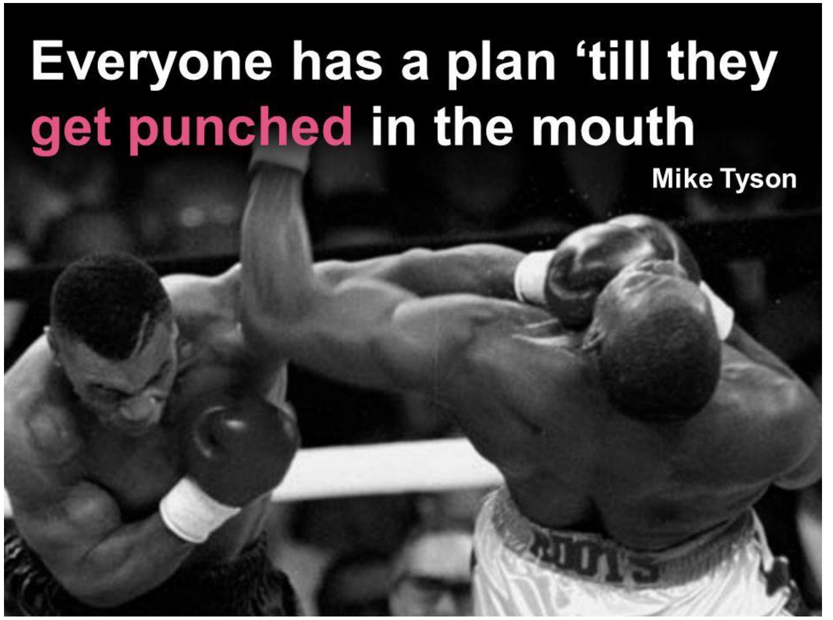
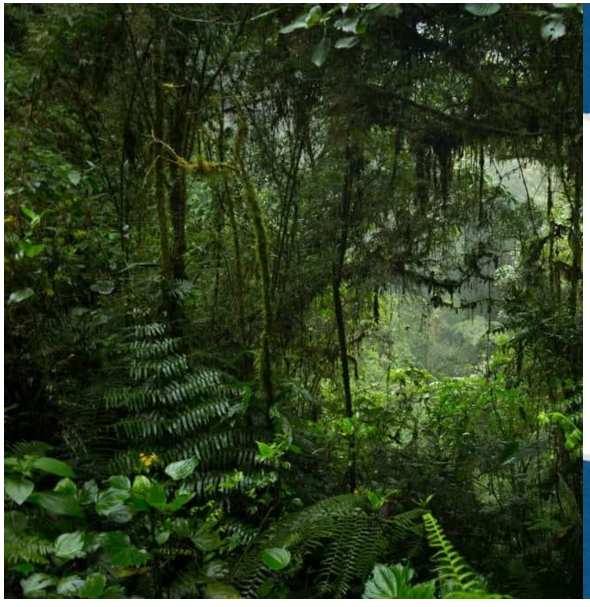
SUNG KYUN KWAN UNIVERSITY(SKKU)

