

# NSF's Quantum Leap

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MPS Advisory Committee Meeting



# NSF's Big Ideas for Future NSF Investments

- *Bold questions that will drive NSF's long-term research agenda*
- *Catalyze investment in fundamental research*
- *Collaborations with industry, private foundations, other agencies, universities*
- *Solve pressing problems and lead to new discoveries*

The infographic is titled "Looking Ahead: Ten Big Ideas" and features the NSF logo in the top left corner. It is divided into two main sections: "RESEARCH IDEAS" and "PROCESS IDEAS".

**RESEARCH IDEAS:**

- Navigating the New Arctic:** An image of a person on a small boat in a vast, icy Arctic sea.
- Harnessing Data for 21st Century Science and Engineering:** A graphic with the text "DATA SCIENCE" and "ANALYTICS & DATA MINING" surrounded by terms like "STATISTICAL COMPUTATIONAL FOUNDATIONS", "OPEN SCIENCE", "EDUCATION WORKFORCE", and "MACHINE LEARNING".
- Work at the Human-Technology Frontier: Shaping the Future:** An image of a hand reaching towards a futuristic, glowing robotic arm.
- Understanding the Rules of Life: Predicting Phenotype:** An image of various colorful mushrooms.
- The Quantum Leap: Leading the Next Quantum Revolution:** An image of a quantum circuit or chip, highlighted with a red circle.
- Windows on the Universe: The Era of Multi-messenger Astrophysics:** An image of a satellite or telescope in space.

**PROCESS IDEAS:**

- Growing Convergent Research at NSF:** An image of colorful, glowing particles or cells.
- NSF-Includes: Enhancing Science and Engineering through Diversity:** An image of a diverse group of people.
- Mid-scale Research Infrastructure:** An image of a large steel truss bridge over water.
- NSF 2050: Seeding Innovation:** An image with the text "NSF 2050" and "SEEDING INNOVATION" over a blue, abstract background.

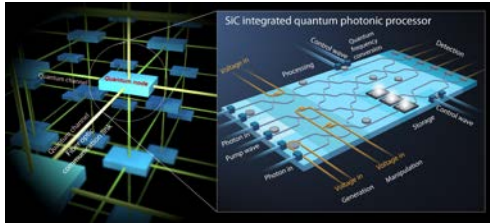
# NSF's Quantum Leap: Leading the Next Quantum Revolution

*Discovery and exploitation of quantum science and engineering to realize dramatic advances in devices, systems, and in science and engineering itself.*

- *Exploiting quantum mechanics to observe, manipulate, and control the behavior of particles at atomic and subatomic scales;*
- *enabling breakthrough discoveries in both naturally-occurring and in engineered quantum systems; and*
- *developing next-generation quantum technologies and devices for sensing, information processing, communications, and computing*

# The Quantum Leap: Realizing Ambitious Goals

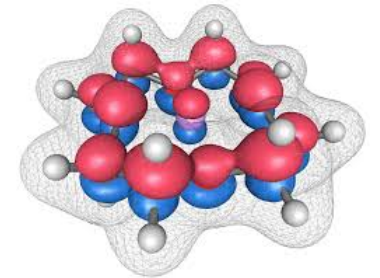
Technologies and devices



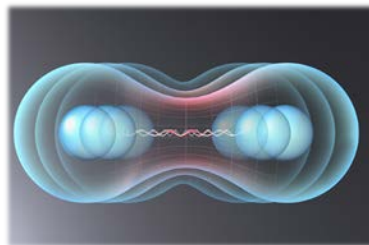
Materials, metrology, sensing, secure communications, computing

Understanding natural and engineered quantum systems

Complexity, simulation, emergent behavior, theory, quantum/classical



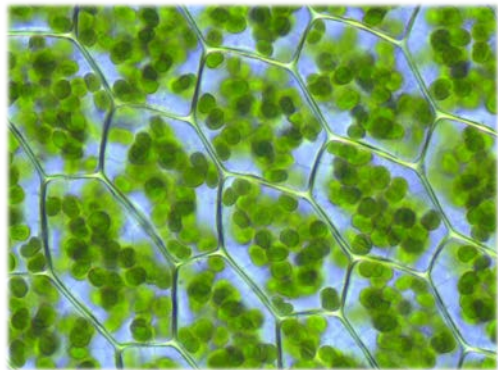
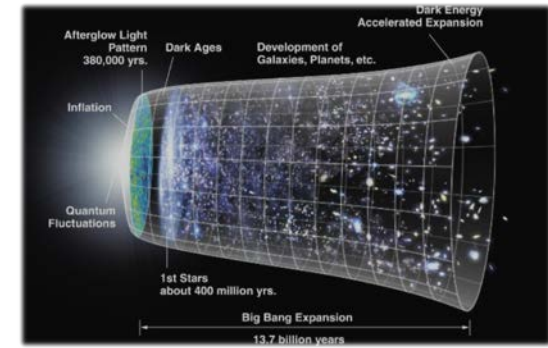
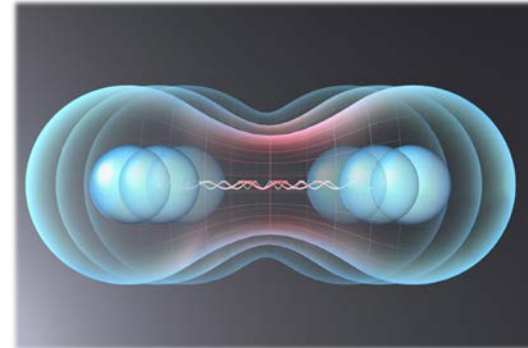
Fundamental science



