An opinionated Overview of the Quantum Industry

Quantum Computing Boot Camp
Jefferson Lab
June 30th, 2023

Philip Makotyn, PhD
PMG Quantum Advisors LLC

CAREER

Motorola
Antenna Engineer

Graduate RA
CU Boulder
JILA

Researcher
Lockheed Martin

Researcher
Honeywell Quantum Solutions

Honeywell Quantum Solutions
Quantum Marketing Manager

University of Colorado
Exec. Dir. CUbit Quantum Initiative

NPI
NQI Steering Committee Member

EXCITEMENT IN QUANTUM

OPPORTUNITIES

CHIPS for AMERICA

NSF's Regional Innovation Engines Program

TECH HUBS
U.S. Economic Development Administration

NATIONAL QUANTUM COORDINATION OFFICE

⟨quantum|gov⟩

TECHNOLOGY

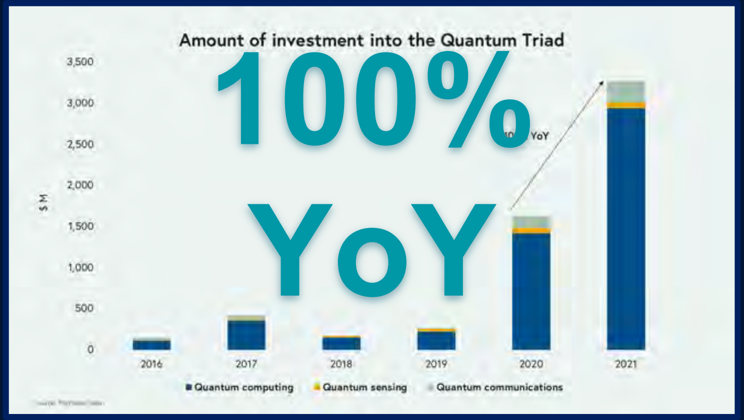
Fine-grain control of Hamiltonians

Scaling of devices

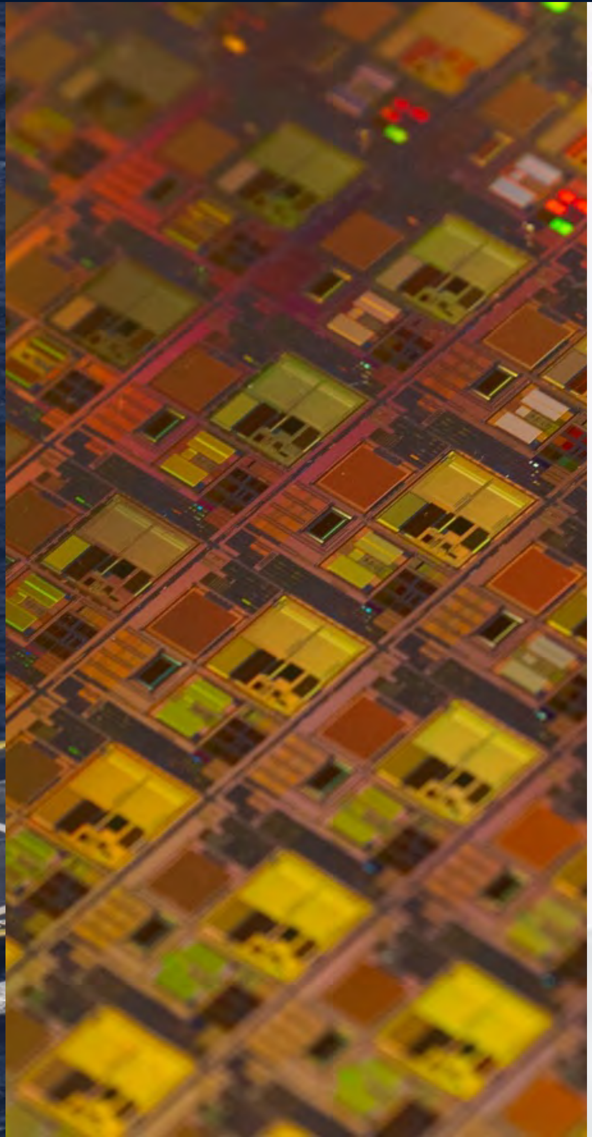
Error correction

Emerging ecosystem

INVESTMENTS



EMERGING TECHNOLOGIES



AN ELEPHANT
in the room

HYPE

Science News

How to stop quantum computers from breaking the internet's encryption

1 day ago

Business Wire

Cancer to Be Treated as Easily as Common Cold When Humans Crack Quantum Computing

DUBAI, United Arab of Emirates--(BUSINESS WIRE)--Breakthroughs in quantum computing will enable humans to cure diseases like cancer,...

PC Tech Magazine

The Rise of Quantum Computing in Gaming

The tech world is never static; it evolves at a speed unmatched by any other industry. The last few years have witnessed an influx of...

ZDNET

Could quantum computers fix political polls?

If a quantum system can predict the locations of air molecules in a hurricane, you'd think predicting election results would be a much...