2023 양자정보겨울학교

초전도 양자컴퓨터
- 간단한 원리와 현황

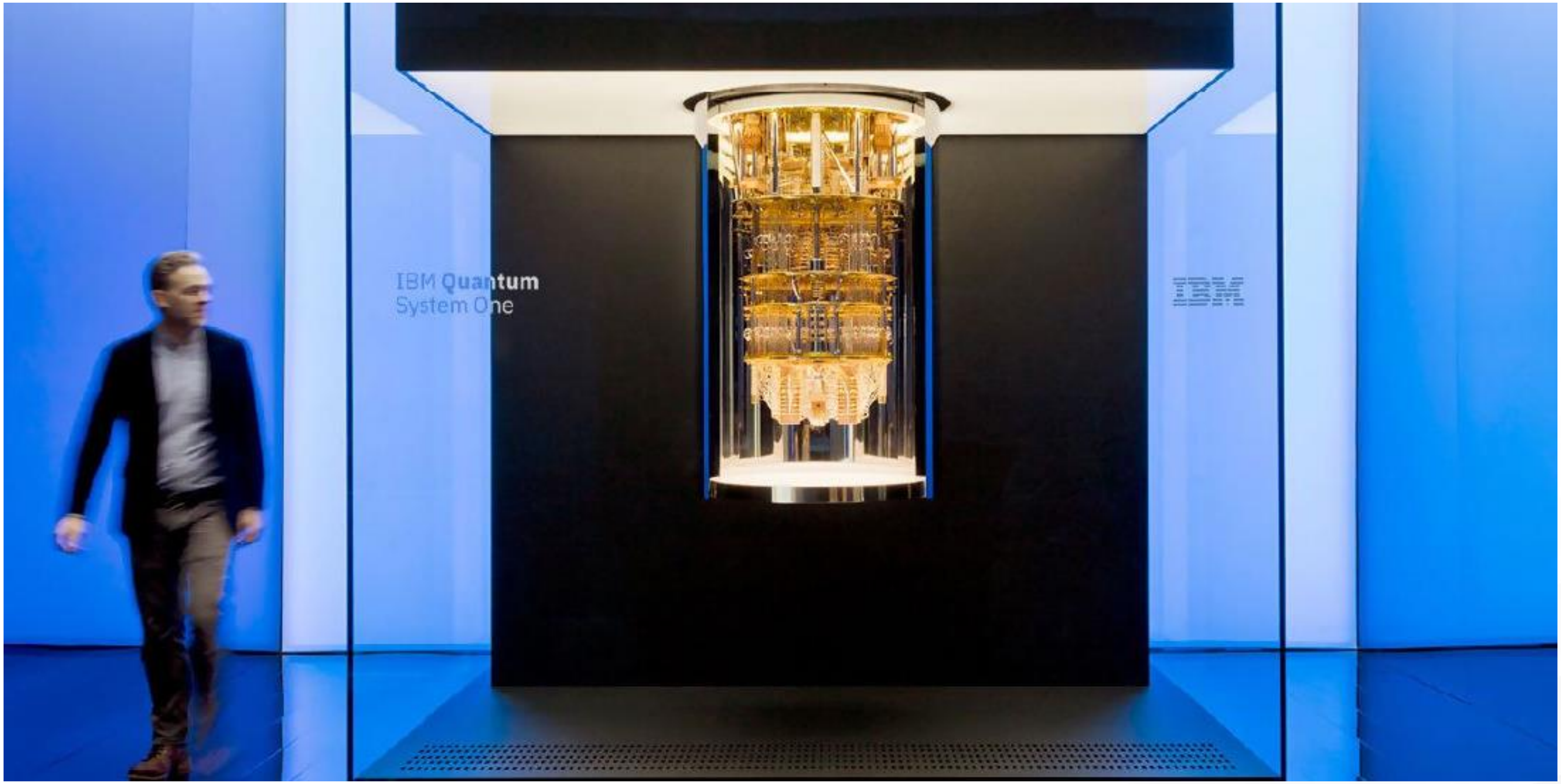
정연욱 성균관대학교


Everyone has a plan 'till they get punched in the mouth
Mike Tyson



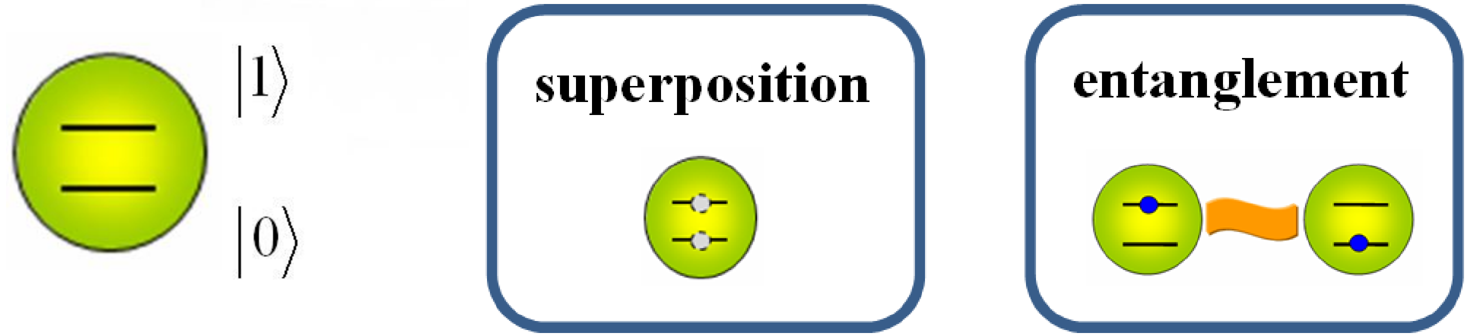

신영준
주언규
지음
인생은 실전이다.
아주 작은 날갯짓의 시작
상상스퀘어

양자컴퓨터



양자컴퓨터

Qubit : A quantum system with two states



$$\alpha|0\rangle + \beta e^{i\phi}|1\rangle \qquad |01\rangle - |10\rangle$$

DiVincenzo Criteria (2001)

1) A scalable physical system with well characterized qubits.
2) The ability to initialize the state of the qubits.
3) A coherence times much longer than the gate operation time.
4) A “universal” set of quantum gates
5) A qubit-specific measurement capability

초전도 (Superconducting) 양자컴퓨터

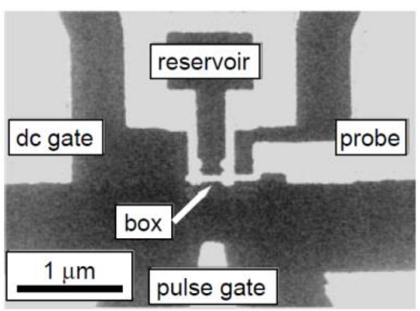
letters to nature

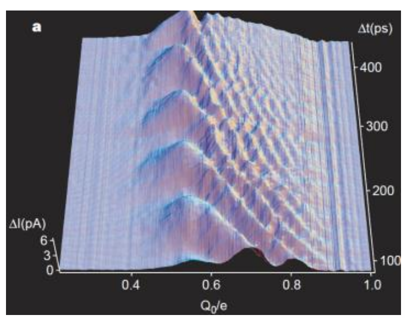
Coherent control of macroscopic quantum states in a single-Cooper-pair box

Y. Nakamura*, Yu. A. Pashkin† & J. S. Tsai*

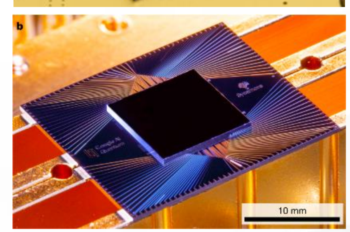
* *NEC Fundamental Research Laboratories, Tsukuba, Ibaraki 305-8051, Japan*
† *CREST, Japan Science and Technology Corporation (JST), Kawaguchi, Saitama 332-0012, Japan*

