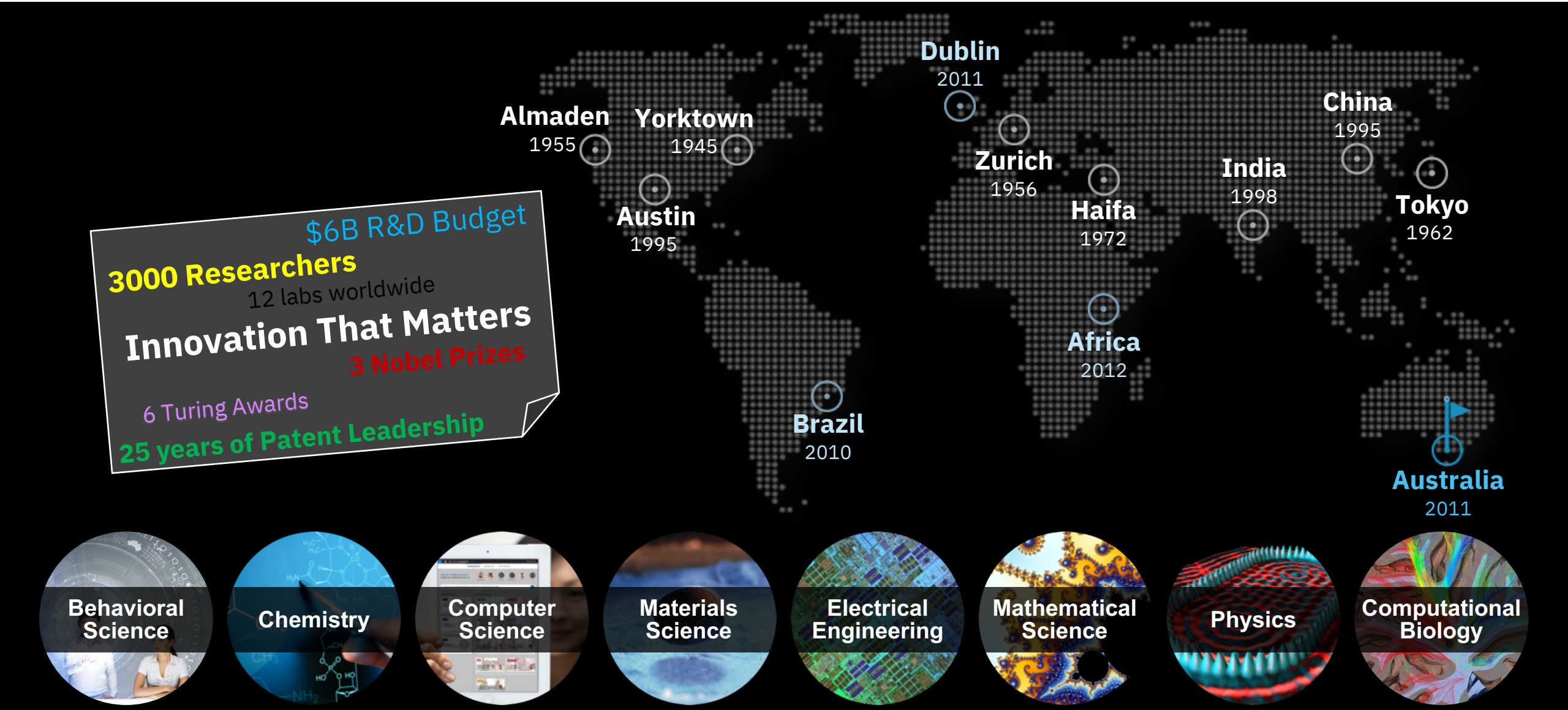
Quantum Computing at IBM

Anna Phan

September 10, 2019

IBM Research - *famous for science and vital to IBM*

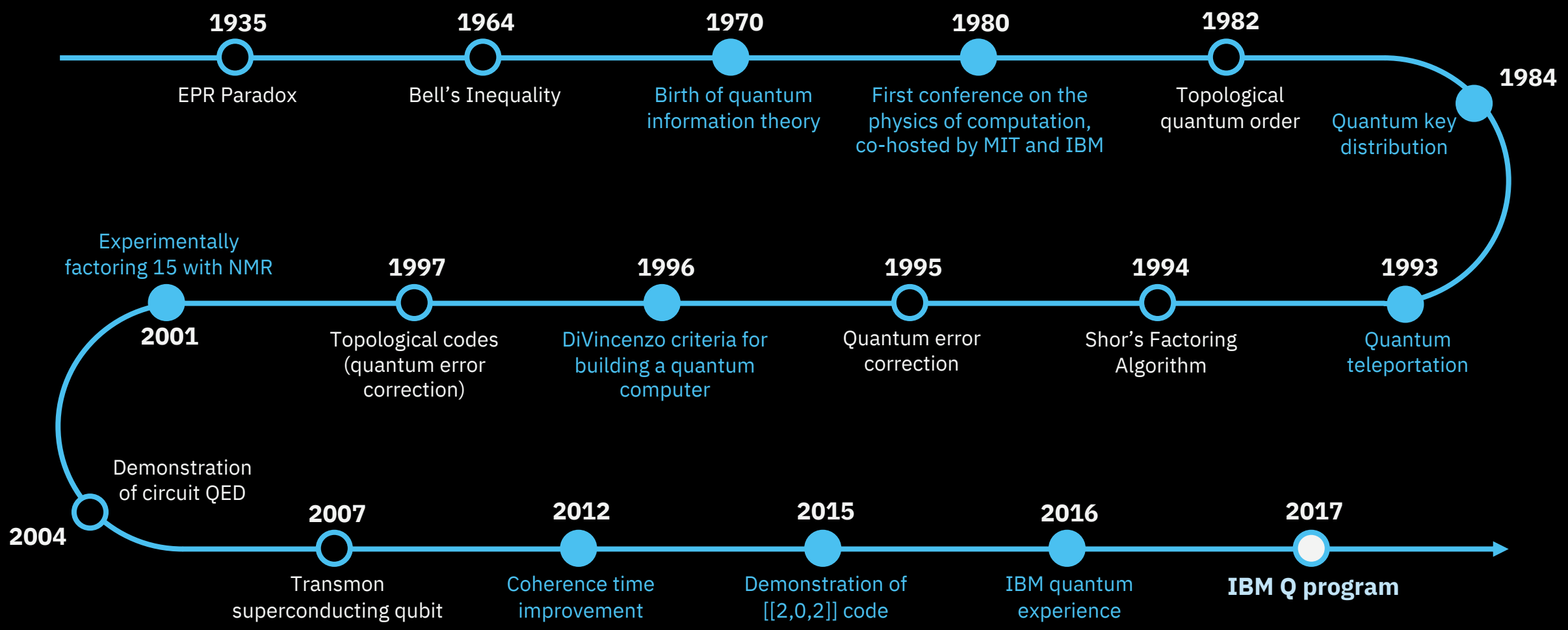
IBM Q



IBM Research & Quantum Computing

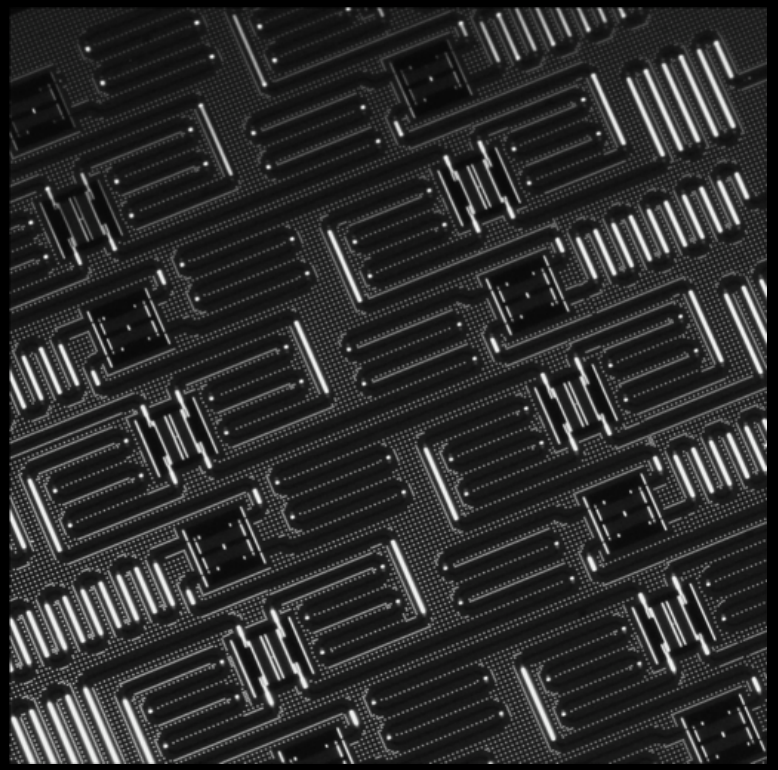
IBM Q

"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

IBM Q



Hardware & Engineering

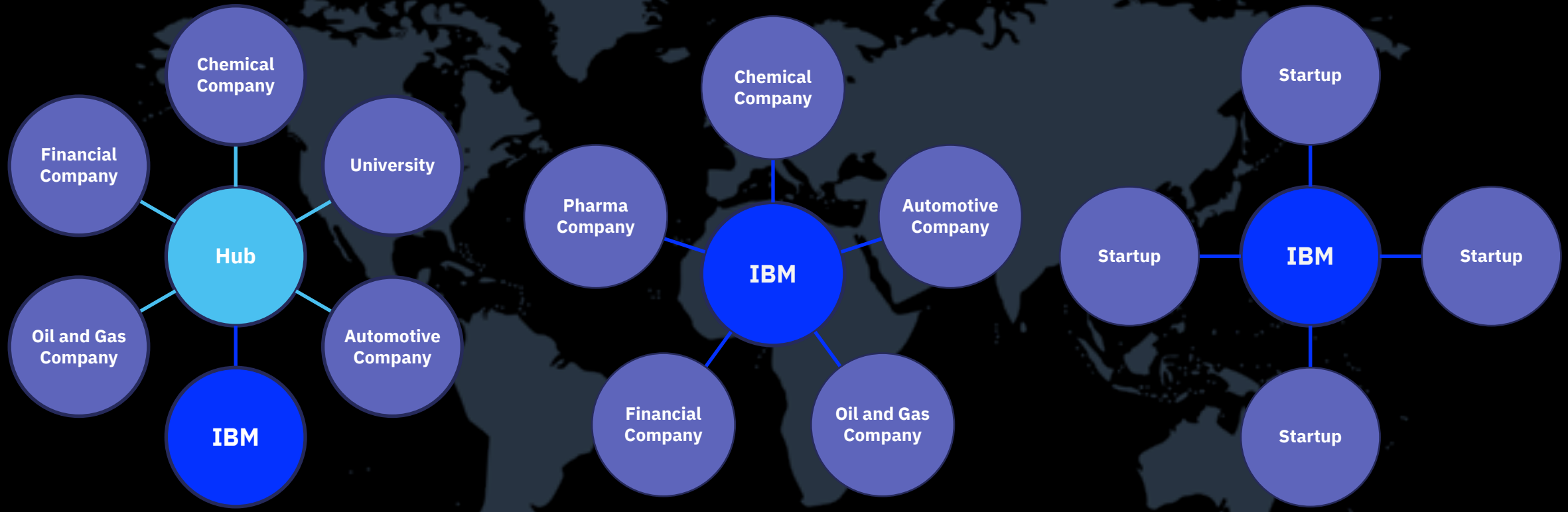
Software & Ecosystem

Algorithms & Applications

IBM Q Network

IBM Q

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 R&D and ecosystem

Partners
Pioneers of quantum computing in a specific industry or academic field

Startups
Rapidly advance early applications

IBM Q Network

77 members

- 7 industry partners
- 9 hubs
- 15 members
- 20 startups
- 26 academic partners

Industry Partners

ExxonMobil

JP Morgan Chase & Co.