Entanglement, coherence, squeezing

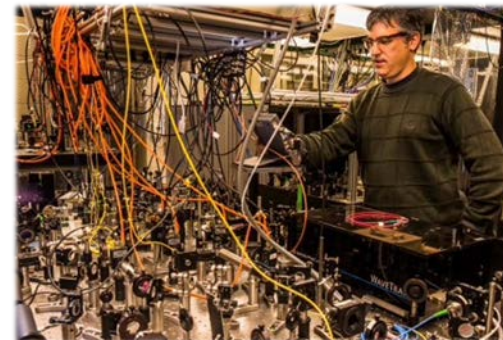
# Quantum Leap : Asking Ambitious Questions

Q1: Are there fundamental limits to how far we can push the **entanglement and coherence** frontiers for quantum states? Are there limits in time, distance, or scale?



Q2: What can we learn from quantum phenomena in **naturally-occurring and engineered quantum systems**, including emergent behavior, complexity, quantum-classical boundaries, and their theoretical foundations?

Q3: How do we galvanize the science and engineering **community** to enable quantum devices, systems, and technologies that **surpass classical** capabilities?



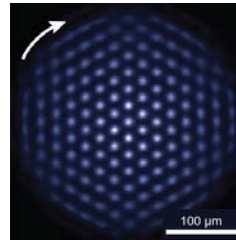
# Answering Big Questions

Q1: Are there fundamental limits to how far we can push the **entanglement and coherence frontiers** for quantum states? Are there limits in time, distance, or scale?

**Scale limits:** How many qubits can we entangle?

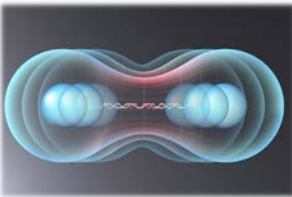


Sequential loading of Yb ions into a linear Paul trap. (physic.uni-siegen.de)



Quantum simulator formed with trapped Be ions in a Penning trap. Britton/NIST.

**Distance limits:** How far can we entangle quantum states?



**Time limits:** How long can quantum states live? Can we send them into the future?



[www.wired.com/2011/01/timelike-entanglement/](http://www.wired.com/2011/01/timelike-entanglement/)

