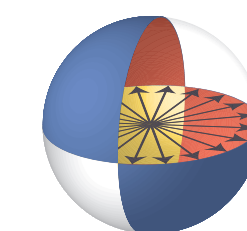


Credit: G.E. Marti/JILA

# The National Quantum Initiative

Jake Taylor  
QuICS/JQI/NIST  
@quantum\_jake

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



JOINT CENTER FOR  
QUANTUM INFORMATION  
AND COMPUTER SCIENCE



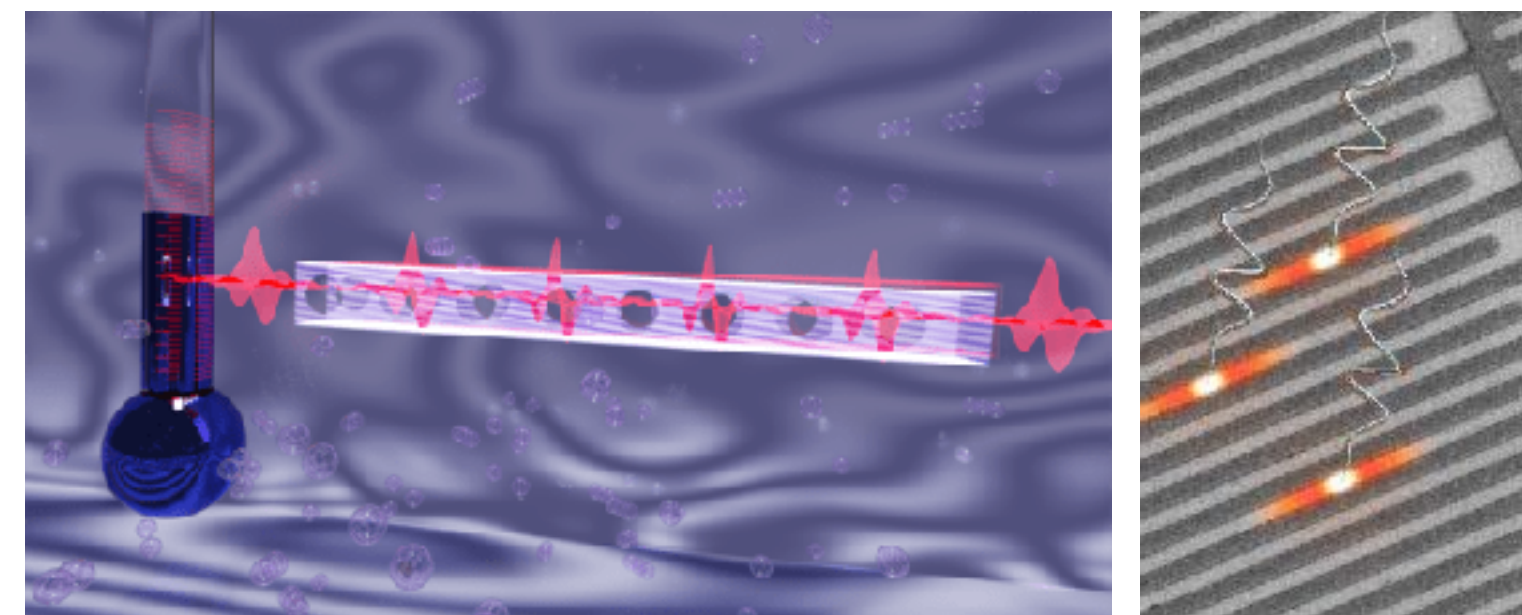
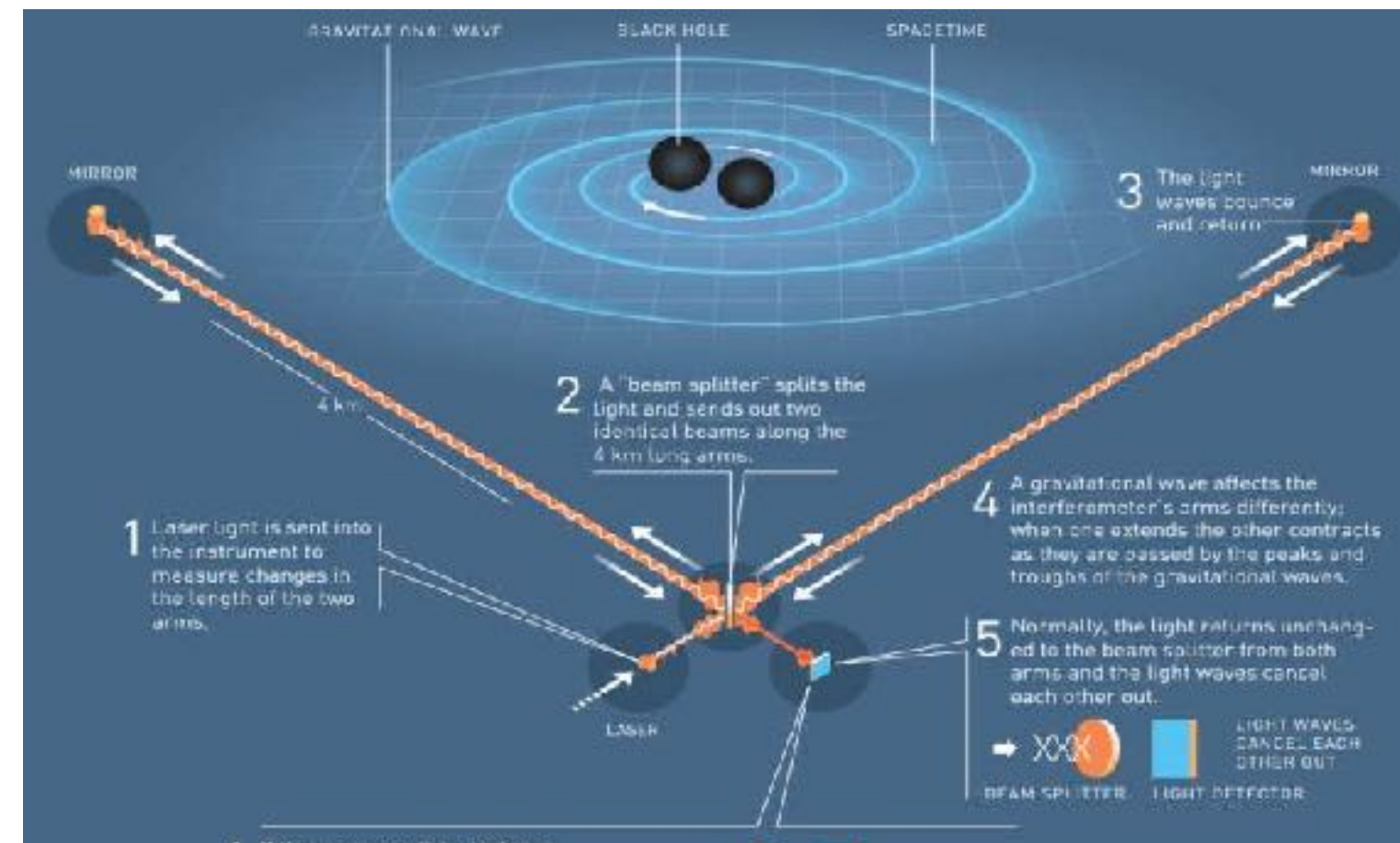
# Quantum Sensing

