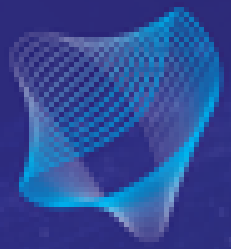


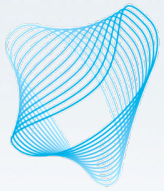
Center for
Quantum Networks

CQN Innovation Ecosystem

Stephen Fleming

Director of Strategic Partnerships and Innovation
University of Arizona — stephenfleming@arizona.edu

Funded by National Science Foundation Grant #1941583



WHO AM I?

Who Am I?

3 years as Vice President, University of Arizona

Corporate engagement, Arizona Space Business Roundtable, and more…

11 years as Vice President, Georgia Institute of Technology.

Responsible for economic development, including commercialization, corporate engagement, manufacturing support, incubators, accelerators, ecosystem development, and more. Helped create and launch NSF I-Corps program.

What Did I Do Before?

10 years VC experience at General Partner level:

18 investments as lead investor

12 profitable exits (including 4 IPOs, one $650M acquisition); 47% annualized cash-on-cash IRR

15 years corporate operations:

AT&T Bell Labs

Nortel Networks

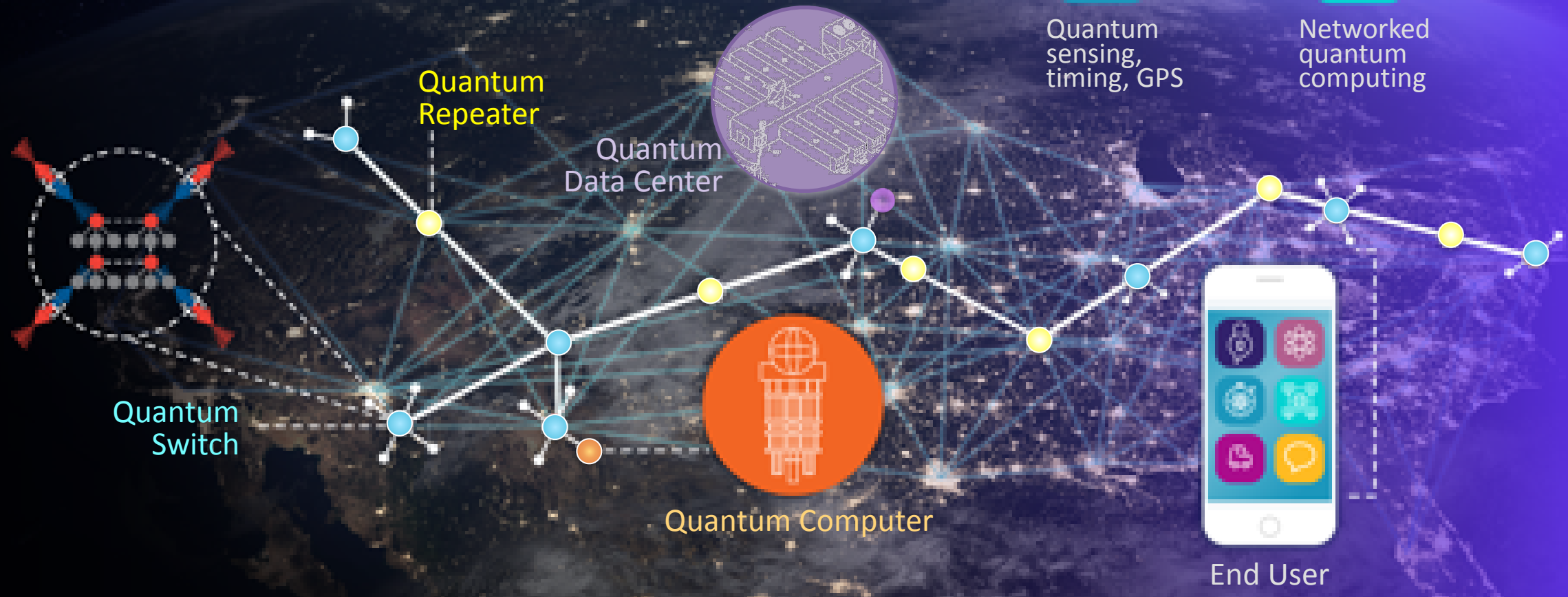
LICOM (venture-backed telecom equipment startup)

BS, Physics, Georgia Tech *(Highest Honors)*

WHY QUANTUM NETWORKS?

The Quantum Internet

Fault-tolerant quantum memories are used to build quantum repeaters and switches for high-fidelity high-rate quantum communications over thousands of kilometers.