Nature 1999





1999, NEC



2021, Google, IBM

What you need to know for superconducting qubit

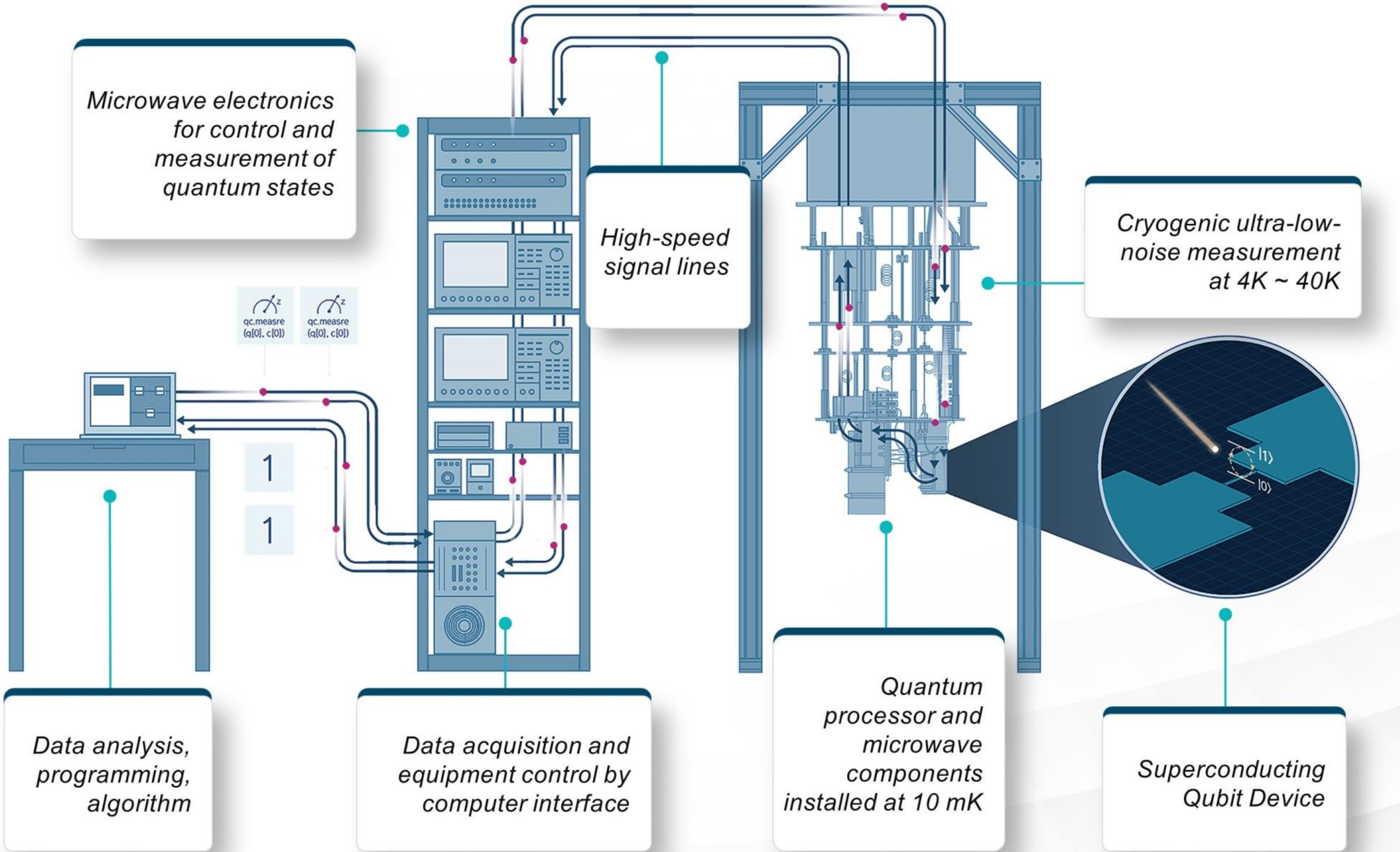
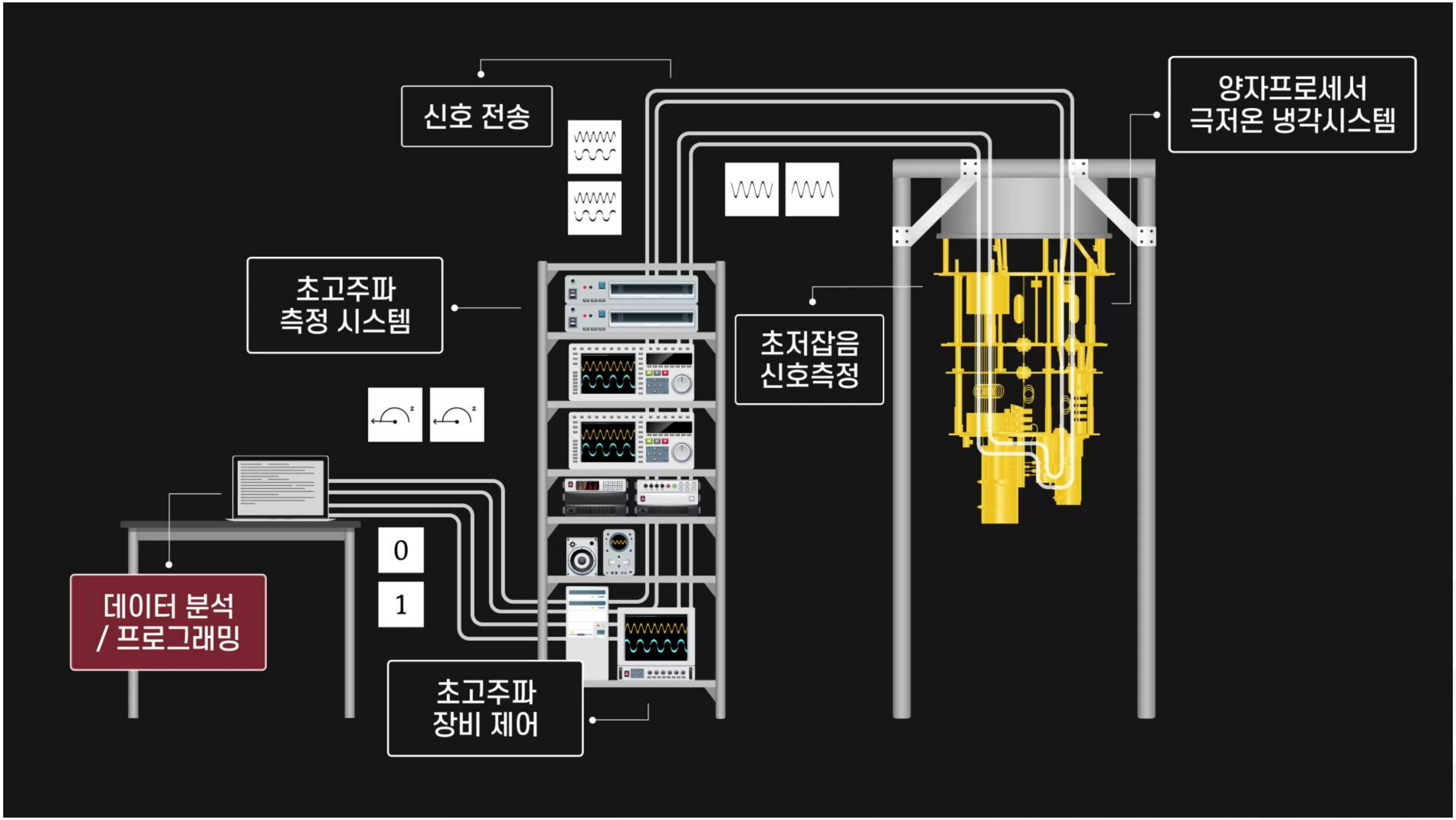


