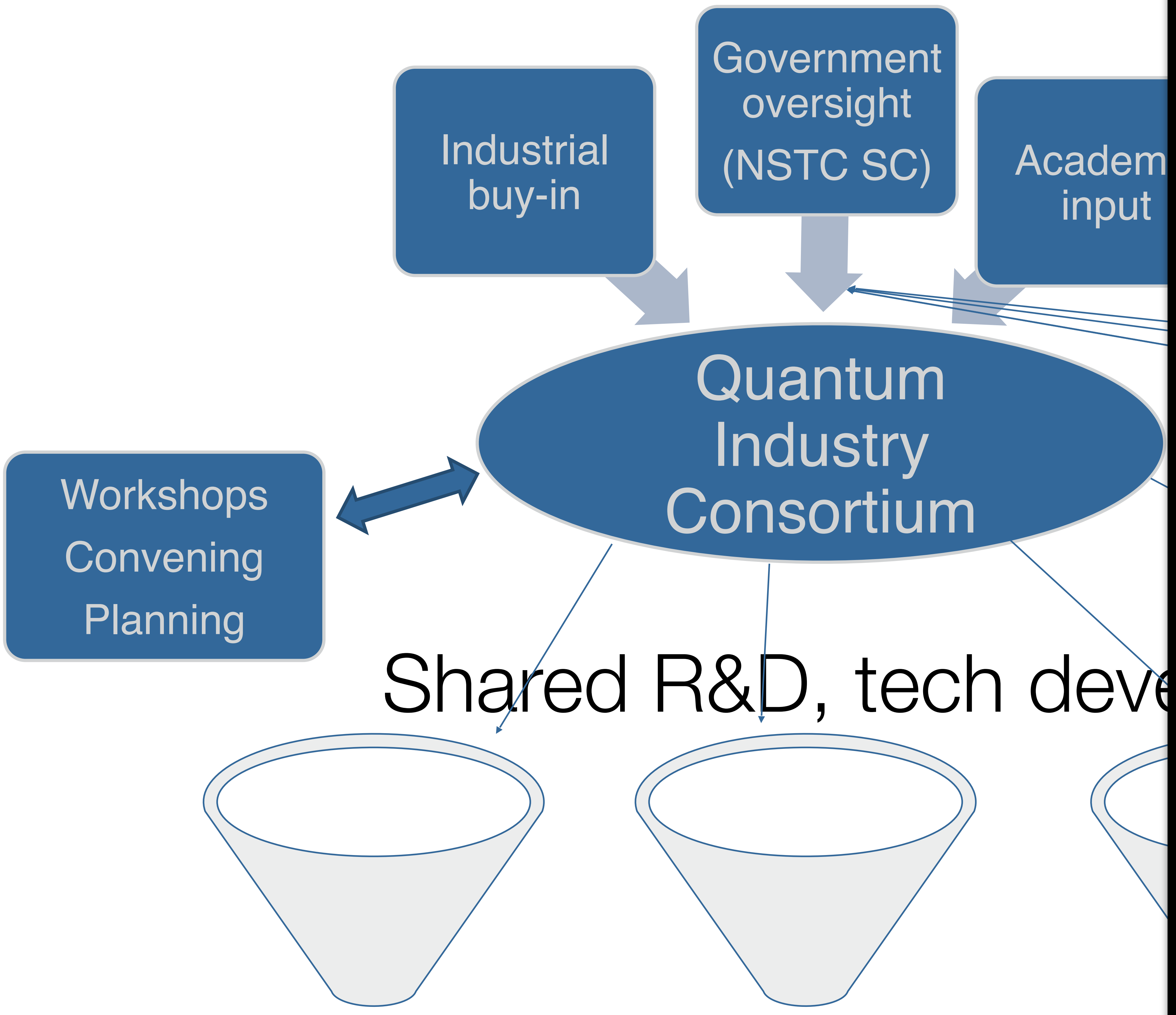
Award Number:2016136; Principal Investigator:Brian DeMarco; Co-Principal Investigator:Mark Saffman, Paul Kwiat, Hannes Bernien; Organization:University of Illinois at Urbana-Champaign;NSF Organization:OMA Start Date:09/01/2020; Award Amount:$7,700,000.00; Relevance:64.0;