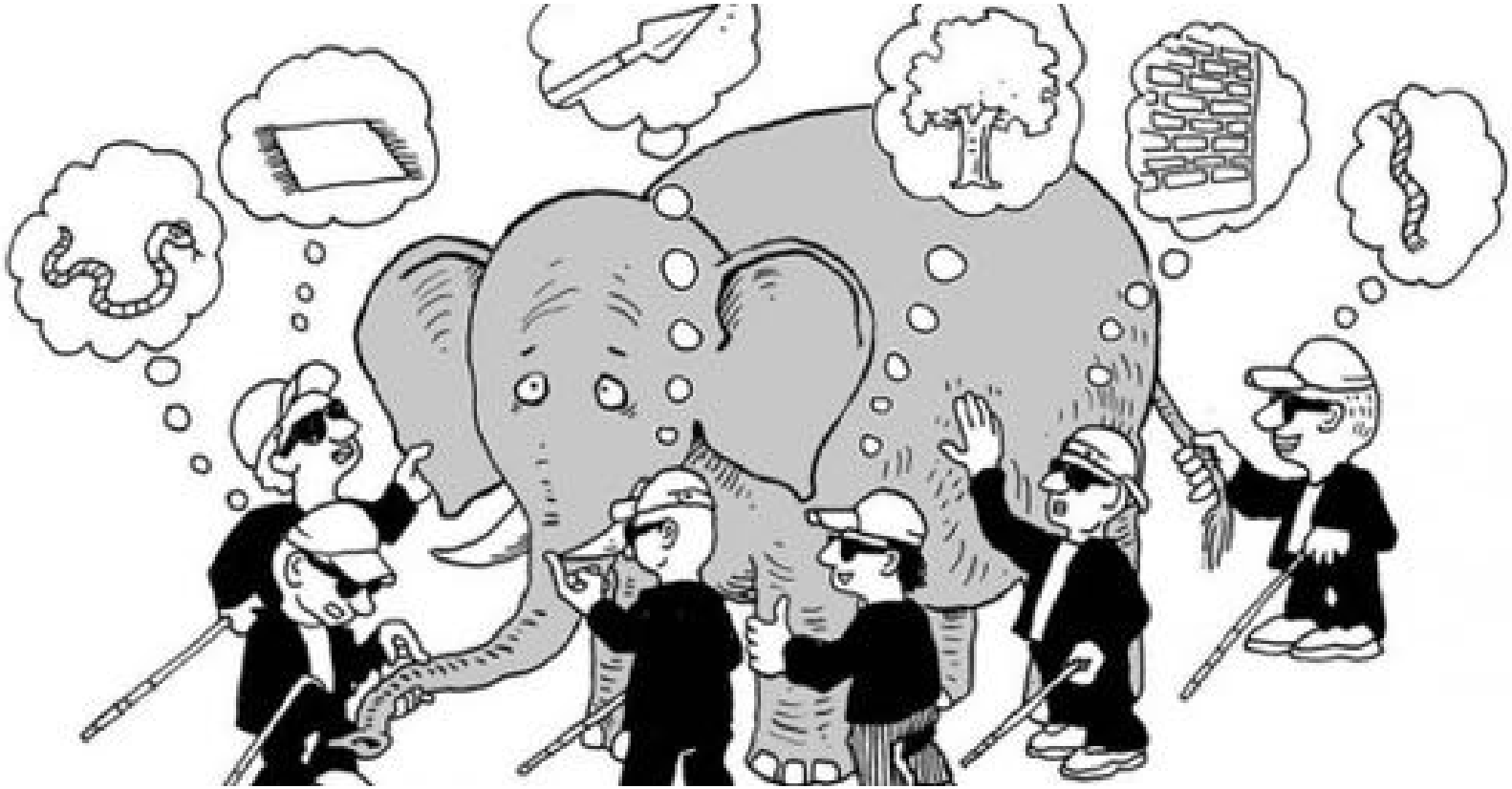


What Will Quantum Networks Do?

Fundamentally powerful **computing**

Provably-secure **communications**

High-resolution **sensing**

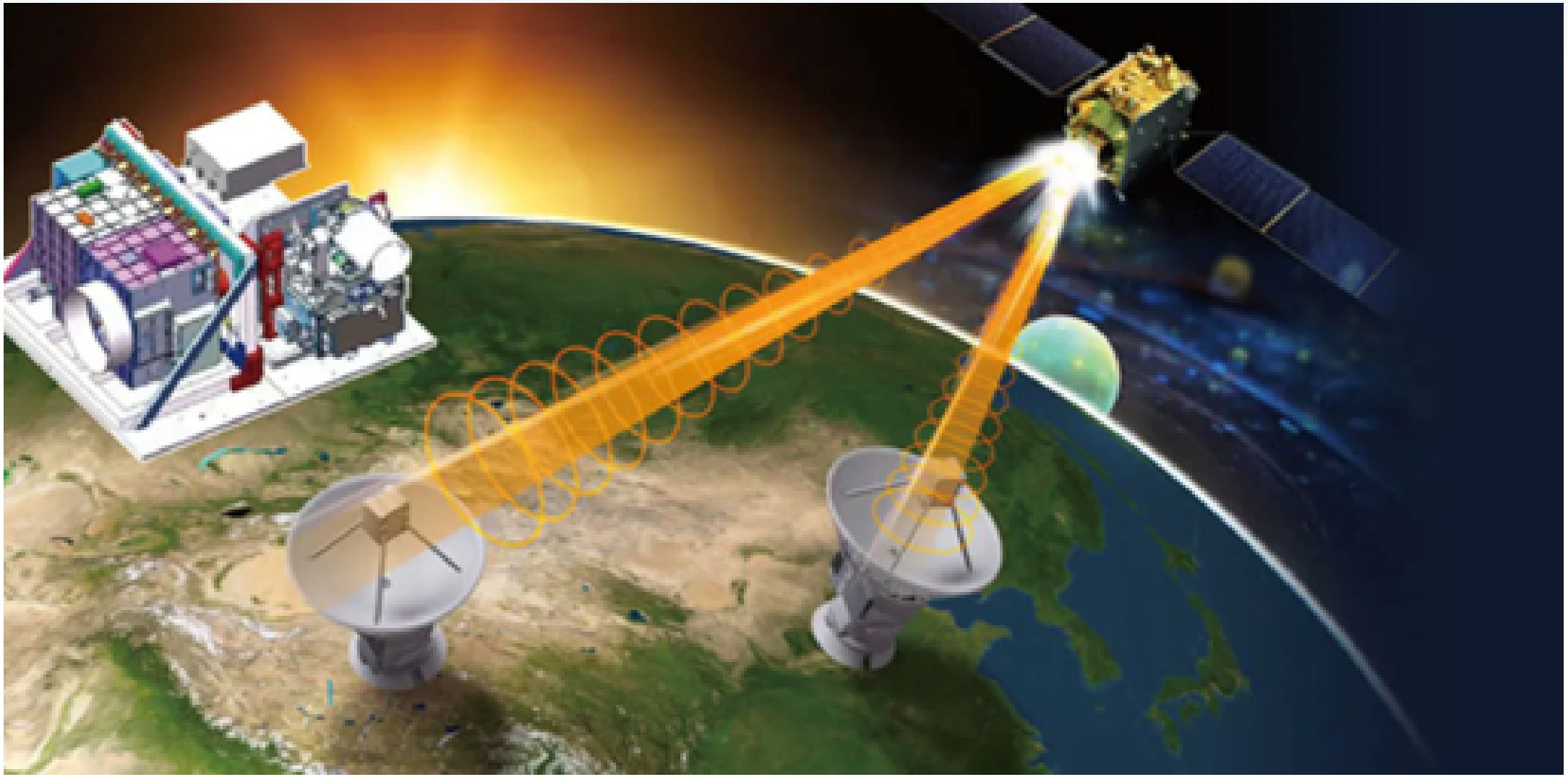


Quantum-enabled applications that we cannot **imagine** today!

