The Case for the Quantum Internet

Dr. Tommy Gardner
Chief Technology Officer, HP Federal
August 30, 2022


Photo: MIT Technology Review

"Those who are not shocked when they first encounter quantum theory cannot possibly have understood it."

- Niels Bohr

Classical Computer

Information stored in Binary Digits (Bits).
All processing is Sequential.

These two limiting principals have not changed.

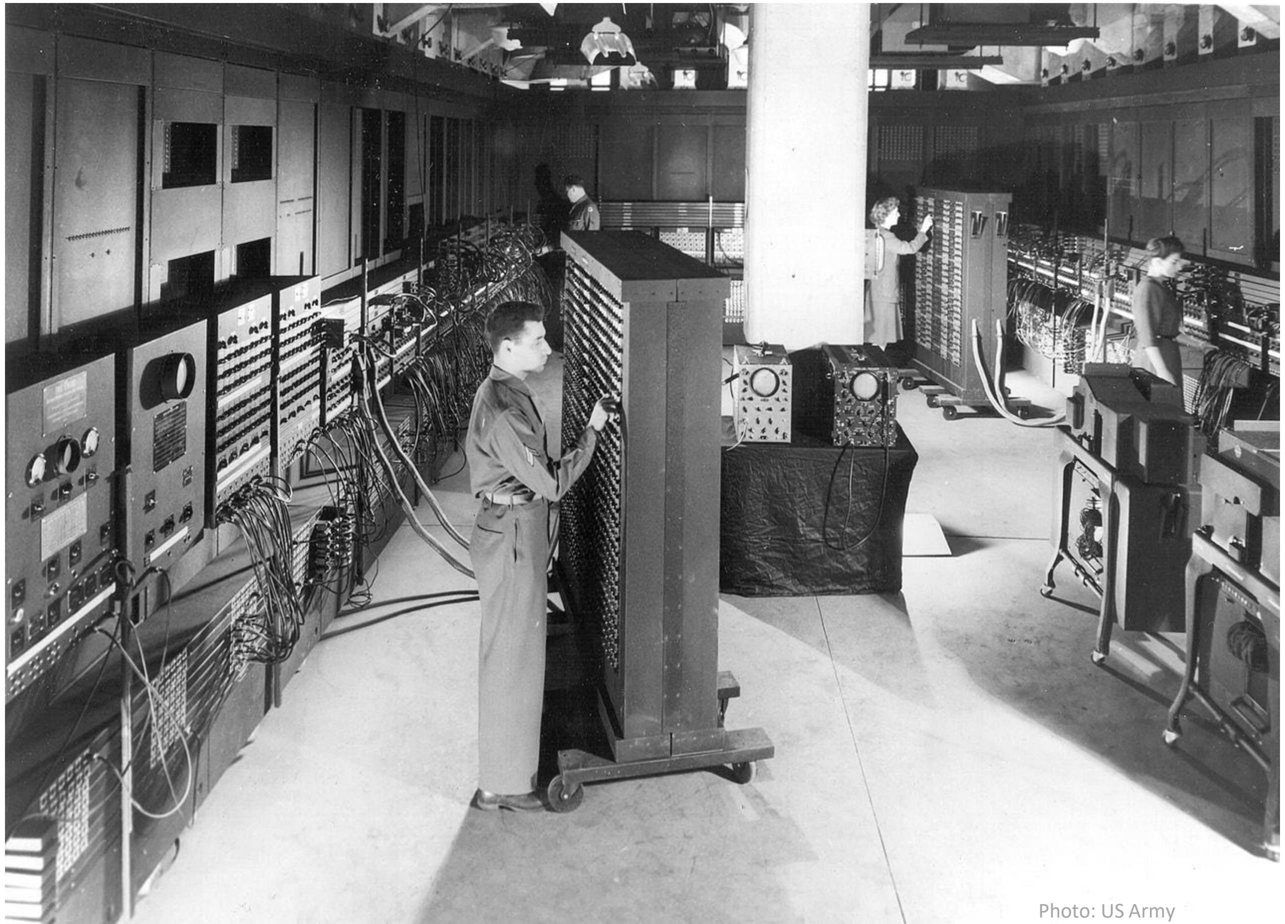


Photo: US Army

Eniac 1946

First general purpose computer.

Speed: 2000 cycles/sec.
(3 square roots/second)
Memory: Twenty 10-bit numbers.
20,000 vacuum tubes.
5,000,000 hand-soldered connections.
27 tons (13 automobiles)
covered 1800 sq ft.
150,000 Watts.
$6.7M (in 2018 dollars).

Quantum Computer

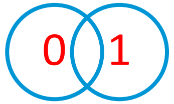
Information stored in Quantum Digits (Qubits).
Processing is truly Parallel.

Quantum computers leverage the quantum states of subatomic particles to store information.

Two key principles that can allow vast number of calculations simultaneously:

Superposition - Multiple states can be stored simultaneously in one particle. Waves constructively and destructively interfere.

A Qubit can store a 0 or a 1, or both 0 and 1 at the same time in a superposition state.



Entanglement – Two or more quantum particles can be linked in perfect (instantaneous) unison, even if separated by great distances.
Einstein call this “spooky action at a distance”.

Photo: Electronics Weekly

IBM “Quantum Experience”
5 qubit system

Quantum Security Research

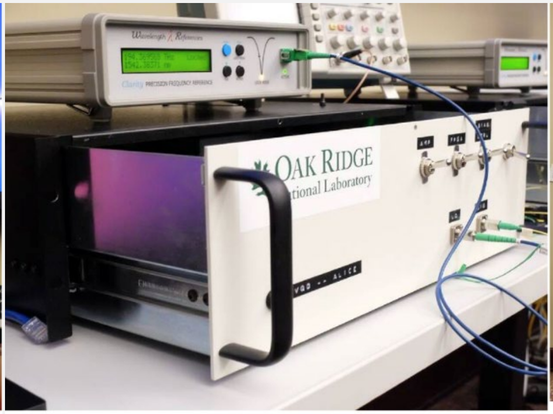
DOE National Labs and Private Sector Partner Qubitekk

Business Around the Region

Chattanooga's EPB takes quantum leap with test of new cybersecurity system

March 5, 2020 | by **Dave Flessner** | Copyright © 2021

Staff photo by Tim Barber / Oak Ridge National Laboratory Quantum Information Science Group Leader Nicholas Peters sits at a computer Thursday inside EPB's Control Center Conference Room in Chattanooga, March 5, 2020.



Staff photo by Tim Barber / A table displays equipment used for data field testing in the EPB Control Center Conference Room Thursday in Chattanooga, March 5, 2020.