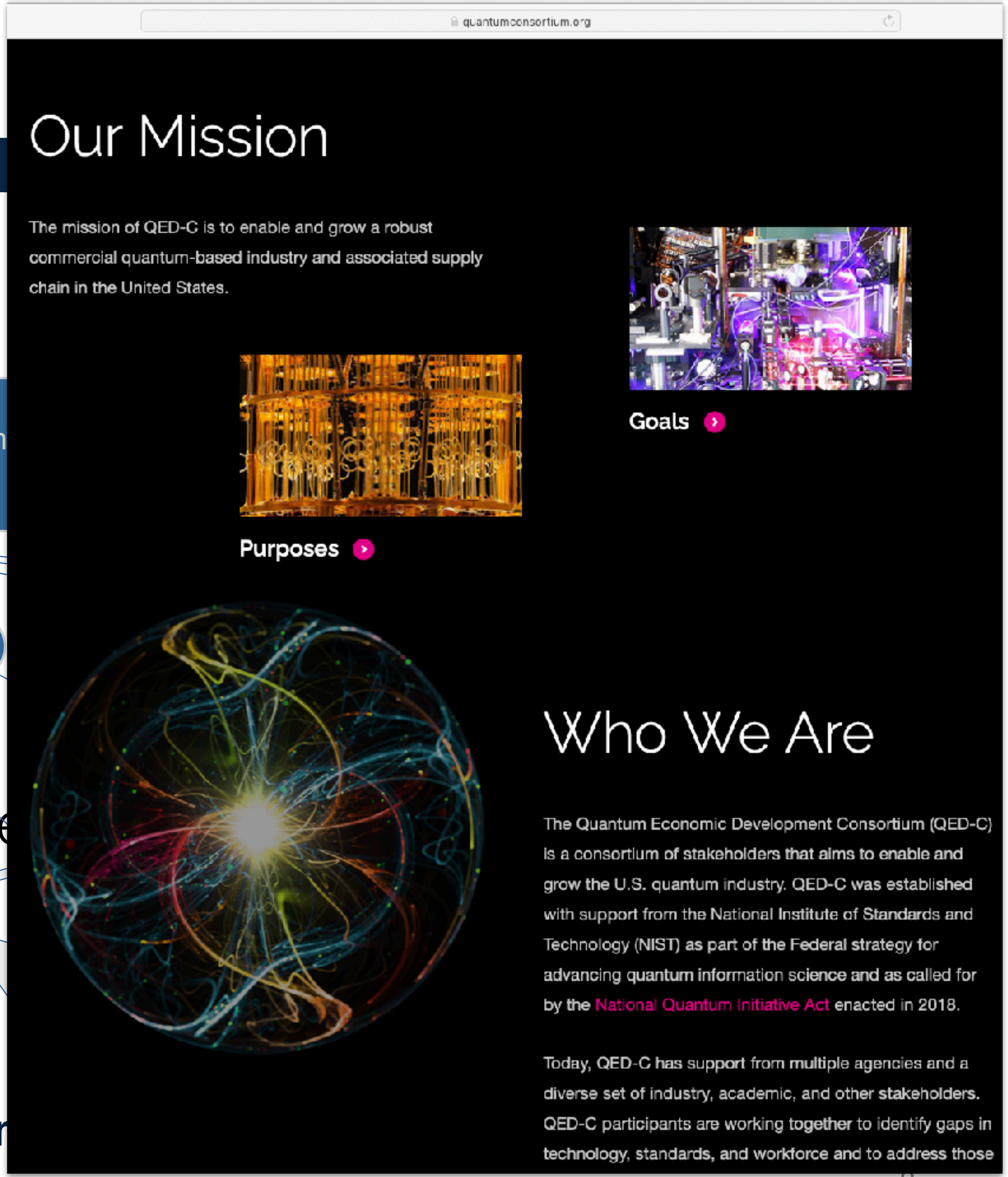
QLCI-CI: NSF Quantum Leap Challenge Institute for Enhanced Sensing and Distribution Using Correlated Quantum States

Award Number:2016244; Principal Investigator:Jun Ye; Co-Principal Investigator:Mark Kasevich, Marianna Safronova, Gregory Rieker, Svenja Knappe; Organization:University of Colorado at Boulder;NSF Organization:OMA Start Date:09/01/2020; Award Amount:$7,700,000.00; Relevance:64.0;