Image courtesy of mollers.dk

Fundamentally Powerful Computing

Provably-Secure Communications



High-Resolution Sensing

What Will Quantum Networks Do?

Quantum-enabled applications that we cannot **imagine** today!

Image courtesy of mollers.dk

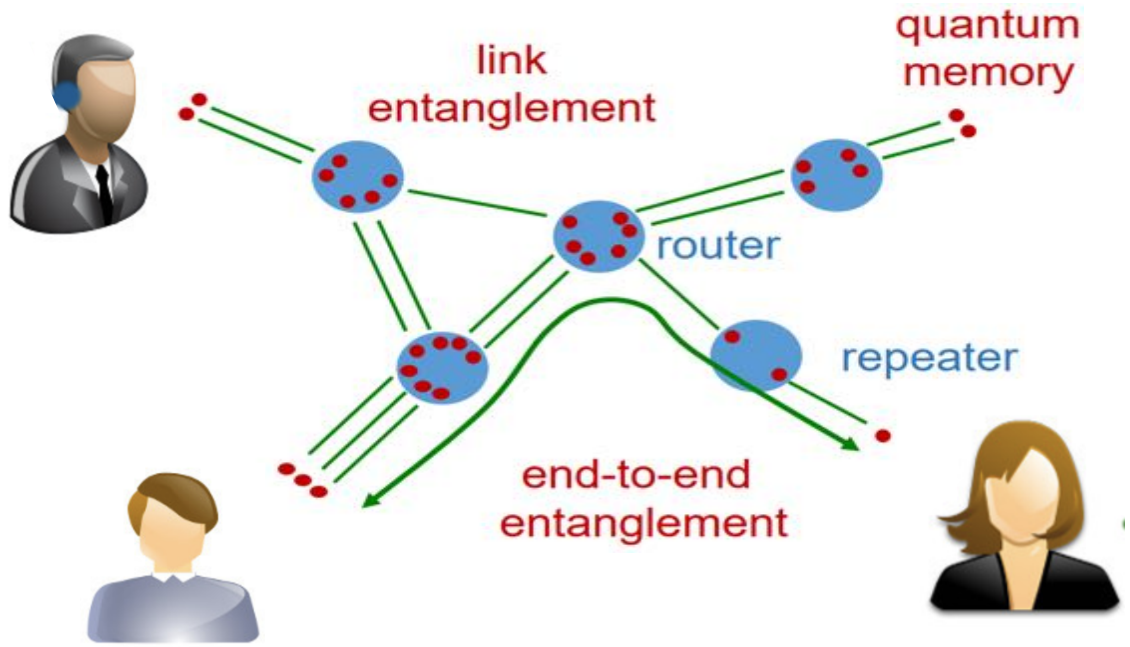
What We Can Do Now

Two-party entanglement across a single point-to-point, loss-limited connection

Quantum Networks We Will Build

Quantum networks that provide shared entanglement over long distances

Quantum information transfers among many users that are robust to noise, workload dynamics, eavesdroppers, and failures