## 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 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

New worldwide approach: the Quantum SI, started May 2019

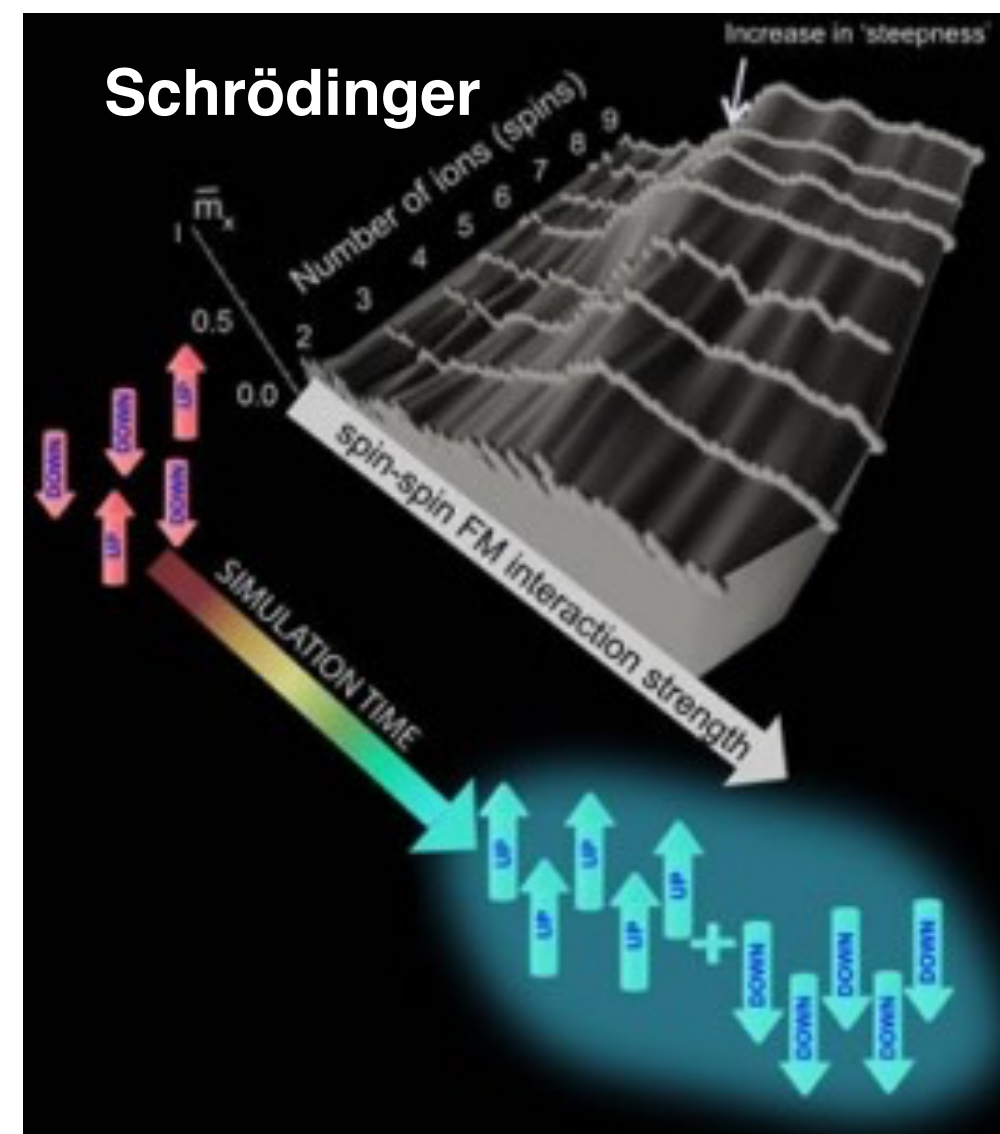
# Quantum Computing

## Quantum simulation

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

Recall: Simulating quantum mechanics is hard...

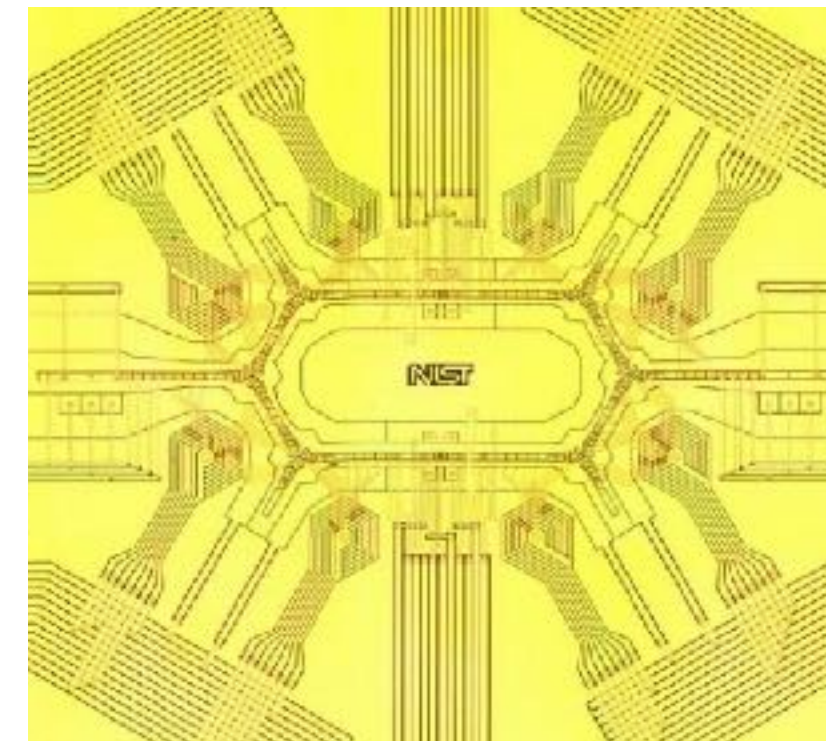
Solution: Use one system to simulate another