Current approach: ~$500m

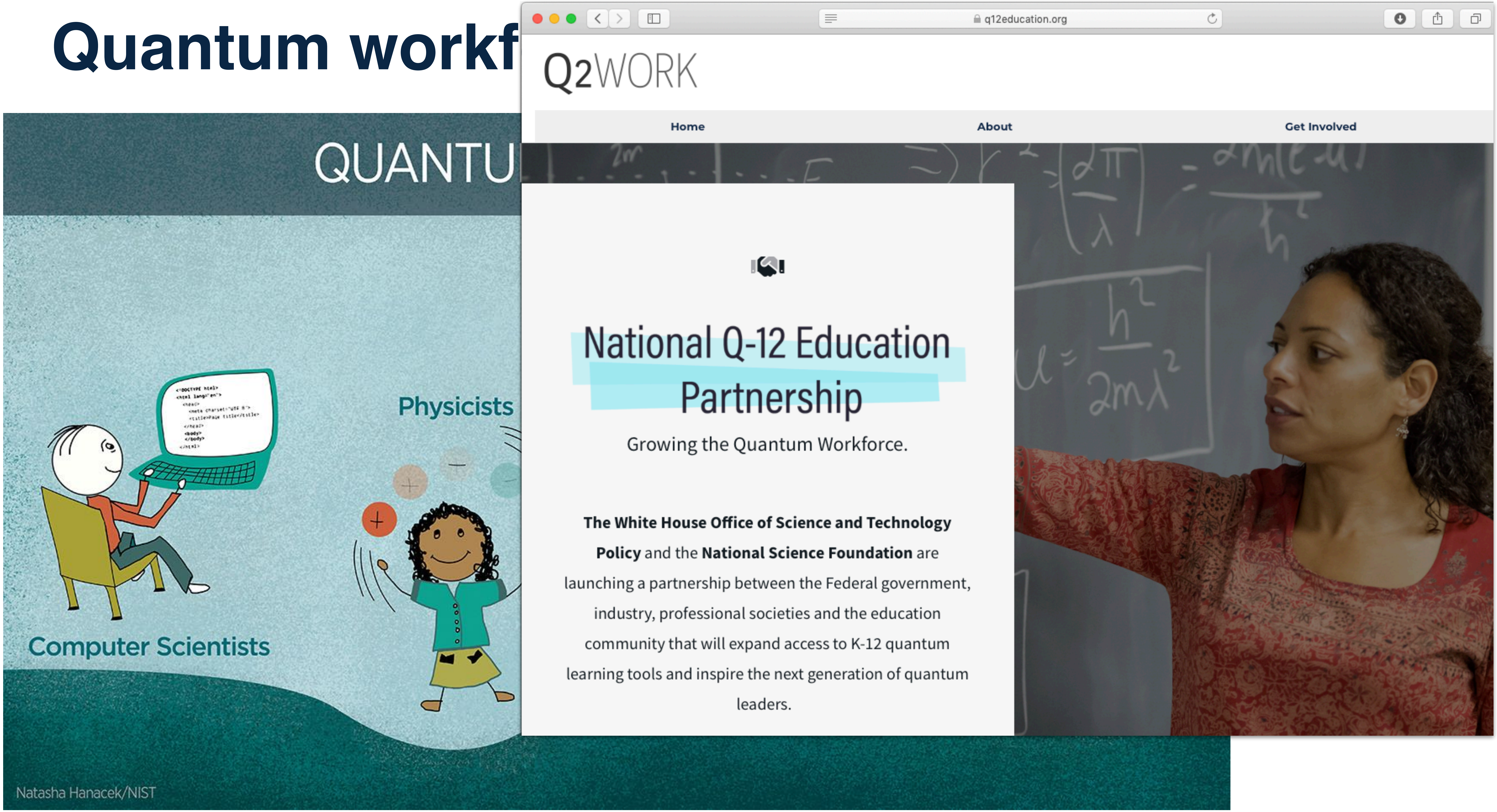
Quantum industry coo