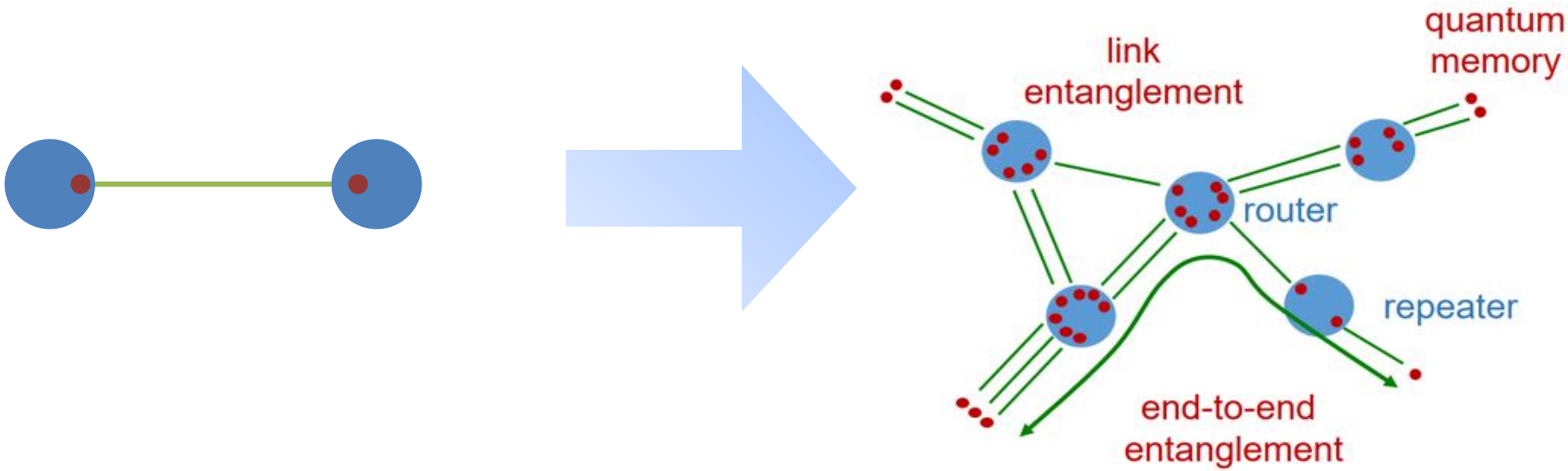


Challenges

Quantum network design is entirely different from classical counterpart

Loss & noise kill quantum entanglement

Single photons with no equivalent to an amplifier in quantum networks



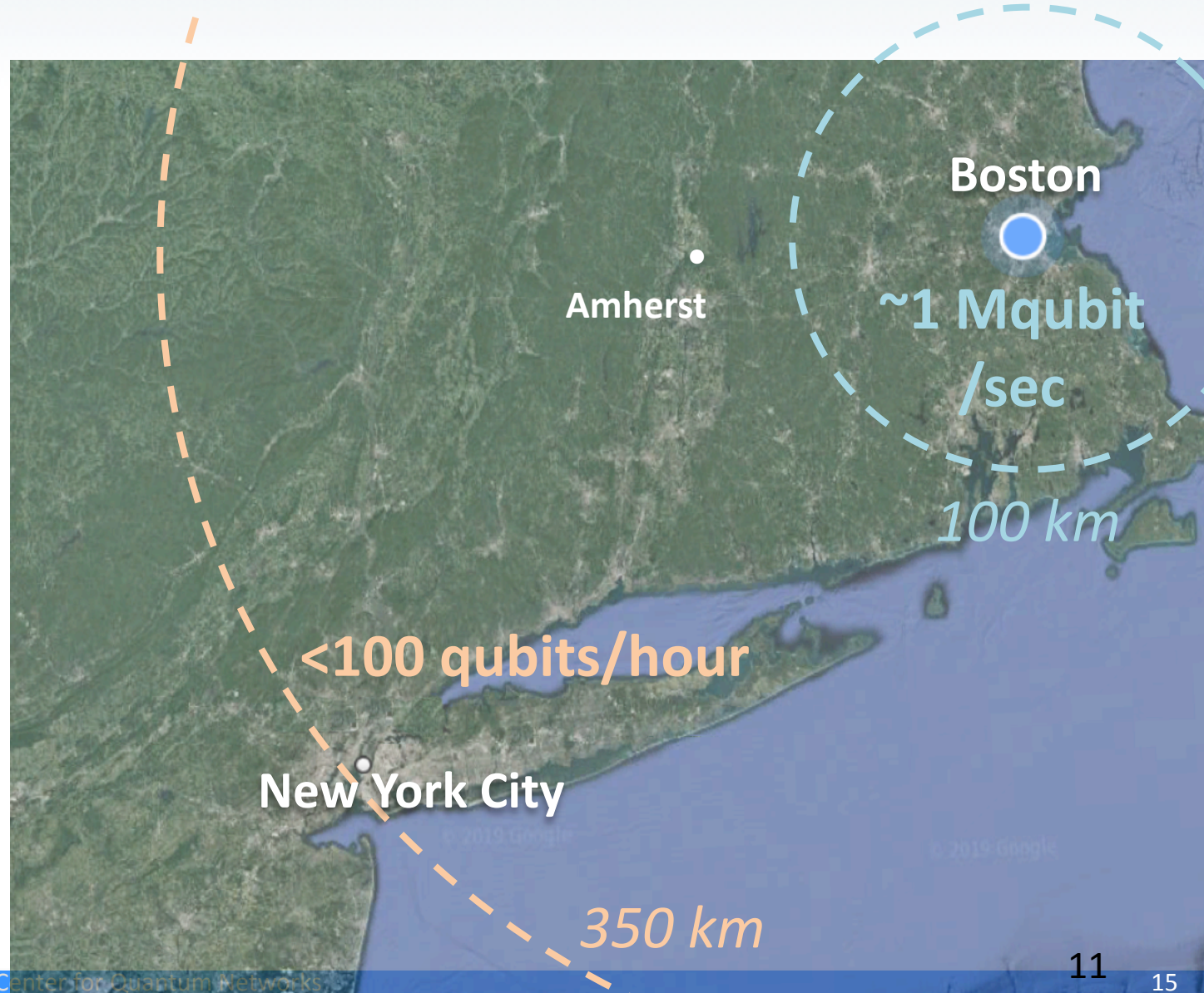
Why Quantum Repeaters?

Qubit transmission rate in fiber decays **exponentially** with distance.

- Cannot be extended by measure-and-repeat without compromising security.

Quantum repeaters:

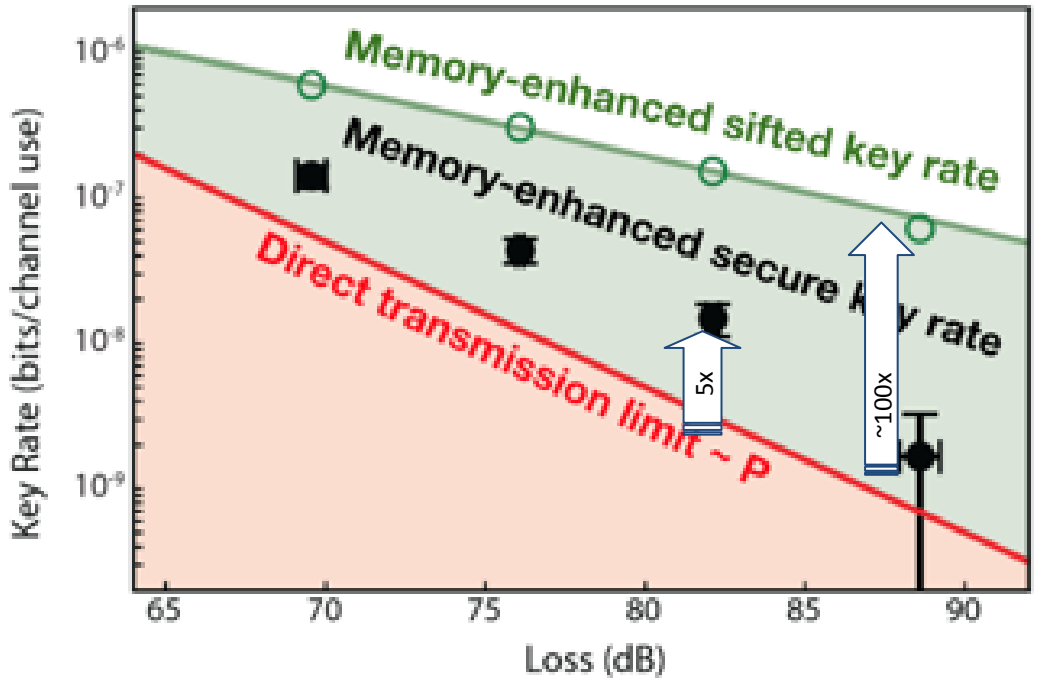
- Intermediate quantum memory nodes
- Quantum error correction



Experimental demonstration of memory-enhanced quantum communication

M. K. Bhaskar,[1,*] R. Riedinger,[1,*] B. Machielse,[1,*] D. S. Levonian,[1,*] C. T. Nguyen,[1,*]
E. N. Knall,[2] H. Park,[1,3] D. Englund,[4] M. Lončar,[2] D. D. Sukachev,[1] and M. D. Lukin[1,†]

[1] *Department of Physics, Harvard University, Cambridge, MA 02138*
[2] *John A. Paulson School of Engineering and Applied Sciences, Cambridge, MA 02138*
[3] *Department of Chemistry and Chemical Biology, Harvard University, Cambridge, MA 02138, USA*
[4] *Research Laboratory of Electronics, MIT, Cambridge, MA 02139, USA*



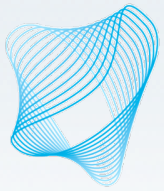
npj | Quantum Information

www.nature.com/npjqi

ARTICLE OPEN

Routing entanglement in the quantum internet

Mihir Pant[1,2], Hari Krovi[2], Don Towsley[3], Leandros Tassiulas[4], Liang Jiang[5,6], Prithwish Basu[7], Dirk Englund[1] and Saikat Guha[2,8]



WHY QUANTUM NETWORKS… NOW?

