

UPDATE ON NIST AND THE NQI

CARL WILLIAMS, ACTING DIRECTOR PML

National Quantum Initiative (NQI) Act



H. R. 6227

One Hundred fifteenth Congress
of the
United States of America

AT THE SECOND SESSION
*Begun and held at the City of Washington on Wednesday,
the third day of January, two thousand and eighteen*

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:

[Sec. 1. Short title; table of contents.](#)

[Sec. 2. Definitions.](#)

[Sec. 3. Purposes.](#)

[TITLE I—NATIONAL QUANTUM INITIATIVE](#)

[Sec. 101. National Quantum Initiative Program.](#)

[Sec. 102. National Quantum Coordination Office.](#)

[Sec. 103. Subcommittee on Quantum Information Science.](#)

[Sec. 104. National Quantum Initiative Advisory Committee.](#)

[Sec. 105. Sunset.](#)

[TITLE II—NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY QUANTUM ACTIVITIES](#)

[Sec. 201. National Institute of Standards and Technology activities and quantum consortium.](#)

[TITLE III—NATIONAL SCIENCE FOUNDATION QUANTUM ACTIVITIES](#)

[Sec. 301. Quantum information science research and education program.](#)

[Sec. 302. Multidisciplinary Centers for Quantum Research and Education.](#)

[TITLE IV—DEPARTMENT OF ENERGY QUANTUM ACTIVITIES](#)

[Sec. 401. Quantum Information Science Research program.](#)

[Sec. 402. National Quantum Information Science Research Centers.](#)

1. H.R. 6227 (NQI) introduced June 26, 2018; passed House unanimously on Sept 16, 2018
2. December 13, 2018 passed Senate unanimously with an amendment
3. December 19, 2018 resolved in the House
4. December 21, 2018 presented to and signed by the President



SEC. 102. NATIONAL QUANTUM COORDINATION OFFICE – Interim Director is Jacob Taylor



SEC. 103. SUBCOMMITTEE ON QUANTUM INFORMATION SCIENCE – previously established under the NSTC



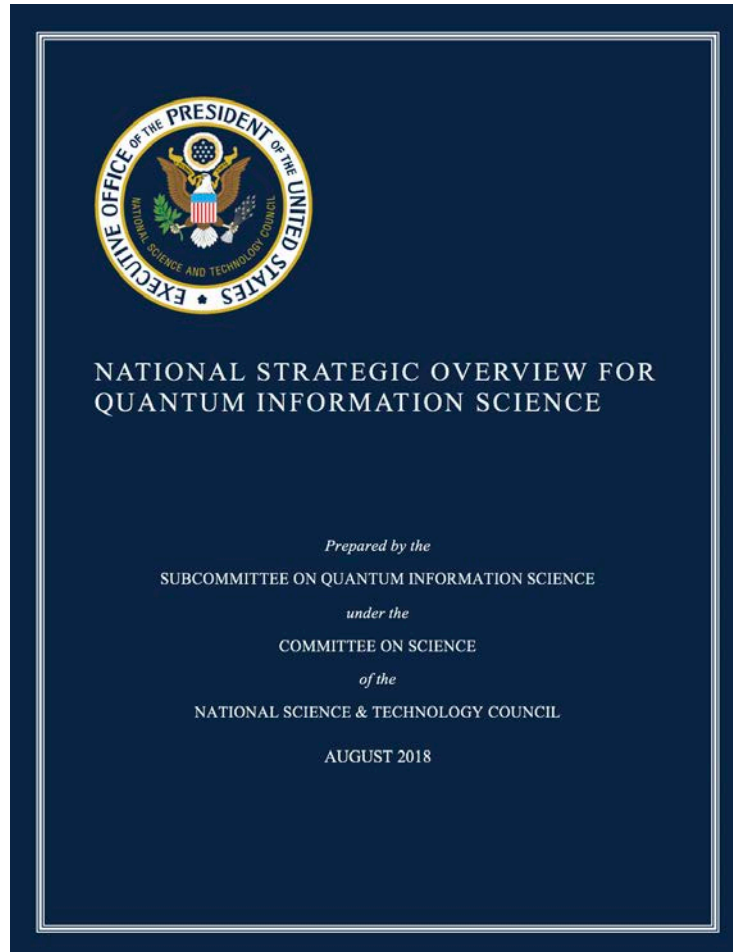
SEC. 104. NATIONAL QUANTUM INITIATIVE ADVISORY COMMITTEE – FACA committee being set up by DOE

Advancing a New National Strategy for QIS

- On September 23, 2018, OSTP/NSTC released a new national strategy for QIS – *consistent with the NQI Act*.
- On September 24, 2018, OSTP held a *Summit on Advancing American Leadership in QIS* with about 100 participants from academy, industry, and the USG. **Closing remarks were by Lamar Smith.**
- On May 31, 2019, OSTP held an *Academic Roundtable on Innovation in Quantum Information Science*



Key QIS Policy Opportunities



- Choosing a science-first approach to QIS
- Creating a quantum-smart workforce for tomorrow
- Deepening engagement with quantum industry
- Providing critical infrastructure
- Maintaining national security and economic growth
- Advancing international cooperation

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, a Quantum Consortium, and the NQI



SEC. 201. Quantum Consortium:

Not later than 1 year after the date of enactment of this Act, the Director of the NIST shall convene a consortium of stakeholders to identify the future measurement, standards, cybersecurity, and other appropriate needs for supporting the development of a robust quantum information science and technology industry in the United States.



