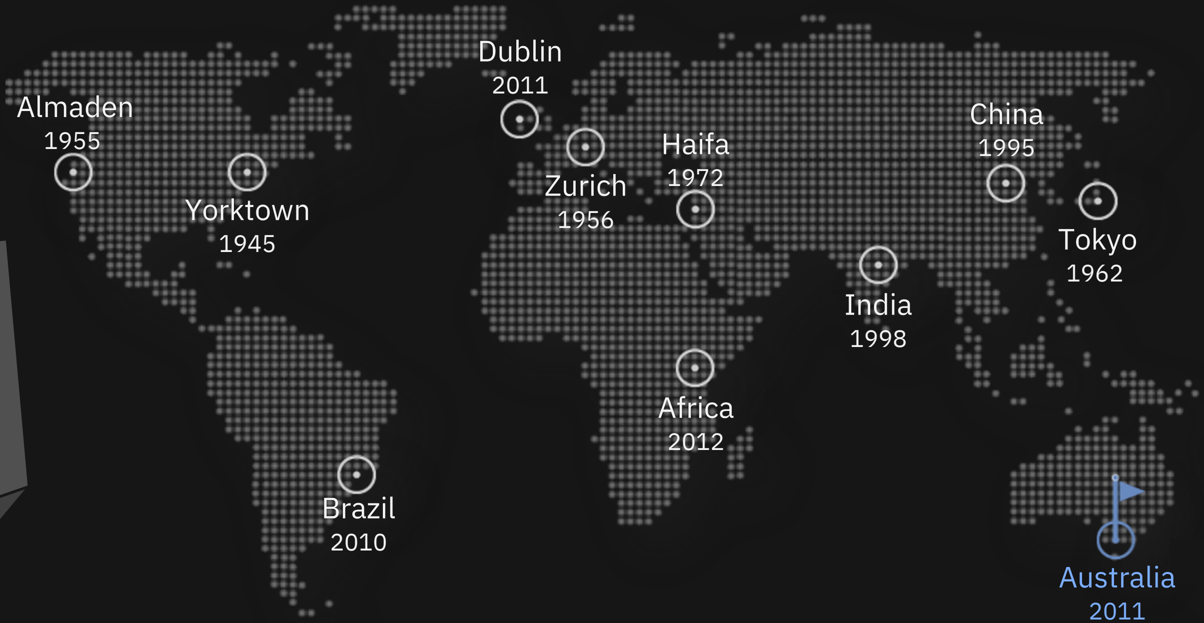
Quantum Computing at IBM

Anna Phan
Research Scientist

IBM **Quantum**

IBM Research



Inventing What's Next in Science and Technology

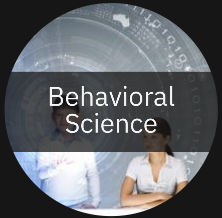
3000 Researchers

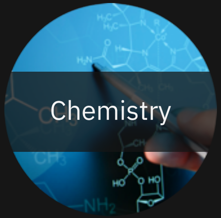
6 Nobel Laureates

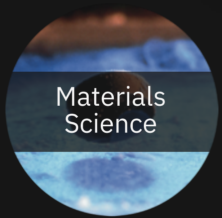
5 US National Medals of Science

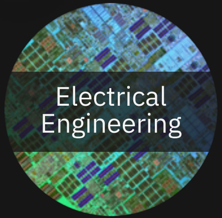
6 Turing Awards

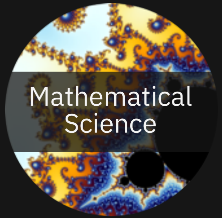
25+ years of Patent Leadership

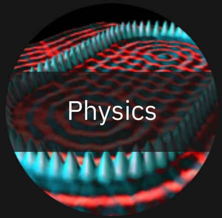






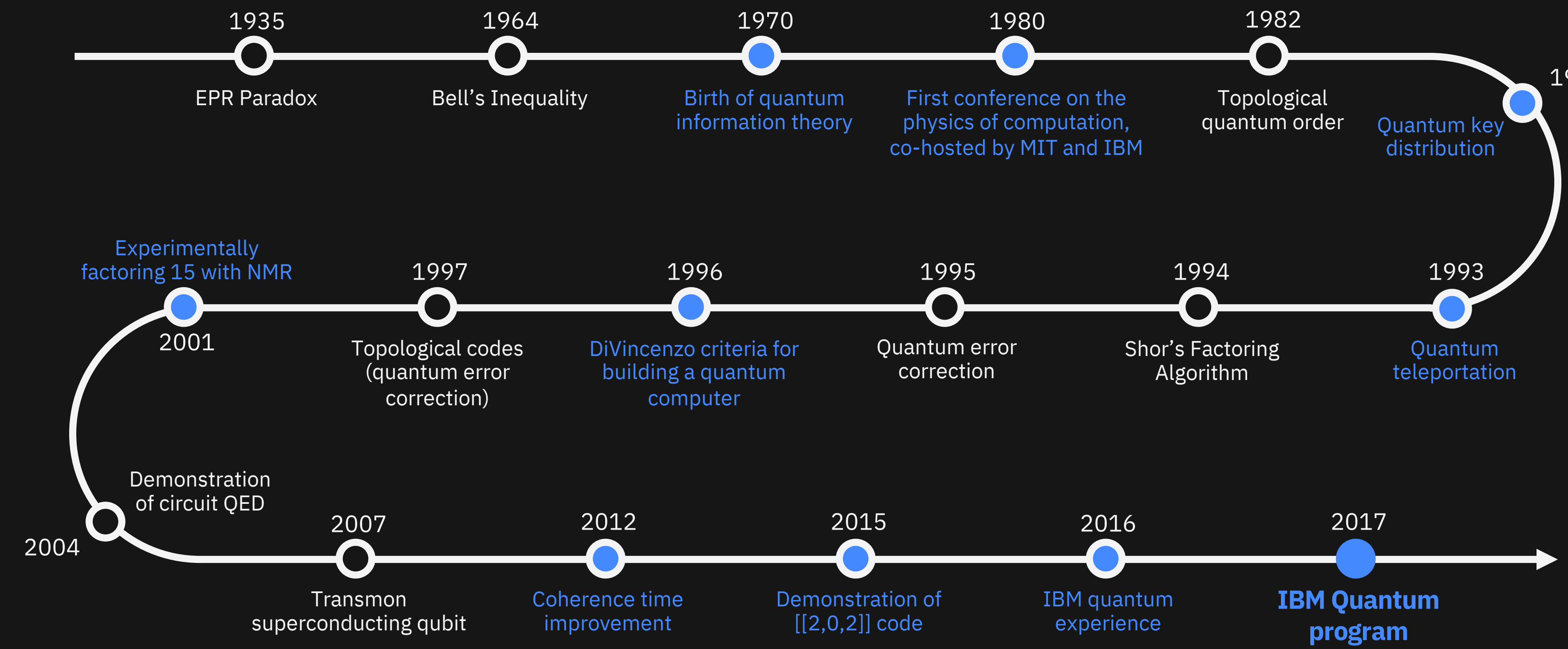




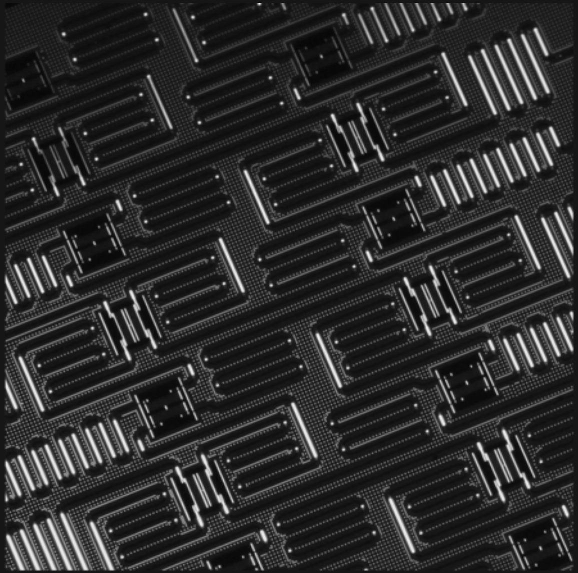


IBM Research & Quantum Computing