Tech.eu

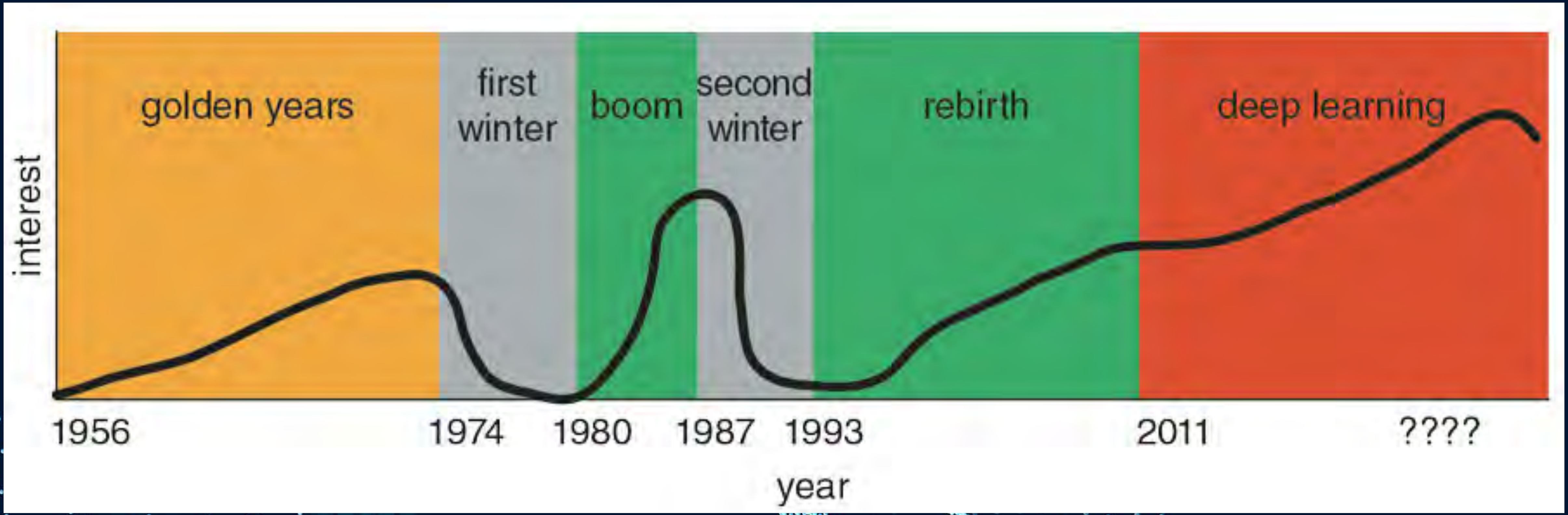
Nitrogen helped take the world's population to 8 Billion. Quantum computing will ensure it doesn't destroy our planet

Runa Capital Associate Francesco Ricciuti discusses how modern agriculture uncorked the climate crisis and explains how quantum computing...

NEWSWEEK MAGAZINE

Quantum Computers Will Make Your Laptop Look Like an Abacus

AI Winter



Refs:

Denning and Lewis DOI: 10.1511/2019.107.6.346 (2019)

Crevier, Daniel (1993). *AI: The Tumultuous Search for Artificial Intelligence*.