2017: “Sputnik Moment” for USA

“Trusted node” repeaters

Goal: Reaffirm US Supremacy

Full Spectrum of Research Interests

Computer Science
Mathematics
Electrical Eng'rg
Materials Science
Physics
Optical Sciences
Law
Economics
Social & Behavioral Sciences
Public Policy
Business

Highly transdisciplinary and convergent research, spanning:

Quantum memory development	*Harvard, MIT*
Quantum transduction	*Yale*
Scalable programmable integrated photonics	*UArizona, MIT*
Integrated single photon detectors	*MIT*
Quantum error correction theory	*UArizona, Yale*
Spin-photon interfaces	*Harvard*
Quantum material research and discovery	*Harvard, NAU, Howard*
Computer network theory	*UMass*
Societal impacts of the quantum internet	*UArizona, MIT, Yale*

… and more!

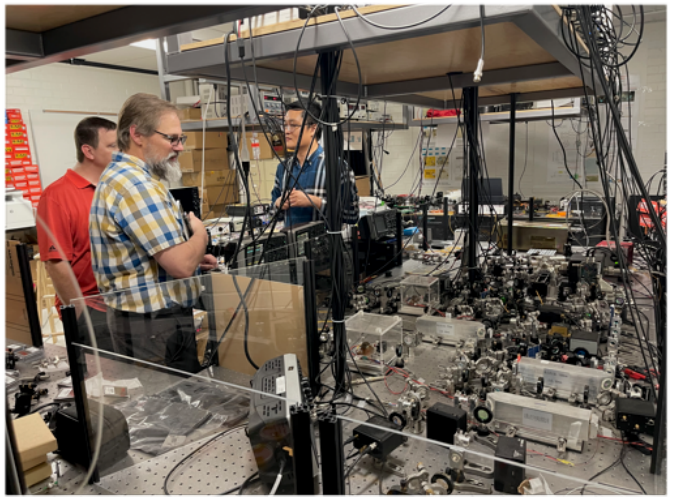
The Timing is Perfect for Quantum Networks

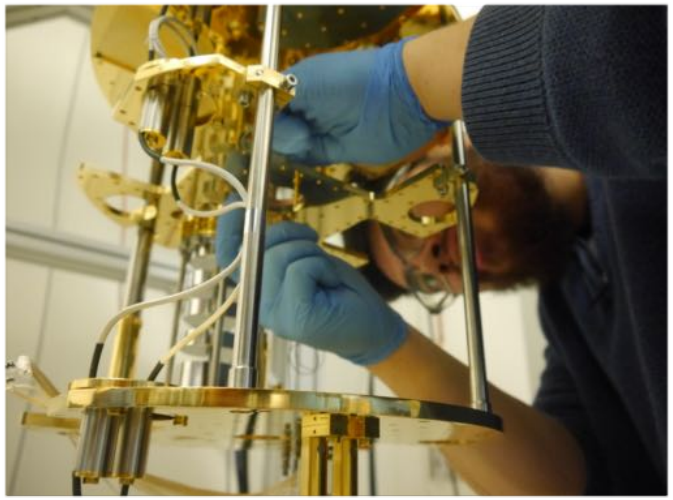
- Right now we have . . .
  - Quantum computers
  - Quantum sensing
  - A very wide range of quantum devices
- Fascinating frontiers in the engineering use of entanglement (e.g. precision timekeeping)
- But we have ***no way*** to interconnect these technologies
- We ***need*** quantum networks!

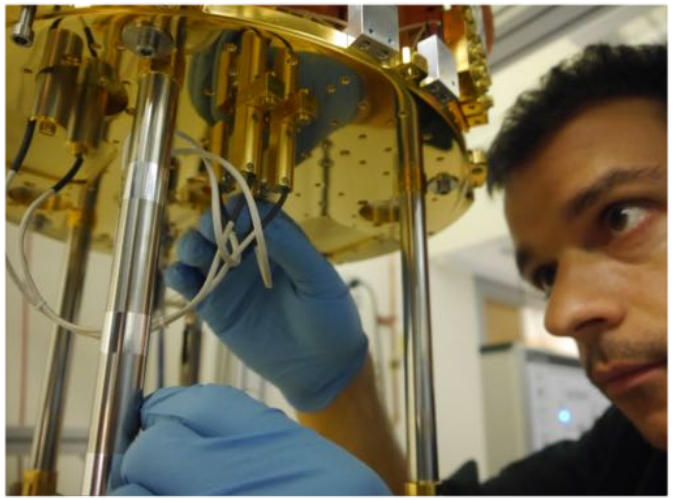
Slide courtesy of Chip Elliott, Raytheon BBN

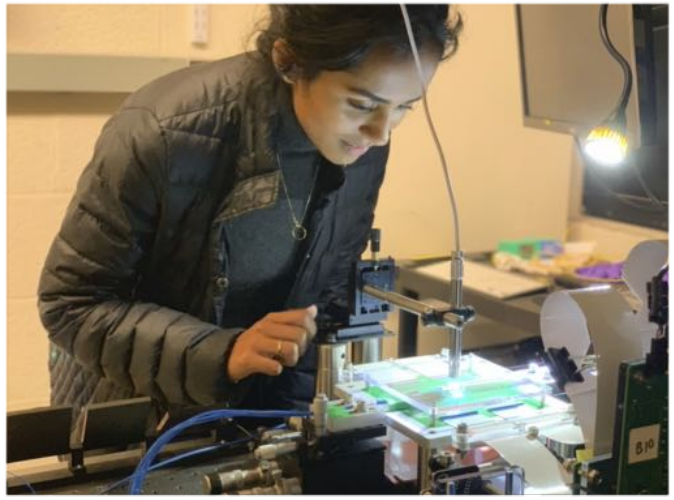
- Intellectual merit
  - Extremely exciting field
  - Many significant discoveries will occur in the next 5-10 years
    - Ranging from fundamental research to experimental systems
- Broader impact
  - Opens the door to engineering devices and systems we can't imagine today
  - American industry stands to gain tremendously from close collaboration with the CQN team
  - **Important area for workforce development**