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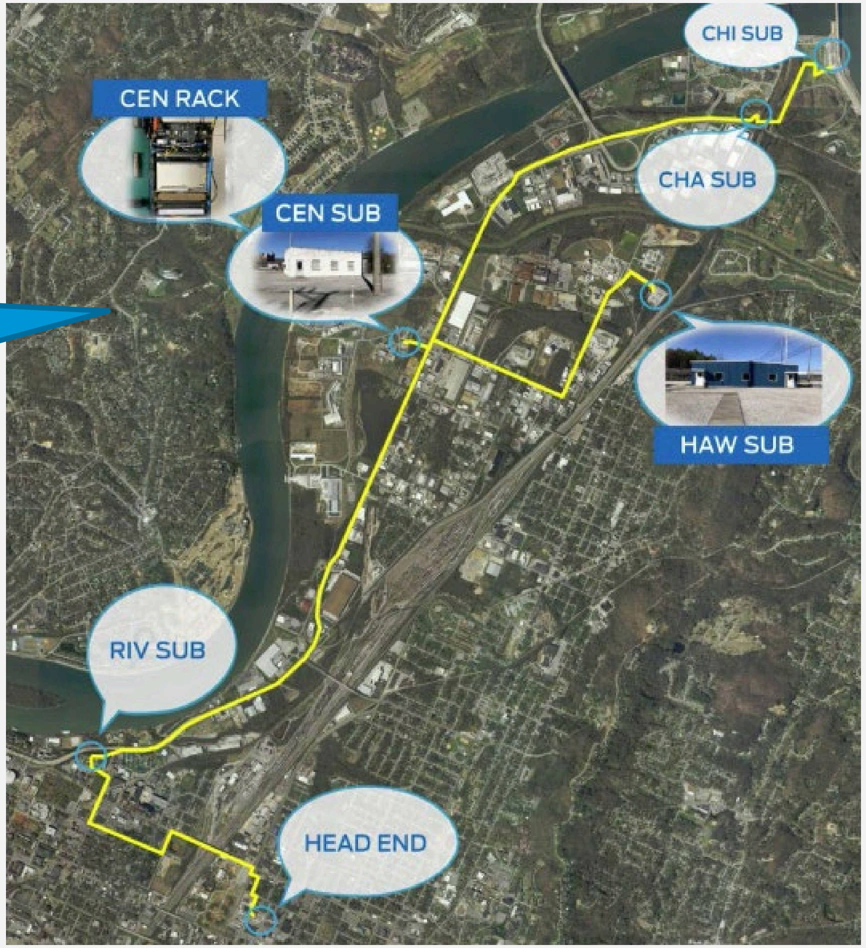
$14M in 5 Successful DOE Funded Quantum Key Distribution Projects at EPB

DOE EPB Quantum Research

Building on Success from 2016

8 miles
Fixed Time
Experiments



EPB Fiber Optics Quantum Testbed 1.0 is ready to evolve and grow.

Quantum Research Award

EPB Excellence in Quantum Research & Development Recognition.

2021 R&D 100 Award winners announced in Process/Prototyping and Software/Services categories

By Paul Heney | October 21, 2021

The winners in the 2021 R&D 100 Awards in the Process/Prototyping and Software/Services categories have been announced by *R&D World* magazine in a virtual ceremony broadcast from Cleveland, Ohio. This renowned worldwide competition, now in its 59th year, received entries from 17 countries/regions. This year, the judging panel included nearly 40 well-respected industry professionals across the globe.

Winner, Finalist, and Medalist logos are available at: **https://www.rdworldonline.com/2021-rd-100-winner-logos**. Each winner receives one plaque; the order form to purchase additional plaques can be downloaded **here**.

Other winners, already announced, are the **Special Recognition medalists,** the **winners in the Analytical/Test and IT/Electrical categories**, and the **winners in the Mechanical/Materials category**. These presentations have been sponsored by Park Systems.

The newest batch of Winners are listed below by category, and then alphabetically by submission name. Sincere congratulations to all of the winning teams!

R&D 100 AWARDS

Park SYSTEMS

Qubitekk

Qubitekk won the 2022 Edison Gold Award for it's work with EBP and the Air Force at Tinker AFB for research efforts on Quantum Protected Networks

2021 R&D 100 WINNER

QED: Quantum Ensured Defense of the Smart Electric Grid

Los Alamos National Laboratory

Oak Ridge National Laboratory and EPB

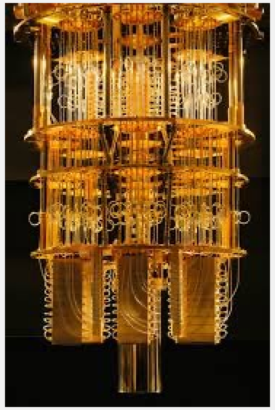
EPB Quantum Network

Mission: Create a quantum lane in the community economy.

QUANTUM INTERNET

QUANTUM COMPUTING

ELECTRIC SYSTEM



ARTIFICIAL INTELLIGENCE APPLICATIONS DRIVE:

1. INTERNET-OF-THINGS
2. AUTO TRANSPORTATION
3. METAVERSE WORK & PLAY
4. DEFI COMMERCE

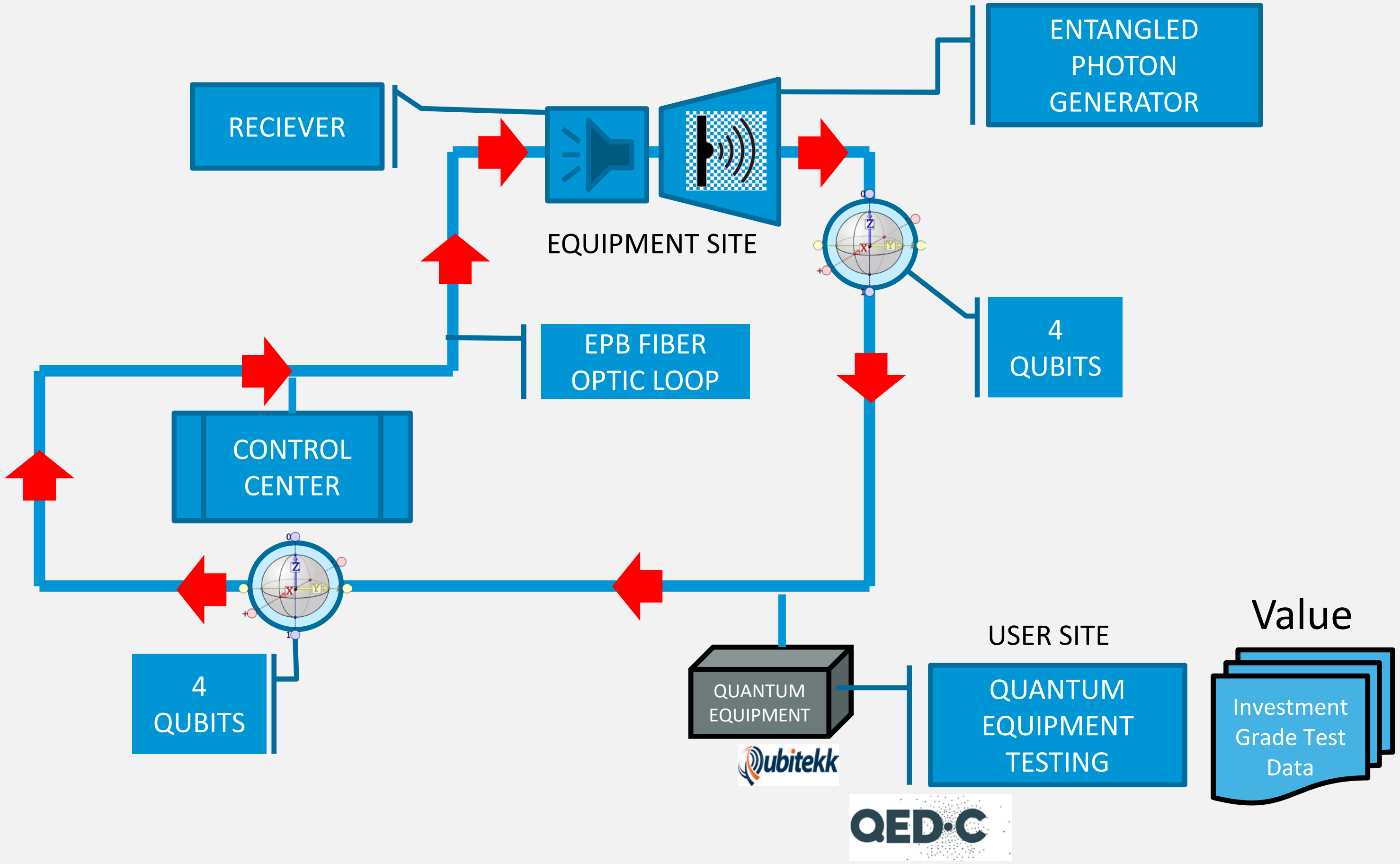
FROM DIGITAL TO QUANTUM COMPUTING

CYBERSECURITY DEFENSE

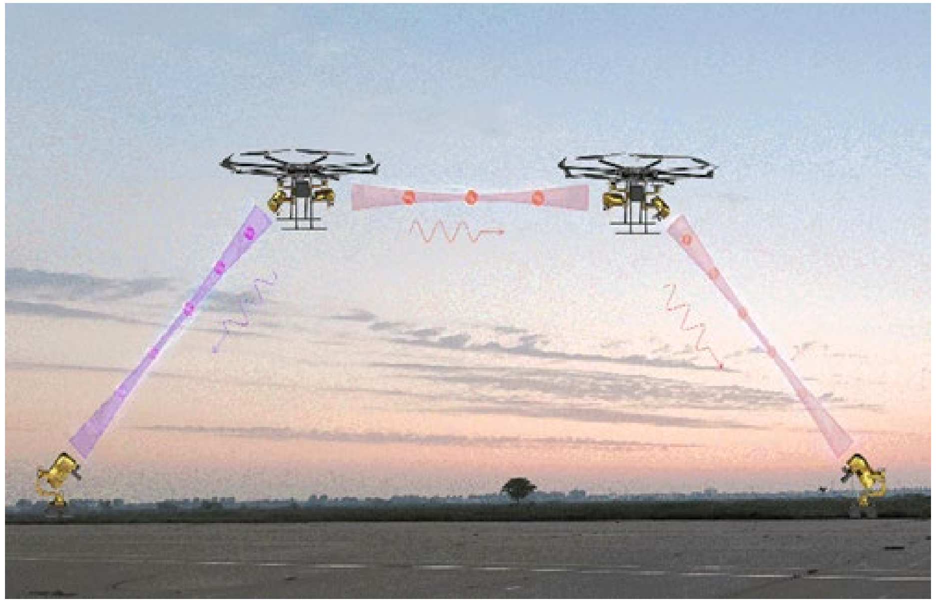
Financial Services, Logistics, Transportation Manufacturing, Healthcare, and coming soon Quantum Equipment and Services.

EPB QUANTUM NETWORK

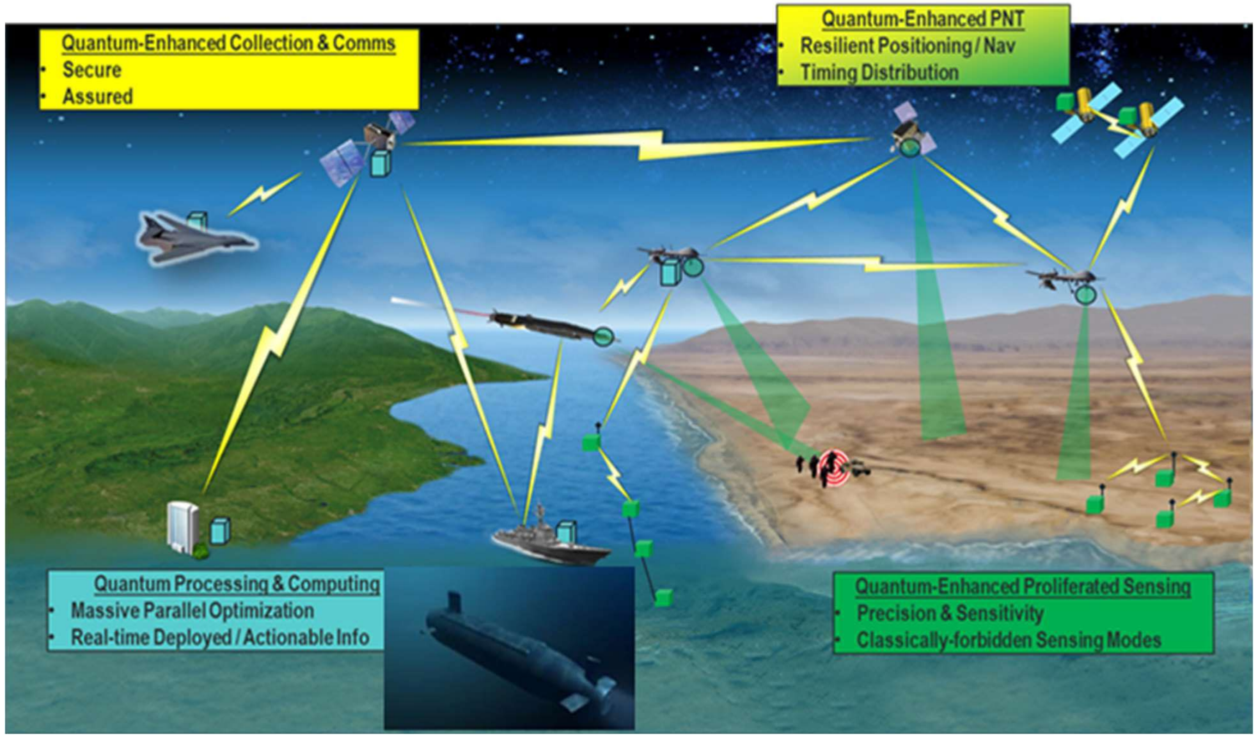
Quantum testbed for commercial, government and academic research



Qubitekk Drone-based Entanglement Distribution Project with the US Air Force



Quantum Entanglement on Drones AFRL Rome



Potential applications enabled by free space quantum networks (image courtesy of L3Harris).