QUANTUM COMPUTING
Bootcamp

QUANTUM Ambassador

Quantum Ambassador

01

QUANTUM

The science

02

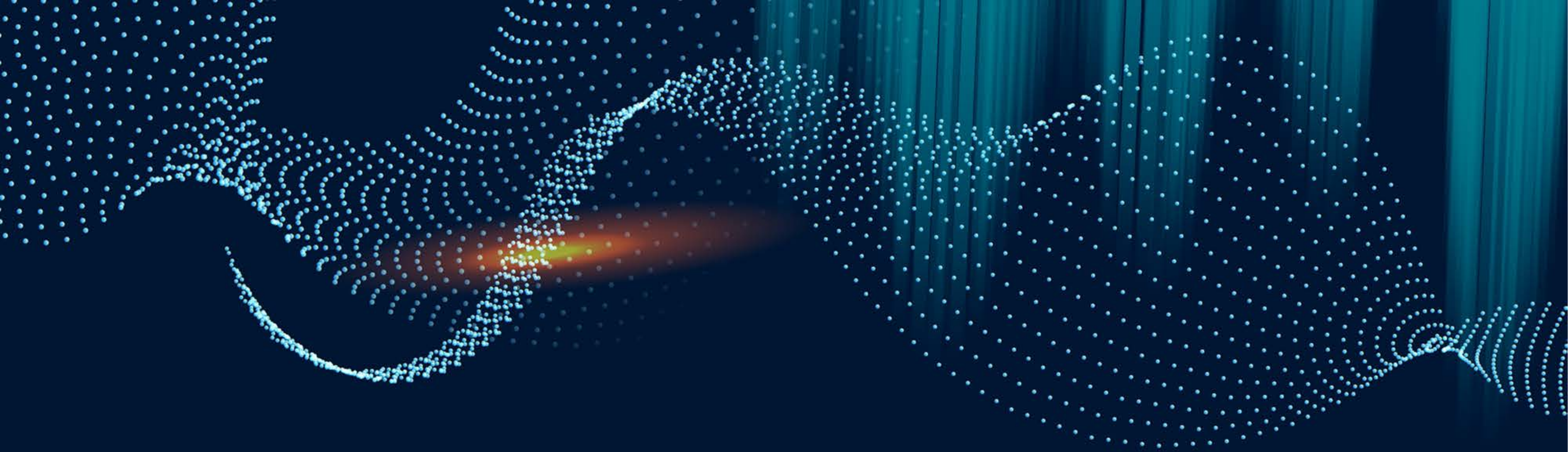
INDUSTRY

The organizations

03

ECOSYSTEM

How they fit together

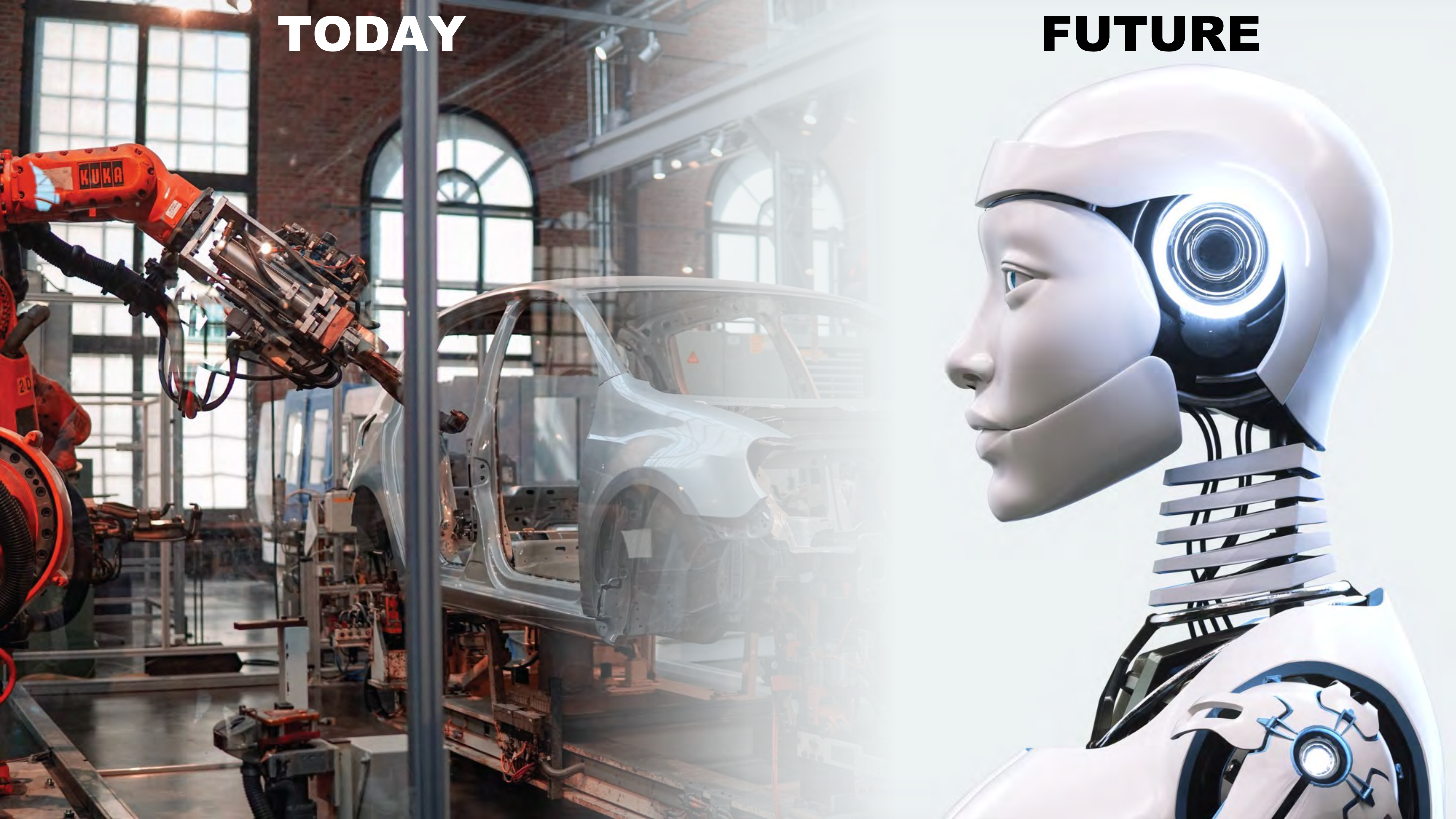


01 QUANTUM

The science

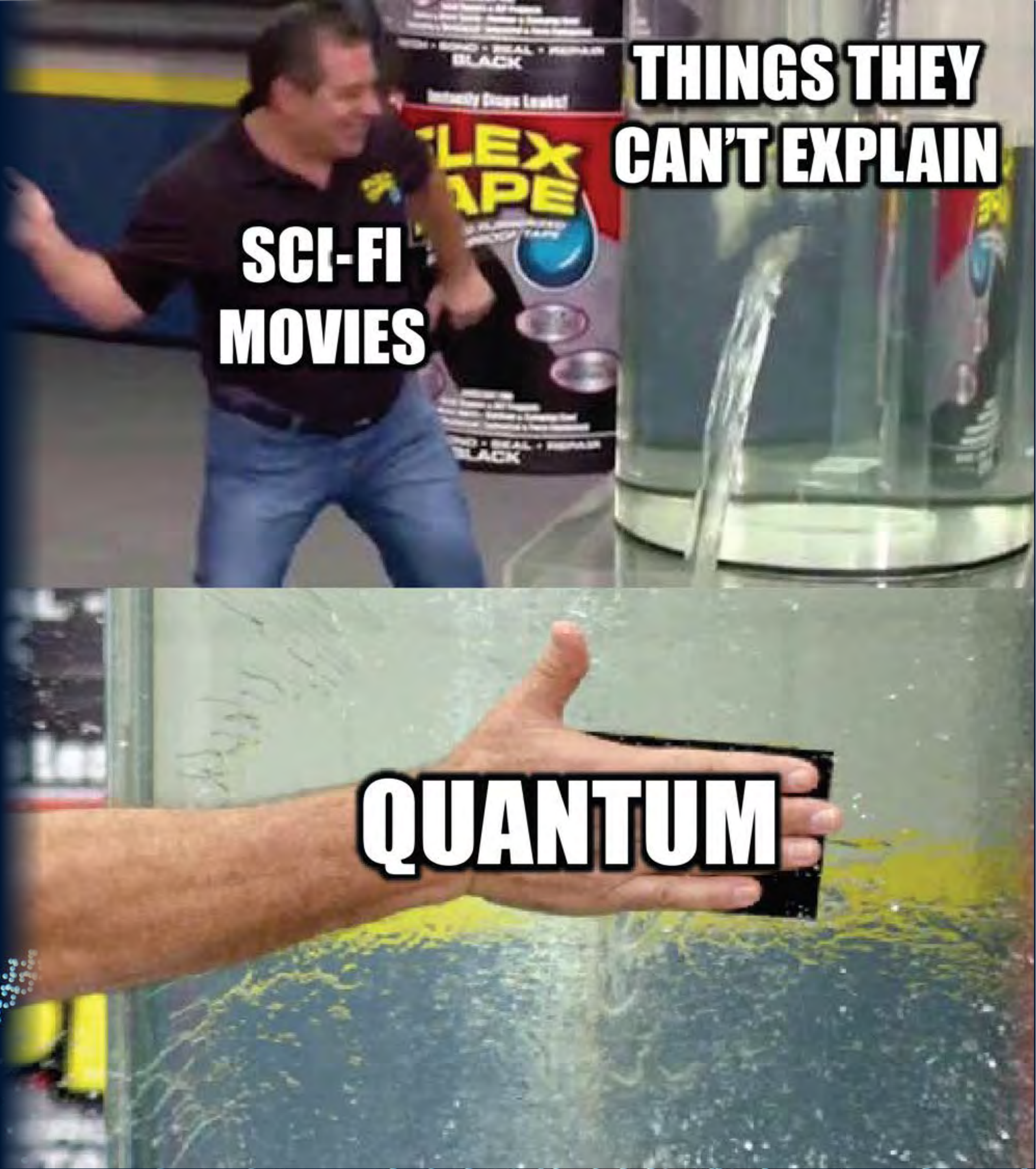
What is QUANTUM?


TODAY
TOMORROW
SPACEX


TODAY
FUTURE
KUKA

What is QUANTUM?