“Nature isn’t classical, dammit, and if you want to make a simulation of nature, you’d better make it quantum mechanical, and by golly it’s a wonderful problem, because it doesn’t look so easy.” - Richard Feynman, Physics of Computation Conference, co-hosted by MIT and IBM, 1981



IBM Quantum Computing Program



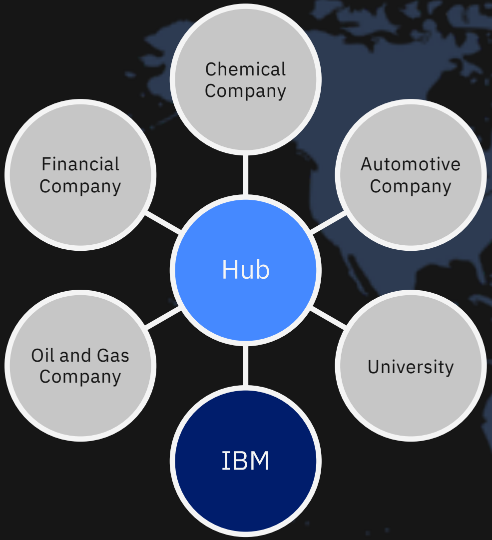
Hardware
&
Engineering

Software
&
Ecosystem

Algorithms
&
Applications

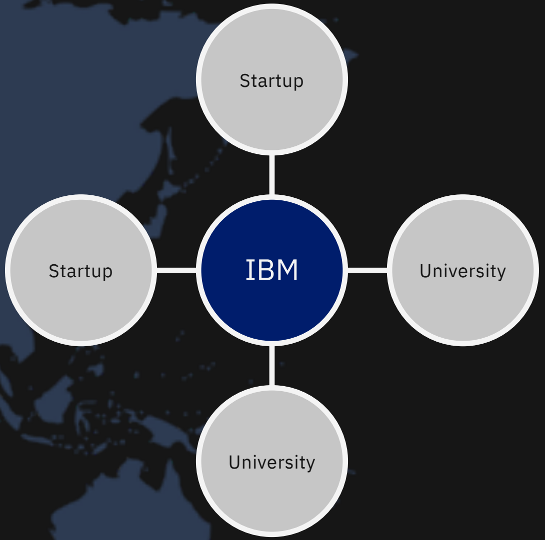
IBM Q Network

A collaboration with leading Fortune 500 companies and research institutions with the shared mission of *advancing quantum computing*, launching the *first commercial applications*, and *educating and preparing* the future workforce.