*Are there fundamental thermodynamic limits?*

## Expected advances

Quantum Communications across the Globe



scmp.com

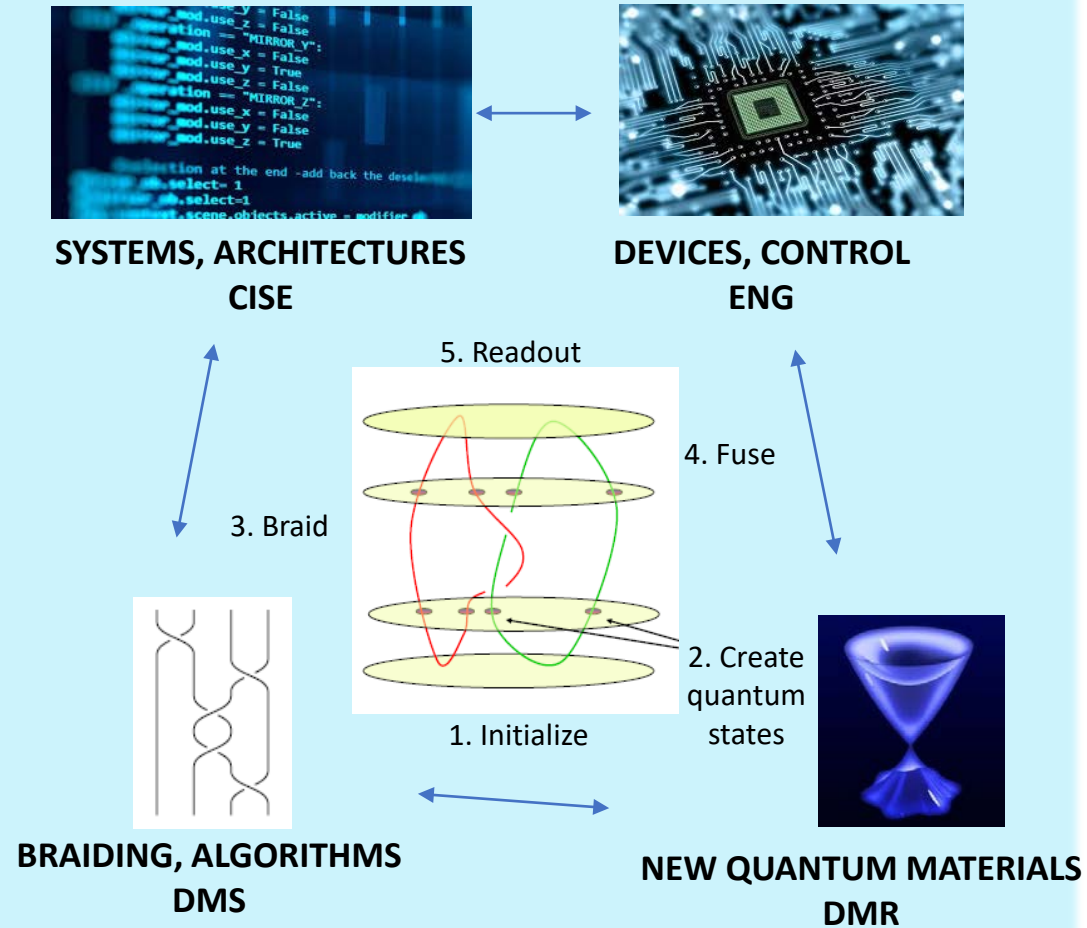
Scalable quantum computer



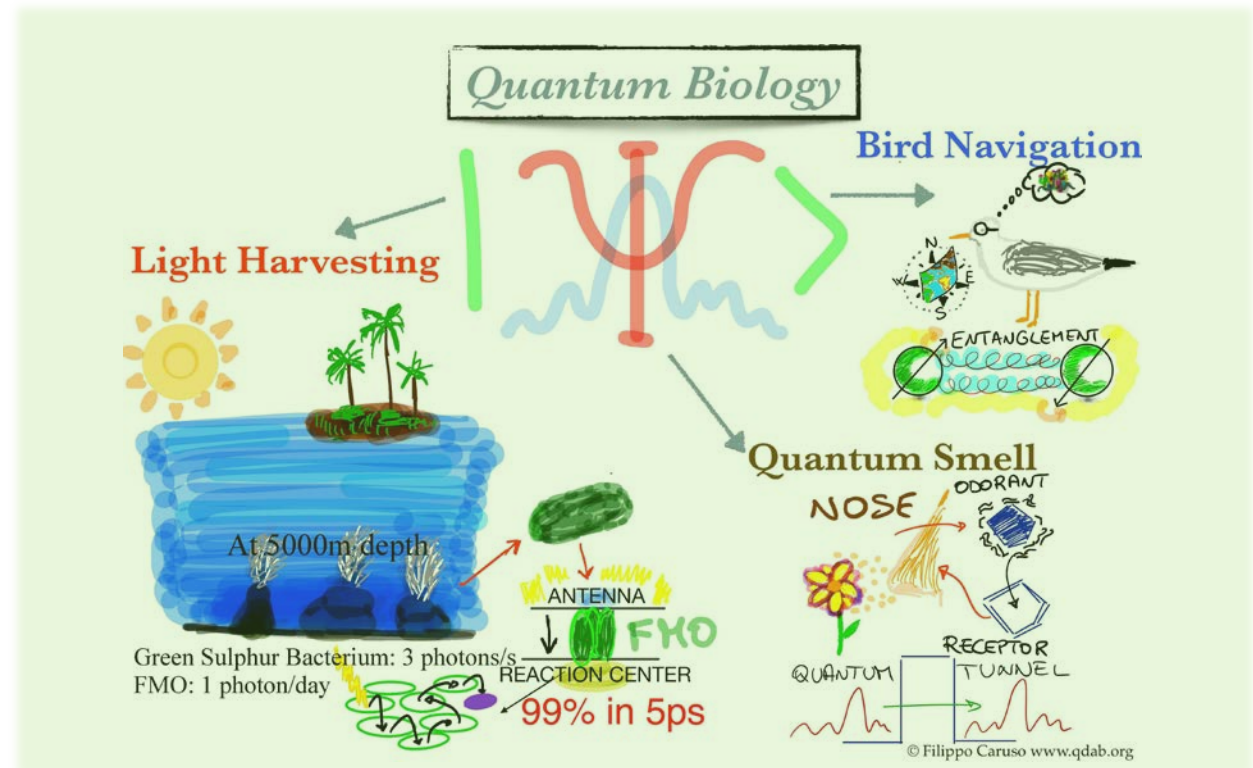
IBM Q

# Answering Big Questions

## Topological Quantum Computing: An Emerging Area



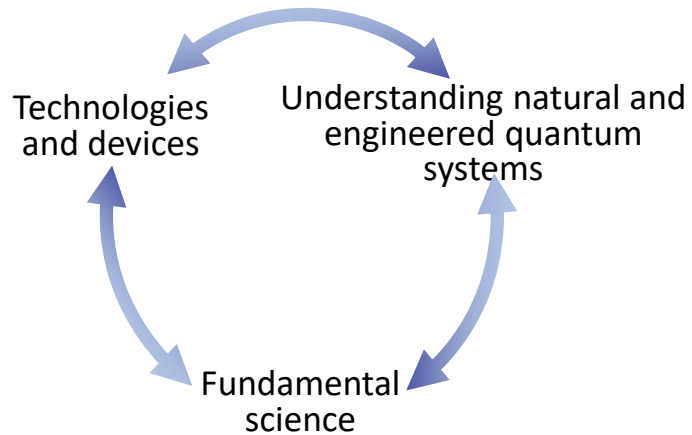
Q2: What can we learn from quantum phenomena in **naturally-occurring and engineered quantum systems**, including emergent behavior, complexity, quantum-classical boundaries, and their theoretical foundations?



[Filippo Caruso (Lindau Meeting, 2016)]

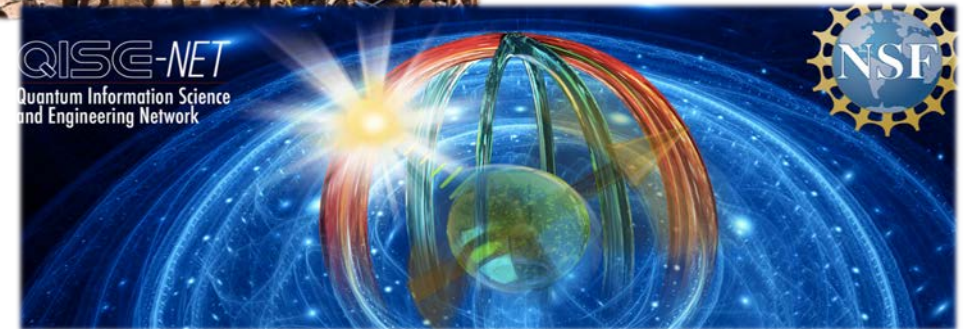
# Answering Big Questions

Q3: How do we galvanize the science and engineering **community** to enable quantum devices, systems, and technologies that **surpass classical** capabilities?



- Instill quantum thinking
- New curricula in Quantum Science & Engineering
- Partnerships: federal agencies, private sector, international funders, and private foundations.

capacity building, workforce



$$i\hbar \frac{\partial}{\partial t} |\Psi(\mathbf{r}, t)\rangle = \hat{H} |\Psi(\mathbf{r}, t)\rangle$$

*I do not like it, and I am sorry I ever had anything to do with it.* – Erwin Schrödinger

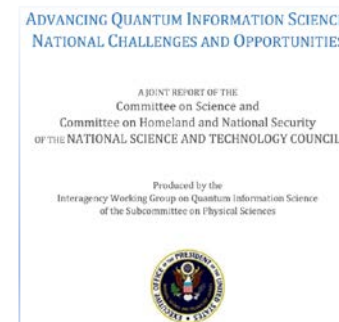


# The Quantum Leap: Why Now?

- inflection point in science advances, technology/instrumentation capabilities enables opportunity, rapid advances
- international competition
- opportunities for collaboration
- “to promote the progress of science; to advance the national health, prosperity, and welfare; to secure the national defense...”