What is QUANTUM?



What is QUANTUM?

What is QUANTUM?

$$i\hbar\frac{\partial}{\partial t}|\psi(t)\rangle = \hat{H}|\psi(t)\rangle$$

Postulates

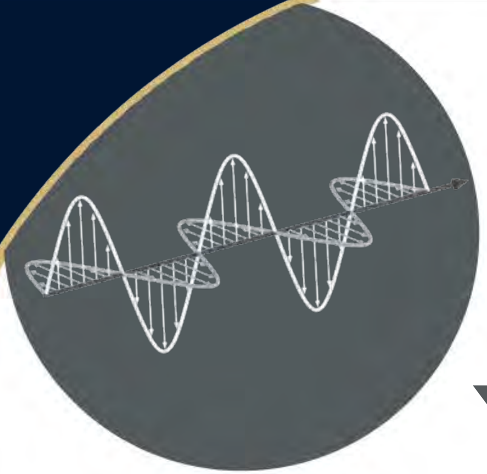
1. State of a system describe by a wavefunction
2. Every observable described by an operator
3. Only possible results are eigenvalues of observable operator
4. The observable measurement outcome is given by inner products
5. After a measurement, the observable has the state of the measured eigenstate
6. Time evolution is described by the time-dependent Schrödinger equation

Systems

Condensed matter physics
Low temperature physics
Particle physics
Nuclear physics
Atomic and molecular physics
Among others…

What is QUANTUM?

SMALL is DIFFERENT



Waves & Particles simultaneously

Tunneling

Discrete Energies

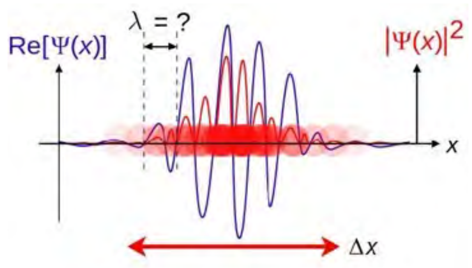
Entanglement

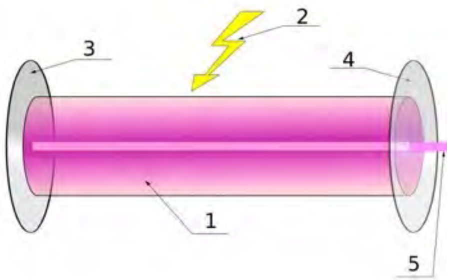
Probability

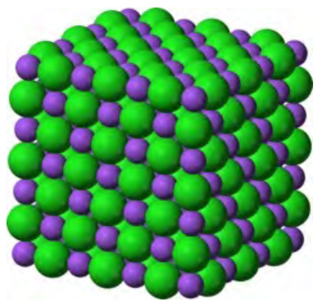
QUANTUM MECHANICS is the behavior of the SMALL

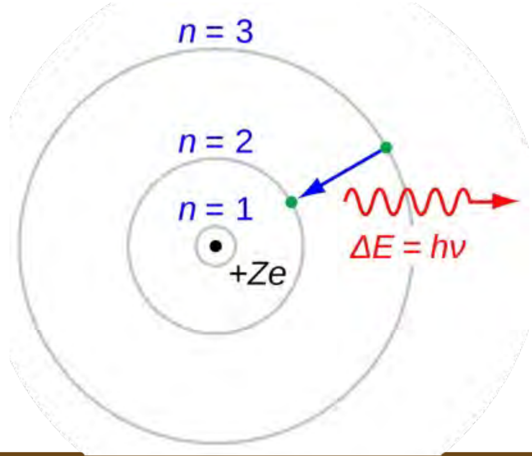
Quantum 1.0
SYSTEMS

Wave Packets	Lasers	Electrons in a Lattice	Quantized Energy

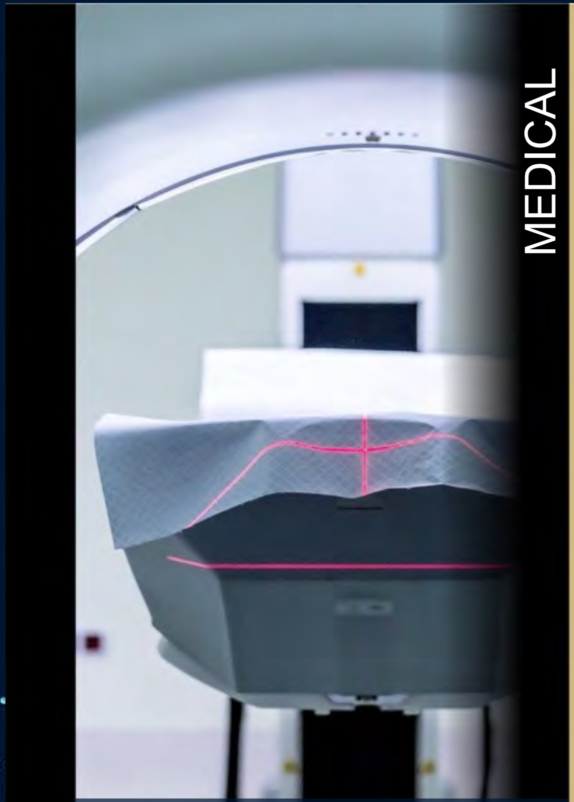








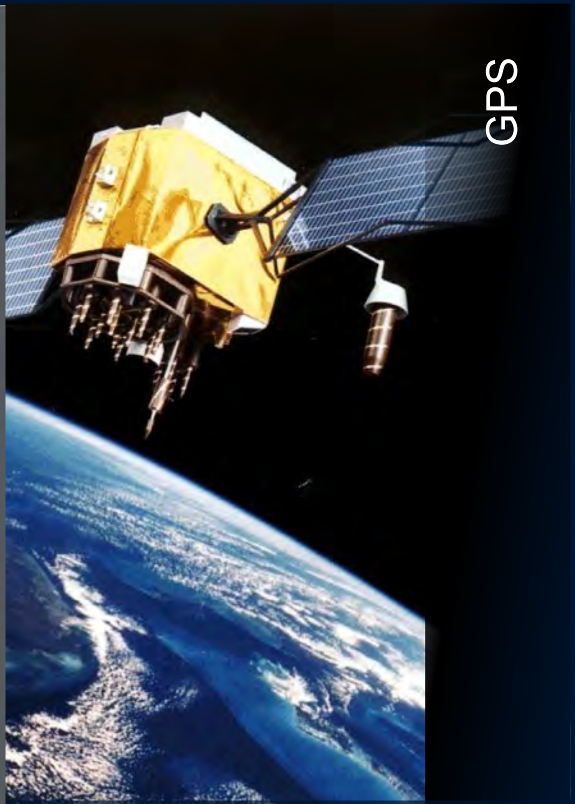
QUANTUM 1.0
Impacts



Global MRI market size $5 B

Global telecom market size $2.6 T

Global semiconductor market size $452 B



GPS $1.4 T lifetime US economic benefit

economy, technology, quality of life, security

QUANTUM 2.0
Revolution

QUANTUM TECHNOLOGY:
THE SECOND QUANTUM REVOLUTION.