GOALS:

- to assess the current research on the needs identified *to the left*
- to identify any gaps in the research necessary to meet the needs *to the left*
- to provide recommendations on how the NIST and the Program can address the gaps *to the left*

REPORT TO CONGRESS:

Not later than 2 years after the date of enactment of this Act, NIST shall submit Congress a report summarizing the findings of the consortium.



But what does it take to build a quantum industry and the supporting ecosystem?

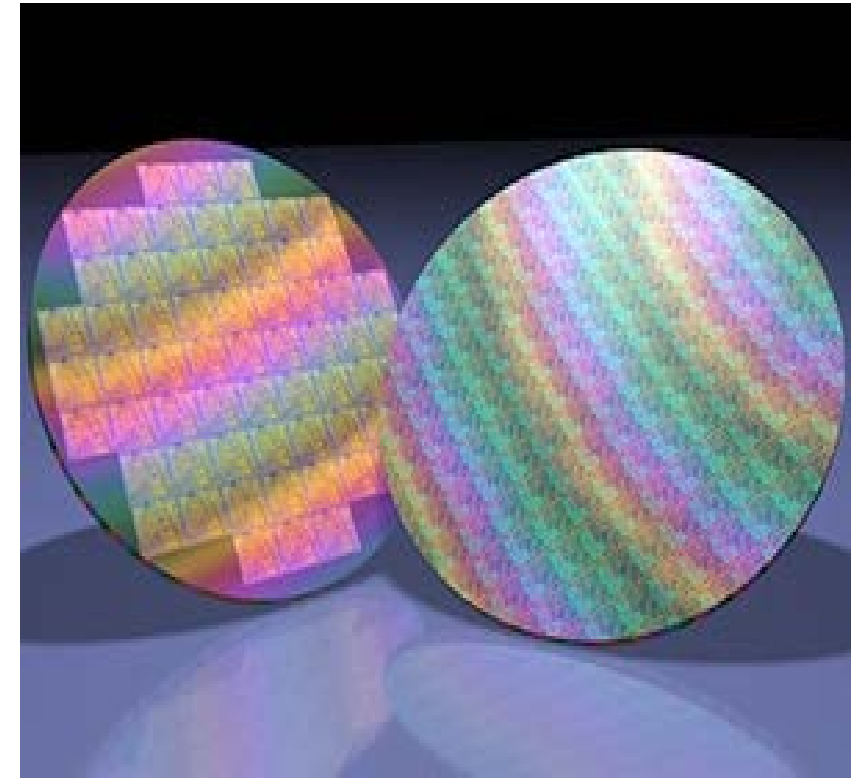
Birth and Development of an Industry



First Transistor, 1947
William Shockley, John Bardeen, and
Walter Brattain

INDUSTRY & INFRASTRUCTURE

- Wafer processing
 - Wet cleans
 - Cleaning by solvents
 - Piranha solution
 - RCA clean
 - Photolithography
 - Ion implantation
 - Dry etching
 - Wet etching
 - Plasma ashing
 - Thermal treatments
 - Rapid thermal anneal
 - Furnace anneals
 - Thermal oxidation
 - Chemical vapor deposition (CVD)
 - Physical vapor deposition (PVD)
 - Molecular beam epitaxy (MBE)
 - Electrochemical deposition (ECD)
 - Chemical-mechanical planarization (CMP)
- Wafer testing
- Wafer backgrinding
- Die preparation
 - Wafer mounting
 - Die cutting
- IC packaging
 - Die attachment
 - IC bonding
 - Wire bonding
 - Thermosonic bonding
 - Flip chip
 - Wafer bonding
 - Tape Automated Bonding (TAB)
 - IC encapsulation
 - Baking
 - Plating
 - Lasermarking
 - Trim and form
- IC testing



2018, IC (12", < 10 nm)

Complements J. Broz, SRI

Quantum Economic Development Consortium



← QED-C Quantum Consortium Activities →

STAGE & TRL:	Basic R&D 1	Application R&D 2	Device Prototypes 3	Enabling Component Development 4	Prototype Components and Subsystems 5
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ACTIVITY:

Understanding Physical Phenomena	Exploiting & Controlling Phenomena	Create First of a Kind Devices	Create Key Sub-Components & Devices/ T&E/ Performance Stds.	Develop Efficient Common Purpose-Driven Device Designs/ T&E/ Stds.
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EFFICIENCIES:

Public/Private Support: Funding & Collaboration	Introduce New Common Enabling Devices Performance Standards
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ENGAGED DISCIPLINES:

AMO Physics / Scientific Theory / R&D / Materials

T&E / Engineering Design & Development

- De-risked components
 - Robust infrastructure
 - Common standards
 - Testbeds
- Create Device Production Equipment Standards

- Competitive R&D And Industry Activities:**
- Production Equipment Fabrication & Sales
 - COTS Device Manufacturing & Sales
 - Full Quantum Systems
 - Deploy Quantum Systems at Utility Scale
- COTS Device & Systems Performance Standards

QED-C is being established in partnership with SRI International under the leadership of Joe Broz, Vice President of SRI's Advanced Technology and Systems Division (ATSD)

Contact: joe.broz@sri.com

Purpose and Objectives of the QED-C:



- To support enabling technology R&D and enhance the quantum ecosystem: (e.g., quantum device components, instrumentation, and performance standards)
- To facilitate industry coordination & interaction with Government agencies
- Determine workforce needs essential to the development of quantum technologies
- Provide efficient public-private sector coordination
- Identify technology solutions for filling gaps in research or infrastructure
- Highlight use cases & grand challenges to accelerate development efforts
- Foster sharing of intellectual property, efficient supply chains, technology forecasting and quantum literacy

Meetings:

1st August 21, 2018 at SRI International in Menlo Park, CA

2nd October 29-30, 2018 at NIST in Boulder, CO

3rd January 22-23, 2019 at CU in Boulder, CO

4th April 30 - May 1 in Gaithersburg, MD



Governing Board & TACs

- Governing Board elected: 3 large and 4 small/start-up companies, 2 government agencies 10/29/2018
- Technical Advisory Committee established 10/29/2018



NIST Support

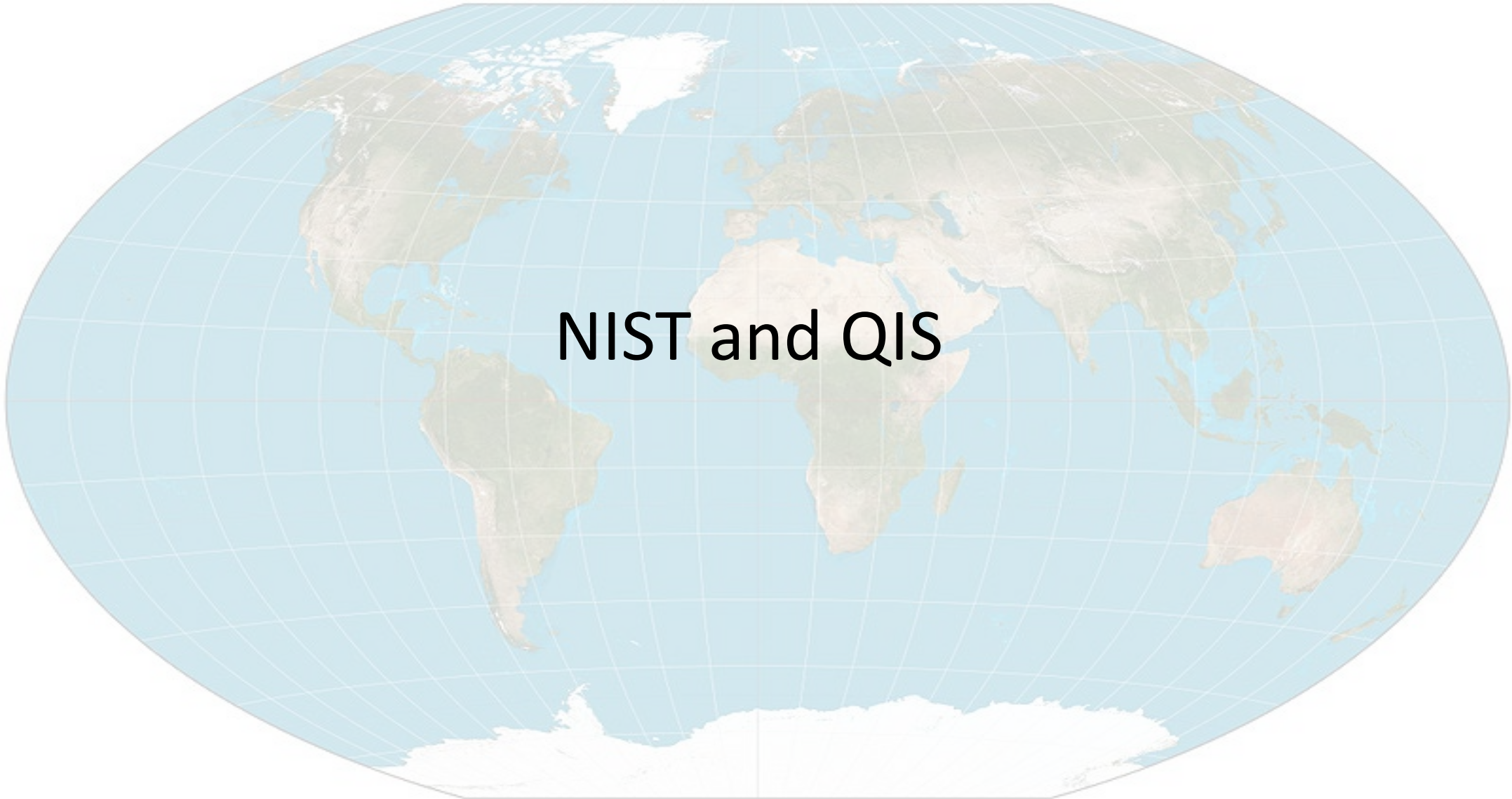
Initiated under a CRADA in June 2018 the QED-C will be the first use of *Other Transaction Authority*



Legal Structure

Formal legal structure and participation agreements are expected in fall 2019.

More than 60 Letters of Intent have been received



NIST and QIS

NIST and the NQI (SEC. 201.)