figure credit: IBM

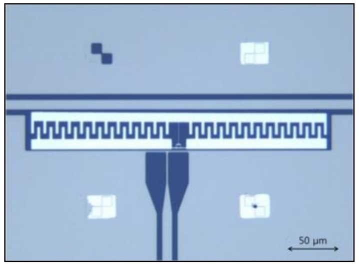
Superconducting Quantum Computer System



What you need to know for superconducting qubit

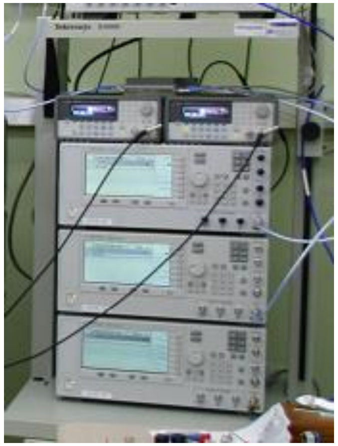
$\downarrow$ $k_B T << \hbar\omega$ $\uparrow$

Device Fab. + **Ultra-low T** + **RF Meas.**



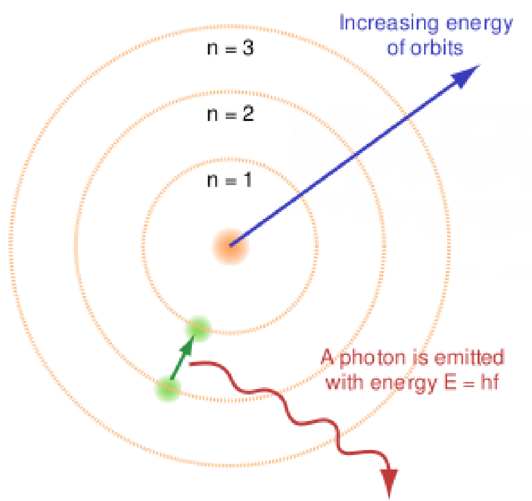
Superconducting Electronics (Josephson + Microwave)

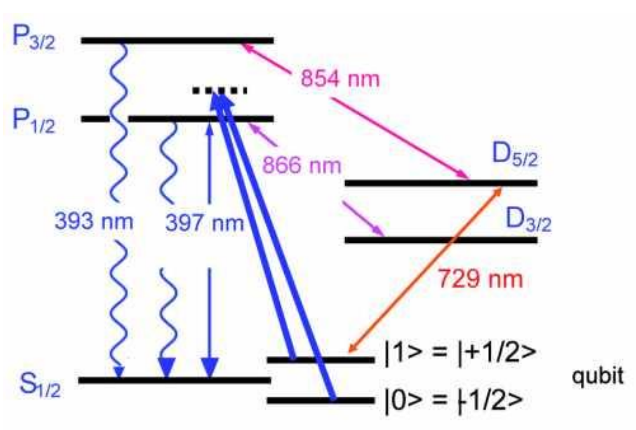
Dilution Refrigerator (~10 mK)



Precision MW Measurement
< or @ single photon

How to make an Artificial Atom?