Hubs
Regional centers of quantum computing research, development and education

Partners
Deep collaborative research on applications utilising IBM Quantum Systems



Members
Enabling organisations to learn and leverage IBM Quantum technology

IBM Q Network Today

126 members

- 11 industry partners
- 14 hubs
- 30 members
- 34 startups
- 37 academic members and partners

Partners

JP Morgan Chase & Co.
ExxonMobil
Samsung
Daimler
JSR Corp
Accenture
Goldman Sachs
Woodside Energy
BP
Amgen
Boeing

Hubs

University of Tokyo
Fraunhofer
US Air Force Research Lab
Oak Ridge National Lab
Keio University
NC State Uni.
Munich Hub at U. Bundeswehr
National Taiwan University
Iberian Nanotech Lab
CSIC Spain
Los Alamos National Laboratory
U. Melbourne
U. Oxford
U. Sherbrooke

Members

Delta
Anthem
Wells Fargo
Barclays
Mizuho
MUFG
Mitsubishi Chem
Argonne Lab
Fermilab
Berkeley Lab
Brookhaven Lab
Naval Res Lab
ITRI
III Taiwan
CERN
Quemix
Flight Profiler
SVA
Archer
A*Quantum
Tradeteq
Grid
CMC
Lockheed Martin
Sandia National Lab
DIC
Toyota
Hitachi
Toshiba
General Atomics

Startups

CQC
QC Ware
1QBit
Zapata
Strangeworks
Q-CTRL
Quantum Benchmark
MDR
Qu&Co
JoS Quantum
SolidStateAI
ProteinQure
Labber Quantum
MaxKelsen
Netramark
Entropica
Boxcat
Rahko
Qunasys
QuantFi
Agnostiq
AIQTech
Zurich Instruments
BEIT
Quantum Machines
Aliro
Xanadu
Apply Science
Multiverse
Equal1
Miraex
SpftwareQ
Super.tech
Nordic Quantum

Academic

MIT
EDX.org
Virginia Tech
U. Montpellier
Notre Dame
Harvard
Princeton
Florida State
U. Stony Brook
U. Chicago
Duke
CU Boulder
U. Waterloo
U. Illinois
Northwestern
NYU
Wits
Aalto University
U. of Turku
U. Basque Country
U. of Innsbruck
EPFL
Chalmers University
ETH Zurich
Saarland University
Johns Hopkins
Boston University
U. Automata Madrid
Stanford
Georgia Tech
U. New Mexico
National U. Singapore
U. Georgia
U. Minho
U. Tennessee
Cornell
Purdue

Quantum Computing Hardware

Quantum computing technology

Classical Bits

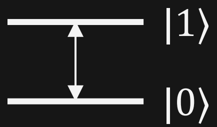
Relays

Vacuum Tube

Transistor

Quantum Bits

Two-Level Systems

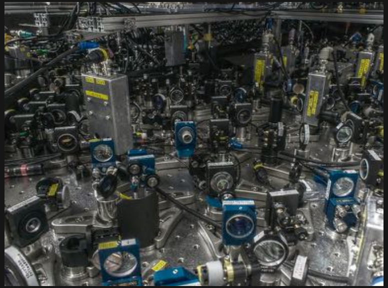


Example:
Atom orbitals with different energetic levels

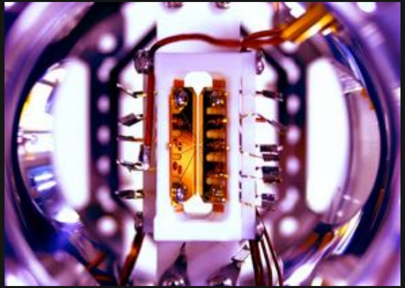
Controllability

Coherence Connectivity

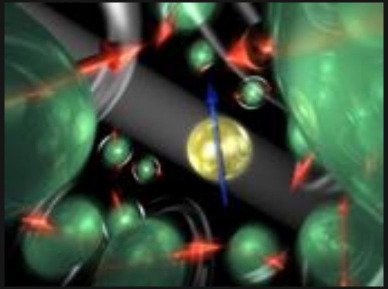
Photons



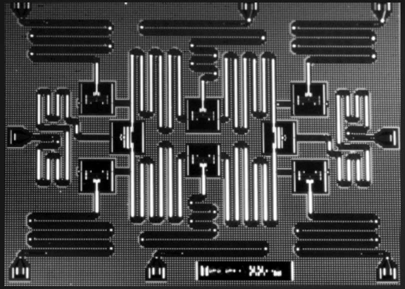
Trapped Ions



Solid State Defects



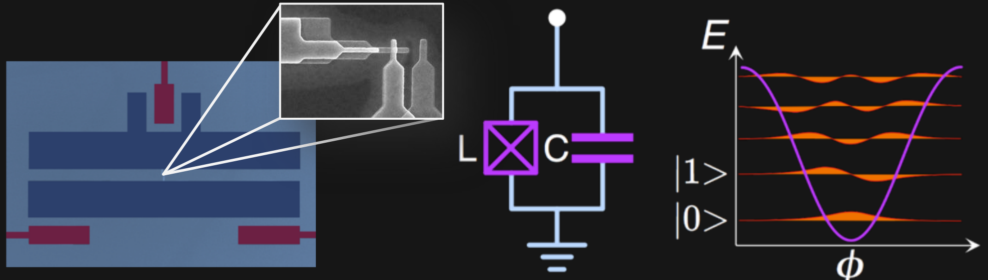
Superconducting Circuits



Superconducting quantum processor

Superconducting transmon qubit:

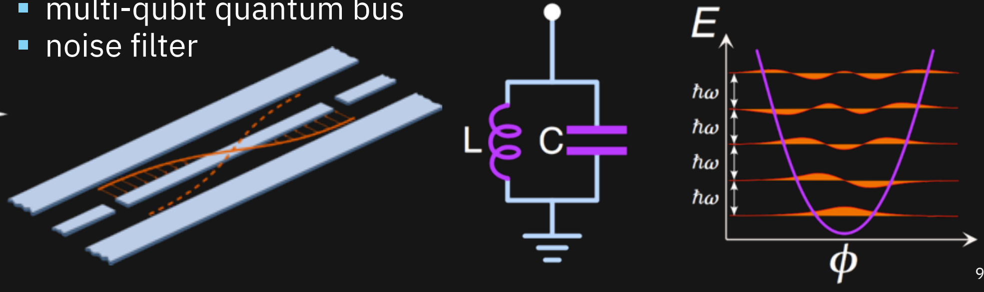
- non-linear Josephson Junction (inductance)
- anharmonic energy spectrum => qubit
- nearly dissipationless



$E_{01} \approx 5$ Ghz ≈ 240 mK

Microwave resonator as:

- read-out of qubit states
- multi-qubit quantum bus
- noise filter



Challenging engineering environment

Microwave electronics

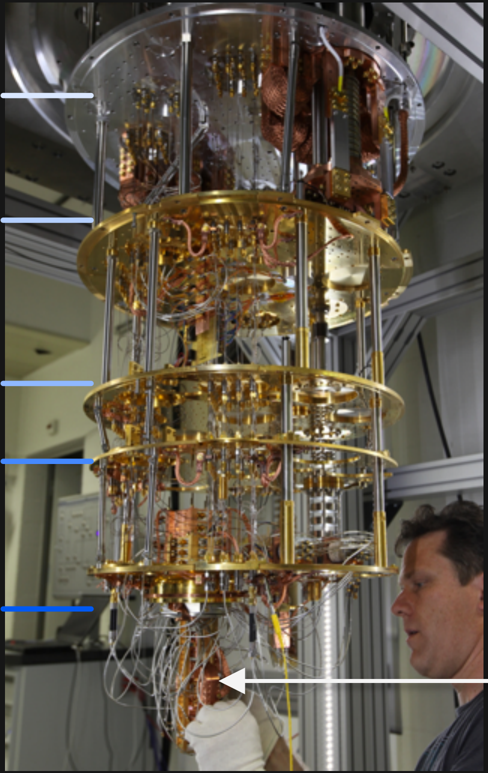
40K

3K