Samsung

Daimler

JSR Corporation

Accenture

US Air Force Research Lab

Hubs

The University of Melbourne

Oak Ridge National Laboratory

Keio University

NC State University

University of Oxford

University of Bundeswehr Munich

National Taiwan University

Iberian Nanotechnology Laboratory

CSIC Spain

Members

Barclays

Mizuho

MUFG

Mitsubishi Chemical

Argonne Lab

Fermilab

Berkeley Lab

Brookhaven Lab

ITRI

III Taiwan

CERN

University of Minho

Honda

Hitachi Metals

Nagase

Startups

QC Ware

Grid

Quemix

CQC

1QBit

Zapata

Strange Works

Q-CTRL

Quantum Benchmark

MDR

Qu&Co

JoS Quantum

SolidStateAI

ProteinQure

Labber Quantum

MaxKelsen

Netramark

Entropica

Boxcat

Rahko

Academic Partners

MIT

EDX.org

Virginia Tech

U. Montpellier

Notre Dame

Harvard

Princeton

Florida State

U. Stony Brook

U. Chicago

U. Tokyo

Duke

UC Boulder

U. Waterloo

U. Illinois

Northwestern

NYU

Wits

Aalto University

U. of Turku

U. Basque Country

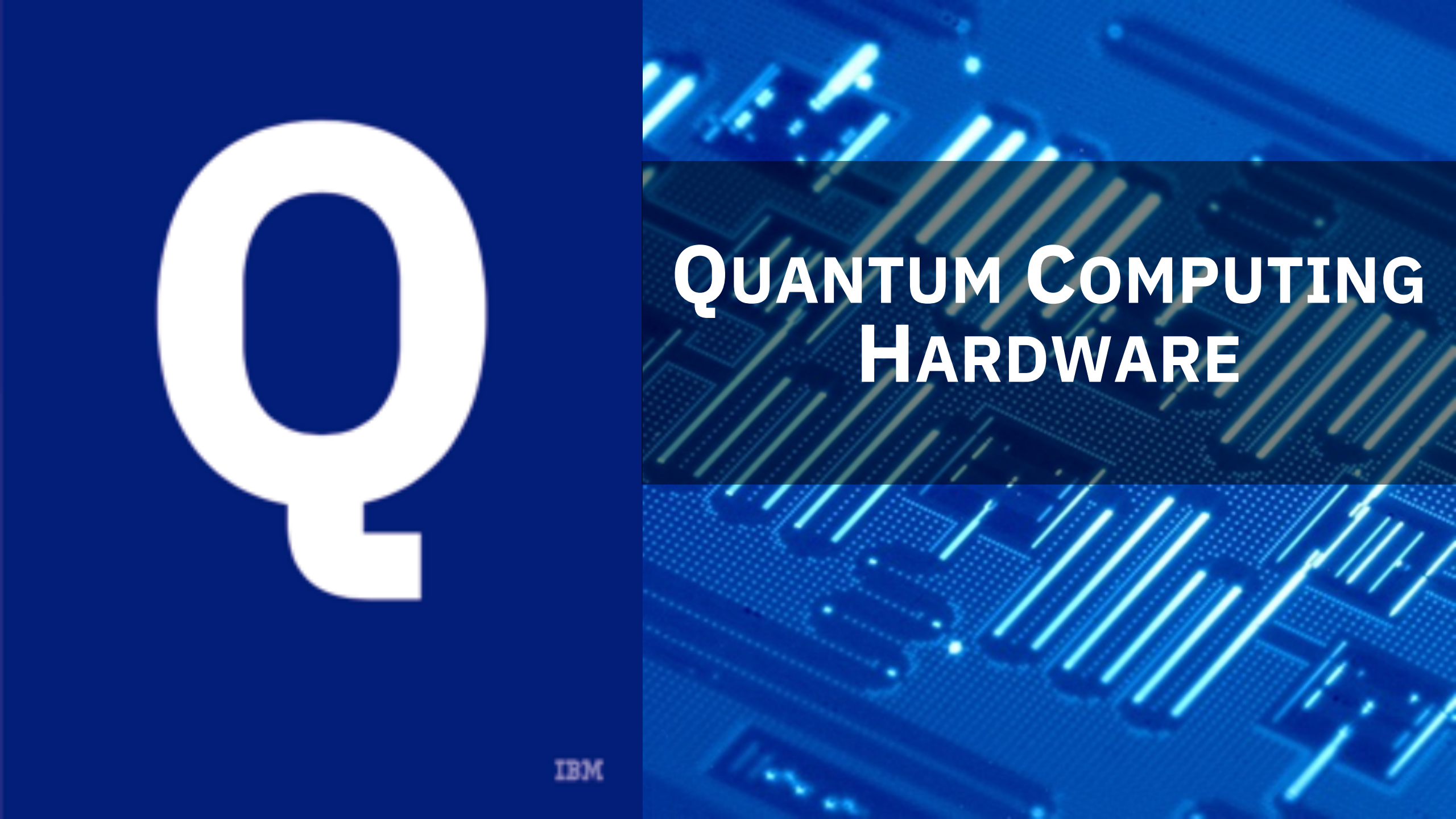
U. of Innsbruck

EPFL

Chalmers University

ETH Zurich

Saarland University


Quantum Computing
Hardware
IBM

Quantum computing technology examples

IBM Q

Classical Bits

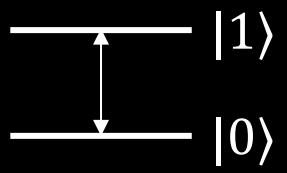
Relays

Vacuum Tube

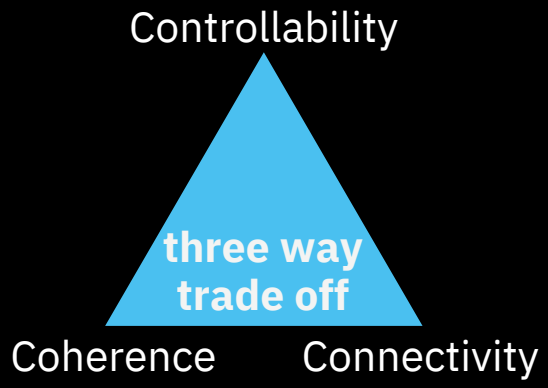
Transistor

Quantum Bits

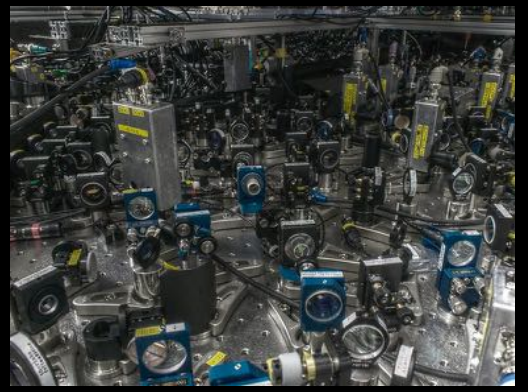
Two-Level Systems



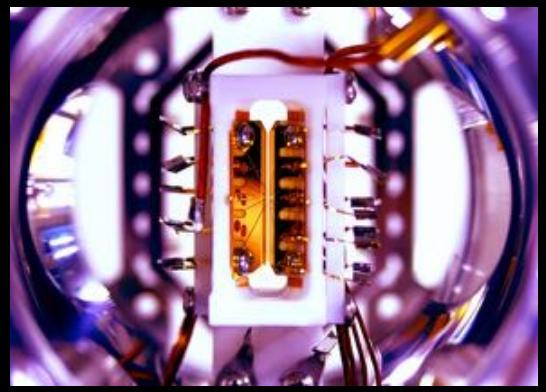
Example:
Atom orbitals with different energetic levels