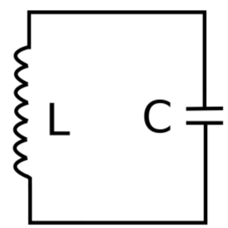


(Quantum) Harmonic Oscillator

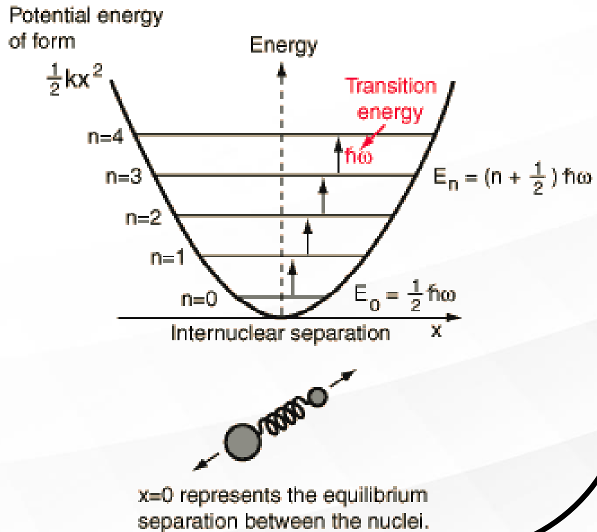
$$H = \frac{1}{2m}(\hat{p}^2) + \frac{1}{2}k(\hat{x}^2) \qquad [x, p] = i\hbar$$

$$E = \hbar\omega_{HO}(a^{+}a + \frac{1}{2}) \qquad \omega_{HO} = \sqrt{\frac{k}{m}}$$

LC Oscillator

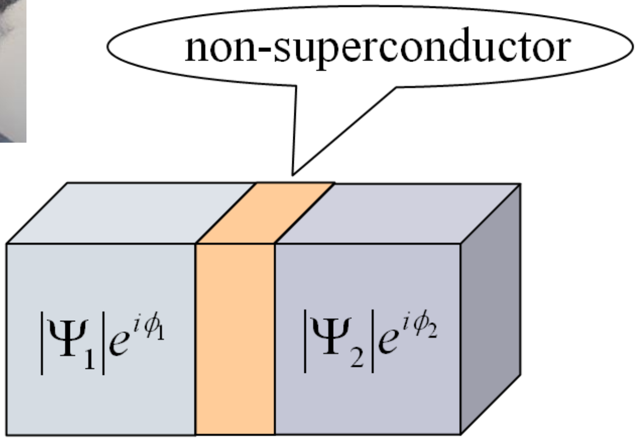


$$\omega_{LC} = \frac{1}{\sqrt{LC}}$$



→ Need Nonlinearity (Anharmonicity) for Qubit

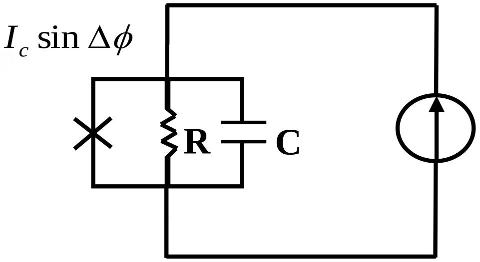
Josephson Junction



$\Rightarrow$ Josephson Relations

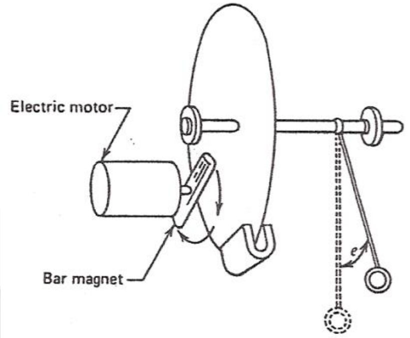
$$I = I_c \sin(\phi_1 - \phi_2)$$

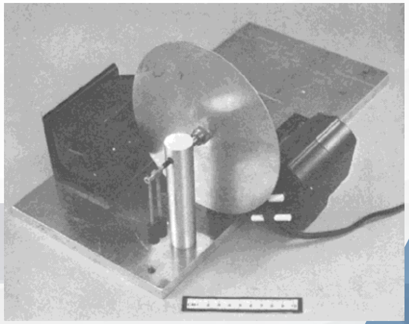
$$V(t) = \frac{\hbar}{2e}\frac{d}{dt}(\phi_1 - \phi_2)$$



$$I_{dc} = \frac{\hbar}{2e} C \frac{d^2\phi}{dt^2} + \frac{\hbar}{2e}\frac{1}{R}\frac{d\phi}{dt} + I_c \sin(\phi)$$

const. torque | **mass** | **damping** | **pendulum**

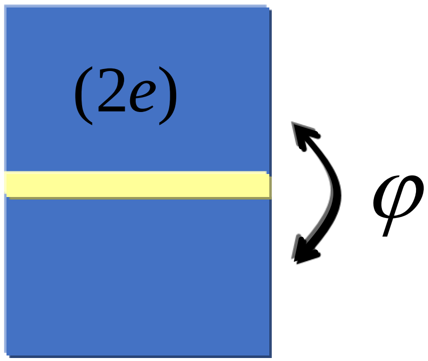




Sullivan and Zimmerman, Am. J. Phys. 39, 1504 (1971)