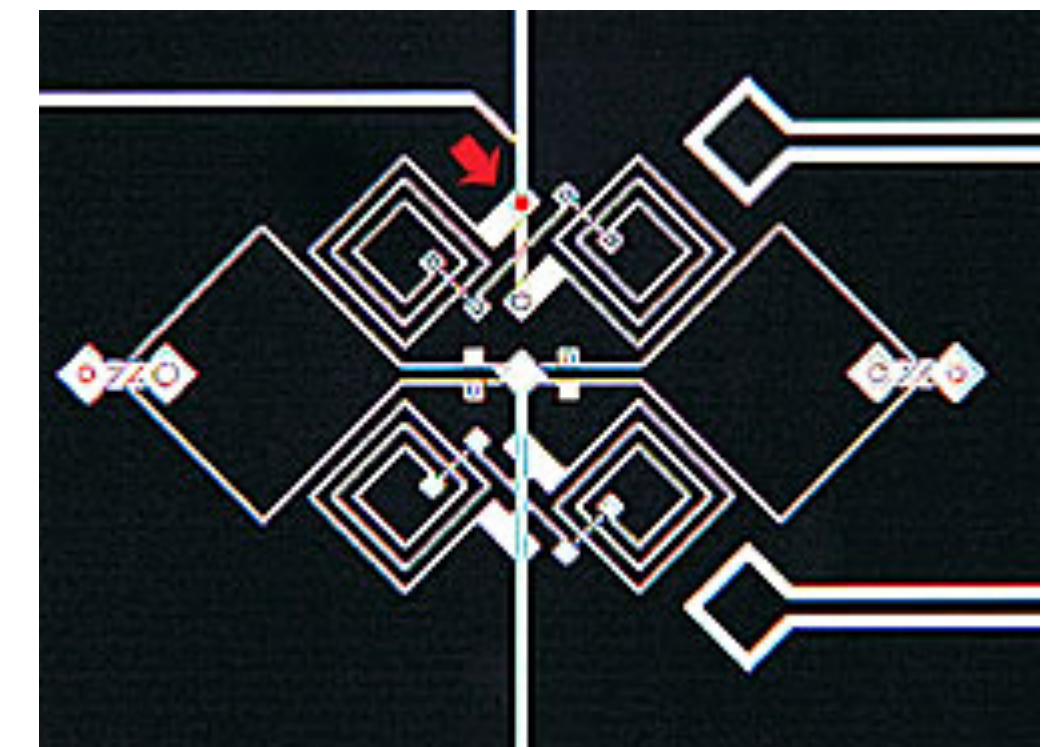
## Quantum computation

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

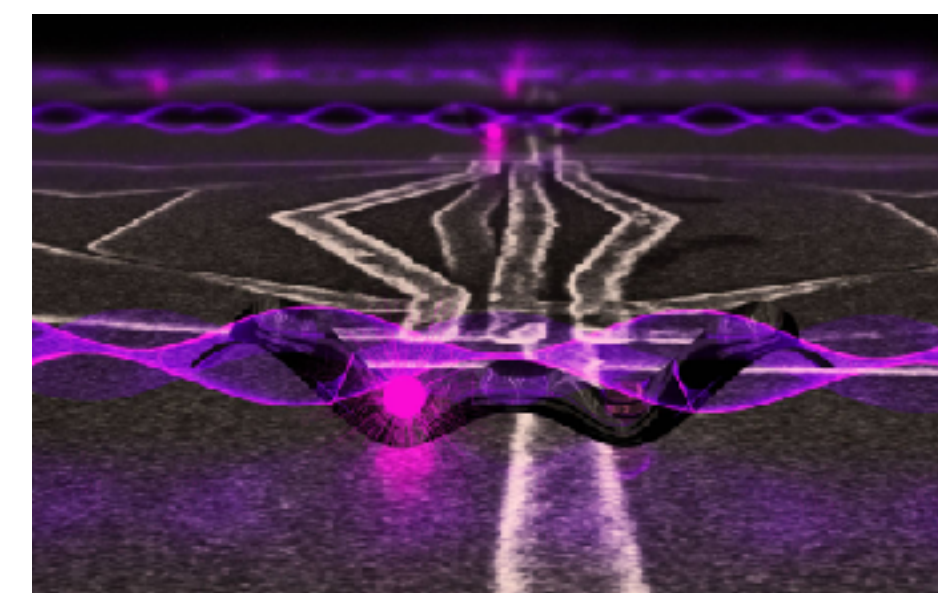
Atomic qubits



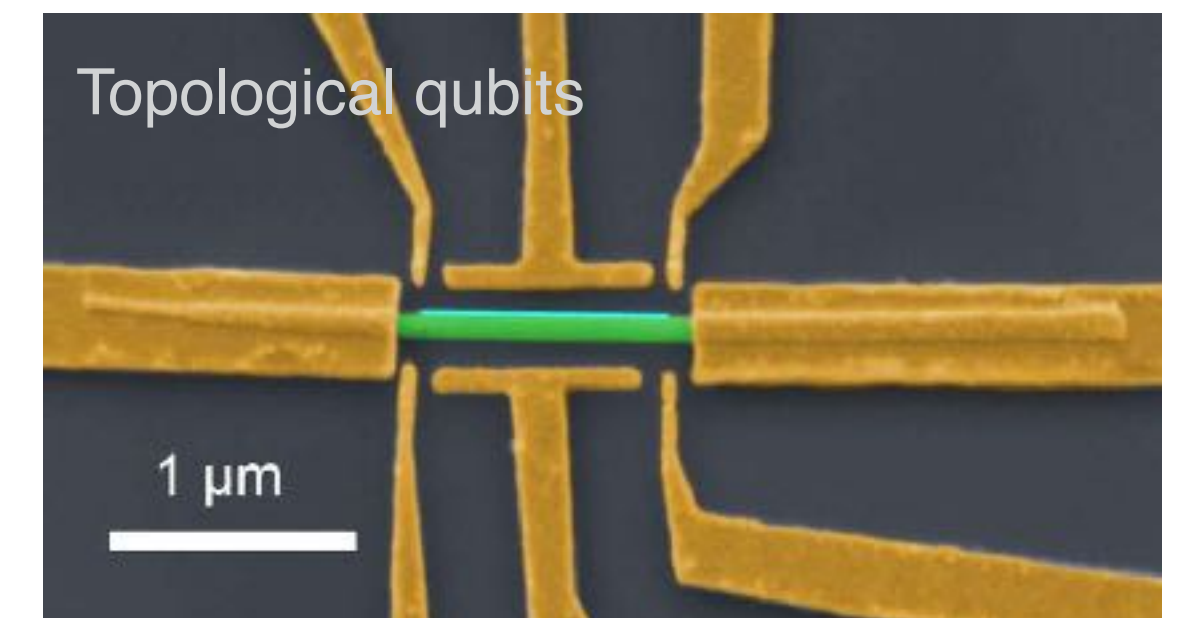
Superconducting qubits



Semiconductor spins



Topological qubits



# 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<sup>2</sup> cloud computing

Distributed quantum computing:

- quantum error correction (inside data center)