Jonathan P. Dowling[1].
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Jet Propulsion Laboratory,
Pasadena, California 91109, USA.

Gerard J. Milburn[2],
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University of Cambridge, Wilberforce Road, Cambridge,UK.
and
Centre for Quantum Computer Technology.
The University of Queensland
St Lucia, QLD 4072, Australia;

Ref: 2002 arXiv:0206091

QUANTUM 2.0
Technologies

COMPUTING

SENSING

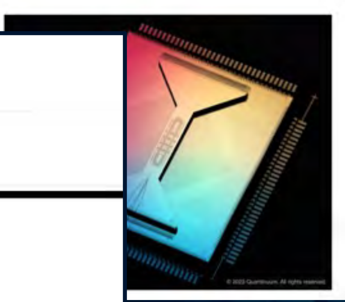
NETWORKING

QUANTUM 2.0
Impacts

RESEARCH Breakthroughs

A Race Track Trapped-Ion Quantum Processor

S. A. Moses,[1,*] C. H. Baldwin,[1,*] M. S. Allman,[1] R. Ancona,[1] L. Ascarrunz,[1] C. Barnes,[1] J. Bartolotta,[1] B. Bjork,[1] P. Blanchard,[1] M. Bohn,[1] J. G. Bohnet,[1] N. C. Brown,[1] N. Q. Burdick,[2] W. C. Burton,[1] S. L. Campbell,[1] J. P. Campora III,[1] C. Carron,[3] J. Chambers,[1] J. W. Chan,[1] Y. H. Chen,[1] A. Cher



nature

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Article | Open Access | Published: 22 February 2023

Suppressing quantum errors by scaling a surface code logical qubit

nature

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Article | Published: 22 March 2023

Real-time quantum error correction beyond break-even

nature

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nature > articles > article

Article | Open Access | Published: 14 June 2023

Evidence for the utility of quantum computing before fault tolerance

Youngseok Kim, Andrew Eddins, Sajant Anand, Ken Xuan Wei, Ewout van den Berg, Sami Rosenblatt, Hasan Nayfeh, Yantao Wu, Michael Zaletel, Kristan Temme & Abhinav Kandala

nature

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nature > articles > article

Article | Published: 16 February 2022

Resolving the gravitational redshift across a millimetre-scale atomic sample

Tobias Bothwell, Colin J. Kennedy, Alexander Aeppli, Dhruv Kedar, John M. Robinson, Eric Oelker, Alexander Staron & Jun Ye

02

INDUSTRY

Organizations

QUANTUM COMPUTING
Industry

Why?
Who?
What?
Where?

WHY?

Applications

COMPUTING	SENSING	NETWORKING
Shor Grover VQE QAOA NISQ	Clocks Sensors	QKD

WHAT?

RESEARCH

Fundamental Science
Research & Development

Academia & Federal labs

Grants and federal funding

Research groups

INDUSTRY

Product development
Applications

Corporations & startups

Internal or venture funding

(Large) cross-functional teams

WHO?
Quantum Computing

STARTUPS

Inflection
Atom Computing
PASQAL
Planqc
QuEra Computing

IonQ
Alpine Quantum

PsiQuantum
Xanadu Quantum Tech.

Rigetti
IQM
Quantum Circuits Inc.

ENTERPRISE

Google
IBM
aws
NORTHROP GRUMMAN
Honeywell
intel
HRL LABORATORIES
Microsoft

Strategies

Software
Commercialization
Communication
Access

WHO?
Quantum Industry

R&D

Research Centers
FFRDCs
Federal Labs
Universities

Enterprises Companies
Startups

TECH ECOSYSTEM

End users
Integrators
Non-profits
Government
Enabling technologies

EMERGING TECH ECOSYSTEM

Venture capital
Economic development
Education
Conferences
News
Consulting

WHAT?