Josephson Qubit

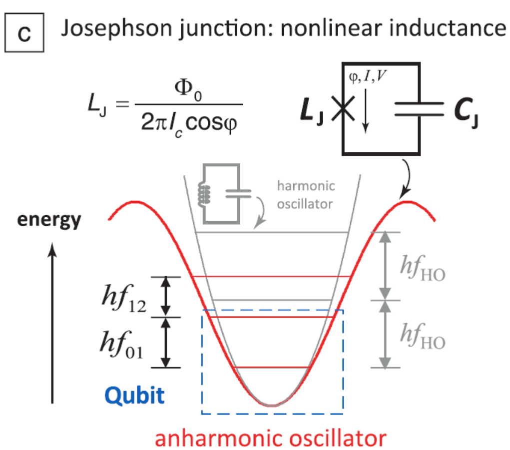
Josephson Qubit



$$E_{\text{Charge}}(n) = \frac{(2e)^2}{2C}(\hat{n})^2 = \frac{1}{2}(8E_C)(\hat{n})^2$$

$$E_{\text{Josephson}}(\varphi) = \frac{\hbar I}{2e}(1-\cos\varphi) \approx \frac{1}{2}E_J\varphi^2$$

$$E_C \equiv \frac{e^2}{2C} \qquad E_J \equiv \frac{\hbar I}{2e}$$



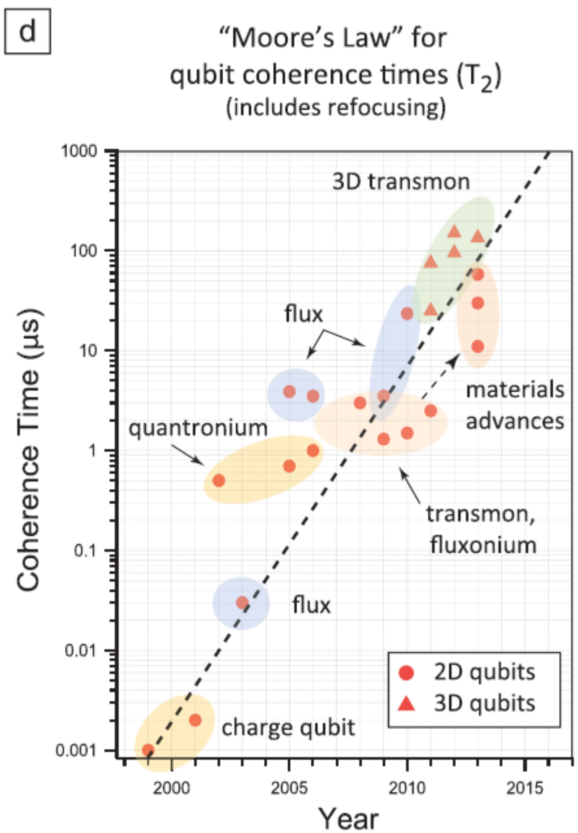
$$H = E_{\text{Charge}}(n) + E_{\text{Josephson}}(\varphi) \approx \frac{1}{2}(8E_C)(\hat{n})^2 + \frac{1}{2}E_J\varphi^2$$

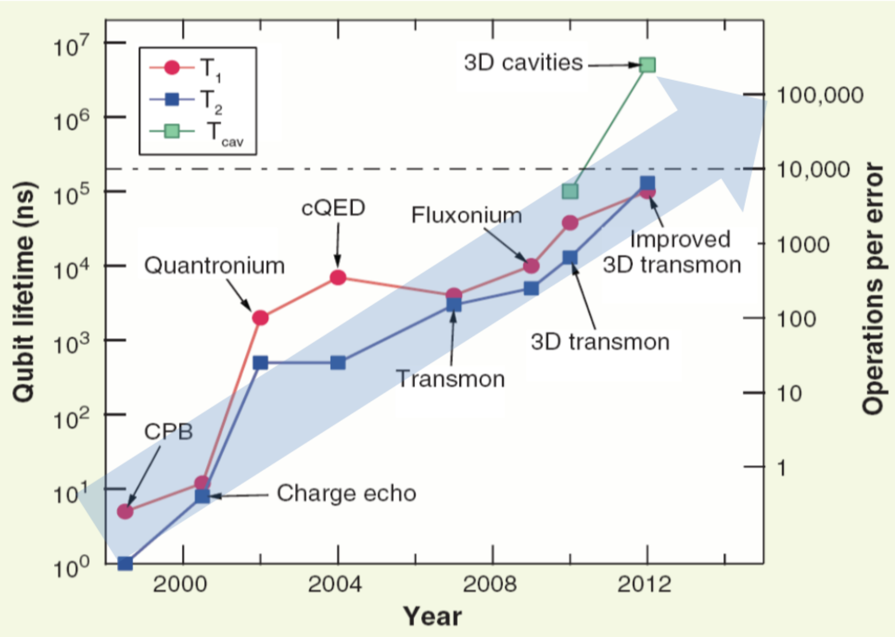
$$\Delta E \sim \sqrt{8E_CE_J} + anharmonicity$$