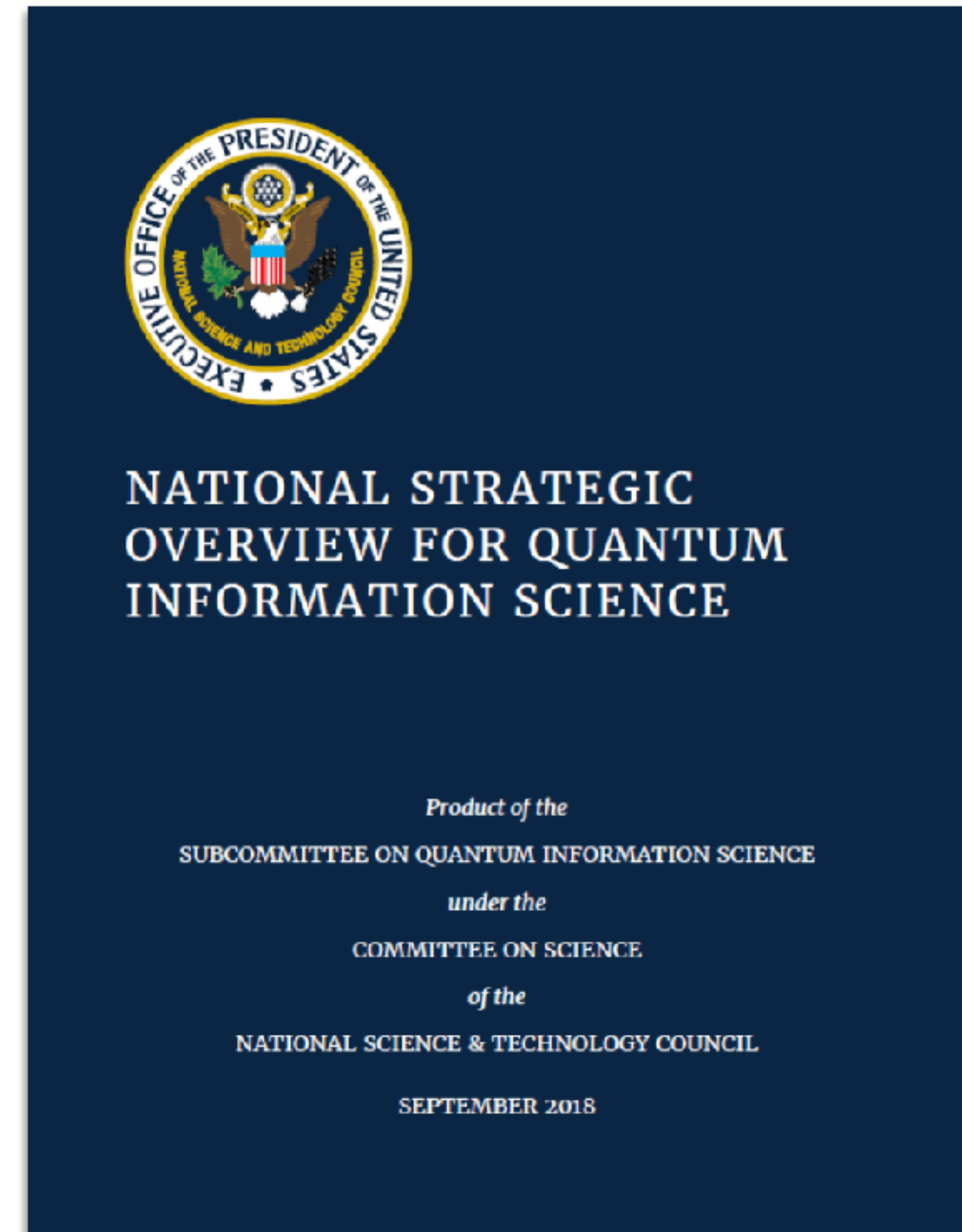
- interactive proofs ( $MIP^* = RE$  😊)

- 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.



on [quantum.gov](https://www.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 Q

- Physical co-location
- Dedicated infrastructure
- Long-term focus
- Information and talent flow

## In addition:

- Novel tech transfer experiments
- Regular interface with OEM commu
- Skills training and transfer