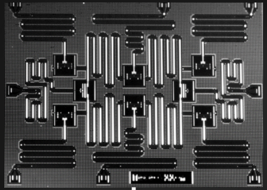
0.9K

0.1K

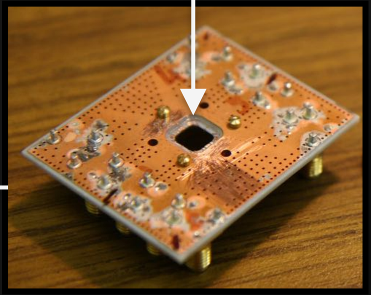
0.015K



Refrigerator to cool qubits to 10 - 15 mK with a mixture of ^{3}He and ^{4}He



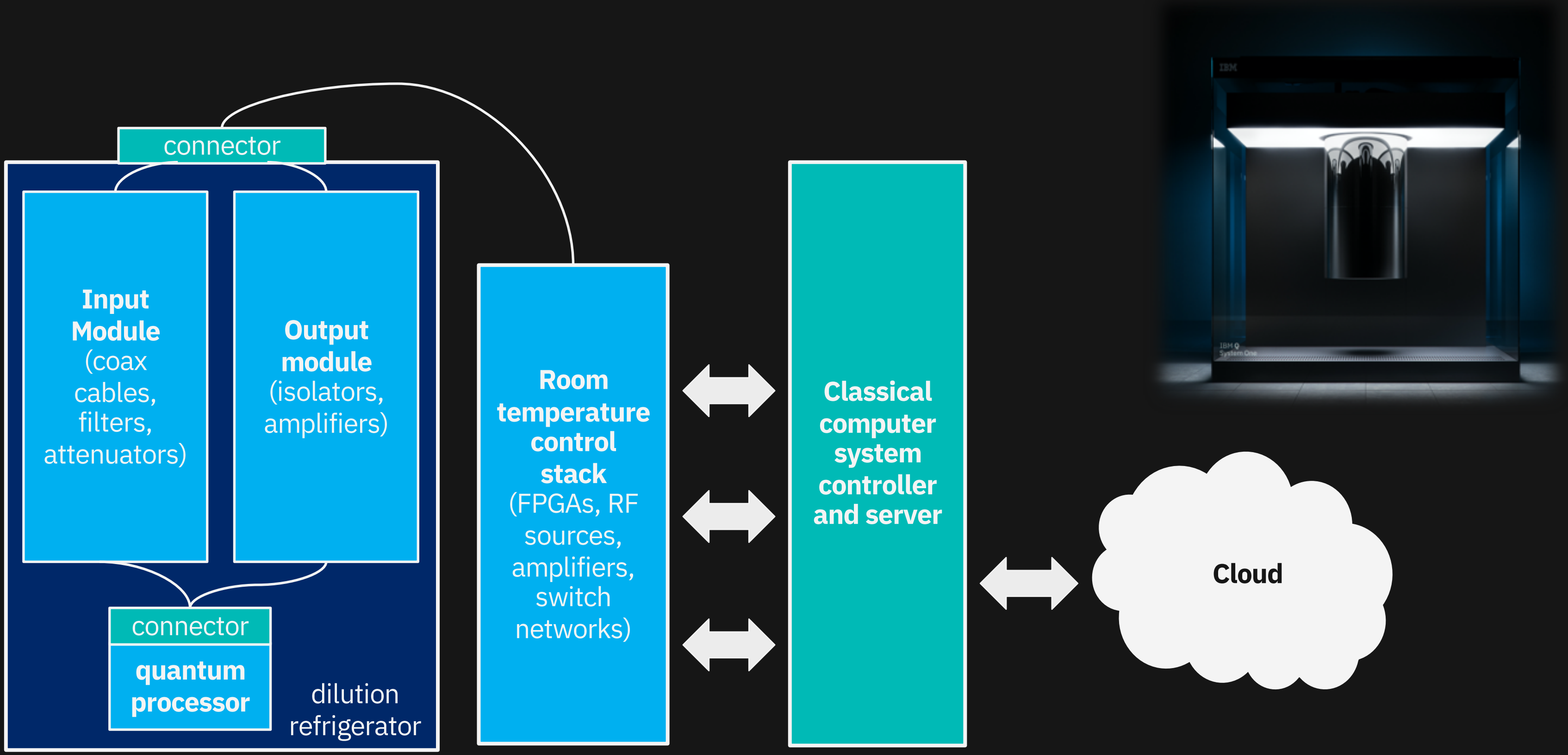
Chip with superconducting qubits and resonators



Printed circuit board with the qubit chip at 15 mK

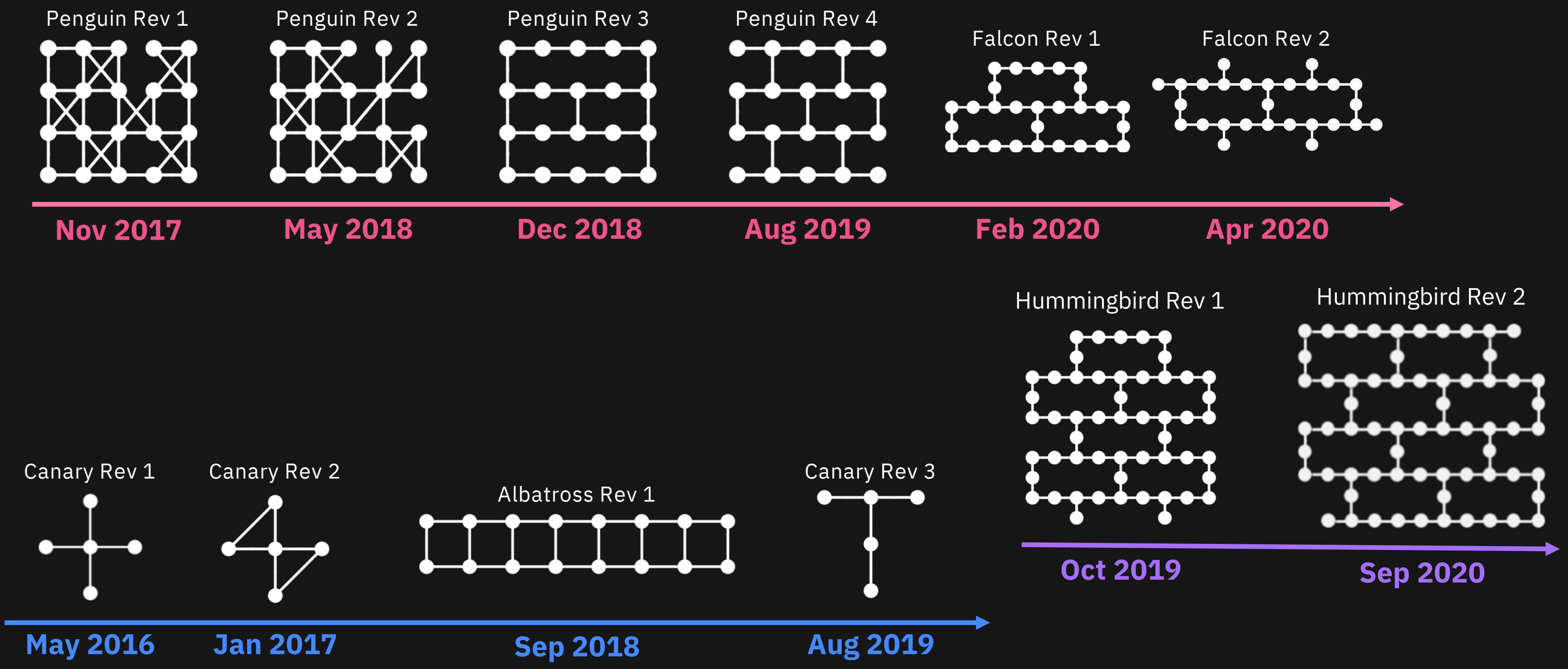
Protected from the environment by multiple shields