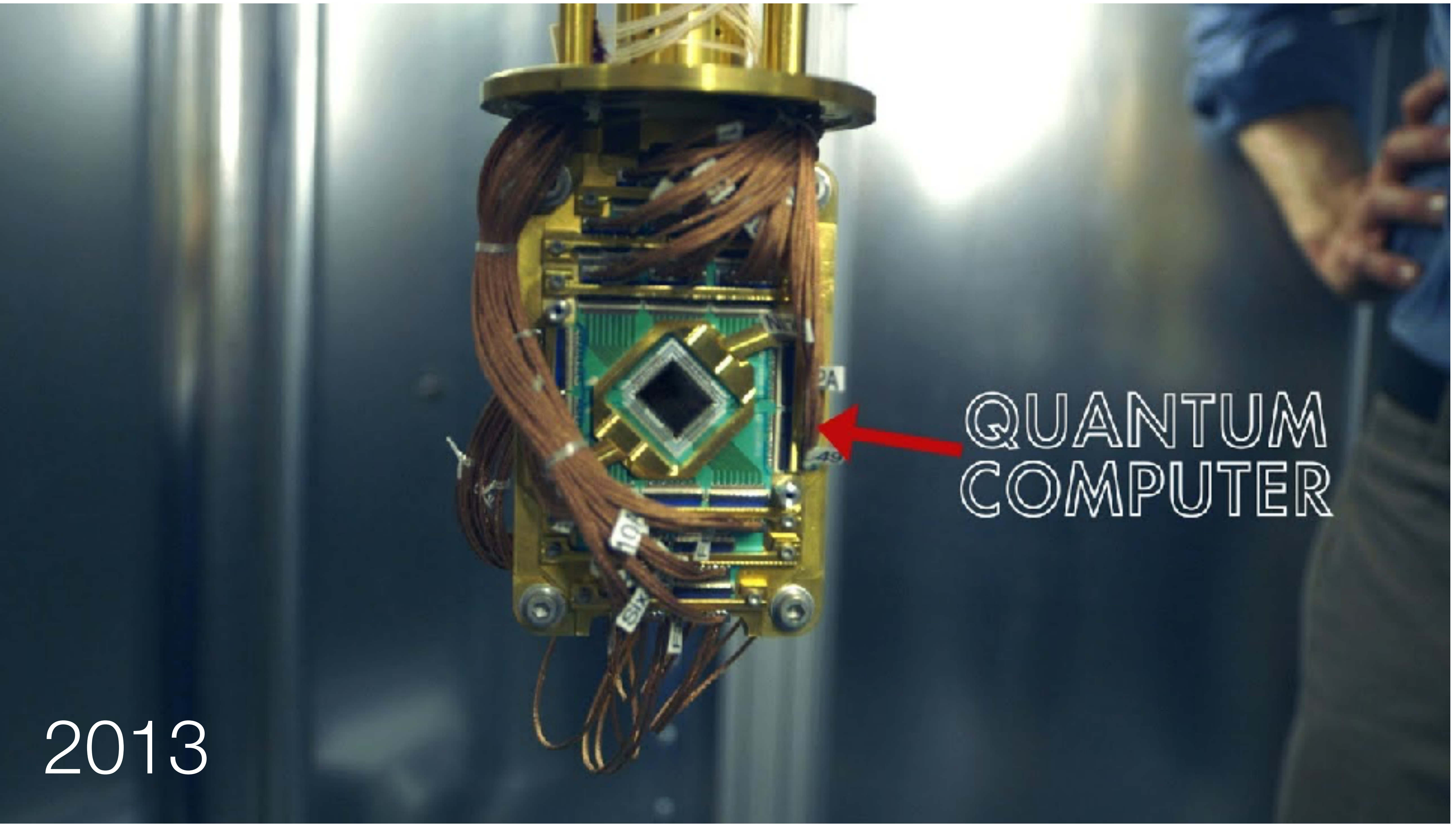


Current approach: NIST partnership with SRI I
+200 companies engaged with the QED-C