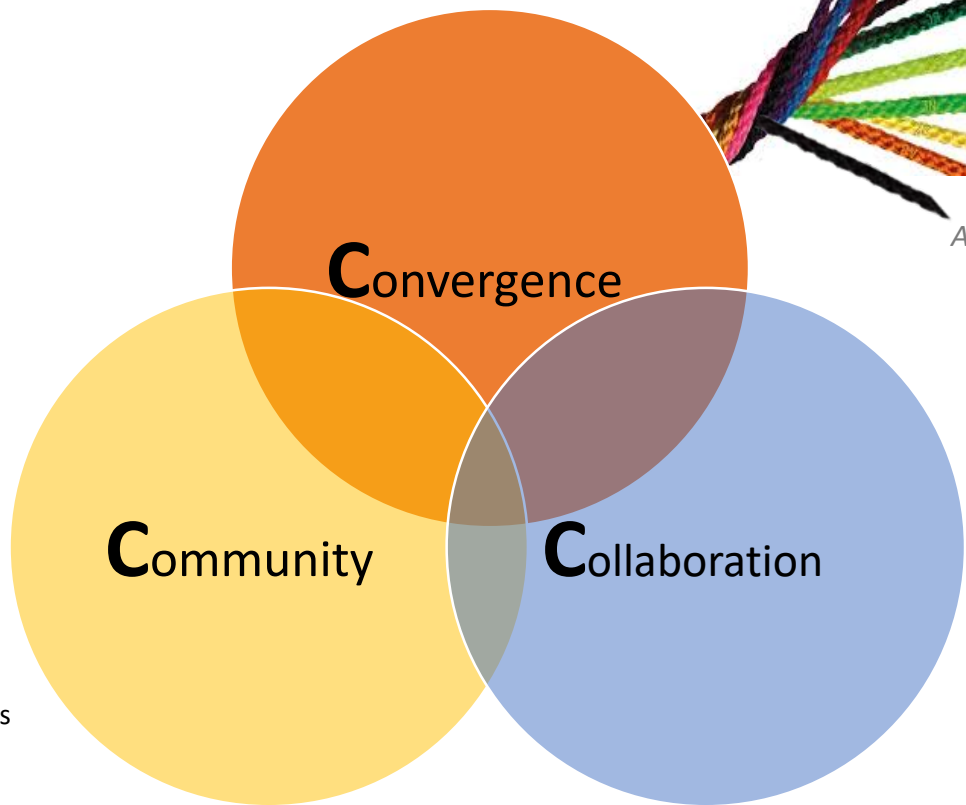
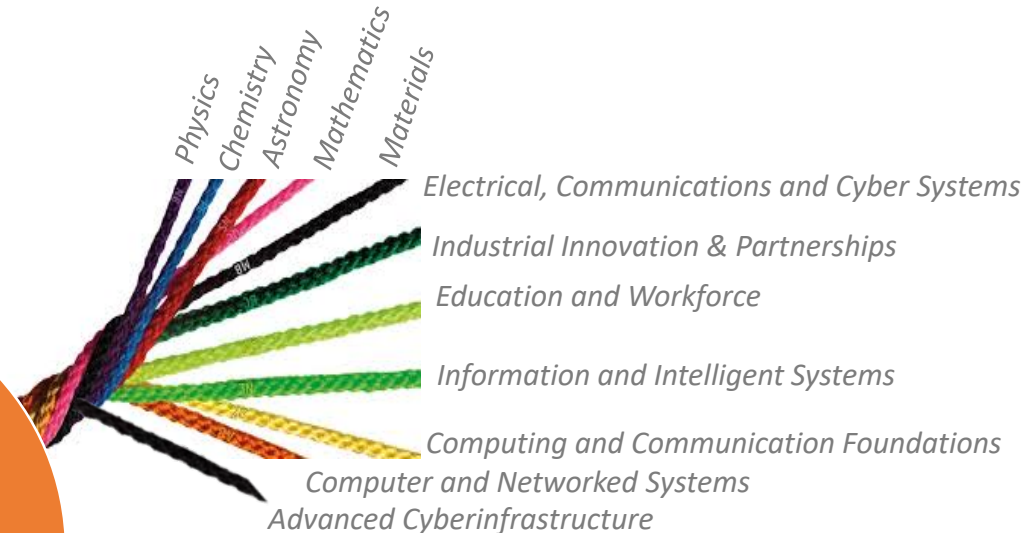
31 “quantum”  
Nobels supported  
by NSF (since ‘64)