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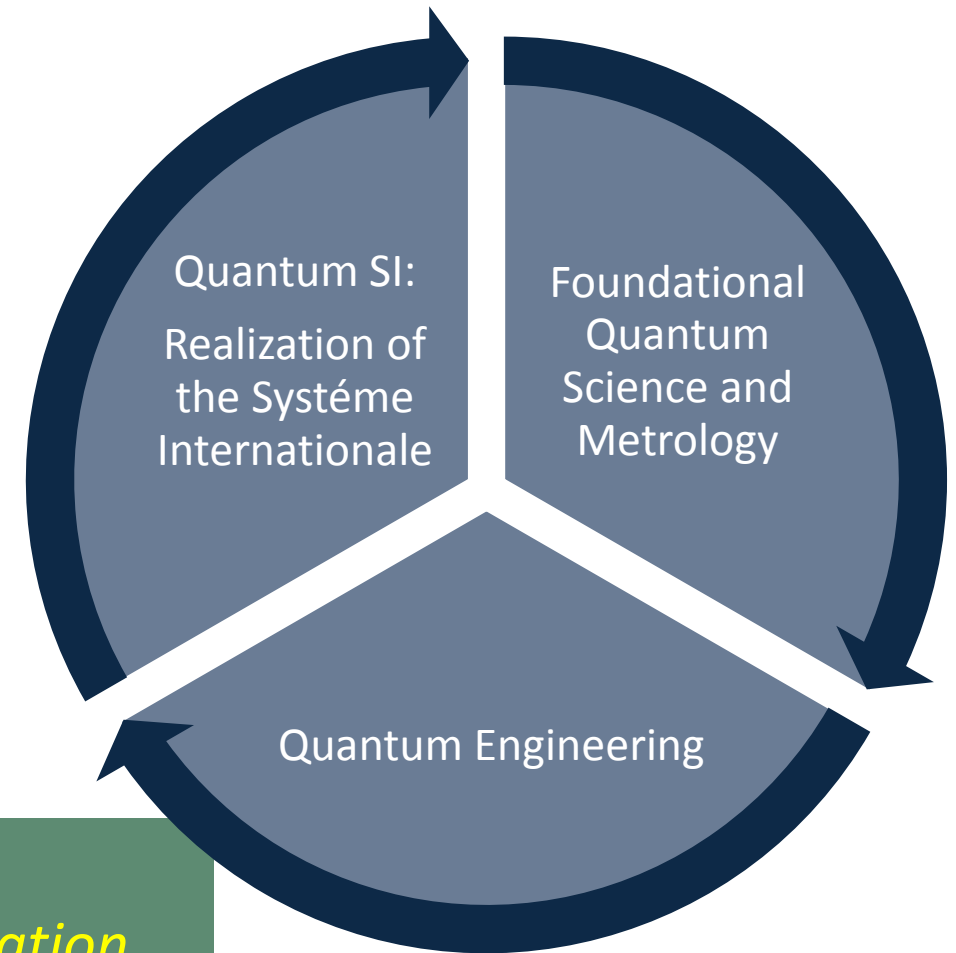
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NIST QIS Strategic Vision

NIST will fulfill its mission in QIS through three coordinated efforts:

- Foundational research emphasizing QIS and Metrology
- Applied research to engineer and improve the robustness of prototypes: Quantum Engineering
- Realization and Dissemination of the units of measure: The Quantum SI



These three activities form an interrelated and self-reinforcing system in which, for example, next-generation atomic clocks are engineered to be smaller and more robust and thereby enable tomorrow's measurement services.

NIST Existing Joint Institutes



Three collaborative institutes at two locations provide opportunities to:

- Attract world class scientists
- Train students and postdocs
- Transfer technology

JILA Background

- Joint institute of NIST and the University of Colorado (CU), established in 1962
- Physically located at CU - Boulder
- 30 JILA Fellows (12 NIST, 18 CU)
- 200 total people
- Known as a leading research center in:
 - Astrophysics
 - Atomic and Molecular Physics
 - Biophysics
 - Chemical Physics
 - Laser Physics
 - Nanoscience
 - Precision Measurement
 - Quantum Information



Joint Quantum Institute (JQI) Background

NIST

- Joint institute of NIST and the University of Maryland, modeled in part on JILA, and established in 2006
- Physically located at UMD - College Park
- 30 JQI Fellows (13 NIST, 16 UMD, and 1 LPS)
- 200 people, and still growing
- Known as a leading center for quantum science, including:
 - Cold quantum matter (AMO Physics)
 - Quantum matter and materials (Condensed Matter Physics)
 - Quantum Information