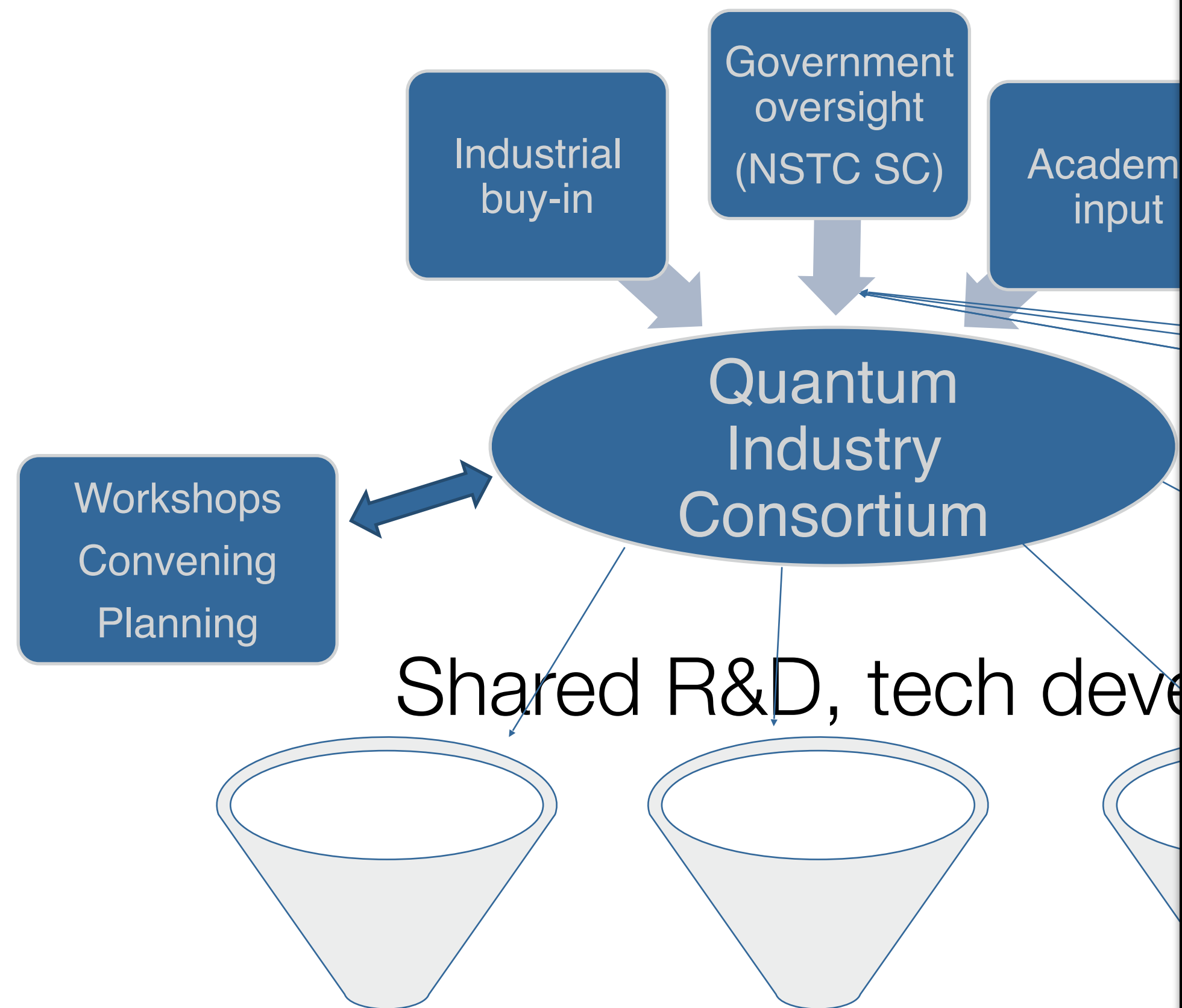
**Current approach: ~\$500m**

The screenshot shows the website for the Office of Science, U.S. Department of Energy. The page is titled "QIS Centers" and is part of the "Quantum Information Science (QIS)" initiative. The navigation menu includes Home, Programs, Laboratories, User Facilities, Universities, Funding, Initiatives, Science Features, and About. The breadcrumb trail is Home | Initiatives | Quantum Information Science (QIS) | QIS Centers. The main content area has a heading "QIS Centers" and a sub-heading "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." Below this, it states "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." On the left side, there are links for "QIS Centers", "Program Offices QIS Pages", and "Community Resources".

The screenshot shows an NSF award search result page. The URL is www.nsf.gov/awardsearch/advancedSearchResult?ProgEleCode=105Y&BooleanElement=Any&BooleanF. The page displays three award entries, each with a title, award number, principal investigator, co-principal investigator, organization, NSF organization, start date, award amount, and relevance score.

- 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;

# Quantum industry cool



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

quantumconsortium.org

## Our Mission

The mission of QED-C is to enable and grow a robust commercial quantum-based industry and associated supply chain in the United States.

Goals →

Purposes →

## Who We Are

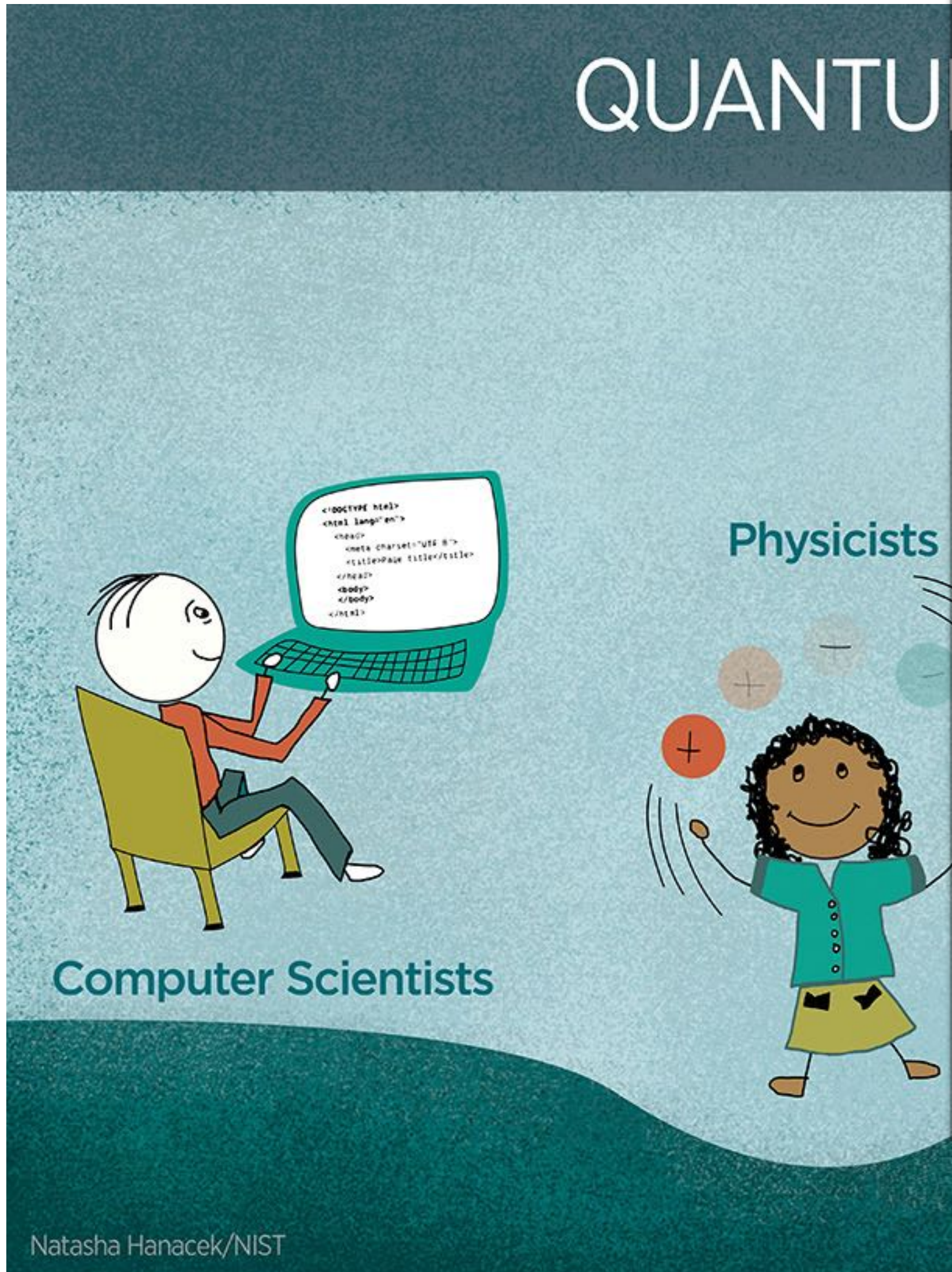
The Quantum Economic Development Consortium (QED-C) is a consortium of stakeholders that aims to enable and grow the U.S. quantum industry. QED-C was established with support from the National Institute of Standards and Technology (NIST) as part of the Federal strategy for advancing quantum information science and as called for by the **National Quantum Initiative Act** enacted in 2018.