Congressional Hearing: *American Leadership in Quantum Technology*

# Our Approach

## The 3 C's

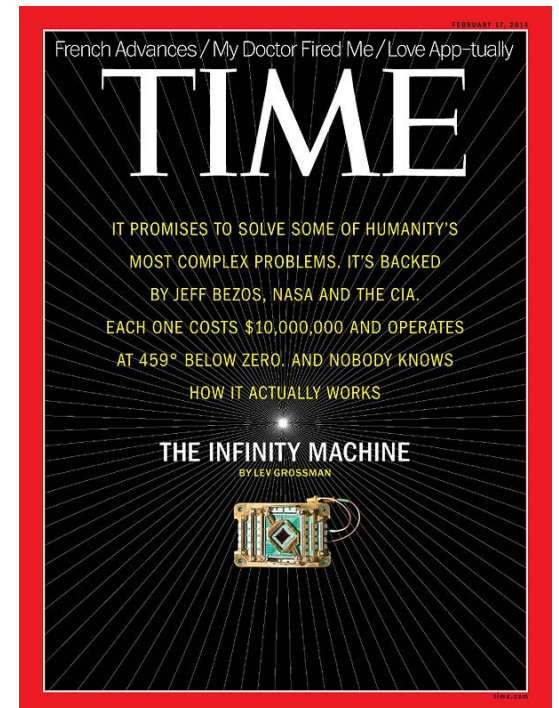


$$\left| \text{Quantum Workforce} \right\rangle = c_1 \left| \begin{array}{c} \text{Materials} \\ \text{Researchers \&} \\ \text{Chemists} \end{array} \right\rangle + c_2 \left| \begin{array}{c} \text{Engineers} \end{array} \right\rangle + c_3 \left| \begin{array}{c} \text{Physicists} \end{array} \right\rangle + c_4 \left| \begin{array}{c} \text{Mathematicians} \\ \text{\& Computer} \\ \text{Scientists} \end{array} \right\rangle$$