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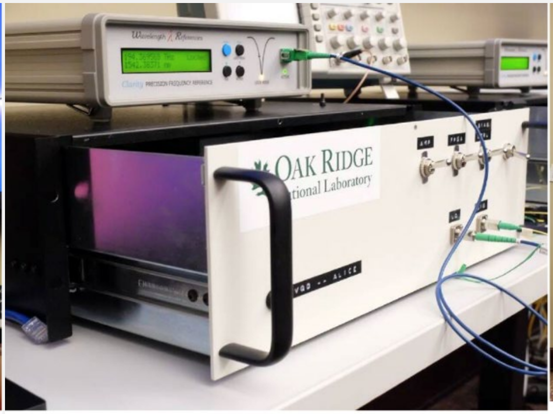

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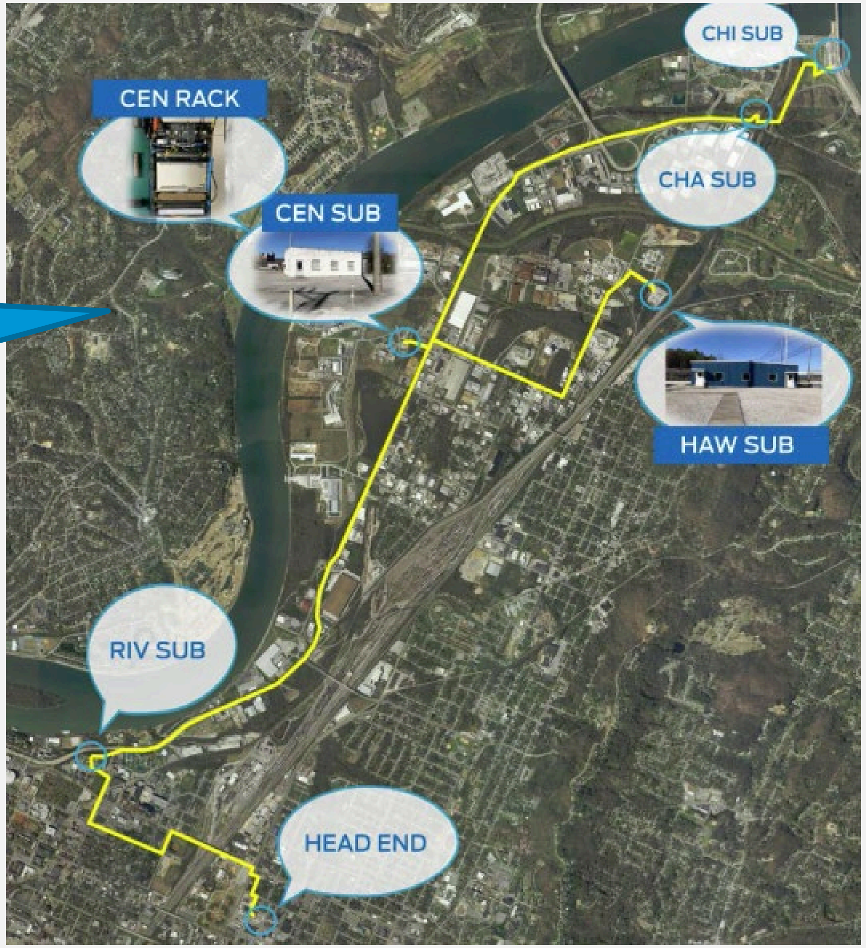

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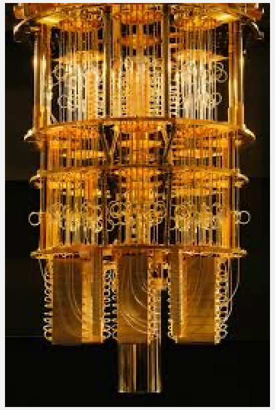

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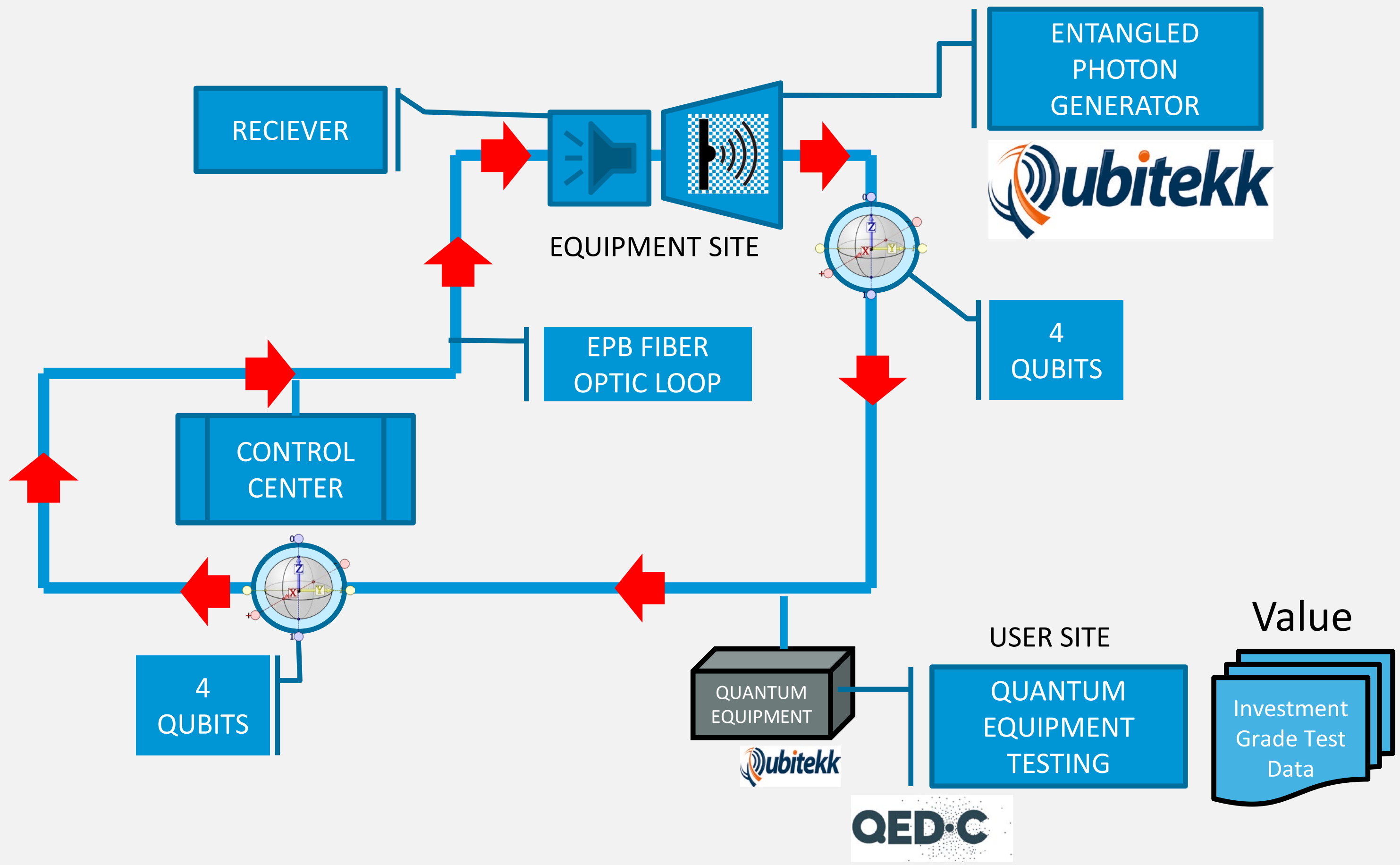