Today, QED-C has support from multiple agencies and a diverse set of industry, academic, and other stakeholders. QED-C participants are working together to identify gaps in technology, standards, and workforce and to address those

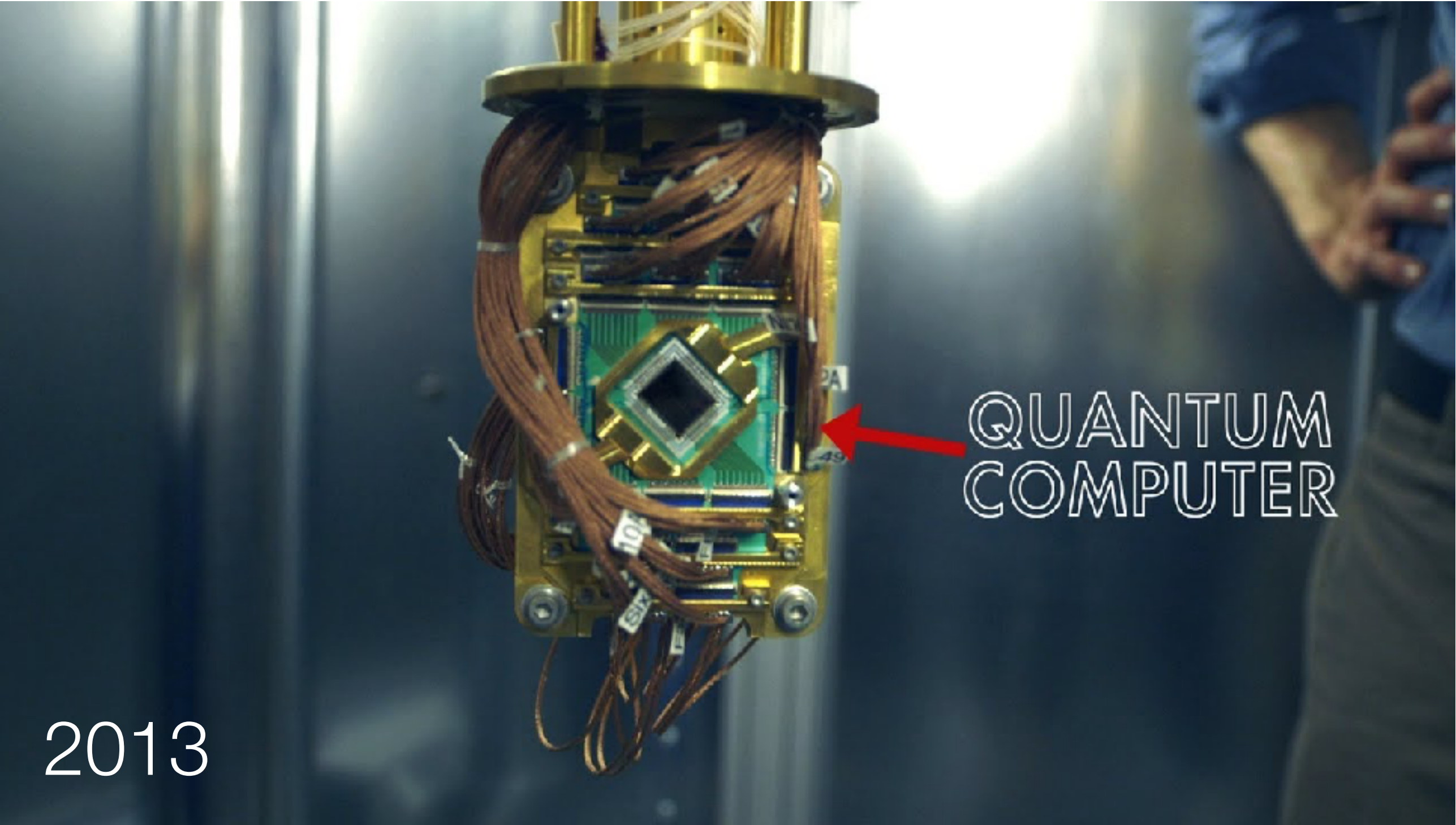


# Quantum workf

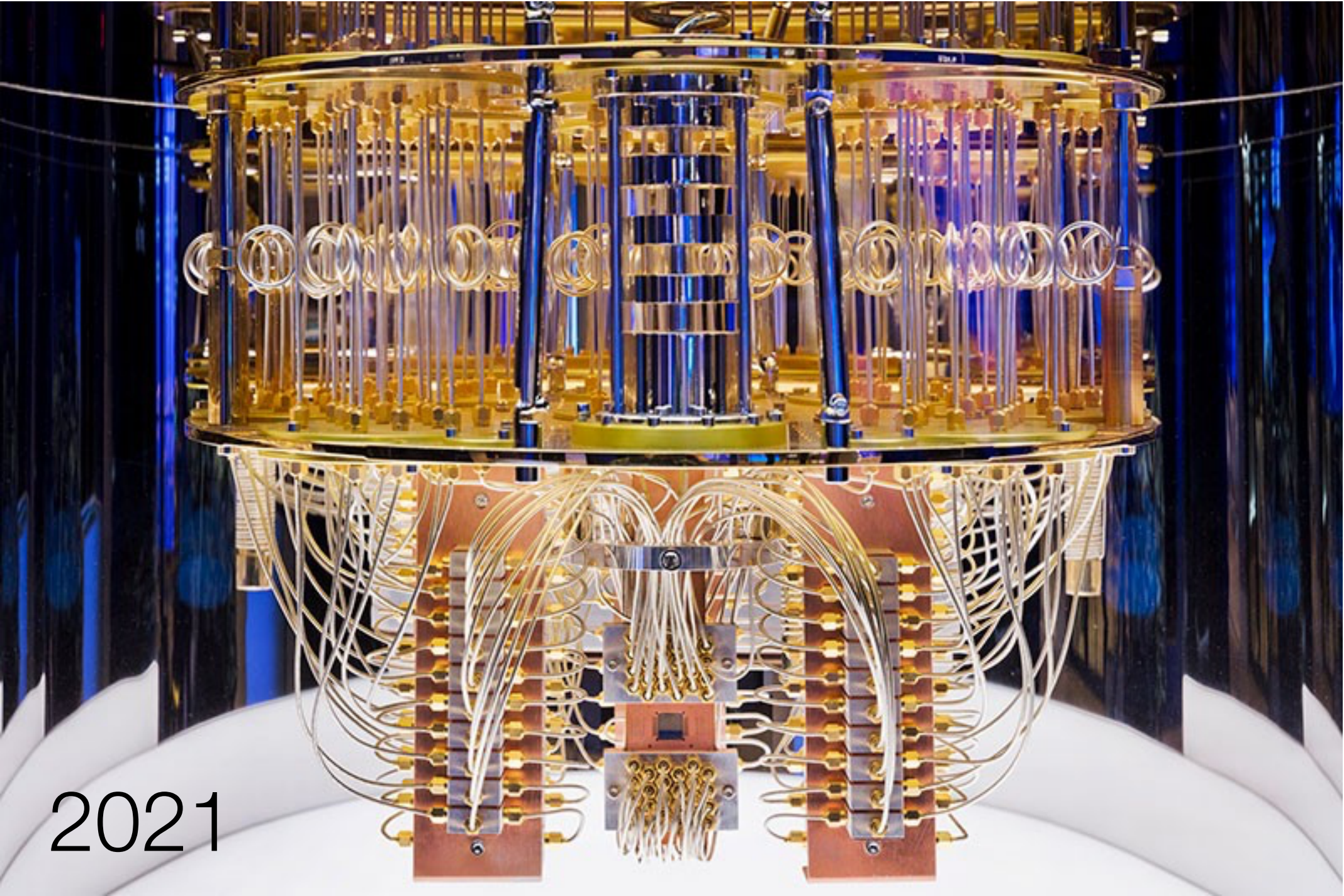
The screenshot shows a web browser window with the URL [q12education.org](http://q12education.org). The page title is "Q2WORK". The navigation menu includes "Home", "About", and "Get Involved". The main content area features a logo of two hands shaking, followed by the heading "National Q-12 Education Partnership" and the tagline "Growing the Quantum Workforce." Below this, a paragraph states: "The White House Office of Science and Technology Policy and the National Science Foundation are launching a partnership between the Federal government, industry, professional societies and the education community that will expand access to K-12 quantum learning tools and inspire the next generation of quantum leaders."