In the Lab Now…









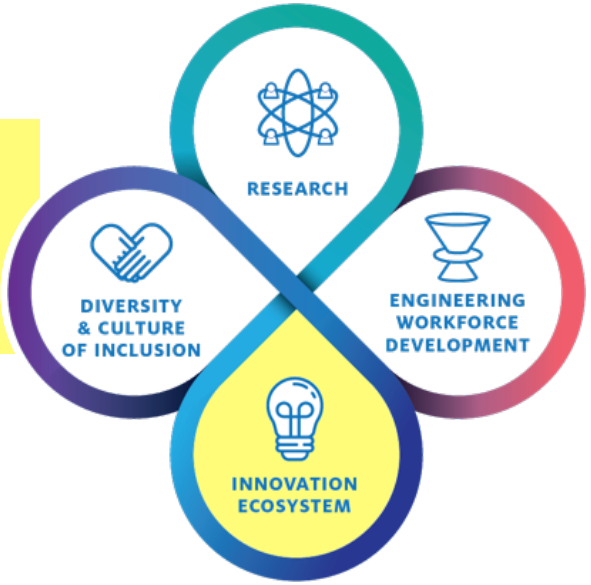
ARPANET, 1969

CQN INNOVATION ECOSYSTEM

NSF 4th Generation ERCs

*The Engineering Research Center program supports **convergent research** that will lead to strong societal impact, including*

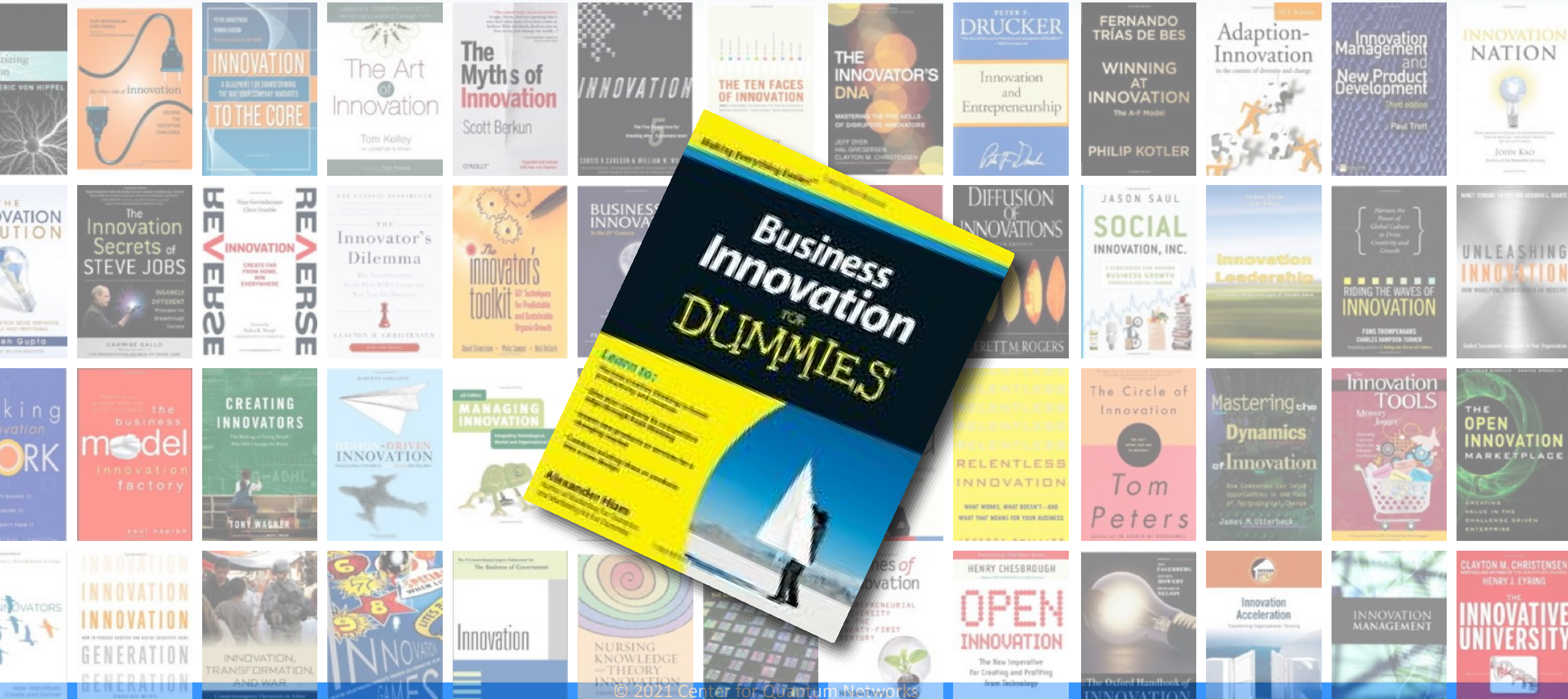
- **engineering workforce development** at all participant stages,
- a culture of **diversity and inclusion** where all participants gain mutual benefit, and
- value creation within an **innovation ecosystem** that will outlast the lifetime of the ERC.