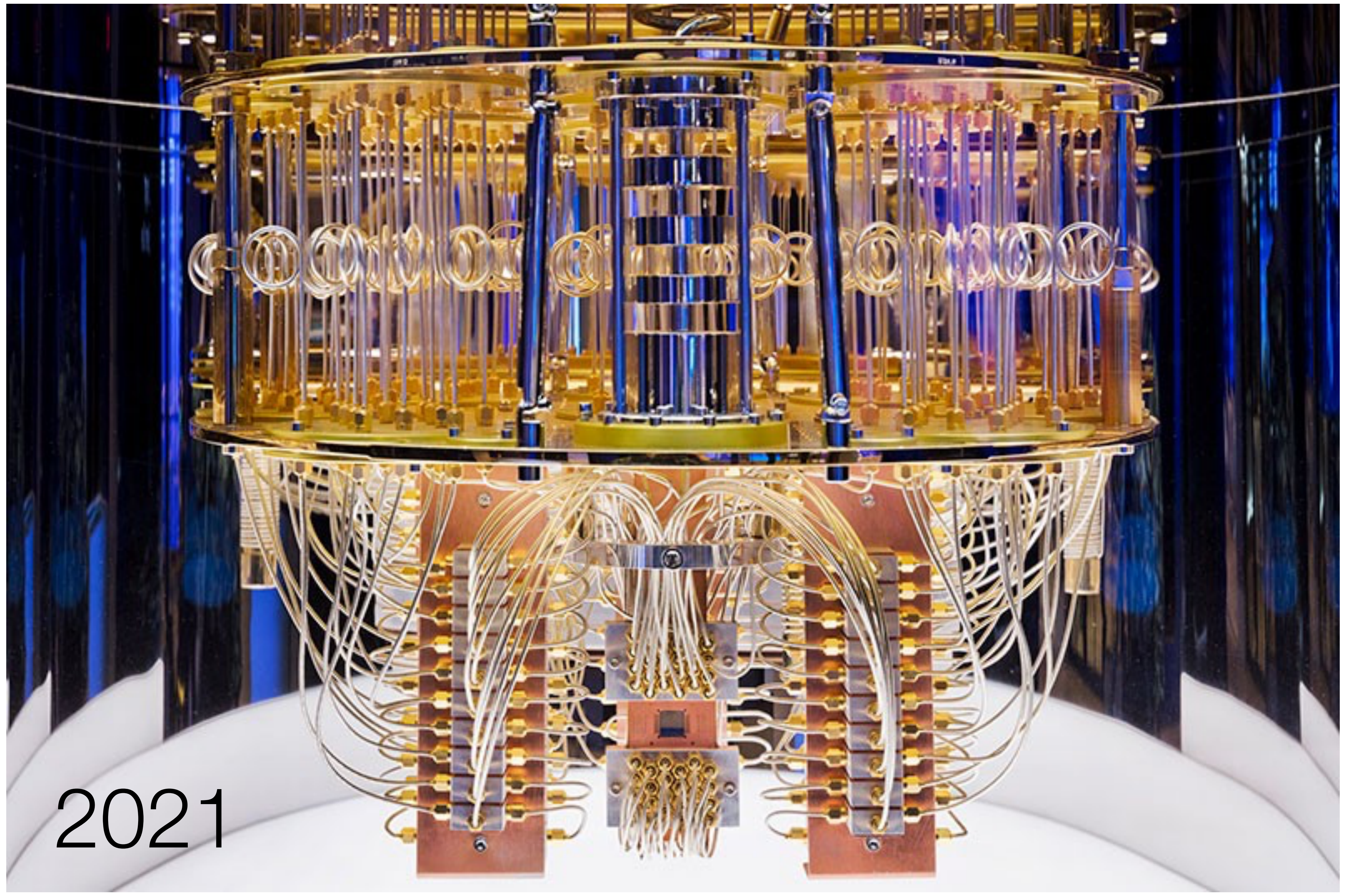
Quantum workf



The engineering need is growing

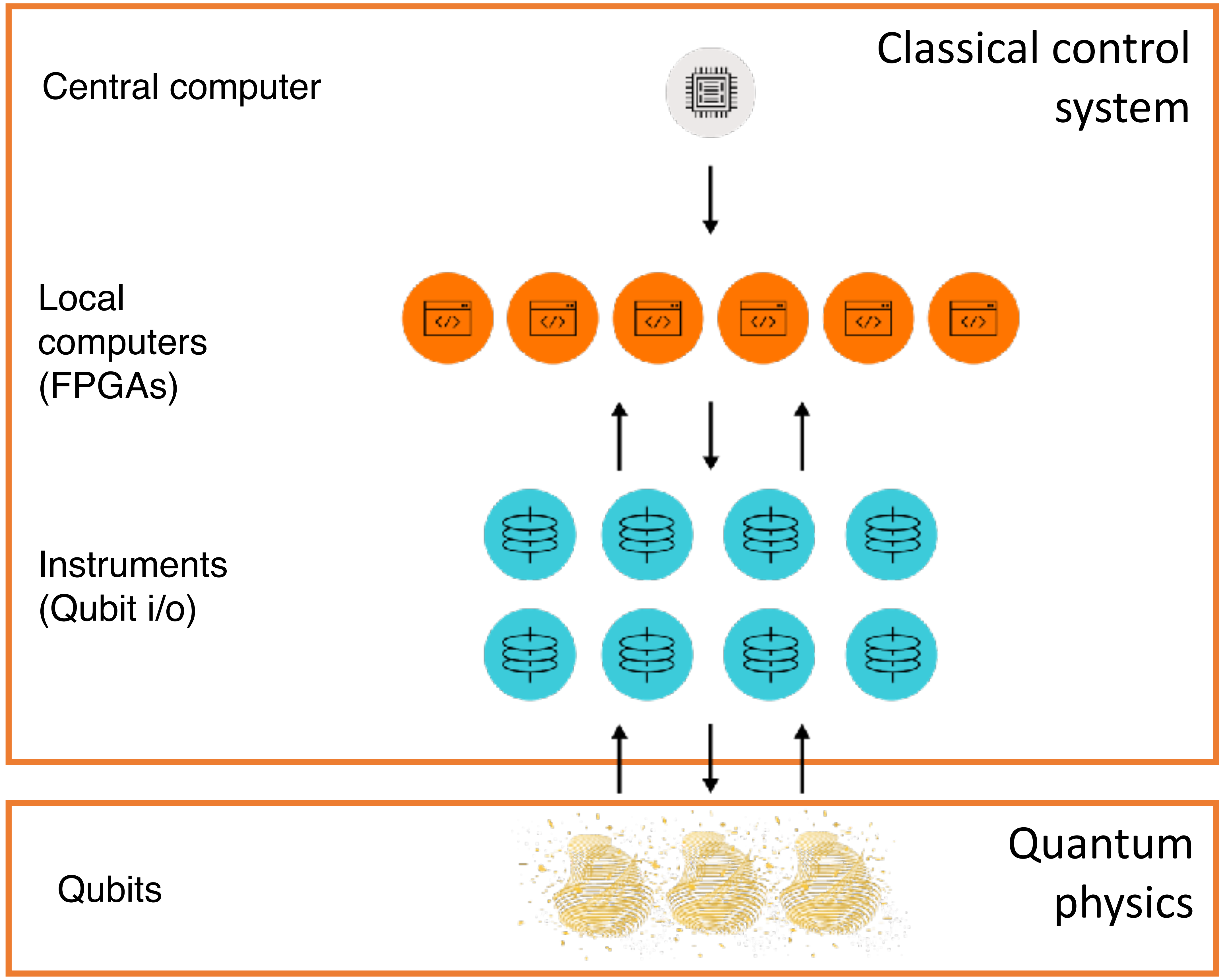


credit:Google



credit:IBM

A scalable machine is a complex classical-quantum system



The tooling for the stack

We are only as good as our tooling!