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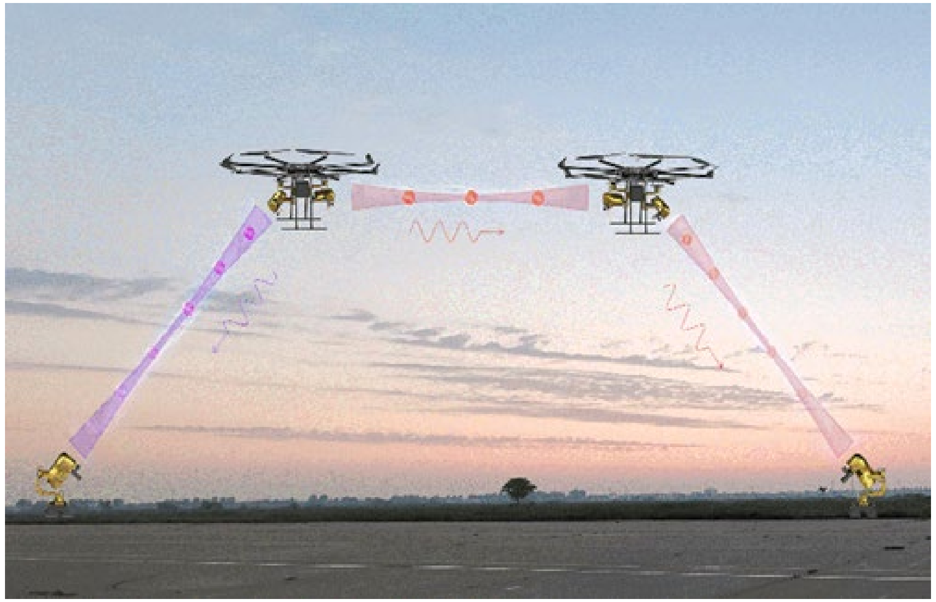

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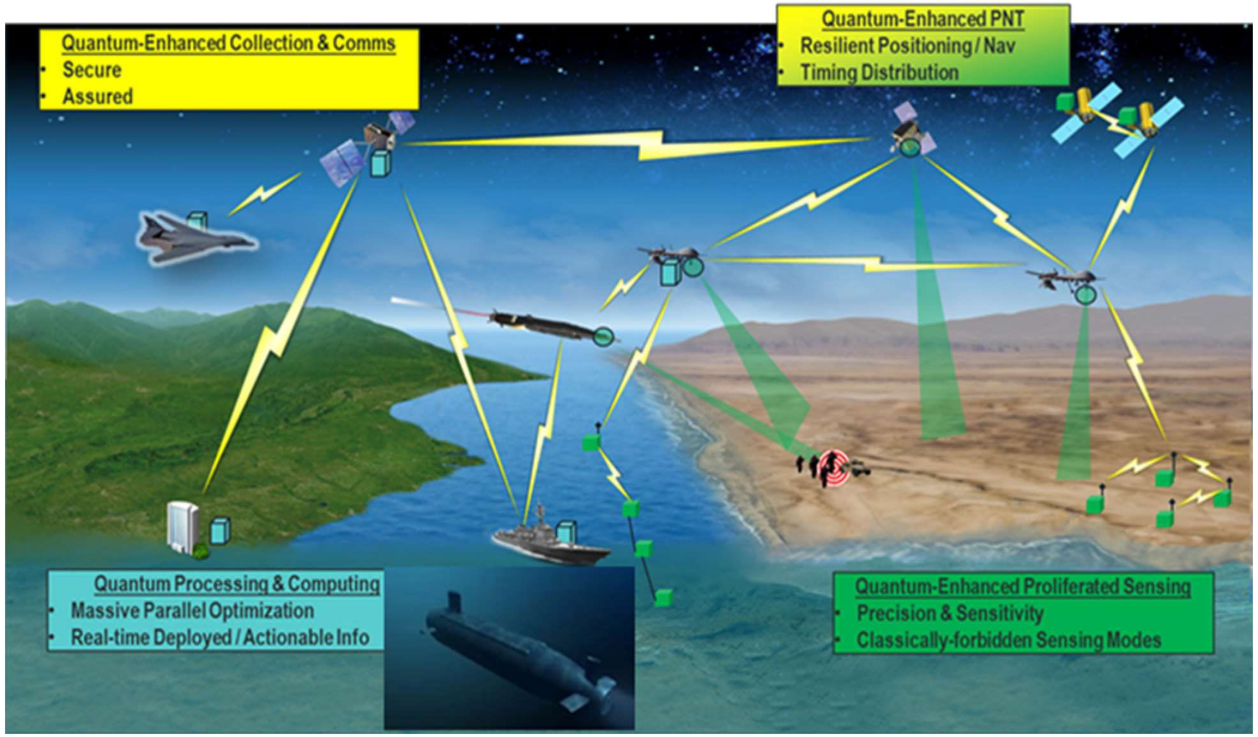

Potential applications enabled by free space quantum networks (image courtesy of L3Harris).

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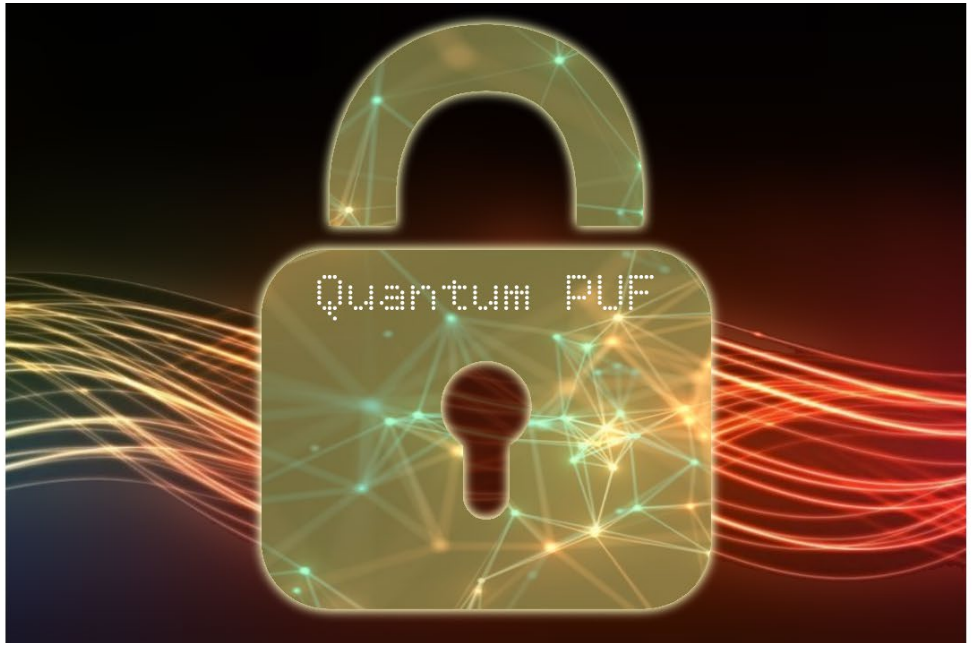


Quantum PUFs

Physical Unclonable Functions

Recently, the inherent unclonability of quantum states has been exploited to derive the quantum analogue of PUF as well as new proposals for the implementation of PUF.

https://quantum-journal.org/papers/q-2021-06-15-475/

QUESTIONS?