The complete system



IBM system evolution

IBM **Quantum**



IBM system roadmap

IBM **Quantum**

Released | In development | Next family of IBM Quantum systems

27 qubits
Falcon

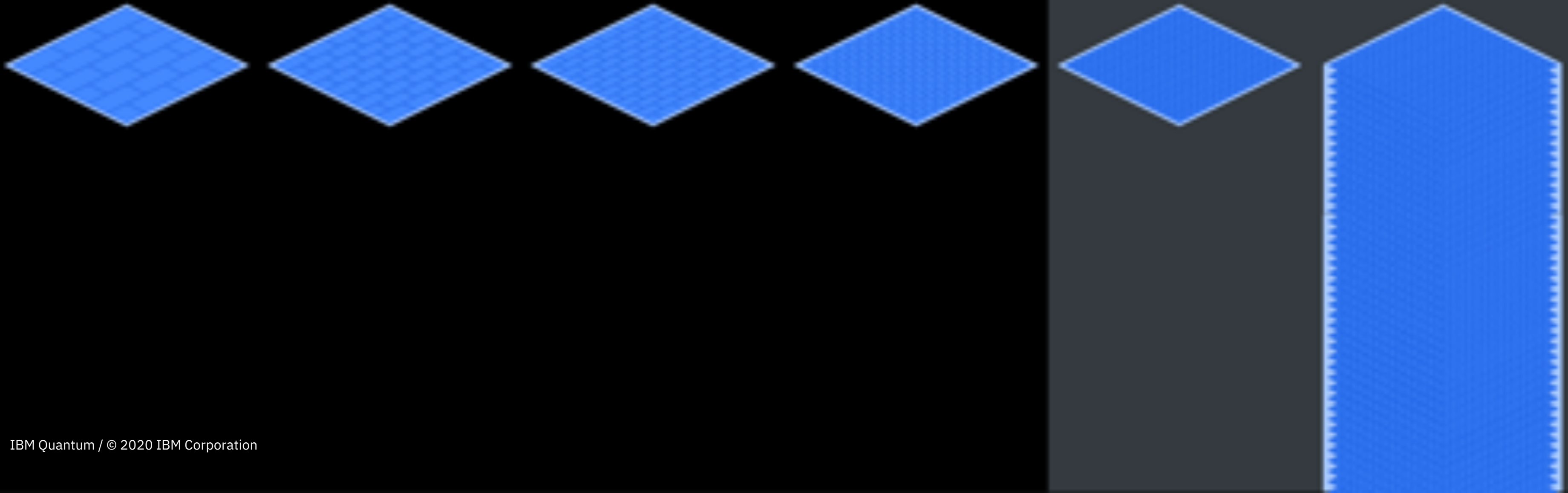
65 qubits
Hummingbird

127 qubits
Eagle

433 qubits
Osprey

1,121 qubits
Condor

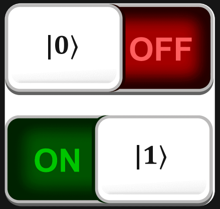
Path to 1 million qubits and beyond
Large scale systems

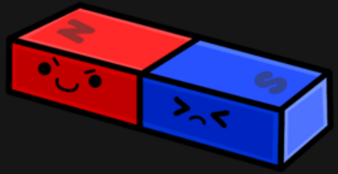


Quantum Computing Software

Bits and Qubits

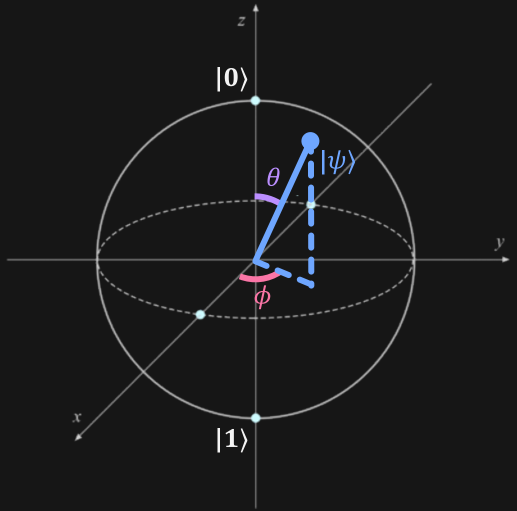
Classical Bits

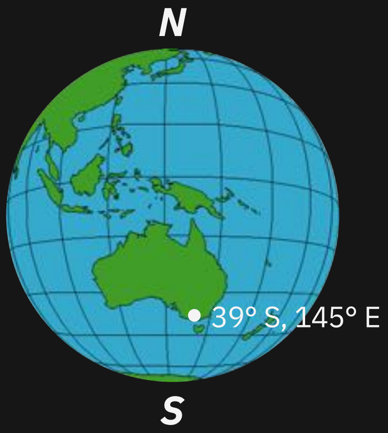




Quantum Bits

- The state of a qubit, $|\psi\rangle$, can be an arbitrary point on the surface of a sphere.
- The state of a qubit is therefore defined by two angles like longitude, θ, and latitude, ϕ, on a globe.