The pieces that go alongside matter

- Compiler/transpiler
- Code simulation
- Qubit simulation
- Scheduler
- Verification/ Validation

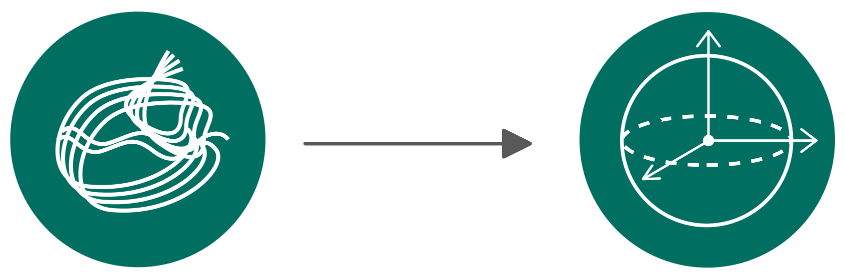
OpenQASM

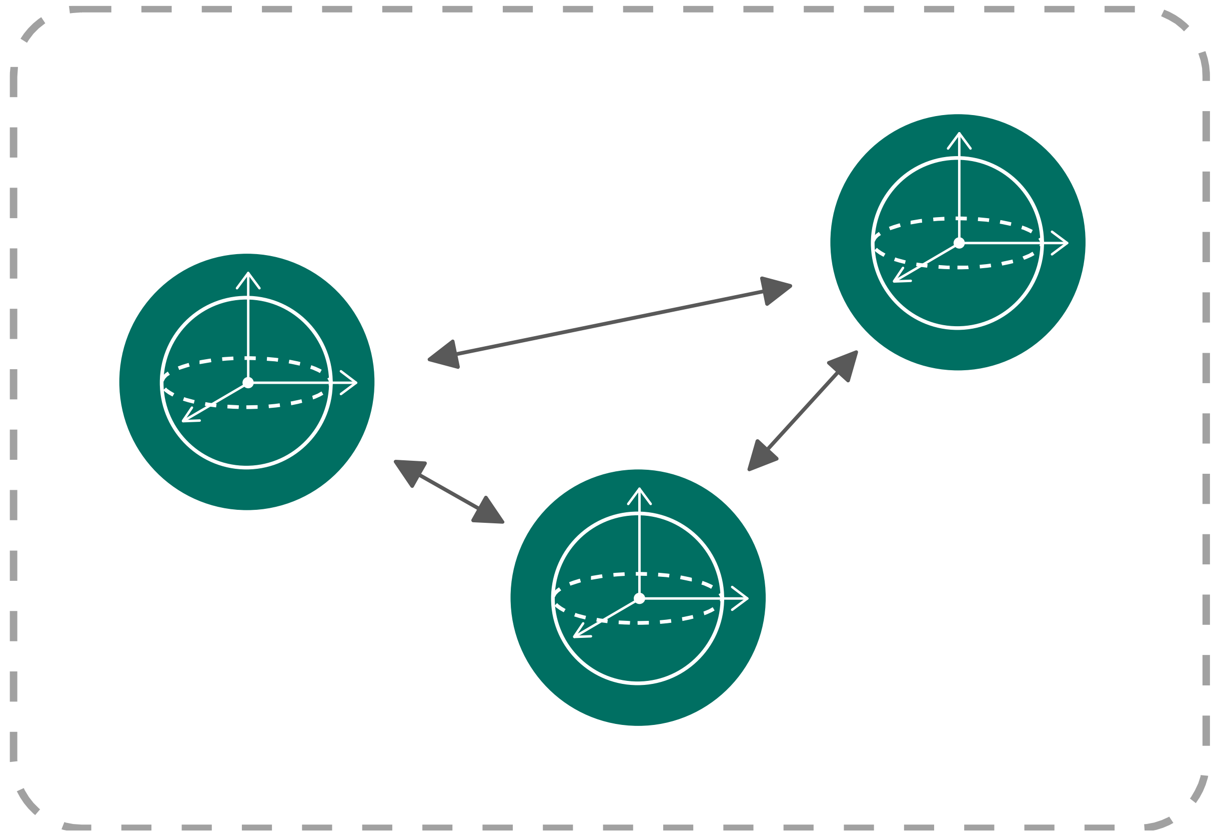
- Circuit abstraction layer
- Embedded software/hardware (decoders, calibrators)
- Qubit abstraction layer