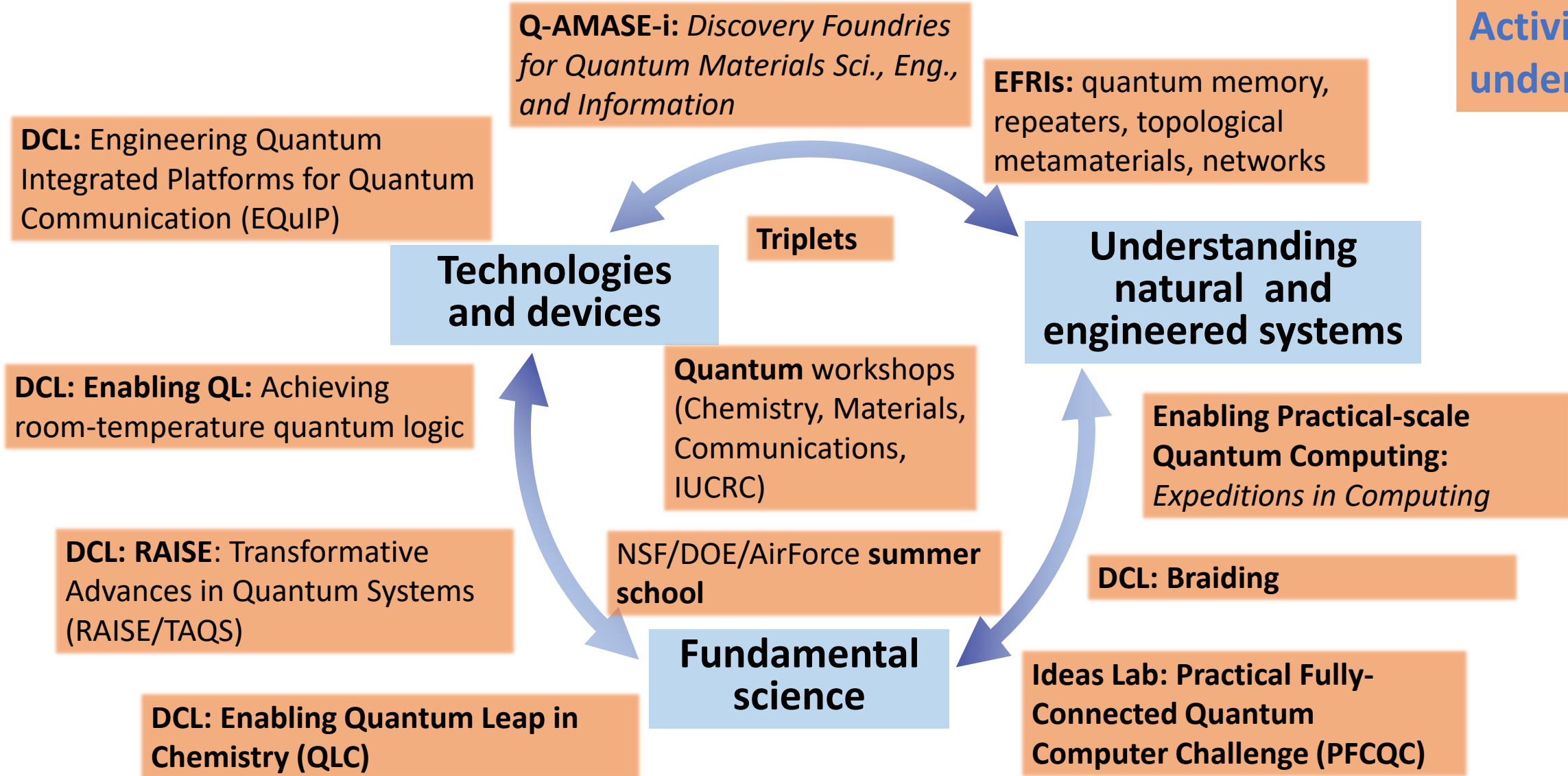
# Taking the Leap

- Quantum Leap builds on years of NSF investment in fundamentals of quantum ideas, discoveries, and people
- It is high risk
  - Quantum Science, Engineering, and Technology are maturing in parallel and as separate communities
  - Convergence of disciplines is necessary (and hard)
  - And there is hype
- It is high reward
  - Future leadership: Scientific discovery, Economic growth, National security
- We have started Quantum Leap activities in FY17
  - Using existing mechanisms like RAISE, DCLs, Ideas Labs, EFRI, plus targeted solicitations
  - Planning for FY 2019 (\$30M for QL in President's request)



# Taking the Leap: First Steps

FY 17-18  
Activities  
underway



# Quantum Leap: An Example

Solicitation NSF 17-548 “**Ideas Lab: Practical Fully-Connected Quantum Computer Challenge (PFCQC)**” A co-design approach to integrating hardware, software and quantum algorithms”

NEW!

NSF Award 1818914

STAQ: “Software-Tailored Architecture for Quantum co-design”

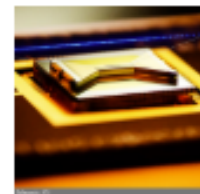
- Develop a fully-connected quantum computer with enough qubits to solve a relevant problem
- “Full stack”: software, algorithms, devices, systems integration



White House OSTP   
@WHOSTP

Following

Fresh from the [@NSF](#) Ideas Lab: \$15 million towards building the world's first practical quantum computer!



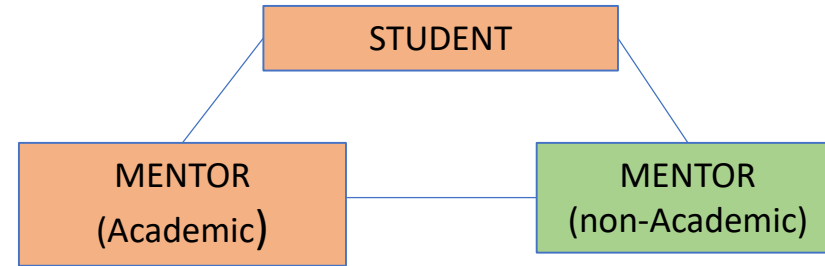
National Science Foundation  @NSF

Quantum computers will change the world, but they remain largely proofs of concept. NSF's STAQ project, with \$15 million of NSF funding awarded today, hopes to change that: [bit.ly/2vo85VX](https://bit.ly/2vo85VX)

August 8, 2018

# Quantum Leap: Triplets

Quantum Information Science and Engineering Network” of “triplets” of students, faculty, industry partners to work on Quantum Leap challenges (nine NSF Divisions participating)




<i>University</i>	<i>Partner</i>	<i>University</i>	<i>Partner</i>
Columbia U	Raytheon BBN	U. Chicago	IBM
Georgia Tech	IBM Watson	UCSC	Argonne
MIT	Sandia Labs	UT Austin	NIST
U. Maryland	IonQ Inc.	Caltech	IBM
MIT	Google	Caltech	Google
U. Maryland	IBM Watson	U. Pitt.	IBM
UW-Madison	Google	U. Illinois	NIST
Georgetown	IBM Almaden	Vanderbilt	ORNL
Georgia Tech	IBM	Sony Brook U.	BNL
Dartmouth	Google	UW Madison	Adamas Nano.
		MT State	MT Instruments

## Quantum Information Science and Engineering Network (QISE-NET)

Building "Triplets" to Bridge Academia and Industry

Sponsored by the National Science Foundation within the "Quantum Leap" and "Growing Convergent Research" Big Ideas



Quantum Information Science and Engineering Network (QISE-NET) is housed at the Chicago Quantum Exchange, an intellectual hub and partnership for advancing academic and industrial efforts in the science and engineering of quantum information. Based in the Institute for Molecular Engineering, this center is designed to coordinate relevant activity across the disciplines and associated laboratories: Argonne National Laboratories and Fermi National Laboratory.