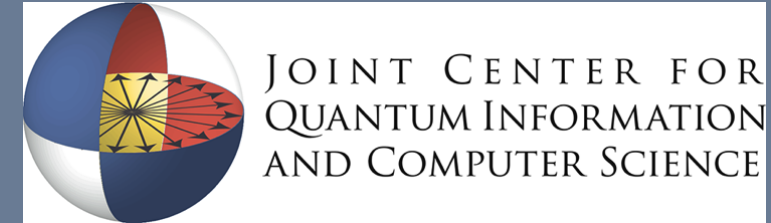


Labs of the JQI
College Park, Maryland

Joint Center for Quantum Information in Computer Science (QuICS) Background



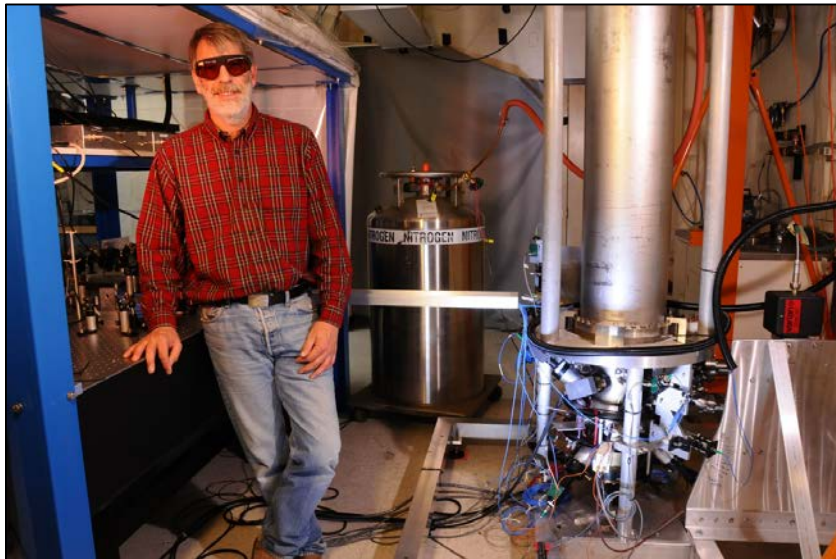
- Established in 2014
- Physically located at UMD - College Park
- 13 QuICS Fellows (6 NIST and 6 UMD)
 - 5 Fellows (4 NIST, 1 UMD) are joint with JQI
- 60 people and growing
- Already a leading center for quantum information in computer science
 - How does quantum mechanics inform the theory of computation and communication?
 - What insight does computer science shed on quantum computing?
 - What are the consequences of quantum information theory for fundamental physics?
 - How can theoretical advances in computation and communication be applied?



QuICS
College Park, Maryland

The Power of One Quantum Bit

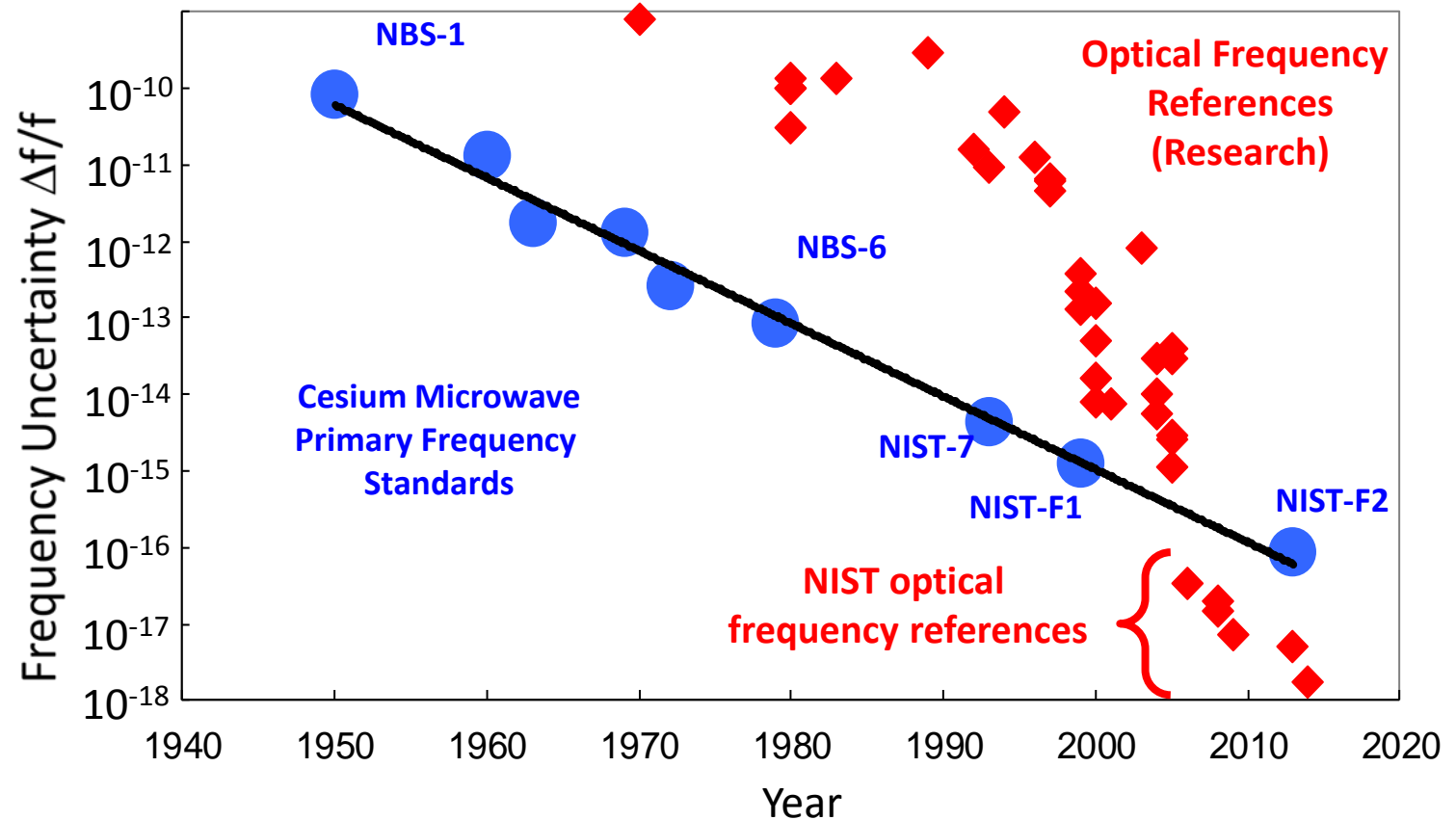
1 second is defined as the duration of 9,192,631,770 cycles of the cesium hyperfine transition.