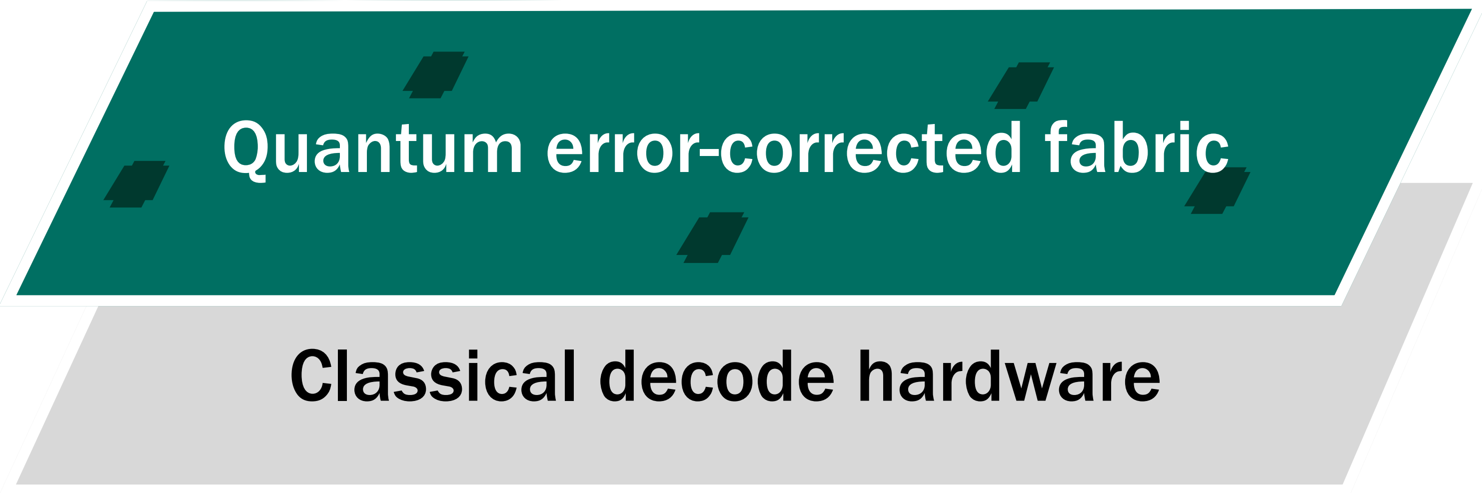
RTL, Verilog

- Pulse generators
- Amplifiers
- Qubit hardware

Example: quantum error correction







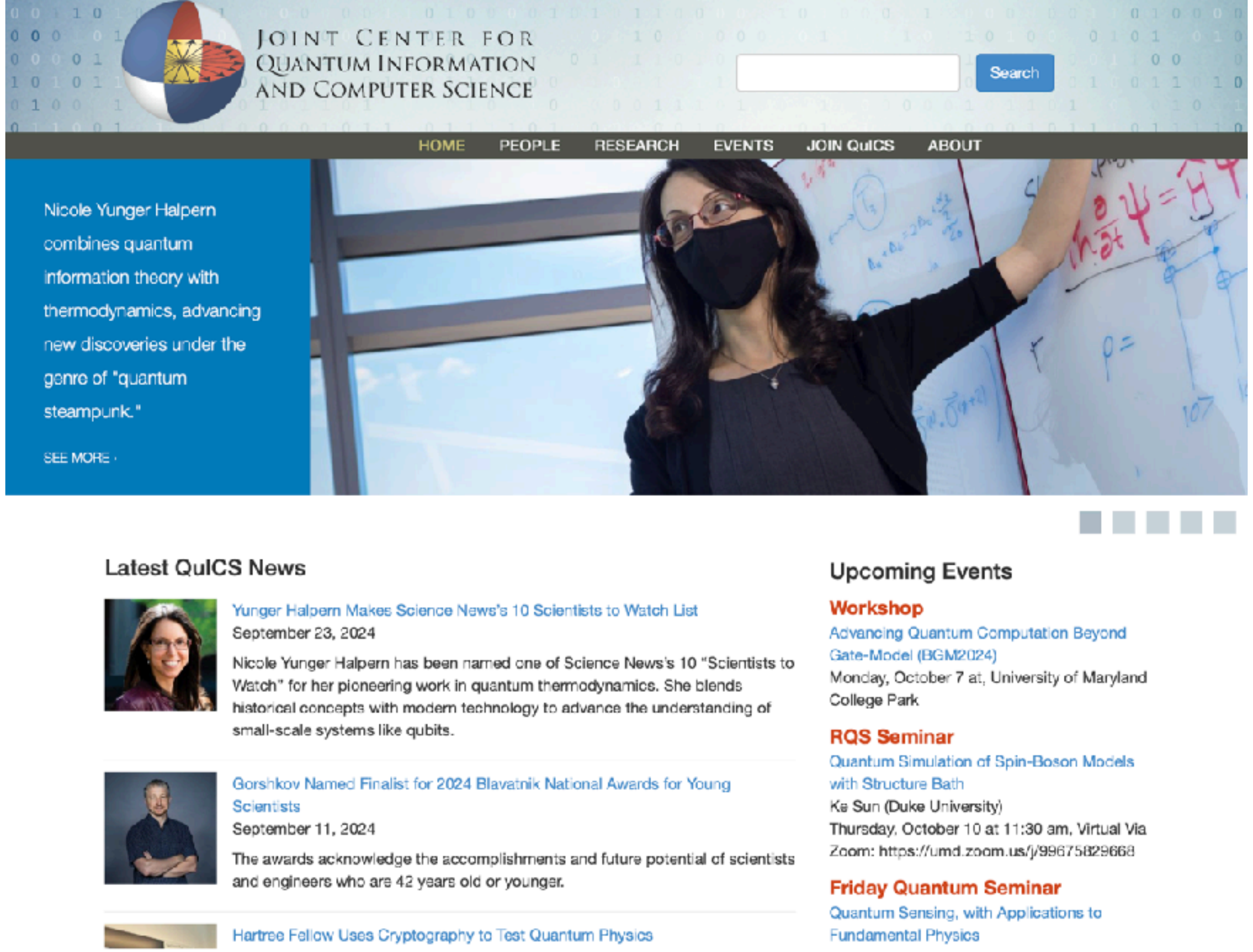
Improve physical system **performance**: calibration, feedback, and control