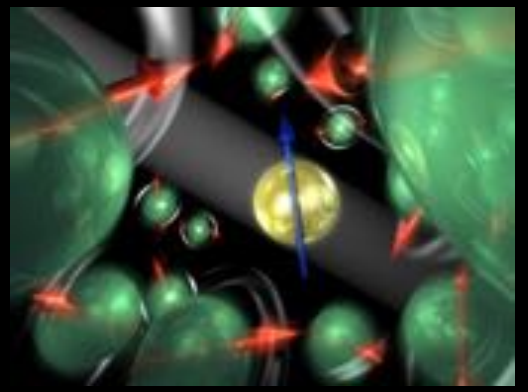
Photons



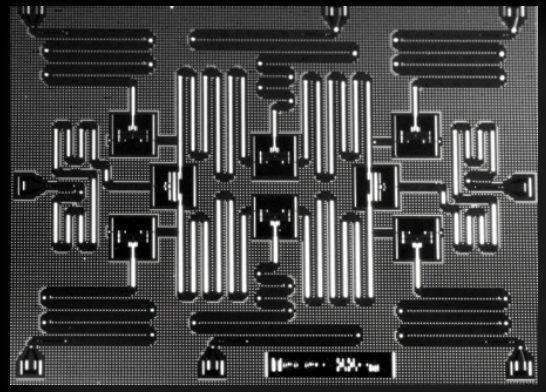
Trapped Ions



Solid State Defects

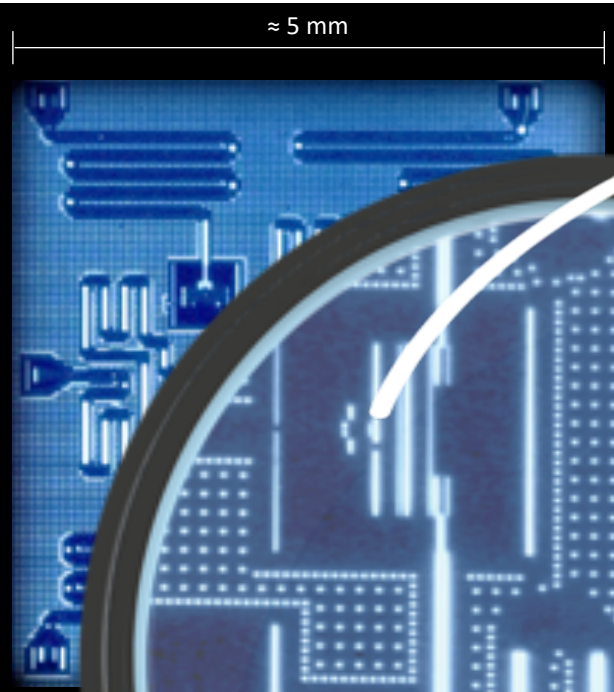


Superconducting Circuits



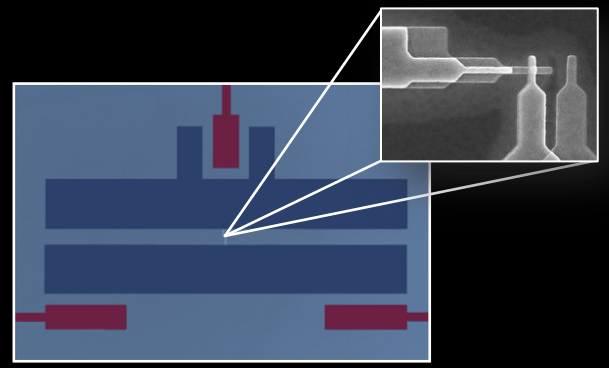
Superconducting quantum processor

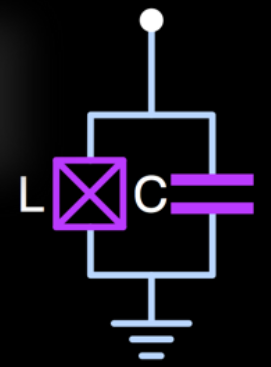
IBM Q

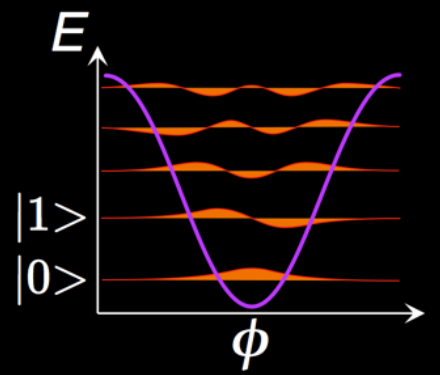


Superconducting transmon qubit:

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



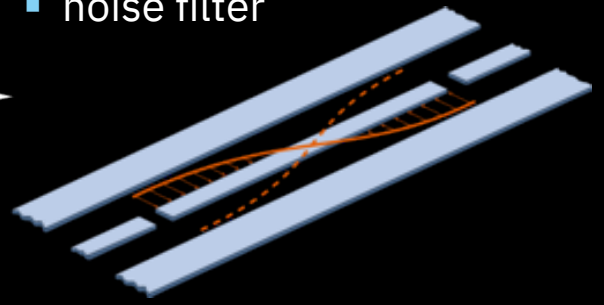


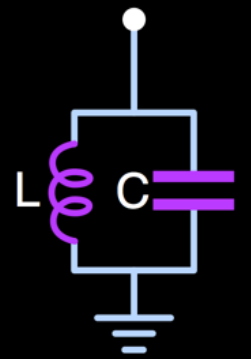


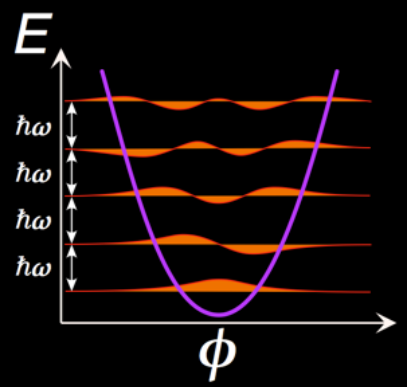
$E_{01} \approx 5\ Ghz \approx 240\ mK$

Microwave resonator as:

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



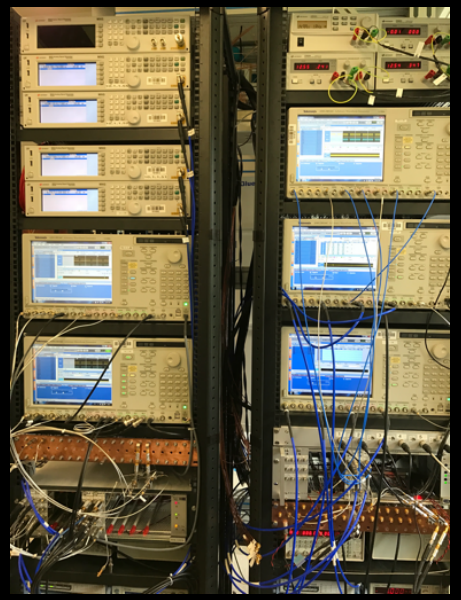


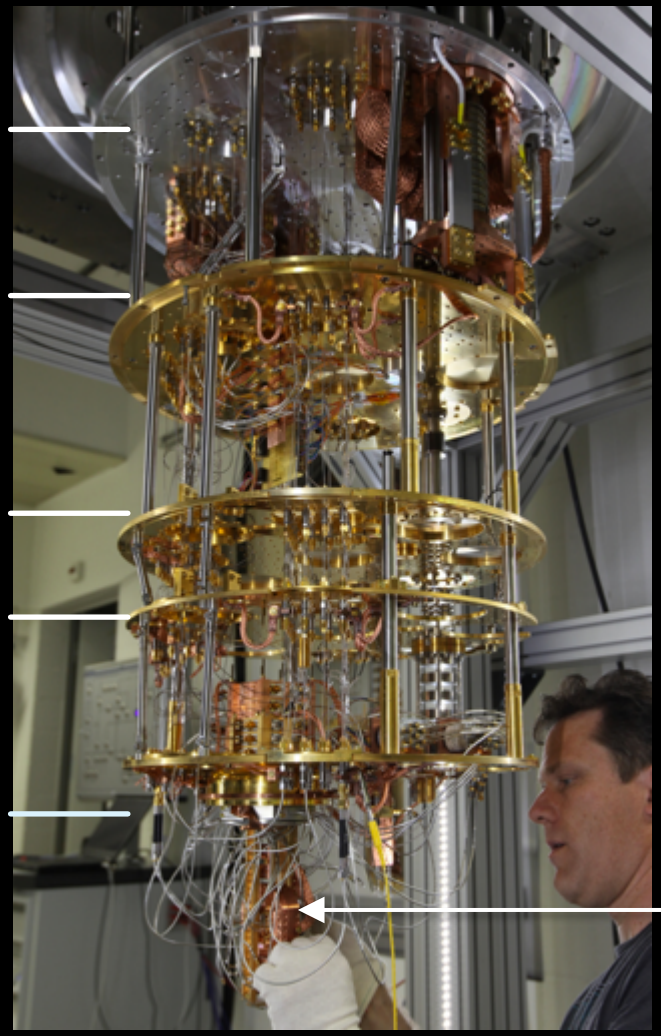


Challenging engineering environment

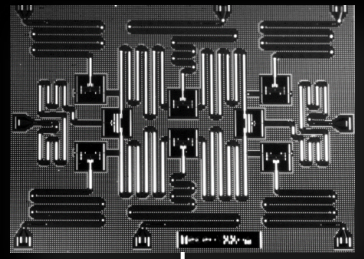
IBM Q

Microwave electronics

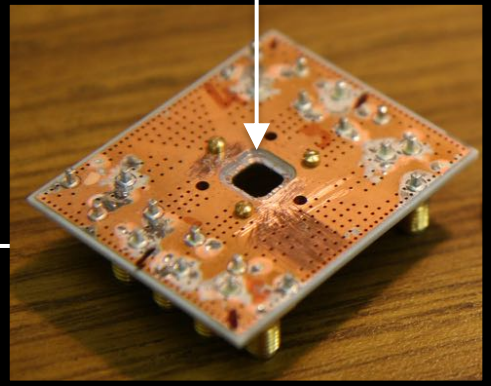




Refrigerator to cool qubits to 10 - 15 mK with a mixture of ^{3}He and ^{4}He



Chip with superconducting qubits and resonators

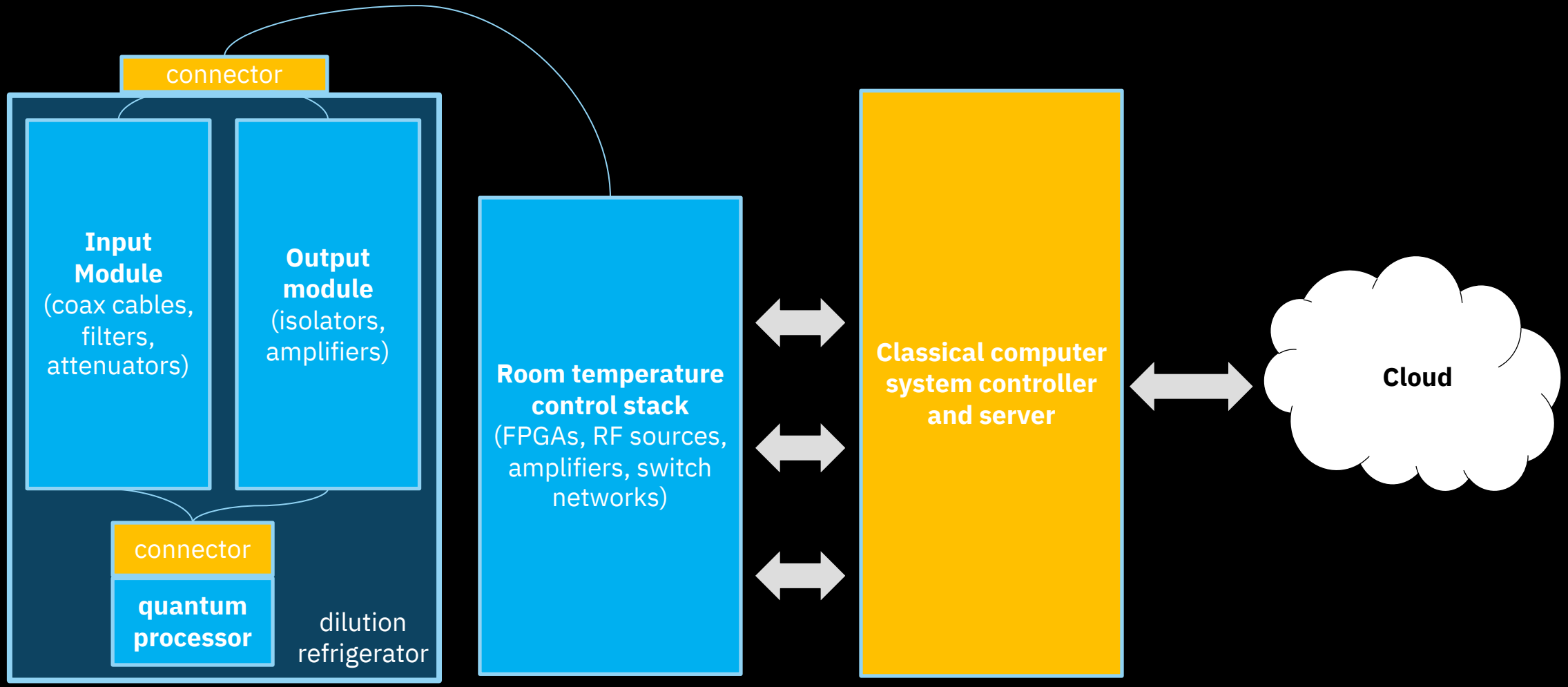


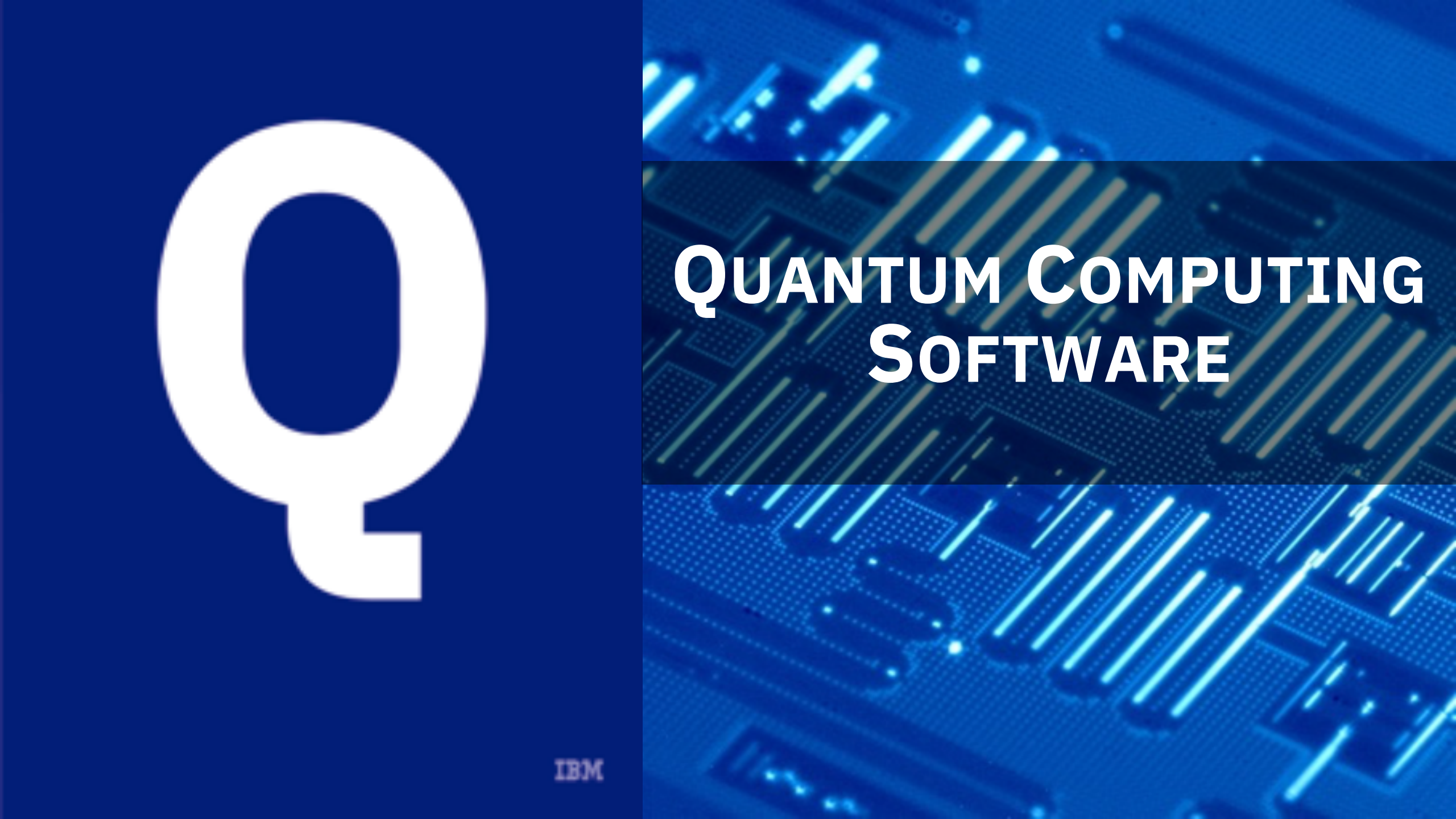
Printed circuit board with the qubit chip at 15 mK