BACKUP Material

The Need

The promise is a faster and better means to solving certain (but not all) problems.

Simultaneous calculations allow for breakthrough speeds for large-scale factorization used in encryption, and search tasks.

Projections are it would take mere hours to complete some tasks that would take today's supercomputers millions of years.

Quantum computers could be exponentially faster at
- running artificial-intelligence and machine learning programs
- handling complex simulations.

For Big data it could make impossibly complex problems solvable.

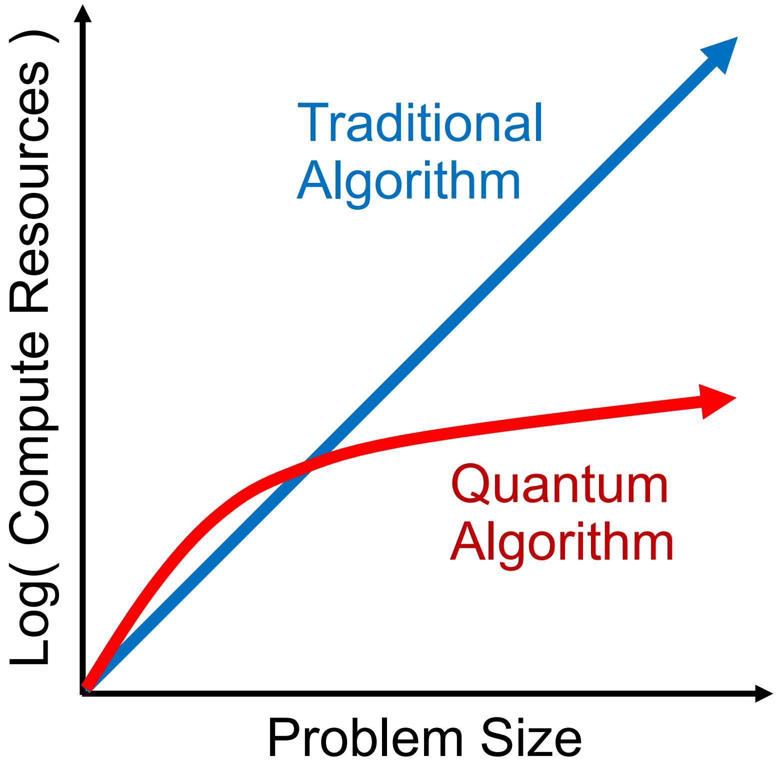


Chart by Intel Research

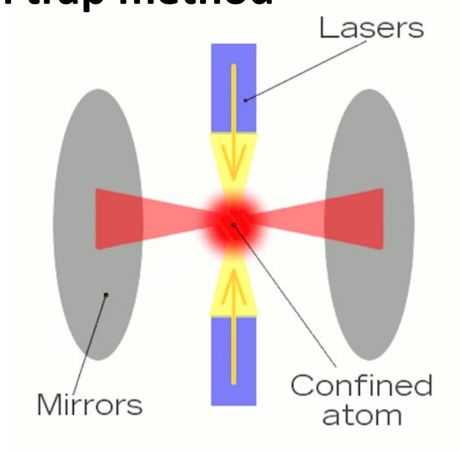
How?

A **Qubit** is
(1) an ion or subatomic particle contained by:

- Laser beams
- Electromagnetic Fields, or
- Radio Waves

(2) A tiny superconducting loop

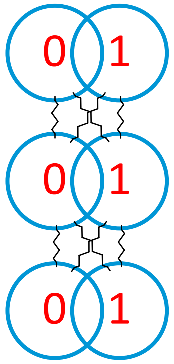
Ion trap method



A single atom can be trapped in an optical cavity and controlled by laser pulses.

Superposition and Entanglement

3 qubits:



Three qubits can store all 8 numbers from 0 (000) to 7 (111). It would take 8 classical bits to encode this.

In general,
N entangled qubits would require 2^N classical bits.

265 qubits would require 10^{80} classical bits, the number of atoms in the universe!

A **Quantum Computer** uses superposition and entanglement to simultaneously process large lists of values.

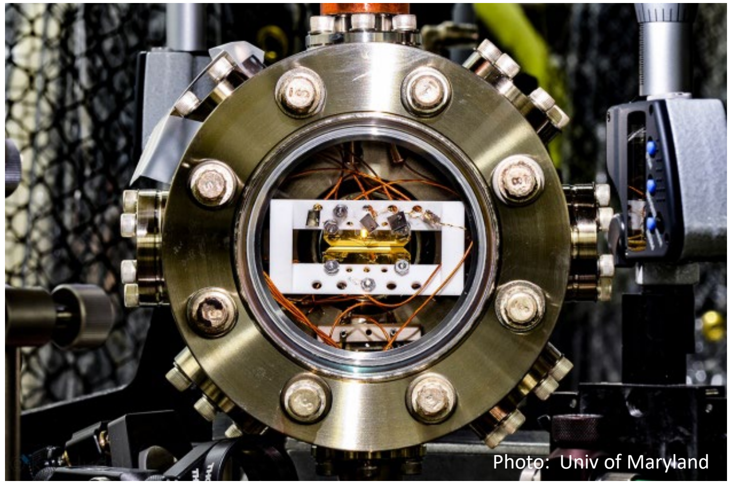
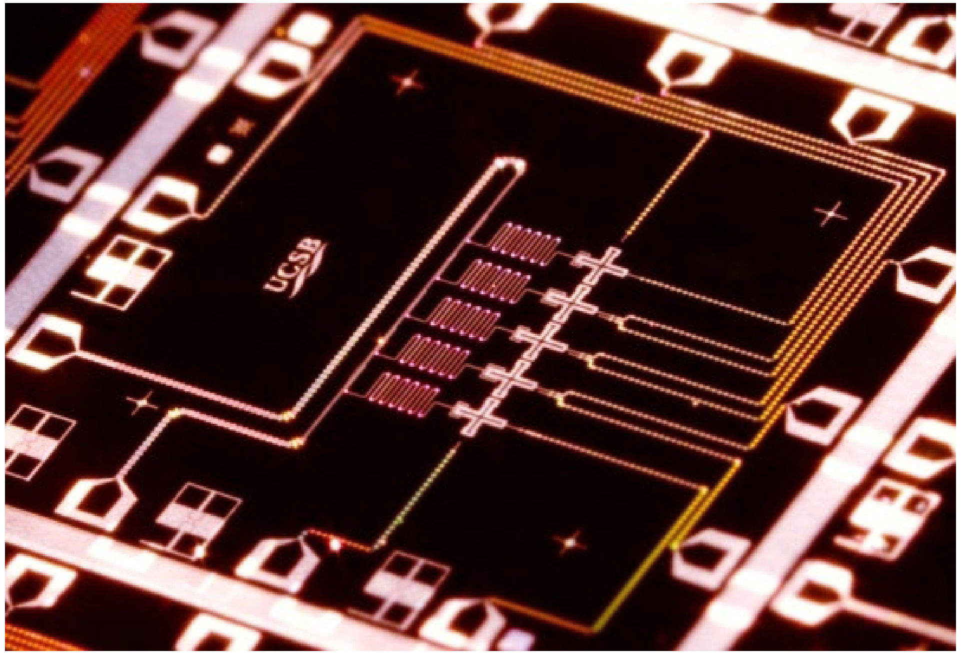