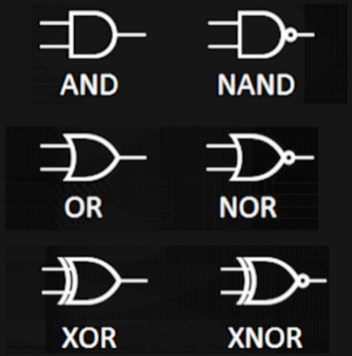


Classical and Quantum Logic

Classical logic

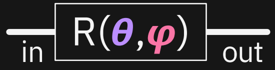
1-bit gates

2-bit gates

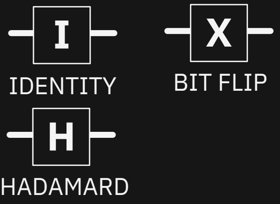


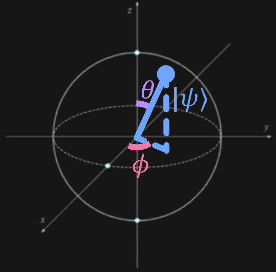
Quantum logic

1-bit gates

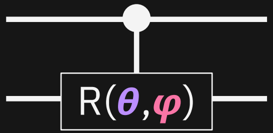


correspond to rotations on the Bloch sphere

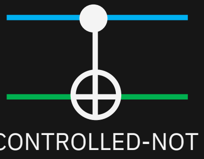




2-bit gates



the state of the second qubit depends on the first



$|00\rangle \rightarrow |00\rangle$

$|01\rangle \rightarrow |01\rangle$

$|10\rangle \rightarrow |11\rangle$

$|11\rangle \rightarrow |10\rangle$

Classical and Quantum Computation

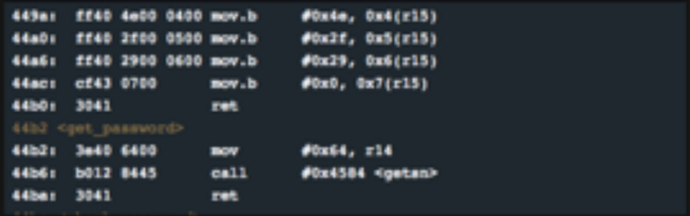
C++, Java, Python, Swift, SQL,

Javascript, Ruby, PHP, Go, R, Scala,

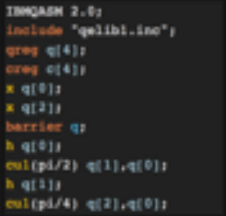
Rust, Julia, Haskell ...

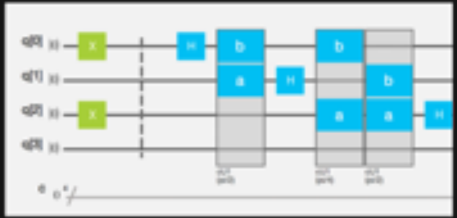
HIGH-LEVEL PROGRAMMING LANGUAGE

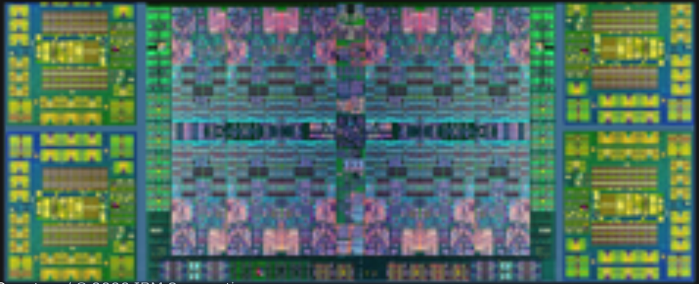
?



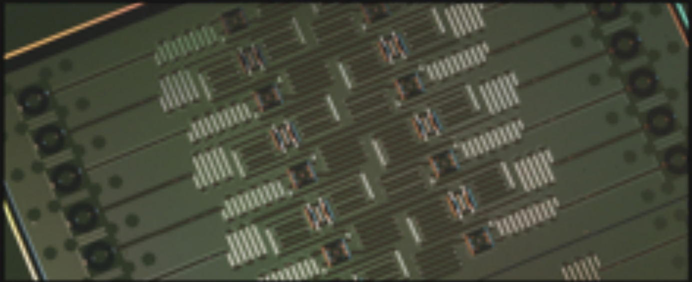
LOW-LEVEL PROGRAMMING LANGUAGE







HARDWARE



IBM Quantum Experience

(https://quantum-computing.ibm.com/)