Protected from the environment by multiple shields

The complete system

IBM Q

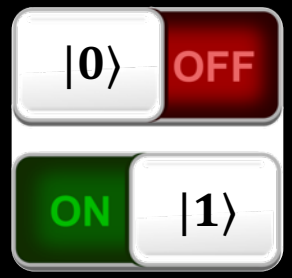


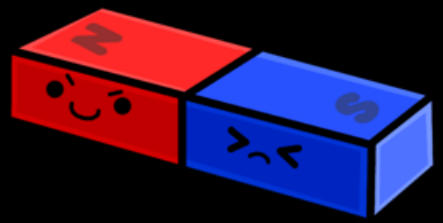

Quantum Computing
Software
IBM

Bits and Qubits

IBM Q

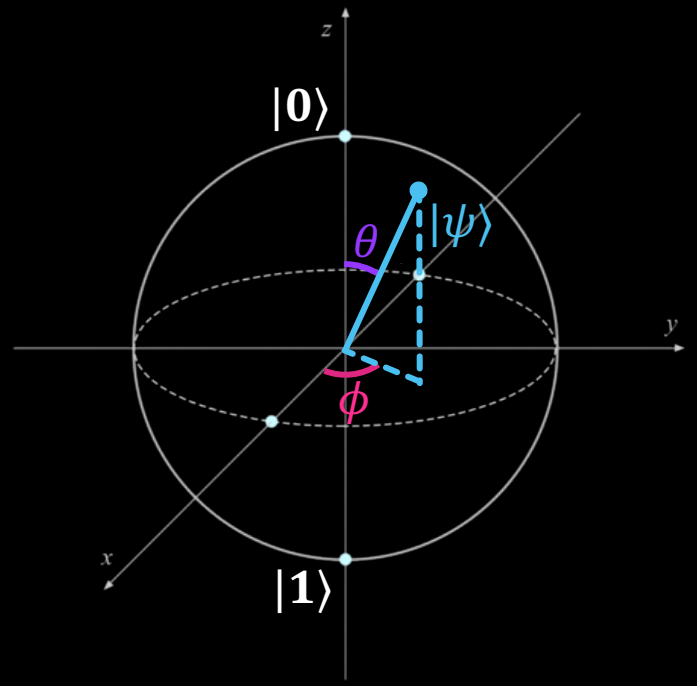
Classical Bits:

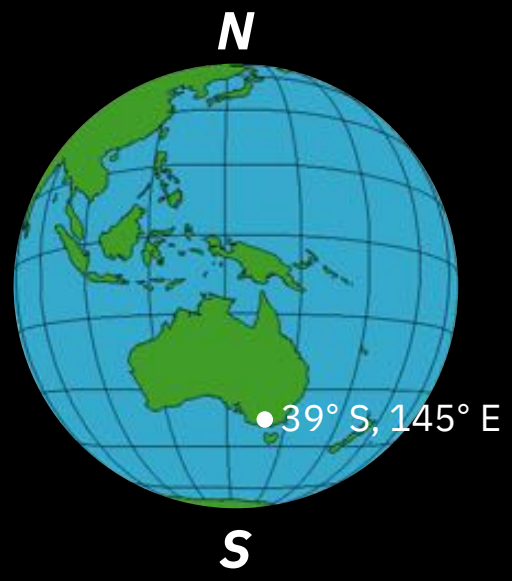


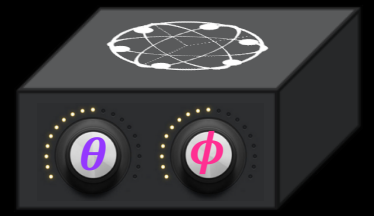


Quantum Bits:

- 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.





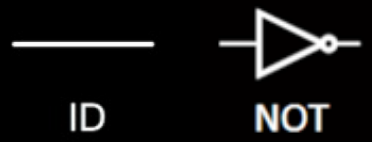


Classical and Quantum Logic

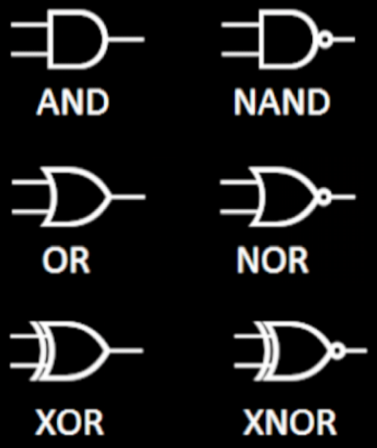
IBM Q

Classical logic

1-bit gates

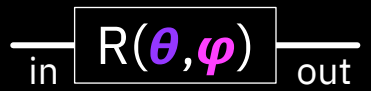


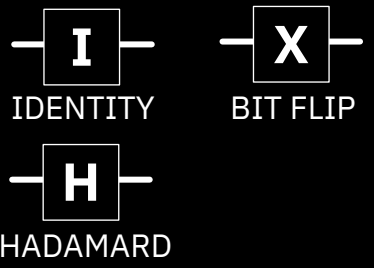
2-bit gates



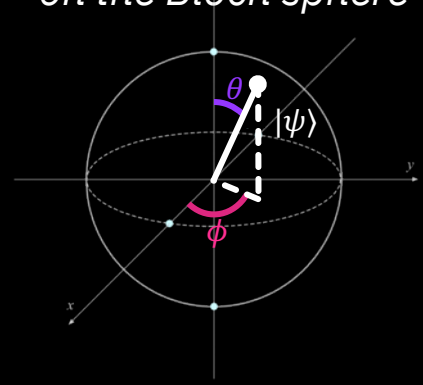
Quantum logic

1-bit gates

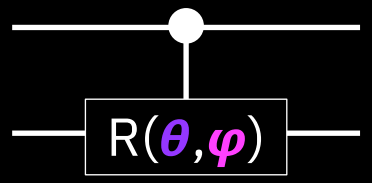




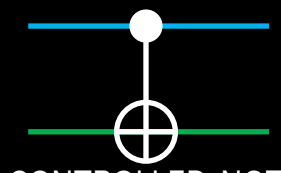
correspond to rotations on the Bloch sphere

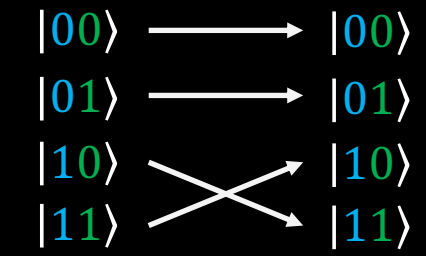


2-bit gates



the state of the second qubit depends on the first





Classical and Quantum Computation

IBM Q

C++, Java, Python, Swift, SQL, Javascript, Ruby, PHP, Go, R, Scala, Rust, Julia, Haskell ...