NIST-F2 laser-cooled atomic clock

- Frequency uncertainty: $\Delta f/f = 1 \times 10^{-16}$
- 1 second in 300 million years.
- Enabled by laser cooling and trapping.

- Optical frequency standards have shown better fractional uncertainty since 2005
- Possible redefinition of time being discussed for 2026



Science 329, 11630, 2010

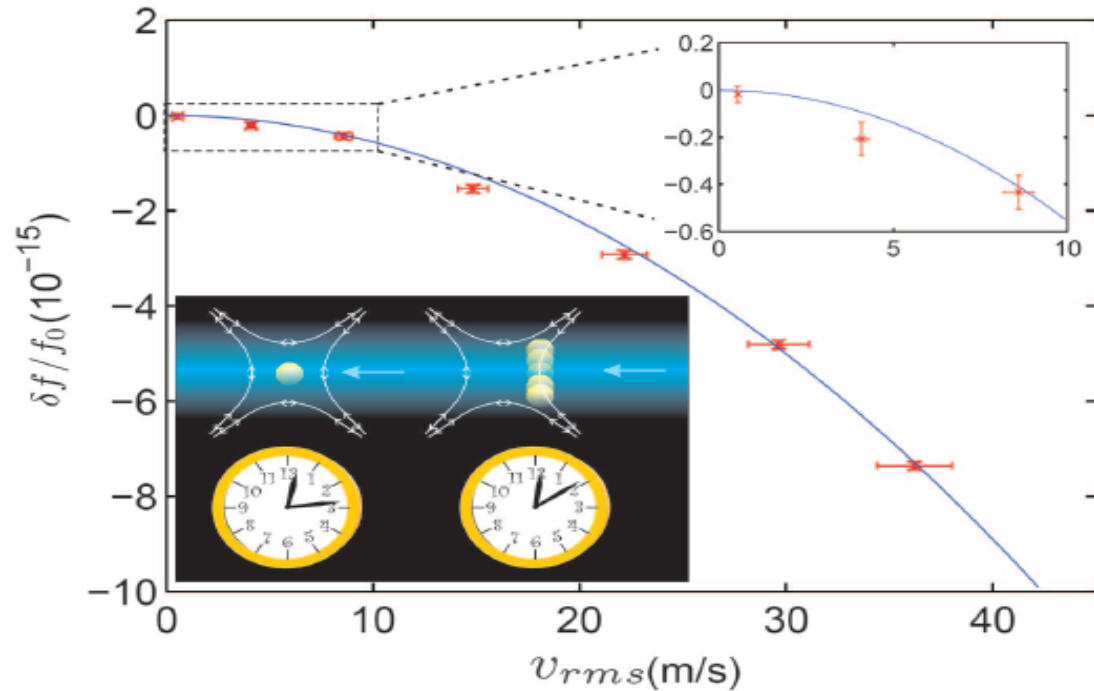


Fig. 2. Relativistic time dilation at familiar speeds ($10 \text{ m/s} = 36 \text{ km/hour} \approx 22.4 \text{ miles/hour}$). (Lower left inset) As the Al^+ ion in one of the twin clocks is displaced from the null of the confining RF quadrupole field (white field lines), it undergoes harmonic motion and experiences relativistic time dilation. In the experiments, the motion is approximately perpendicular to the probe laser beam (indicated by the blue shading). The Al^+ ion clock in motion advances at a rate that is slower than its rate at rest. In the figure, the fractional frequency difference between the moving clock and the stationary clock is plotted versus the velocity ($v_{\text{rms}} = \sqrt{\langle v^2 \rangle}$) (ms, root mean square) of the moving clock. The solid curve represents the theoretical prediction. (Upper right inset) A close-up of the results for $v_{\text{rms}} < 10 \text{ m/s}$ in the dashed box. The vertical error bars represent statistical uncertainties, and the horizontal ones cover the spread of measured velocities at the applied electric fields.