Impacts to Academia

LARGE INVESTMENTS

Caltech
Michigan
Duke
U Chicago

Among others

QUANTUM ENGINEERING

MIT
Harvard
CO Mines
CO Boulder
Delaware

Among others

QUANTUM CENTERS

NQI centers
DOE centers
University initiatives

PARTNERSHIPS

AWS + Harvard
AWS + Caltech
Google + UCSB

Among others

WHAT?
Quantum Ecosystem

BUSINESS CONFERENCES

INSIDE QUANTUM TECHNOLOGY
WORLD TOUR OF CONFERENCES

QT Quantum.Tech

Q2B

SPIE. PHOTONICS WEST

OPTICA

NEWS SITES

THE QUANTUM INSIDER

Quantum Computing Report by GQI

INSIDE QUANTUM TECHNOLOGY NEWS

CONSULTANTS

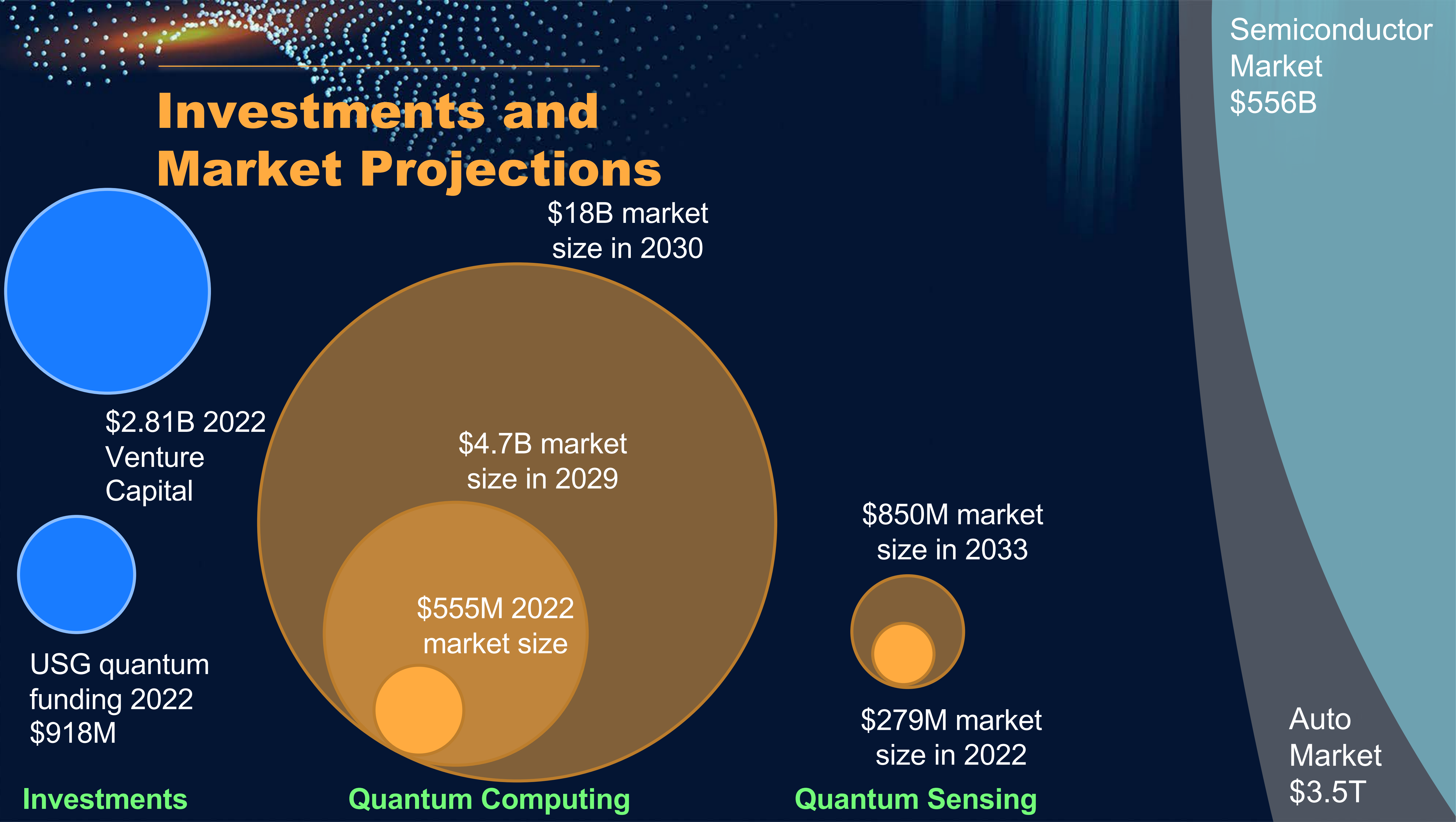
accenture

BCG

Deloitte.

McKinsey & Company

Investments and Market Projections



03 ECOSYSTEM

QUANTUM

The science

INDUSTRY

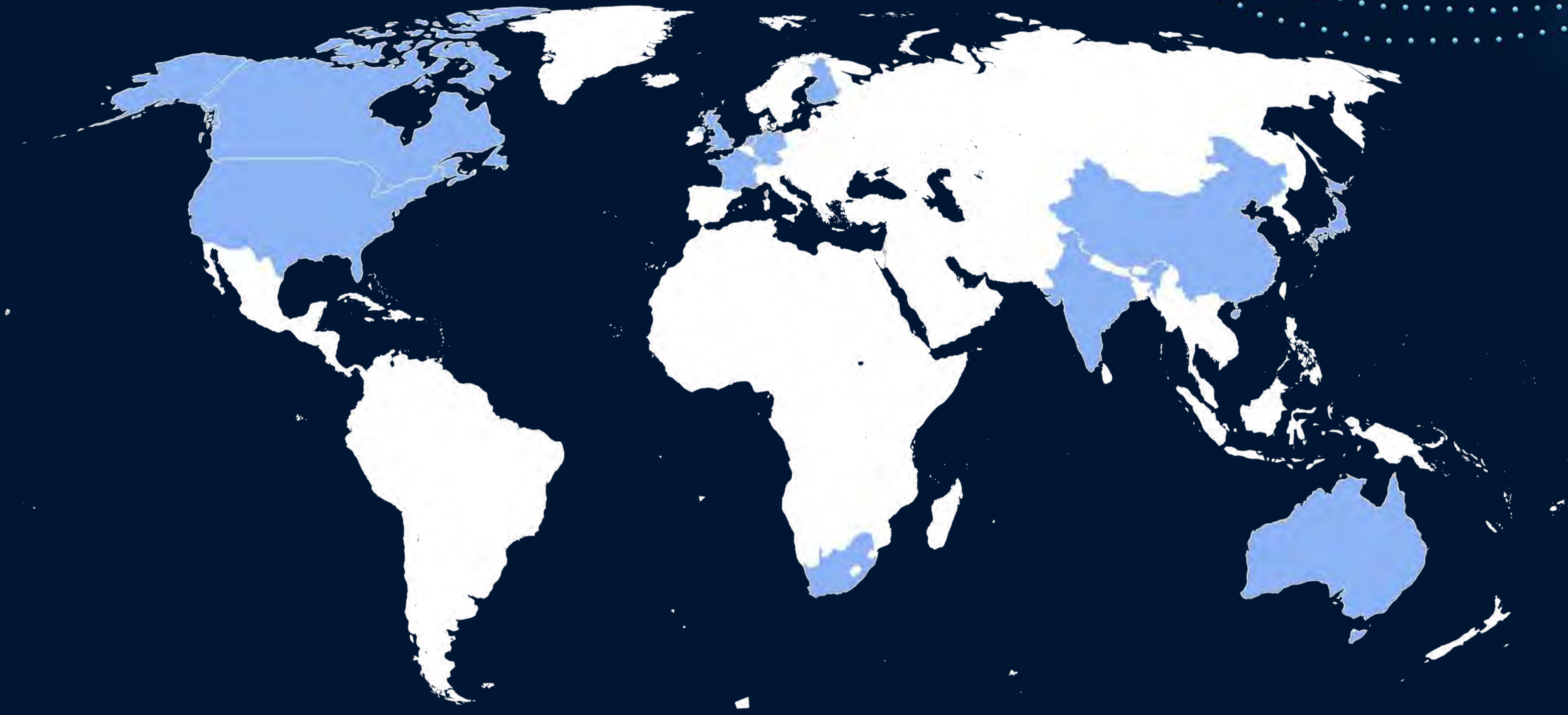
The organizations

ECOSYSTEM

How they fit together

Global QUANTUM INITIATIVES

Over $21B government investments



National Quantum Initiative Act (2018)