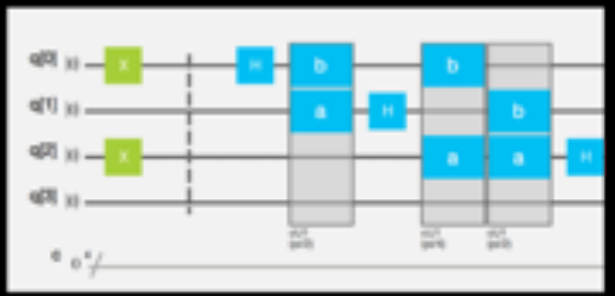
HIGH-LEVEL PROGRAMMING LANGUAGE

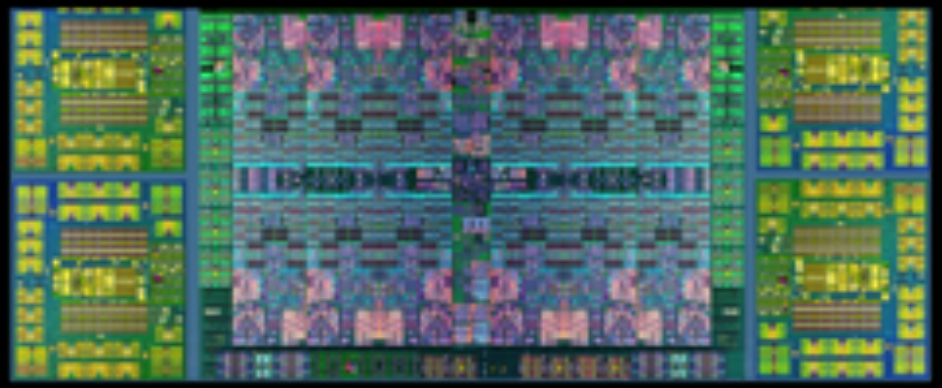
?

```
449a:  ff40 4e00 0400 mov.b    #0x4e, 0x4(r15)
44a0:  ff40 2f00 0500 mov.b    #0x2f, 0x5(r15)
44a6:  ff40 2900 0600 mov.b    #0x29, 0x6(r15)
44ac:  cf43 0700      mov.b    #0x0, 0x7(r15)
44b0:  3041           ret
44b2 <get_password>
44b2:  3e40 6400      mov      #0x64, r14
44b6:  b012 8445      call     #0x4584 <getan>
44ba:  3041           ret
```

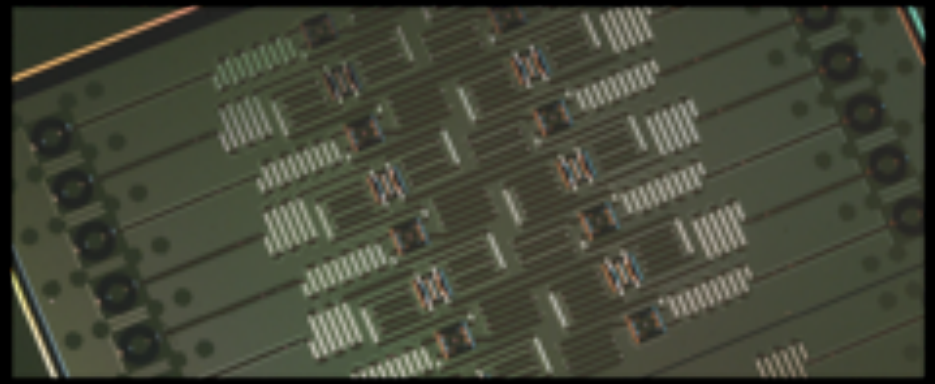
LOW-LEVEL PROGRAMMING LANGUAGE

```
IBMQASM 2.0;
include "qelib1.inc";
qreg q[4];
creg c[4];
x q[0];
x q[2];
barrier q;
h q[0];
cul(pi/2) q[1],q[0];
h q[1];
cul(pi/4) q[2],q[0];
```





HARDWARE



IBM Quantum Experience (https://quantum-computing.ibm.com/)

IBM Q

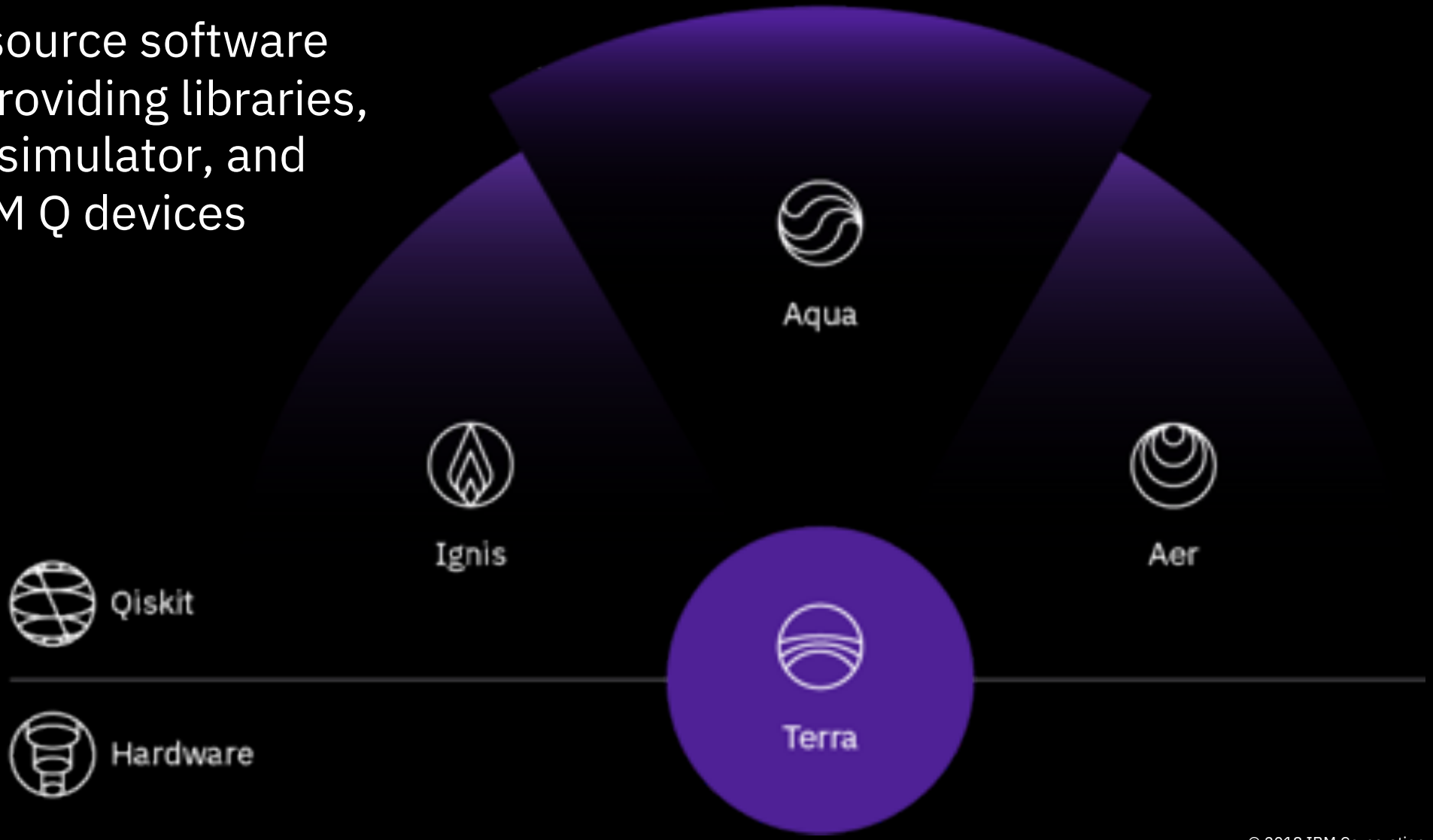
- First quantum computers on the cloud

- **150k+** users
- On all **7** continents
- **10M+** experiments
- **200+** external research papers

Qiskit (www.qiskit.org, @qiskit)