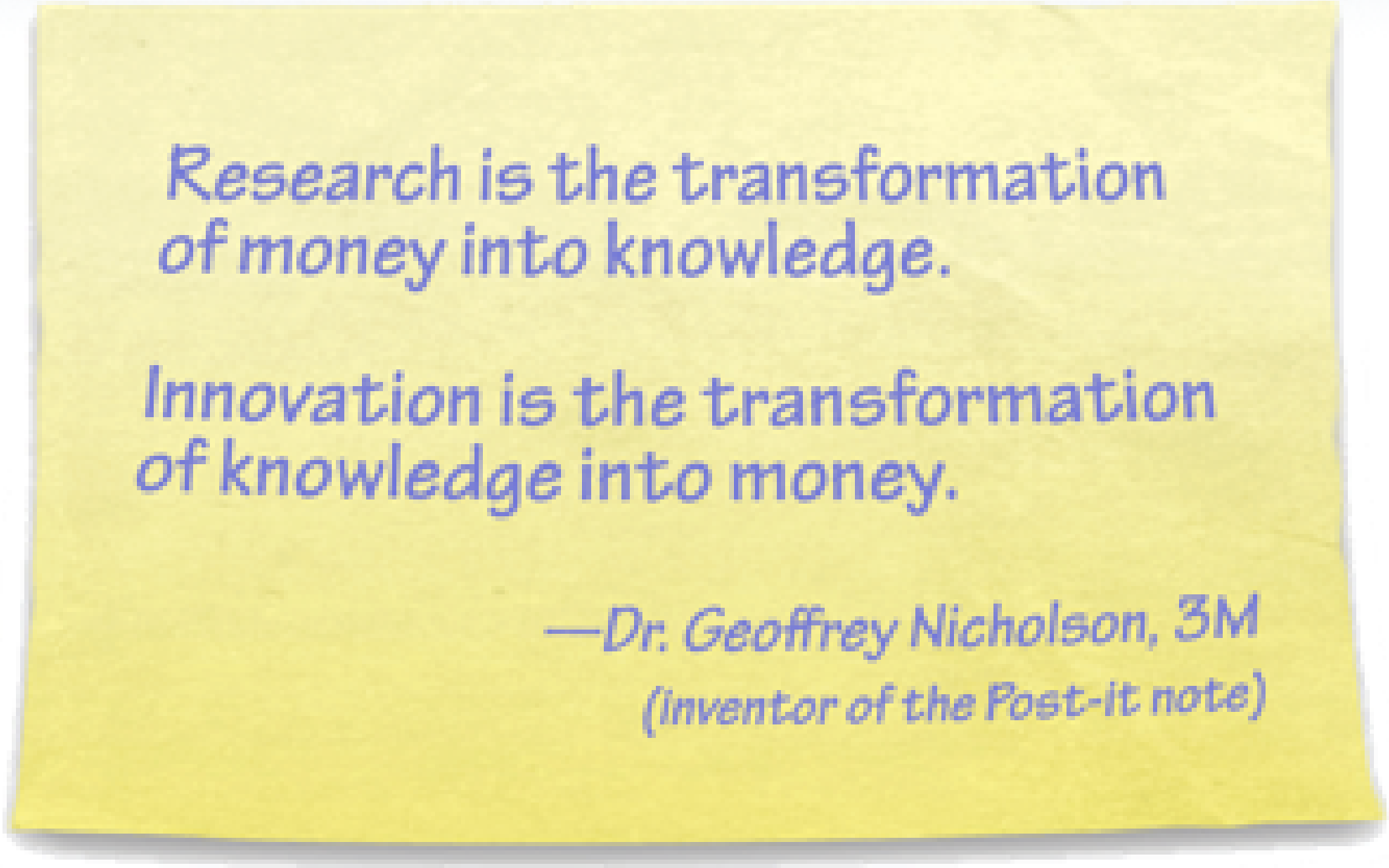
Innovation…


ERIC VON HIPPEL
the other side of innovation
INNOVATION
A BLUEPRINT FOR TRANSFORMING THE WAY YOUR COMPANY INNOVATES
TO THE CORE
The Art of Innovation
Tom Kelley
The Myths of Innovation
Scott Berkun
O'REILLY
INNOVATION
THE TEN FACES OF INNOVATION
TOM KELLEY
THE INNOVATOR'S DNA
MASTERING THE FIVE SKILLS OF DISRUPTIVE INNOVATORS
JEFF DYER
HAL GREGERSEN
CLAYTON M. CHRISTENSEN
PETER F. DRUCKER
Innovation and Entrepreneurship
FERNANDO TRÍAS DE BES
WINNING AT INNOVATION
The A-F Model
PHILIP KOTLER
Adaption-Innovation
Innovation Management and New Product Development
Third edition
Paul Trott
INNOVATION NATION
JOHN KAO
The Innovation Secrets of STEVE JOBS
INSANELY DIFFERENT
CARMINE GALLO
REVERSE
INNOVATION
CREATE FAR FROM HOME, WIN EVERYWHERE
The Innovator's Dilemma
CLAYTON M. CHRISTENSEN
The innovator's toolkit
50 Techniques for Predictable and Sustainable Organic Growth
BUSINESS INNOVATION
PRAVEEN GUPTA
THE INNOVATOR'S WAY
5 Core Methods of Innovation
Sanjoes Sharma
DIFFUSION OF INNOVATIONS
EVERETT M. ROGERS
JASON SAUL
SOCIAL INNOVATION, INC.
Innovation Leadership
RIDING THE WAVES OF INNOVATION
FONS TROMPENAARS
CHARLES HAMPDEN-TURNER
UNLEASHING INNOVATION
the business model
innovation factory
CREATING INNOVATORS
TONY WAGNER
DESIGN-DRIVEN INNOVATION
MANAGING INNOVATION
Innovation is Everybody's Business
THE INNOVATOR'S SOLUTION
CREATING AND SUSTAINING SUCCESSFUL GROWTH
CLAYTON M. CHRISTENSEN
MICHAEL E. RAYNOR
JEFF DEGRAFF
innovation you
FOUR STEPS TO BECOMING NEW AND IMPROVED
RELENTLESS INNOVATION
The Circle of Innovation
Tom Peters
Mastering the Dynamics of Innovation
James M. Utterback
Innovation TOOLS
Memory Jogger
THE OPEN INNOVATION MARKETPLACE
INNOVATION
GENERATION
INNOVATION, TRANSFORMATION, AND WAR
INNOVATION
GAMES
Innovation
NURSING KNOWLEDGE AND THEORY INNOVATION
INNOVATION ECONOMICS
THE RACE FOR GLOBAL ADVANTAGE
Engines of Innovation
THE ENTREPRENEURIAL UNIVERSITY IN THE TWENTY-FIRST CENTURY
Holden Thorp
HENRY CHESBROUGH
OPEN INNOVATION
The New Imperative for Creating and Profiting from Technology
The Oxford Handbook of INNOVATION
Innovation Acceleration
INNOVATION MANAGEMENT
CLAYTON M. CHRISTENSEN
HENRY J. EYRING
THE INNOVATIVE UNIVERSITY

Innovation…



What is Innovation?