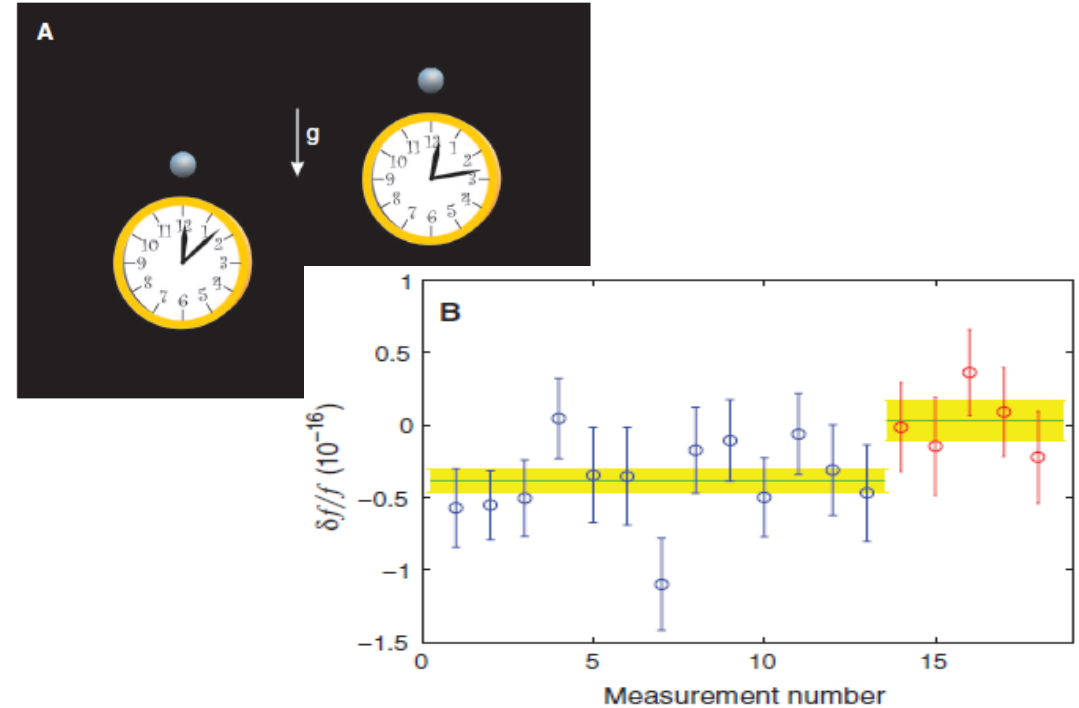
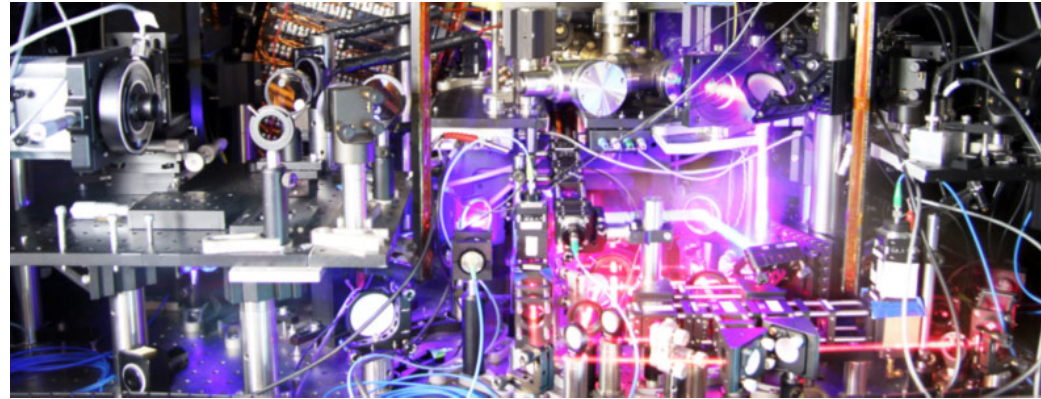
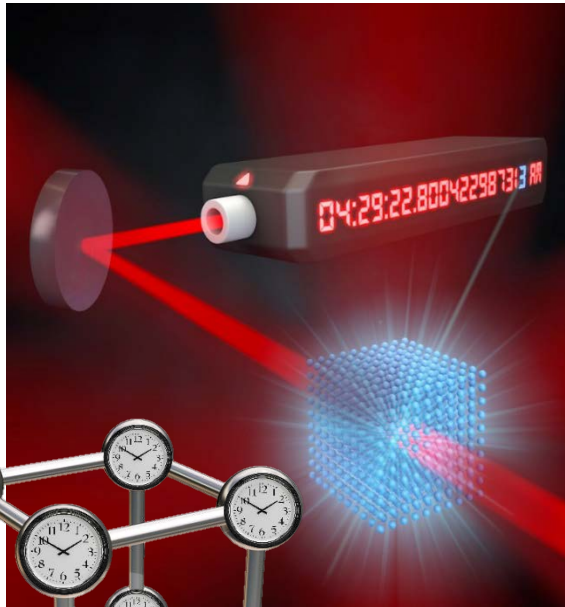


Fig. 3. Gravitational time dilation at the scale of daily life. (A) As one of the clocks is raised, its rate increases when compared to the clock rate at deeper gravitational potential. (B) The fractional difference in frequency between two Al^+ optical clocks at different heights. The Al-Mg clock was initially 17 cm lower in height than the Al-Be clock, and subsequently, starting at data point 14, elevated by 33 cm . The net relative shift due to the increase in height is measured to be $(4.1 \pm 1.6) \times 10^{-17}$. The vertical error bars represent statistical uncertainties (reduced $\chi^2 = 0.87$). Green lines and yellow shaded bands indicate, respectively, the averages and statistical uncertainties for the first 13 data points (blue symbols) and the remaining 5 data points (red symbols). Each data point represents about 8000 s of clock-comparison data.

Quantum Degenerate Fermi Gas Clock

3D Fermi gas strontium (Sr) optical lattice clock



S.L. Campbell *et al.*, *Science* **358**, 90 (2017); G.E. Marti *et al.*, *Phys. Rev. Lett.* **120**, 103201 (2018); Jun Ye group JILA, *unpublished*.