IBM Q

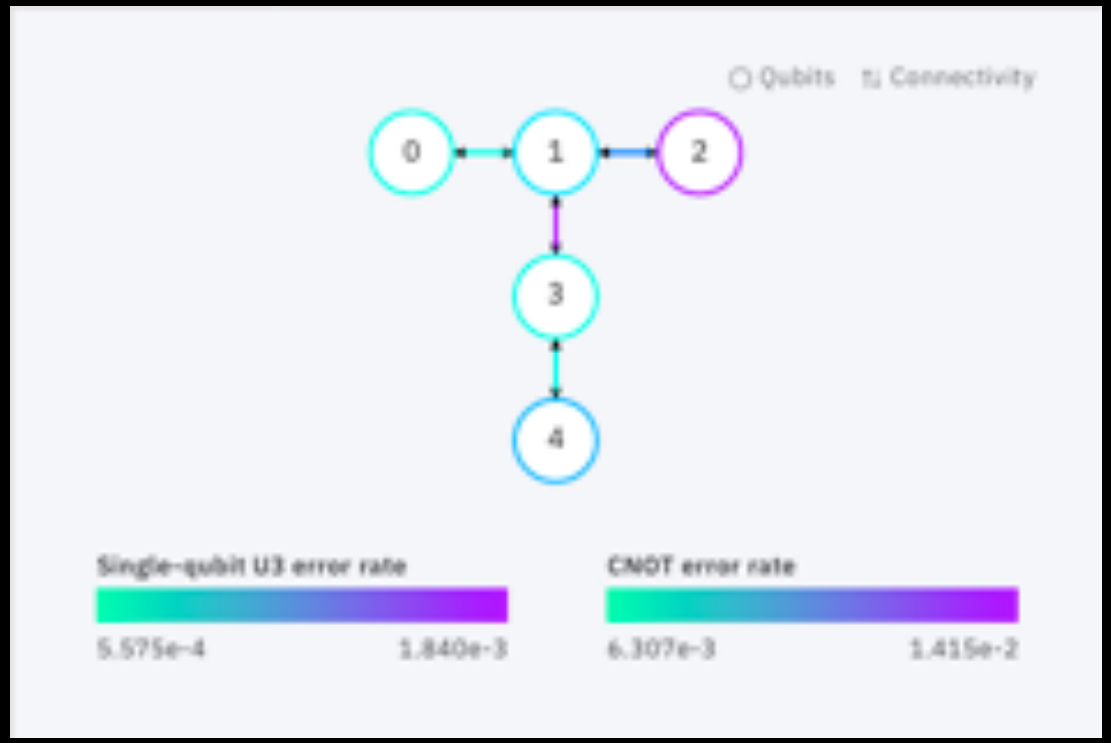
Qiskit is an open source software development kit providing libraries, documentation, a simulator, and connections to IBM Q devices



Quantum Experience Devices

IBM Q

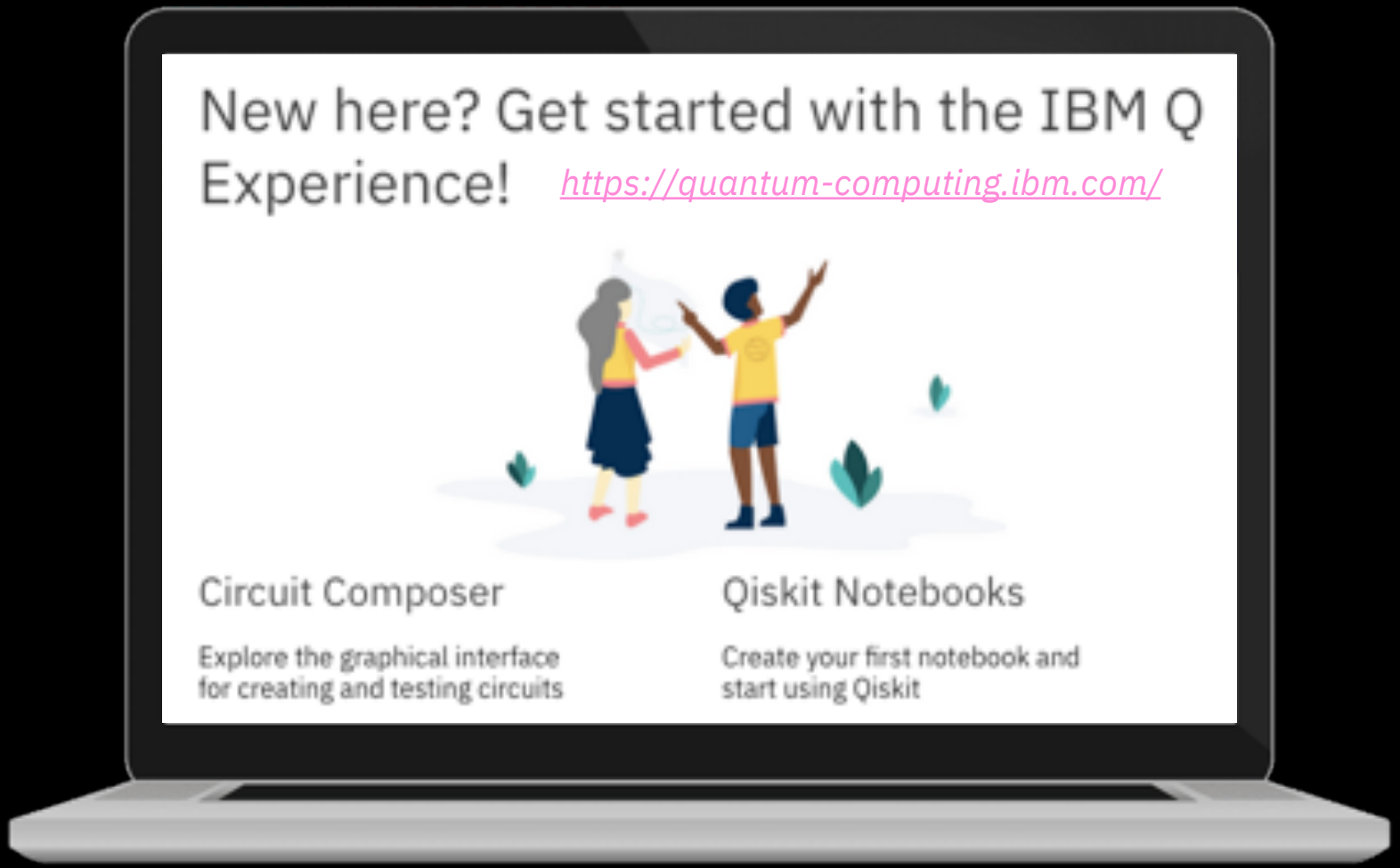
- **5 qubit device (ourense)**
  - T configuration
  - 4 bidirectional CNOTS available



- **14 qubit device (melbourne)**
  - Ladder configuration
  - 18 unidirectional CNOTS available
  - Qiskit API access only

Demonstration

IBM Q



References

IBM Q

- Quantum Experience: https://quantum-computing.ibm.com/
- Quantum Experience Device Information: https://github.com/Qiskit/qiskit-backend-information/

- OpenQASM: https://github.com/Qiskit/openqasm

- Qiskit: https://qiskit.org/
- Qiskit GitHub: https://github.com/Qiskit

- Hello Quantum: http://helloquantum.mybluemix.net/
- Hello Quantum Blog Post: https://medium.com/qiskit/hello-quantum-2c1c00fe830c


Thank You
IBM