CQN as an Innovation Hub

Core Academic Partners

Other Academic Partners

CQN

Spinout / Startup Companies

Venture Capital Investors

Incubators

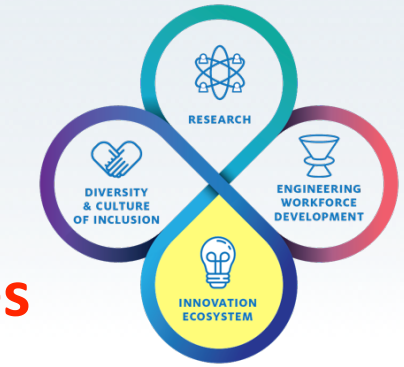
US Industry

FFRDCs / Federal Agencies

International Partners

K-12 Education Partners

CQN Industrial Partners Program



Core Academic Partners

Other Academic Partners

CQN

Spinout / Startup Companies

Venture Capital Investors

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US Industry

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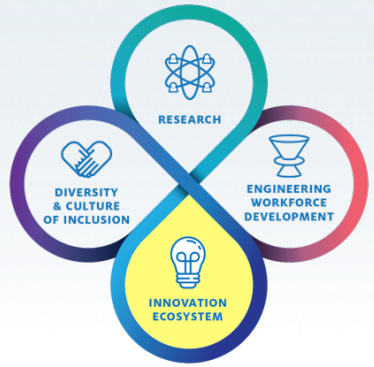
International Partners

K-12 Education Partners

INDUSTRIAL PARTNERS PROGRAM

Industrial Partners Program (IPP)



IPP Membership Level	Associate	Collaborator	Partner
Annual Contribution ‡	$10,000	$40,000	$150,000
Early Access to Research Results	✓	✓	✓
Technical Collaboration		✓	✓
Industry Advisory Board (IAB)		1 seat	2 seats
Access to Facilities, Seminars, Recruiting of Students & Postdocs		✓	✓
Ability to Sponsor Research		✓	✓
Customized Research Opportunities			✓
Early Access to Intellectual Property			✓
Partial Patent Costs Reimbursement			✓
Priority Option for IP Licensing			✓

‡ All Members may adjust cash, in-kind, and IP license credits with the approval of the Center Director.

Industrial Partners Program (IPP)

Special cases:

- Founding Members (pre-award support) receive 20% discount
- Small Business Concerns (by NSF definition: < 500 employees) receive 75% discount
  - *Discounts may be concatenated*
- Spinouts based on CQN University research get Partner-Level Membership *(nonvoting)* benefits for any level of Membership
- Up to $10,000/year of CQN University licensing fees may be applied to Membership annual contribution

INDUSTRY ADVISORY BOARD

Industry Advisory Board

The IAB advises CQN on research directions, industry engagements, and strategic investments from the perspectives of corporate partners, entrepreneurs, and venture capital.

- Provides **guidance** to CQN executive leadership.
- Participates in NSF annual **site visit**.
- Assists in development and maintenance of a comprehensive **application roadmap** for quantum information science and technology.

Industry Advisory Board

Guidance in four areas:

- Creating and demonstrating the scientific and technological **feasibility** of innovative methodologies and systems governing quantum communication networks,
- Assisting in the **transfer** of research discoveries and observations from university to industry and vice versa,
- Developing an interdisciplinary **education** program for quantum information science and technology, including workshops, short courses, certificates, and accredited degrees, including QISE Masters program, and
- Navigating **regulatory** issues, **public policy** challenges, and ensuring **diversity** and a culture of **inclusion** in the U.S. and abroad.

Industry Advisory Board

IAB membership and voting:

- Partner-Level Members have two voting seats.
- Collaborator-Level Members have one voting seat.
- Under certain circumstances, venture capital firms and university spinout companies may have non-voting observation rights.
- IAB Chair to be elected from voting membership for a two-year term.
- Two IAB meetings per year, one as part of NSF site visit.
  - *Each full IAB meeting is expected to include a recruiting event.*
  - *Interim conference-call meetings as required.*

STRATEGIC PARTNERSHIPS AND INNOVATION

Industrial Partners Program (IPP)

Corporate Partners

APPLIED MATERIALS
GENERAL DYNAMICS
CORNING
L3HARRIS
LOCKHEED MARTIN
JUNIPER NETWORKS
Raytheon Technologies
CISCO

FFRDCs / Federal Agencies

NIST
AEROSPACE
NASA
Sandia National Laboratories

Startups / Small Companies

ANAMETRIC
Psi Quantum
Aliro
TOPTICA PHOTONICS

Venture Affiliates

FLYBRIDGE CAPITAL PARTNERS
OSAGE UNIVERSITY PARTNERS

Companies/labs on this page have expressed interest in joining the CQN IPP.

Protection of Complex Center Relationships

An Intellectual Property Management Plan has been negotiated between UArizona, Harvard, MIT, and Yale.

Led by UArizona, core partner institutions will coordinate to develop:

- IP protection plan
- IP licensing process
- Patent prosecution
- Ownership
- Startup candidates
- Fees for membership
- Rights in research results

THE UNIVERSITY OF ARIZONA TECH LAUNCH ARIZONA

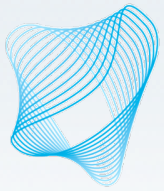
Yale OCR

HARVARD Office of Technology Development

MIT TLO

Activities and Milestones

	Year 1	Year 2	Year 3	Year 4	Year 5	Milestone Based
Trade Show Recruiting	COVID	✓	✓	✓	✓	
Annual Innovation Meeting	Virtual	✓	✓	✓	✓	
Advisory Board Meeting	✓	✓	✓	✓	✓	
Entrepreneurship Training	✓	✓	✓	✓	✓	
S&T Roadmap / Refresh	✓		✓		✓	
Invention Disclosures						✓
Technology Licenses						✓
Startup Formation						✓



Center for
Quantum Networks

QUESTIONS?

Stephen Fleming

Director of Strategic Partnerships and Innovation
University of Arizona — stephenfleming@arizona.edu