1st quantum computers on the cloud

250k+ registered users

300B+ circuit executions

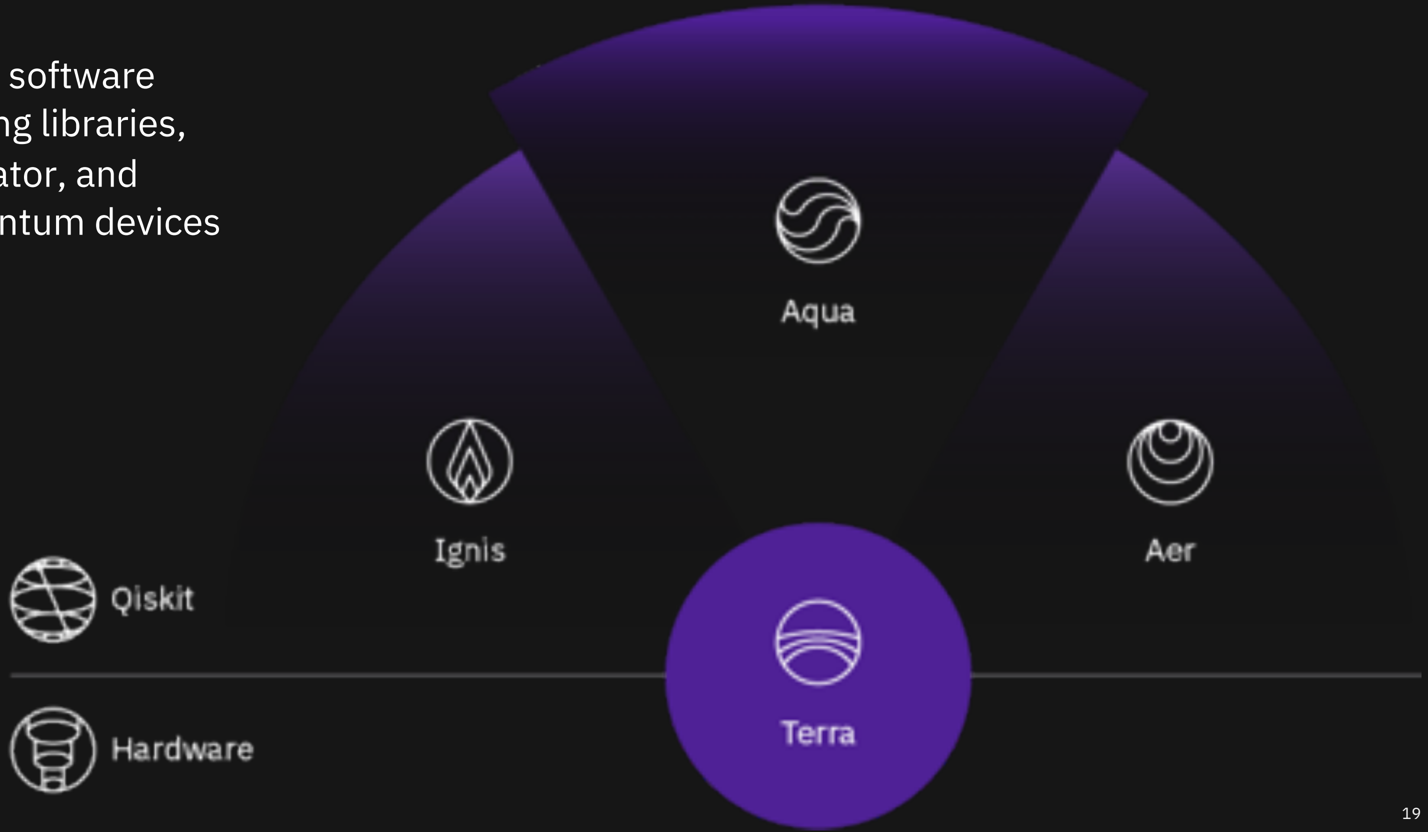
20+ quantum devices

250+ external research papers

Qiskit

(www.qiskit.org)

Qiskit is an open source software development kit providing libraries, documentation, a simulator, and connections to IBM Quantum devices

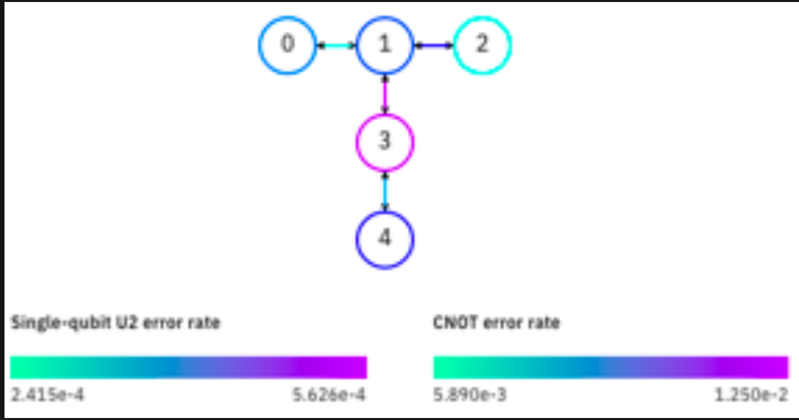


Quantum Experience Devices

5 qubit devices (ourense, valencia, vigo)

T configuration

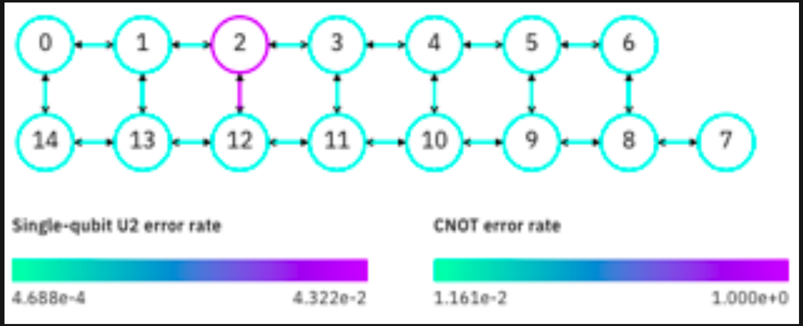
4 bidirectional CNOTS available



15 qubit device (melbourne)

Ladder configuration

20 unidirectional CNOTS available



Demonstration

References

- Quantum Experience: https://quantum-computing.ibm.com/
- Qiskit: https://qiskit.org/
- Qiskit Textbook: https://qiskit.org/textbook/
- Qiskit YouTube: https://www.youtube.com/qiskit