Low-loss Nonlinear Oscillator with 1 photon

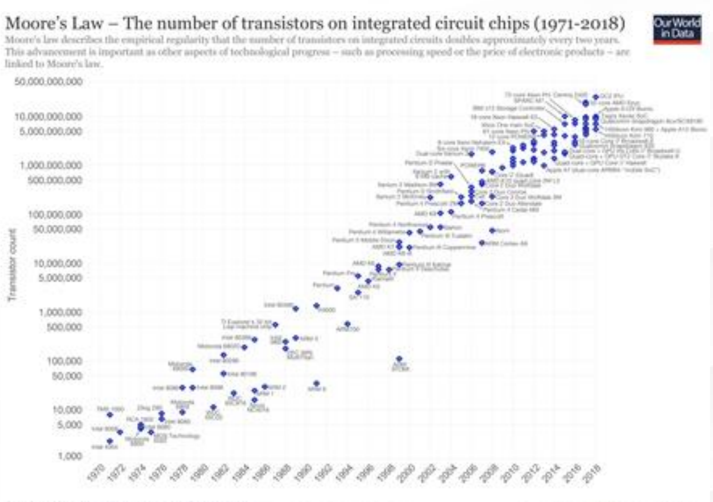
초전도 큐비트의 성능 향상

Schoelkopf Plot
초전도큐비트 결맞음시간
3년에 10 배씩 증가





Moore's Law
반도체 집적도는
대략 2년마다
두 배씩 증가



Josephson Junction

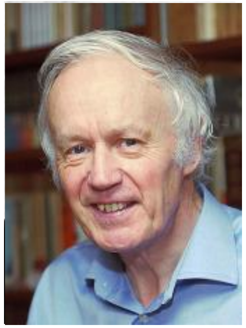
Are macroscopic degrees of freedom governed by quantum mechanics?

80 Supplement of the Progress of Theoretical Physics, No. 69, 1980

Macroscopic Quantum Systems and the Quantum Theory of Measurement

A. J. Leggett

School of Mathematical and Physical Sciences
University of Sussex, Brighton BN1 9QH



Nobel Prize 2003

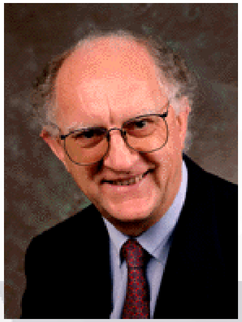
Quantum Mechanics of a Macroscopic Variable: The Phase Difference of a Josephson Junction

John Clarke, Andrew N. Cleland, Michel H. Devoret, Daniel Esteve, John M. Martinis

Experiments to investigate the quantum behavior of a macroscopic degree of freedom, namely the phase difference across a Josephson tunnel junction, are described. The experiments involve measurements of the escape rate of the junction from its zero voltage state. Low temperature measurements of the escape rate for junctions that are either nearly undamped or moderately damped agree very closely with predictions for macroscopic quantum tunneling, with no adjustable parameters. Microwave spectroscopy reveals quantized energy levels in the potential well of the junction in excellent agreement with quantum-mechanical calculations. The system can be regarded as a "macroscopic nucleus with wires."

emphasized, one must distinguish carefully between macroscopic quantum phenomena originating in the superposition of a large number of microscopic variables and those displayed by a single macroscopic degree of freedom. It is the latter that we discuss in this article.

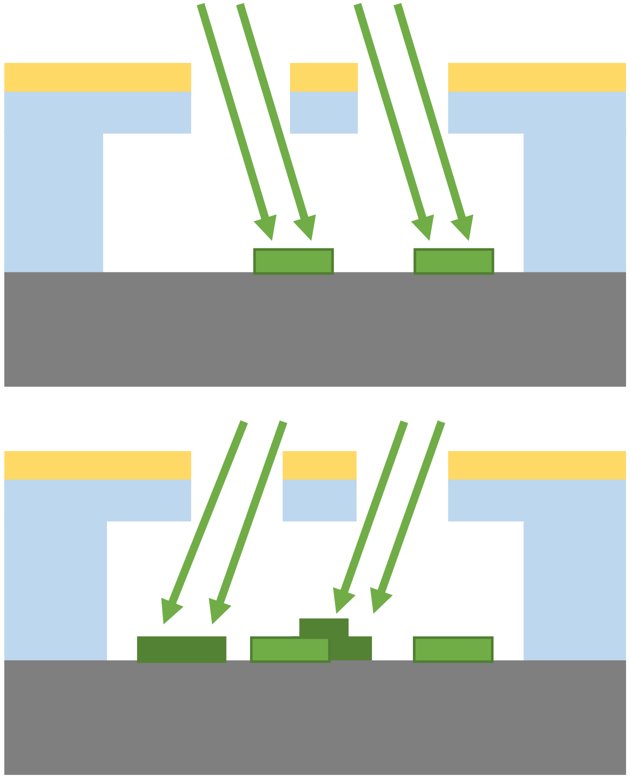
Our usual observations on a billiard ball or Brownian particle reveal classical behavior because Planck's constant $\hbar$ is so tiny. However, at least in principle there is nothing to prevent us from designing an experiment in which these objects are quantum mechanical. To do so we have to satisfy two criteria: (i) the thermal energy must be small compared with the separation of the quantized energy levels, and (ii) the macroscopic degree of freedom must be sufficiently decoupled from all other degrees of freedom if the lifetime of the quantum states is to be longer than the characteristic time scale of the system (*1*). To illustrate the application of these