# The engineering need is growing

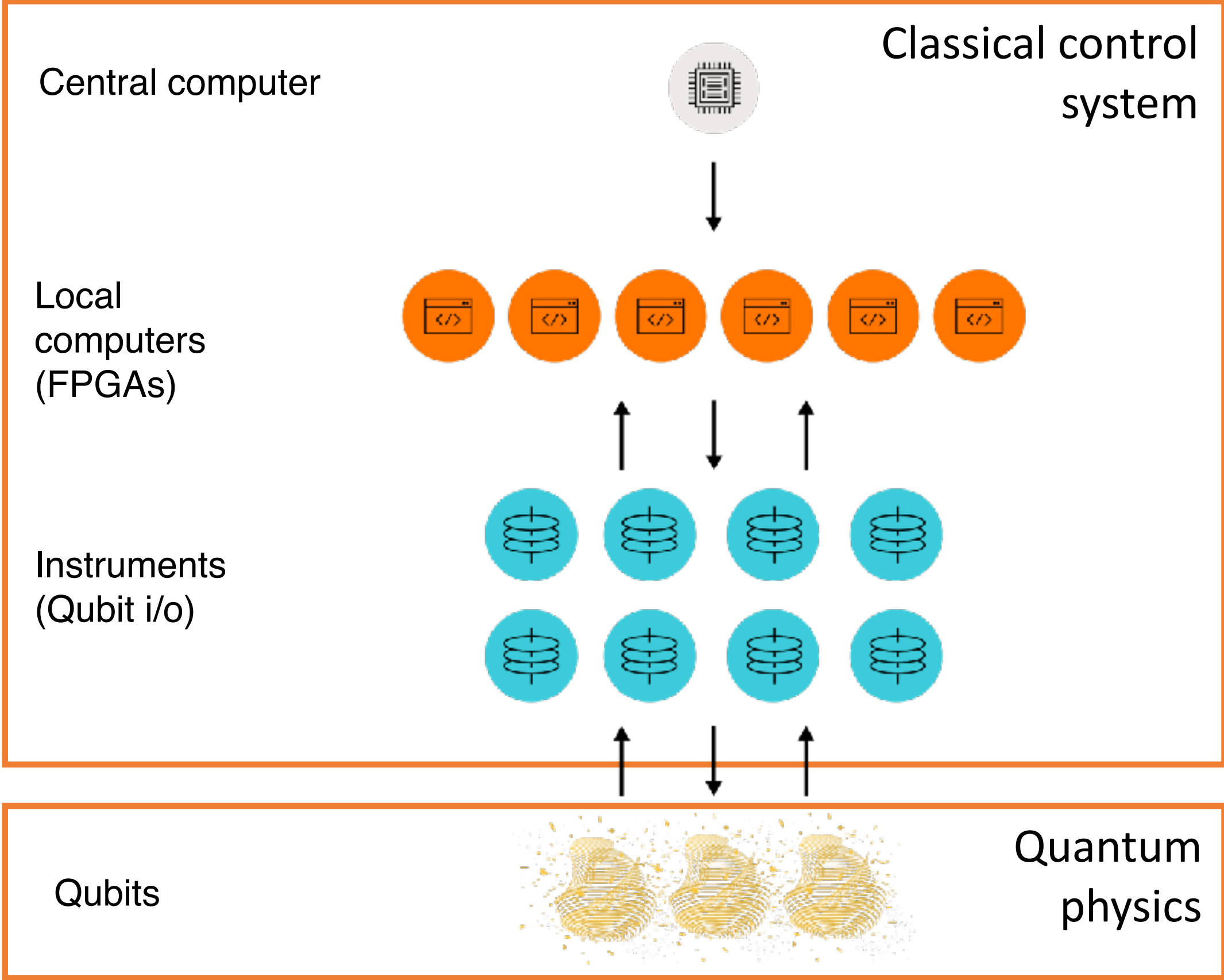


credit:Google



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

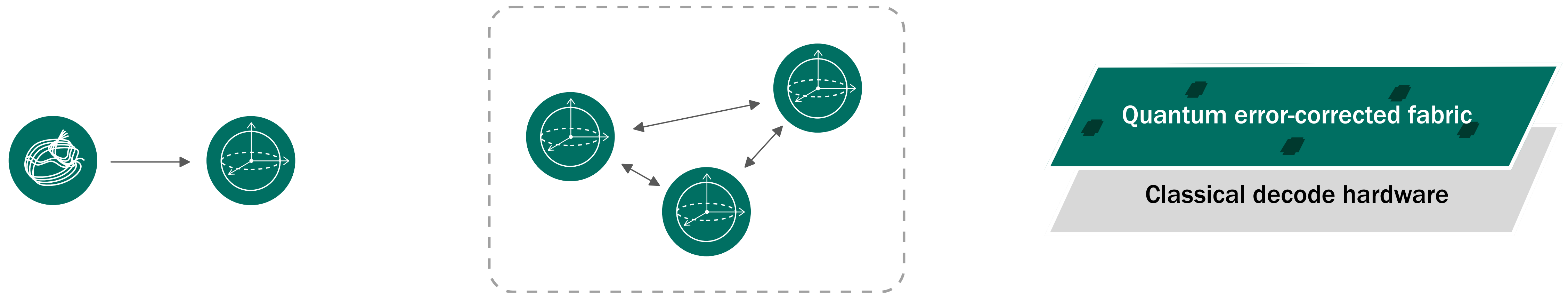
RTL, Verilog

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



Welcome to the error correction zoo!

**Jump to** ▶ Linear binary, Additive  $q$ -ary, RS, RM, LDPC, Polar, Rank-metric, STC, Stabilizer, CSS, Good QLDPC, Kitaev surface, Color, Topological, HQECC, EAQECC, Square-lattice GKP, Cat.

**Classical Domain** ▶ Binary Kingdom, Galois-field Kingdom, Matrix Kingdom, Analog Kingdom, Spherical Kingdom, Ring Kingdom, Group Kingdom.