Photo: Univ of Maryland

Superconducting vs. Particle Qubits

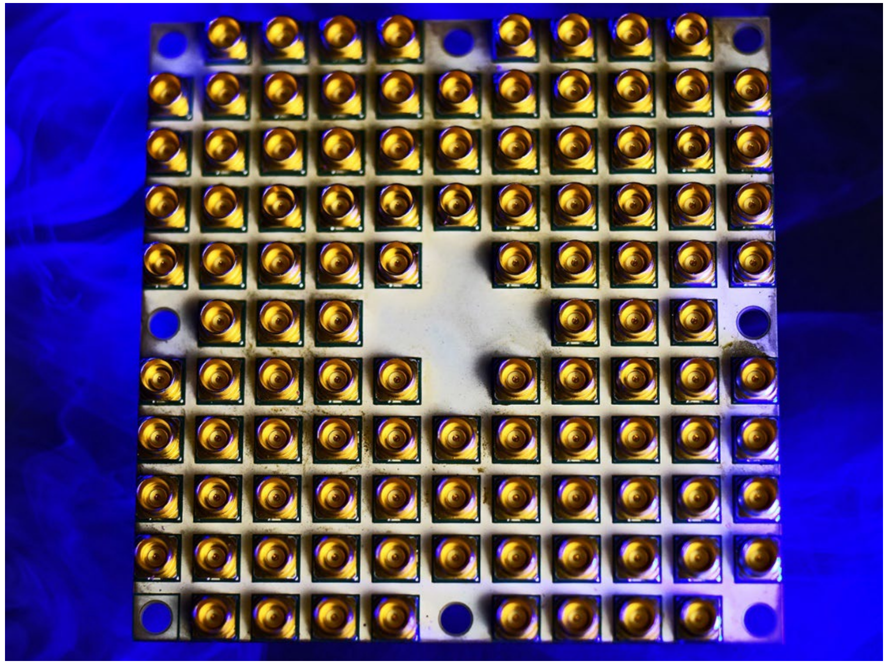


UCSB 5 qubit chip, 2014

Superconducting Qubit

Current flowing a supercooled loop will flow forever in a quantum state, and can flow in both directions simultaneously.

Easier to fabricate , control, and measure.


Intel 49 qubit chip, 2018

Particle-based Qubit

The spin of a supercooled isolated electron is stored. Chips using silicone-based methods can be fabricated.

Can pack more densely in 3D, achieving greater entanglement.

State of the Art and Limitations

“Within five years we will see real quantum computers” - MIT Technology Review 2017.

Software Breakthroughs:
Shor’s Algorithm for Factorization used to break encryption.
Grover’s Algorithm for Sorting large unordered data bases.

Recent Hardware Breakthroughs:
IBM, Google, and Intel demonstrate 50-qubit systems.
Intel fabricates silicon-based qubits (vs super-conducting circuits).

Current encryption keys would be easily cracked, so a new effort in quantum encryption is developing.

Limitations:
Stable qubits are fragile. Systems suffer from “Decoherence”, the irreversible loss of information to the surrounding environment.
So, the system needs to be carefully isolated and cooled to near absolute zero.

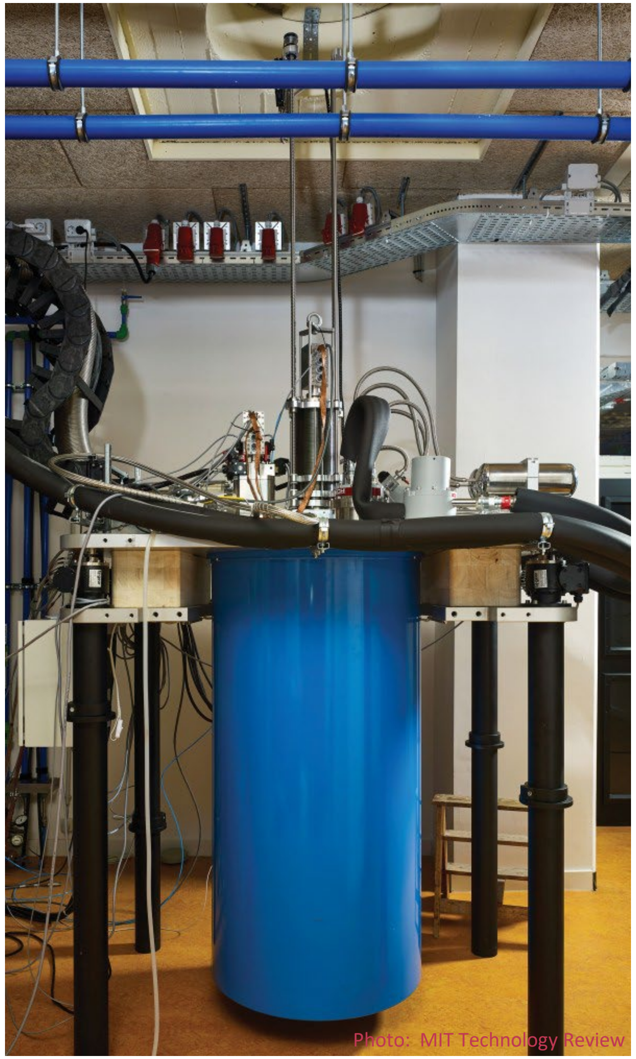


Photo: MIT Technology Review

Necessary Super-cooling

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“Quantum Supremacy”

The term refers to the point when quantum computers outperform the fastest traditional supercomputer; today that means a memory of about a Petabyte.