PUBLIC LAW 115–368—DEC. 21, 2018

NATIONAL QUANTUM INITIATIVE ACT

Public Law 115–368
115th Congress

An Act

Dec. 21, 2018
[H.R. 6227]

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,

National Quantum Initiative Act.
15 USC 8801 note.

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:

NATIONAL QUANTUM COORDINATION OFFICE

⟨quantum|gov⟩

An official website of the United States government

5
NSF Centers

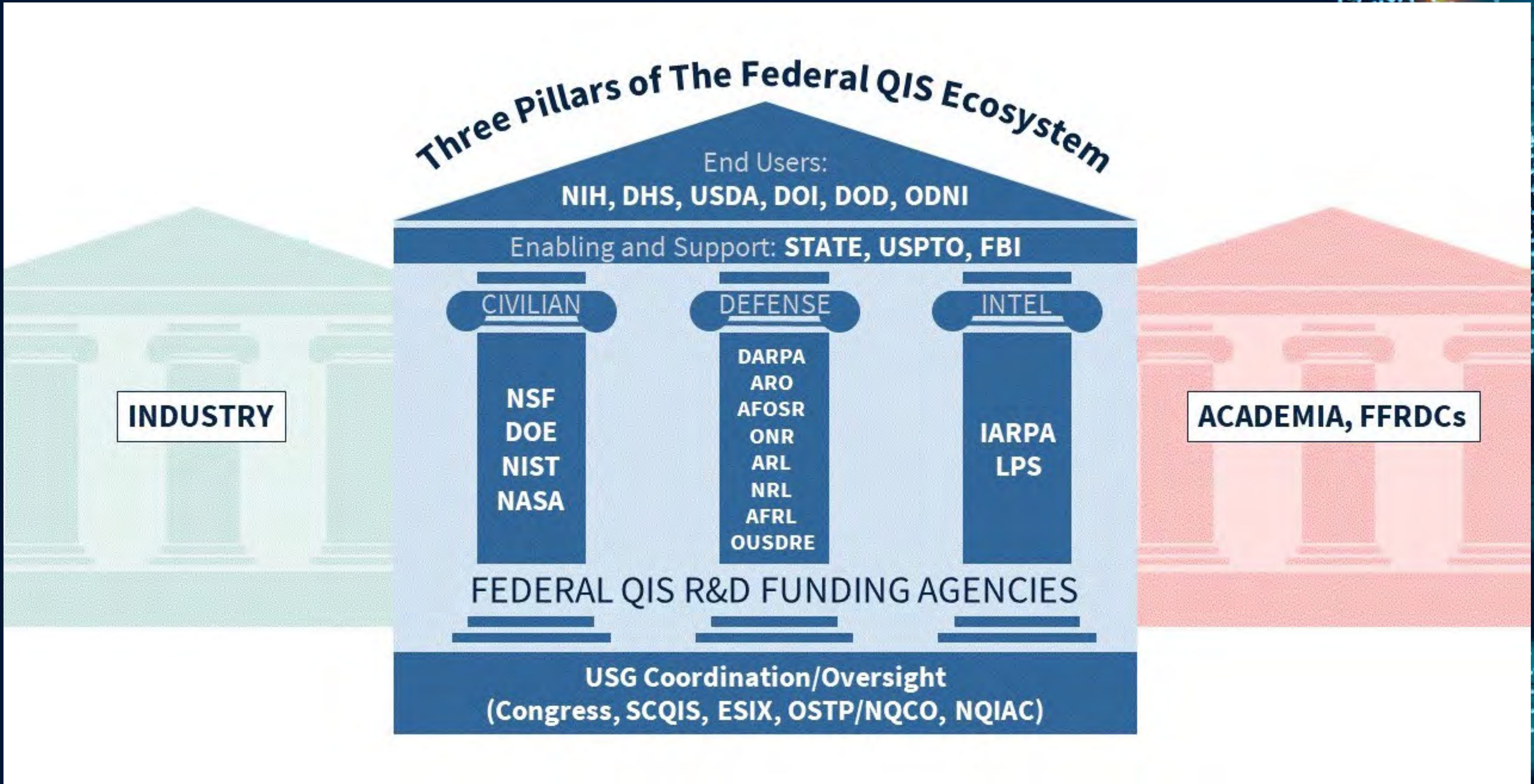
5
DOE Centers

3
NDAA Centers

NIST

QED·C

Quantum Ecosystem



Quantum ECOSYSTEMS

Government labs
- Fundamental Research
- User test beds
- National security and prosperity focus

Quantum makerspace
- Remove barriers to product development

Quantum industry
- Product development
- Sales
- IP generation
- Funding

Education
University
- Foundational Research
- Education/workforce development

Community colleges
- Education & workforce

Ecosystem hub
- Connect the quantum ecosystem
- Unify messaging
- Support workforce