- First application of a quantum degenerate gas to a “practical” measurement: *A quantum-enhanced precision measurement*
 - ✓ ~1 million atoms: 100 x 100 x 100 in a 3D-optical lattice
 - ✓ Pauli exclusion: Only one atom per lattice site
 - ✓ Precision 3×10^{-20} in one second, on path to 10^{-22} in a few years
 - ✓ Coherence time 160 seconds and improving
- Potential laboratory for fundamental physics, including quantum gravity, dark matter detection, and long-baseline astronomical observation

One Concept for a NIST Grand Challenge

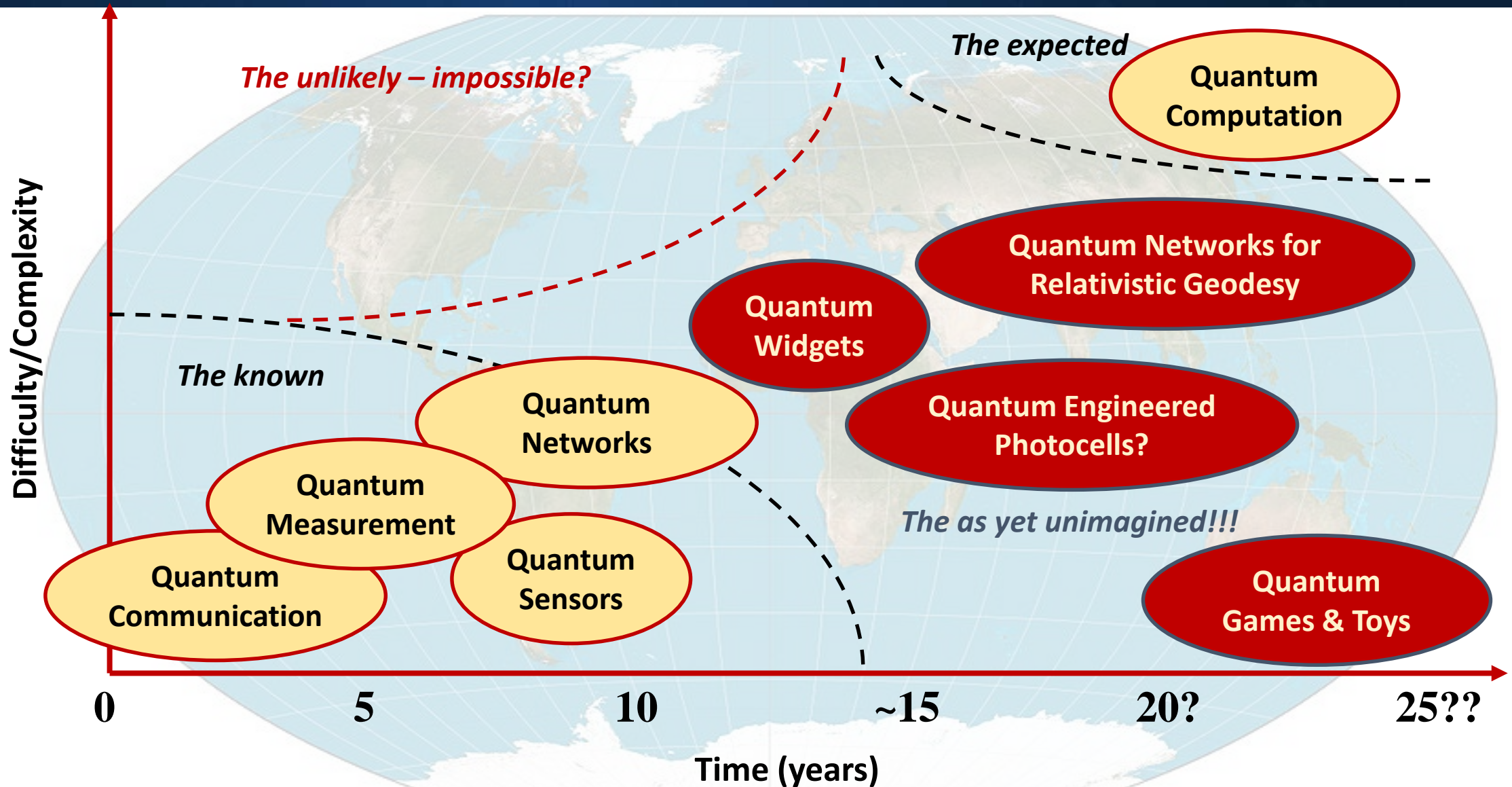
Build a prototype 2-3 node Quantum Network that distributes, stores, and entangles states of matter for sufficient time to support R&D, sensing, and metrology using various technologies – *e.g.* long baseline entangled clocks

Requires: Quantum memory, quantum repeaters, small quantum processors, transduction, quantum error correction, entanglement purification

Provides: A testbed for system components and standards and supports basic R&D

Allows: Development of improved components, entanglement of distant clocks or sensors, exploration of quantum enhanced long baseline interferometry

Quantum Information Timeline





QUESTIONS?

Potential Questions for Discussion

- Is this a reasonable approach to NIST's future activities in QIS?
- How does NIST determine the correct balance between quantum engineering, quantum metrology, and the quantum SI?
- What new methods for effective technology transfer of emerging quantum technologies should NIST explore?
- Are there new new mechanisms and tools that lower barriers and enhance engagement between government, academia, and industry?
- In a larger quantum engineering effort what should be the role of centers?
- What should NIST focus on in a new center and why?
- *Do you have advice about a quantum consortium?*