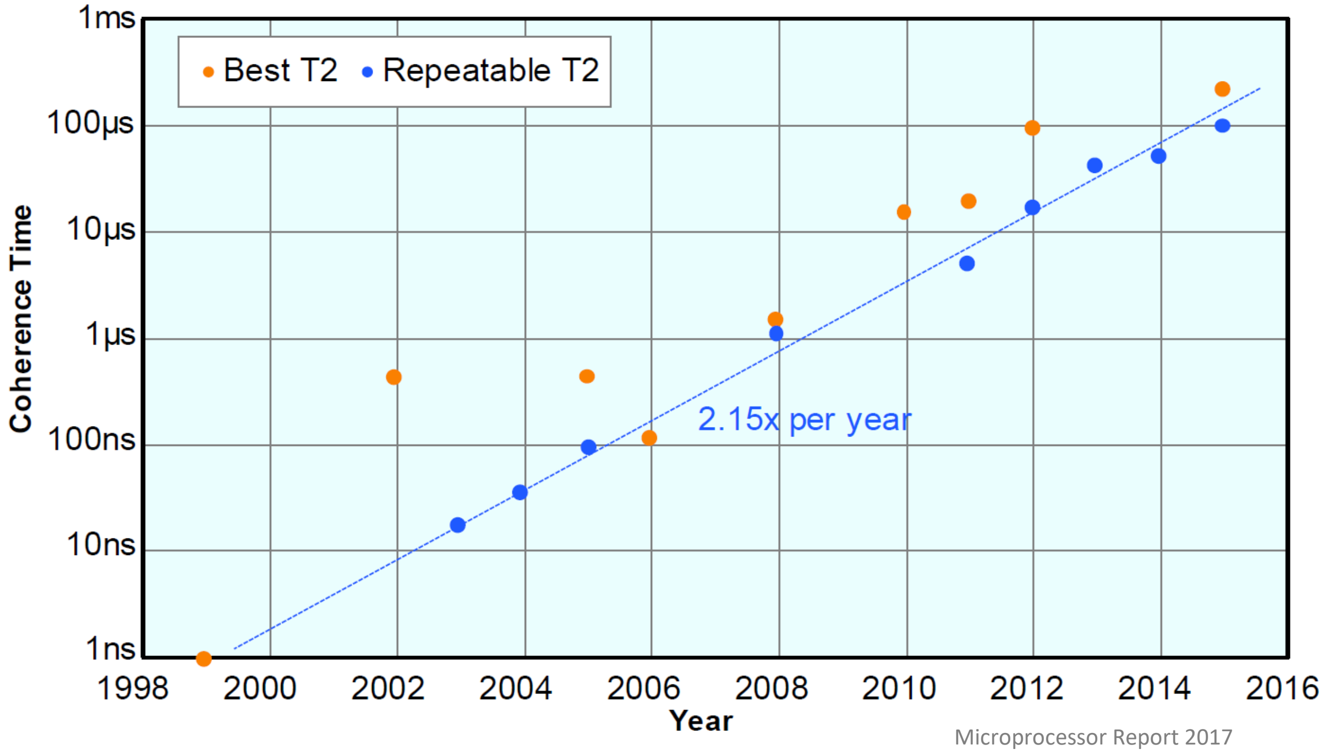
This threshold is reached when the number of entangled qubits exceed 50. (Bits = 2^{50}.)

Chips about that size have been reported in the past month.


Photo: MIT Technology Review

Coherence Time (“T2”) limits number of complex computations

Time before entanglement collapses.

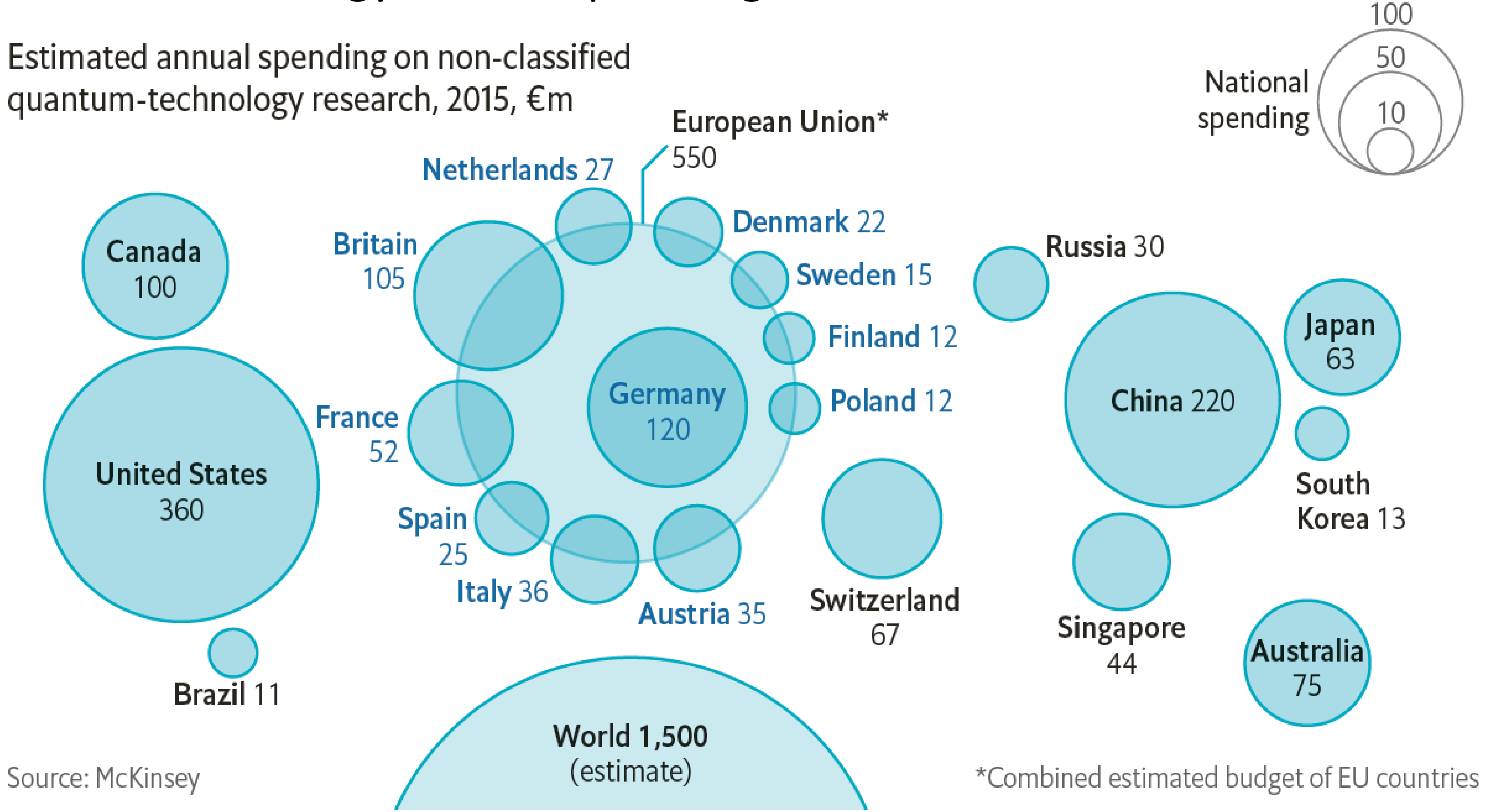


Microprocessor Report 2017

The rate of increase is 10x every 3 years.

The hope is a full second in a decade.

Quantum Technology Global Spending



The Economist, 2017

Recommendations

Developing Quantum Computers is probably not right for HP's business.

- Quantum Computers are seen as the future of supercomputers.
- NOT seen as an improvement over classical computers for the vast majority of tasks.
- Unlikely to be ever be mobile, because of the requirement to be super-cooled…
  - (But remember the Eniac.)

Consider partnering with a Key Player in Quantum Computing to explore high-speed services.

- Industrial Leaders:
- University Leaders:
  - University of Maryland
  - MIT
  - University of Waterloo
  - Delft University