Economic development organizations
- Spur growth
- Job creation

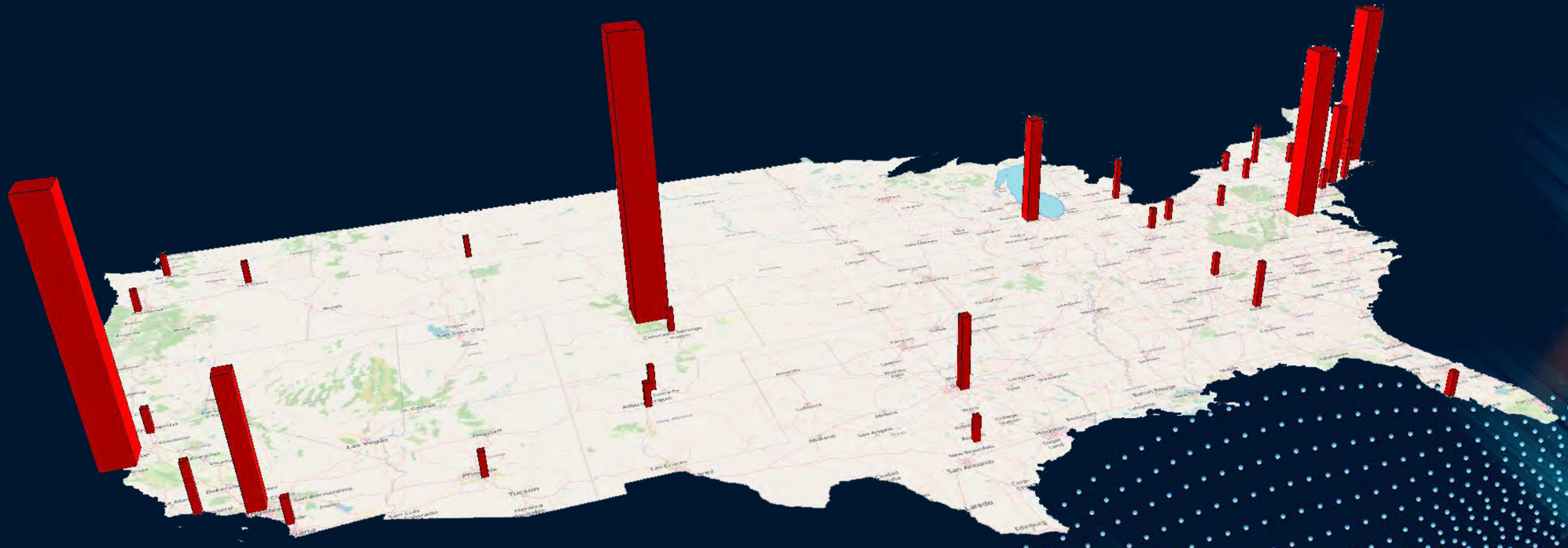
Research Infrastructure
- State of the art facilities

Federal funding
- Science and technology development
- National security and prosperity

State government
- Funding
- Organization

Incubator or accelerator
- Business support
- Startup catalyst

Quantum Industry
LOCATIONS



Ref: QED-C quantum membership (Nov '22)

Quantum Industry
GROWTH

Ref: Pitchbook quantum startups Jan 2019 – Nov 2022

Quantum
HUBS

Quantum Proposals

EDA BBBRC proposal

Washington DC
Knoxville, TN
Bozeman, MN
Northwestern Indiana
Denver, CO
Albuquerque, NM

NSF Engines Type-2

College Park, MA (UMD)
Upstate NY (SUNY-Oswego)
Boston, MA (Harvard University)
Norfolk, VA (Forward Edge AI)
Ohio (Cleveland Clinic)
Chicago (U Chicago)
Southwest USA (Cal State Northridge)

Ref: QED-C quantum membership (Nov '22)

SNAPSHOT:
CO Ecosystem

Academia

Academia
- Colorado School of Mines
- Colorado State University
- CU Denver
- University of Denver
- Front Range Community College
- CU Boulder & JILA

Research Centers
- DOE QSA (JILA)
- NSF Q-SEnSE (JILA)
- NSF STROBE (JILA)
- NSF Physics Frontier Center (JILA)
- NSF NRT-QL: A Program for Training a Quantum Workforce (Mines)
- NSF Quantum Grid (CU Denver)

Government

USG Labs and partners
- US Air Force Academy
- National Institute of Standards and Technology (NIST)
- National Renewable Energy Laboratory (NREL)

Funding Agencies
- NSF
- DOE
- NASA
- DOD

Industry

Quantum Industry

Computing
- ATOM Computing
- ColdQuanta
- Quantinuum
- Resilient Entanglement

End-Users
- Lockhead Martin
- Northrop Grumman

Sensors
- Longpath
- Xairos Systems

Quantum Industry

Photonics
- Vescent Photonics
- Stable Laser Systems
- KM Labs
- Octave Photonics

Cryogenics
- Maybell Quantum Industries
- Formfactor

Components
- Quantum Physics Research Instruments
- Vapor Cell Technologies

SNAPSHOT:
CO Ecosystem

Academia

Academia
- Colorado School of Mines
- Colorado State University
- CU Denver
- University of Denver
- Front Range Community College
- CU Boulder & JILA

Government

USG Labs and partners
- NIST

Industry

Computing
- Eskandarpour - DU → **Resilient Entanglement**
- Bloom – JILA PhD → **ATOM Computing**
- Anderson – JILA fellow → **Infleqtion**
- NIST & JILA → **Quantinuum**

End-Users
- LM Fellow Loftus – JILA → Lockheed Martin
- Northrop Grumman

Sensors
- Rieker – CU ME → **Longpath** ($25M raise)
- Xairos Systems

Economic Development
- Wilson – NIST → **QED-C**

Photonics
- JILA spinout → **Vescent Photonics**
- JILA spinout → **Stable Laser Systems**
- JILA spinout → **KM Labs**
- NIST spinout → **Octave Photonics**

Cryogenics
- Maybell Quantum Industries
- JILA spinout → **Formfactor**

Enabling Tech.
- Quantum Physics Research Instruments
- NIST spinout → **Vapor Cell Technologies**

CO Ecosystem

1000+

People Employed

$400M

Economic Impact

46%

Year-over-year job growth

TODAY
Where are we going?

NQI Reauthorization

A Report of the

National Quantum Initiative Advisory Committee

June 2023

Renewing the National Quantum Initiative: Recommendations for Sustaining American Leadership in Quantum Information Science

ww2.aip.org • 7 min read

Technology Progress

The New York Times

Quantum Computing Advance Begins New Era, IBM Says

A quantum computer came up with better answers to a physics problem than a conventional supercomputer.

THANK YOU

Philip Makotyn, PhD
PMG Quantum Advisors

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