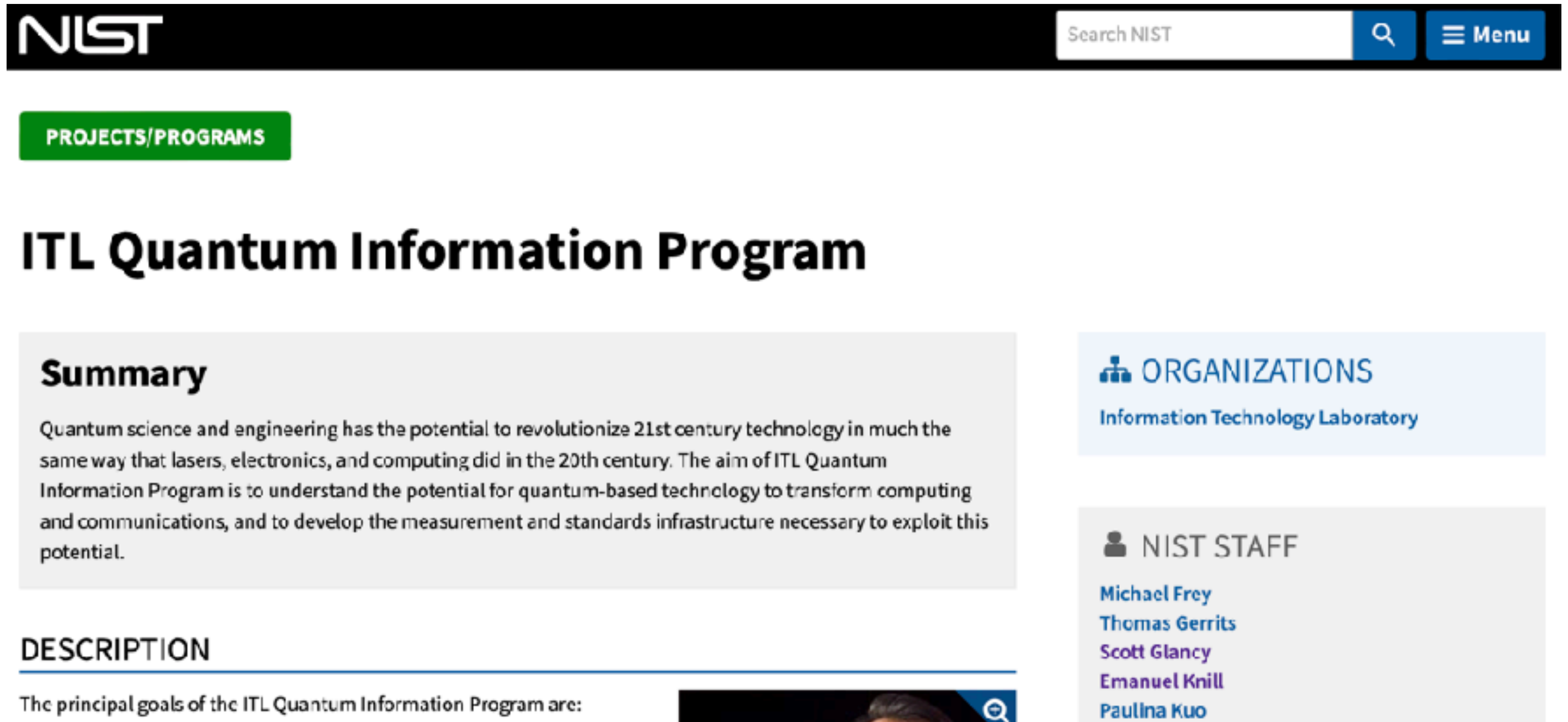
Connect qubits together and use them efficiently through layers of **abstraction**

Perform **rapid** measurement, decoding, and feedback to create an error correction fabric

Leverage application-specific knowledge to identify faster paths to viable end-to-end **implementations**

Examples of Applied Math in quantum @ NIST





The Field of Dreams

What we need:
people working hard, taking a systems engineering approach to creating quantum machines that matter.

Q chemistry
Q enhanced optimization
Q sensing

The outfield
Entanglement enhanced sensing
Q computing
Q algorithms
Classical control
Heuristic Q algorithms
High sensing simulation
Q simulation (materials)
Q control
Q programming