<http://news.uchicago.edu/article/2018/05/08/nationwide-program-launches-train-new-generation-quantum-engineers24>

# Quantum Leap: Opportunities

- Emerging Frontiers in Research and Innovation 2016 (EFRI-2016): “Advancing Communication Quantum Information Research in Engineering (ACQUIRE)”
  - NSF News Release 16-091: \$12M to support six interdisciplinary teams of 26 researchers
- Dear Colleague Letter NSF 17-053: “A Quantum Leap Demonstration of Topological Quantum Computing”, EAGERs to demonstrate topological qubits (MPS/DMR)
- NSF 18-046: Dear Colleague Letter: Enabling Quantum Leap: Achieving Room-Temperature Quantum Logic through Improved Low-Dimensional Materials (issued 15 February 2018)
- CCF-1730449: “Collaborative Research: EPIQC: Enabling Practical-scale Quantum Computing”, an award in *Expeditions in Computing* program in CISE; See NSF news release 18-011
- Convergence QL: NSF/DOE Quantum Science Summer School” DMR-1743059 (Funded by: NSF; DOE/BES, DOE/ASCR, + (recent) AFOSR)
- **NSF 18-035 “Dear Colleague Letter: RAISE on Enabling Quantum Leap: Transformational Advances in Quantum Systems” (issued 14 December 2017)**
  - Convergent teams working to develop experimental demonstrations of transformative advances towards quantum systems
- **NSF 18-051 “Dear Colleague Letter: Enabling Quantum Leap in Chemistry (QLC) (issued 8 March 2018)**
- **NSF 18-578 “Enabling Quantum Leap: Convergent Accelerated Discovery Foundries for Quantum Materials Science, Engineering, and Information (Q-AMASE-i)” (issued 2 August 2018)**
  - Foundries to rapidly accelerate quantum materials design, synthesis, characterization, and translation of fundamental materials engineering and information research for quantum devices, systems, and networks.

NEW!

# Taking the Leap: Next Steps

- ENGAGEMENT - NSF community, other Federal agencies, private sector, Foundations: Impressive community response
- CAPACITY BUILDING - Multi-disciplinary quantum science and capacity building
- NATIONAL CONVERSATION - Participating and bringing NSF perspective to national conversation on QIS.
- BUDGET - FY 2019 Budget Request: \$30M for Quantum Leap (MPS/OMA)

White House approach to QIS taking shape



The National Science and Technology Council's Subcommittee on Quantum Information Science held its first meeting on April 27. The House's draft quantum bill would task this group with developing two five-year strategic plans that establish goals and metrics for a National Quantum Initiative.

(Image credit - OSTP)

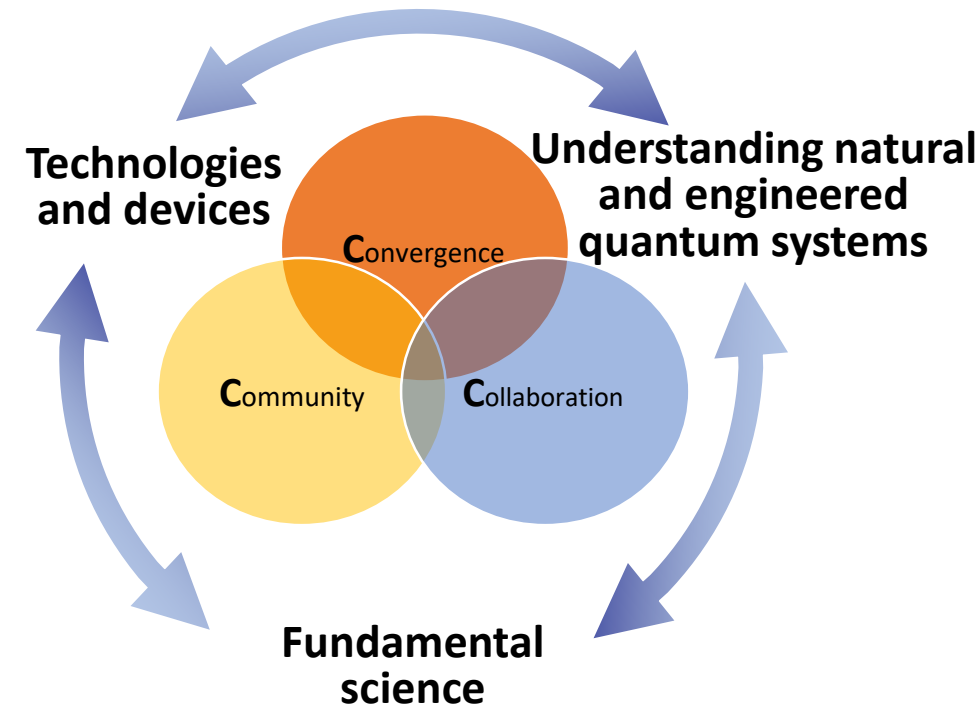
<https://www.aip.org/fyi/2018/science-committee-seeks-launch-national-quantum-initiative>





# The Quantum Leap: Leading the Next Quantum Revolution

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# The NSF Quantum Leap (Structure)