**Quantum Domain** ▶ Qubit Kingdom, Modular-qudit Kingdom, Galois-qudit Kingdom, Bosonic Kingdom, Spin Kingdom, Group Kingdom, Category Kingdom.

**Classical-quantum Domain** ▶ Binary c-q Kingdom, Bosonic/analog c-q Kingdom.

**Code lists** ▶ 2D stabilizer codes, 3D stabilizer codes, Algebraic-geometry codes, Approximate quantum codes, Asymmetric quantum codes, Asymptotically good QLDPC codes and friends, Binary linear codes, Bosonic Fock-state codes, Bosonic stabilizer codes, Classical codes with a rate, Classical codes with notable decoders, Coherent-state c-q codes, Color code and friends, Combinatorial designs, Concatenated quantum codes, Constant-excitation quantum codes, Constant-weight codes, Cyclic codes, Cyclic quantum codes, Dynamically generated quantum codes.... (see all)

## Home Page

- [Code graph](#)
- [Code lists](#)
- [All codes](#)
- [Glossary of concepts](#)
- [Bibliographic references](#)

## More

- [Add new code](#)
- [Team](#)
- [About](#)

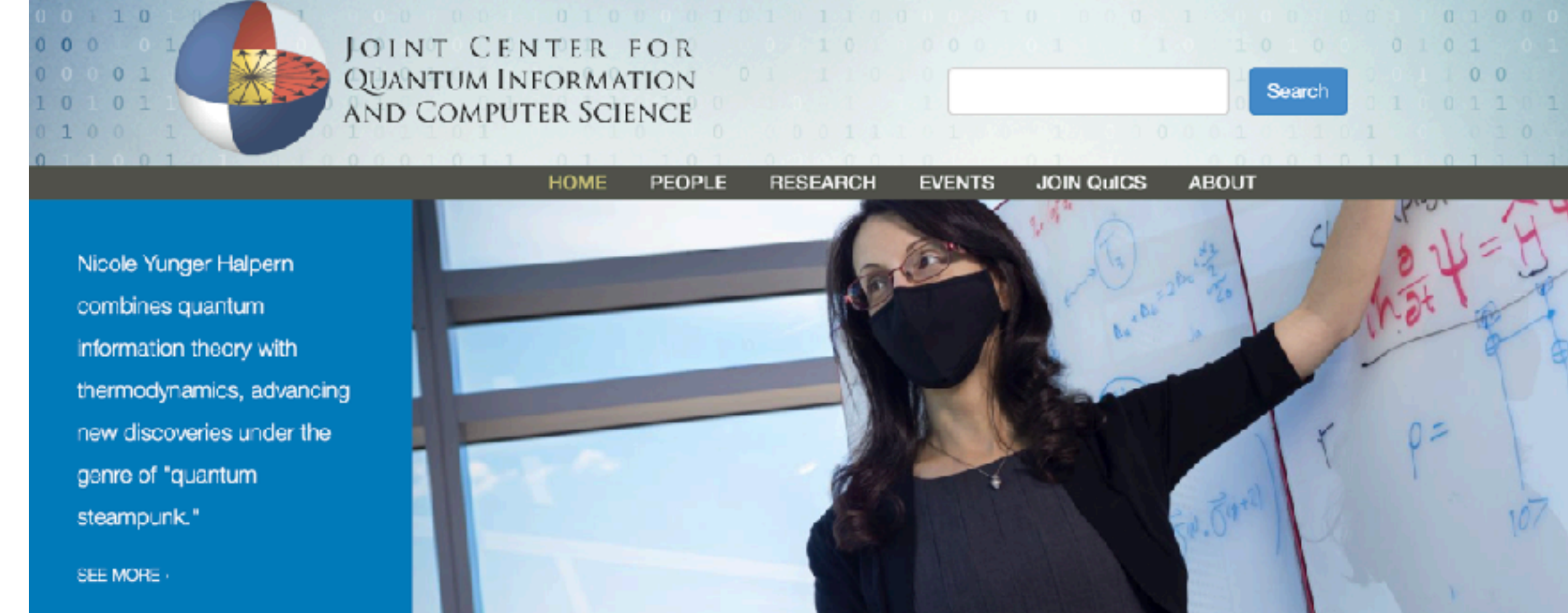


Stats at a glance: **910** code entries, **16** kingdoms, **3** domains, **391** classical codes, **910** quantum codes, **405** c-q codes, **71** topological codes, **140** quantum LDPC codes, **18** dynamically generated codes, **134** CSS codes, and **55** bosonic codes.

## Your Random Code Pick: Haah cubic code (CC)

[go](#) → [refresh](#)

*A 3D lattice stabilizer code on a length- $L$  cubic lattice with one or two qubits per site. Admits two types of stabilizer generators with support on each cube of the lattice. In the non-CSS case, these two are related by spatial inversion. For CSS codes, we require that the product of all corner operators is the identity. We lastly require that there are no ...*



## Latest QuICS News



**Yunger Halpern Makes Science News's 10 Scientists to Watch List**  
September 23, 2024

Nicole Yunger Halpern has been named one of Science News's 10 "Scientists to Watch" for her pioneering work in quantum thermodynamics. She blends historical concepts with modern technology to advance the understanding of small-scale systems like qubits.



**Gorshkov Named Finalist for 2024 Blavatnik National Awards for Young Scientists**  
September 11, 2024

The awards acknowledge the accomplishments and future potential of scientists and engineers who are 42 years old or younger.



**Hartree Fellow Uses Cryptography to Test Quantum Physics**

## Upcoming Events

### Workshop

**Advancing Quantum Computation Beyond Gate-Model (BQM2024)**  
Monday, October 7 at, University of Maryland College Park

### RQS Seminar

**Quantum Simulation of Spin-Boson Models with Structure Bath**  
Ke Sun (Duke University)  
Thursday, October 10 at 11:30 am, Virtual Via Zoom: <https://umd.zoom.us/j/99675829668>

### Friday Quantum Seminar

**Quantum Sensing, with Applications to Fundamental Physics**



## PROJECTS/PROGRAMS

# ITL Quantum Information Program

## Summary

Quantum science and engineering has the potential to revolutionize 21st century technology in much the same way that lasers, electronics, and computing did in the 20th century. The aim of ITL Quantum Information Program is to understand the potential for quantum-based technology to transform computing and communications, and to develop the measurement and standards infrastructure necessary to exploit this potential.

## DESCRIPTION

The principal goals of the ITL Quantum Information Program are:

## ORGANIZATIONS

[Information Technology Laboratory](#)

## NIST STAFF

- [Michael Frey](#)
- [Thomas Gerrits](#)
- [Scott Glancy](#)
- [Emanuel Knill](#)
- [Paulina Kuo](#)

# The Field of Dreams

Factoring  
(S)

## What we need:

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

Q simulation

### The outfield

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

- Q chemistry
- Q enhanced optimization
- Q sensing

2013  
WORLD SERIES