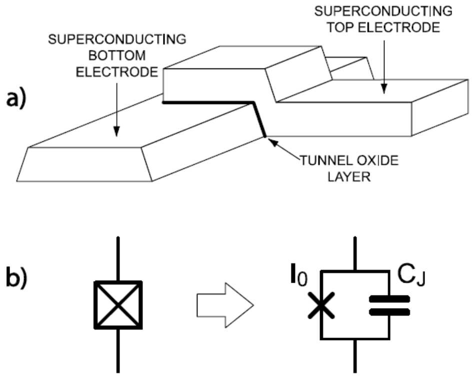
Science 1988

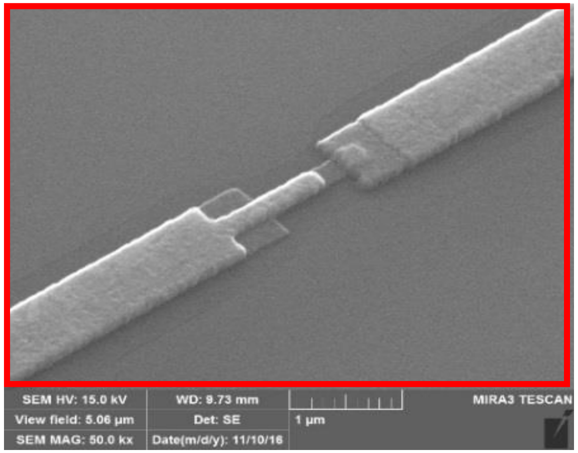
Qubit Fabrication

2-Angle Evaporation



Two-angle evaporation

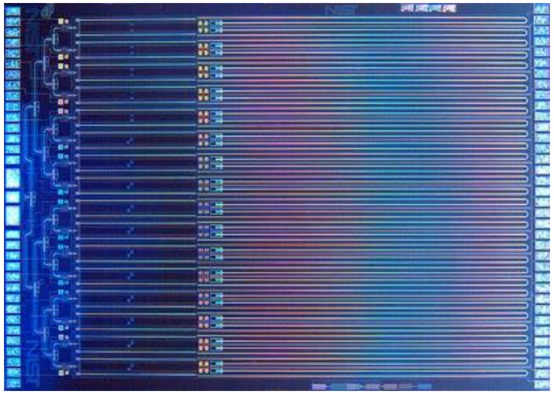




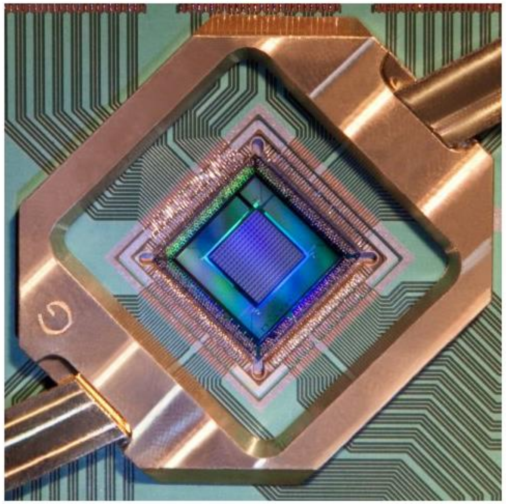
Josephson junction

Josephson Technology

NIST Josephson Voltage Standard
~ 300,000 JJs



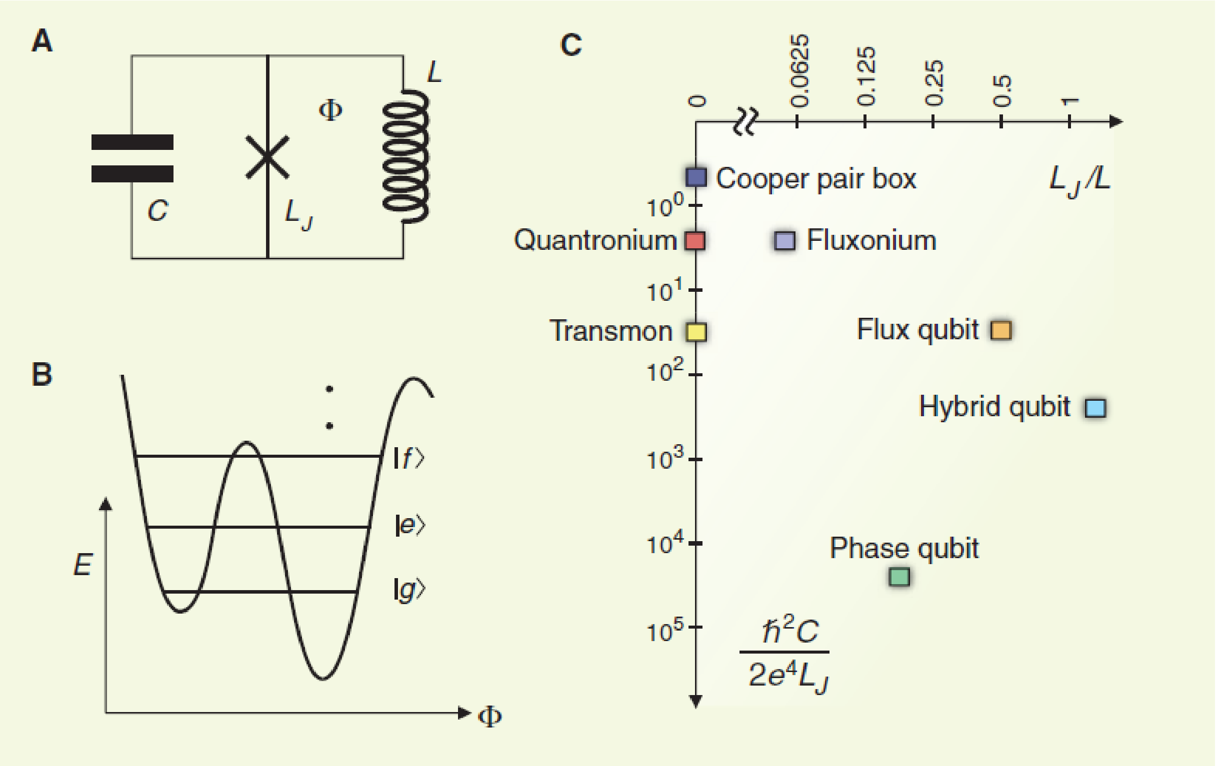
D-wave chip
2000 Qubit



Superconducting electronics foundries

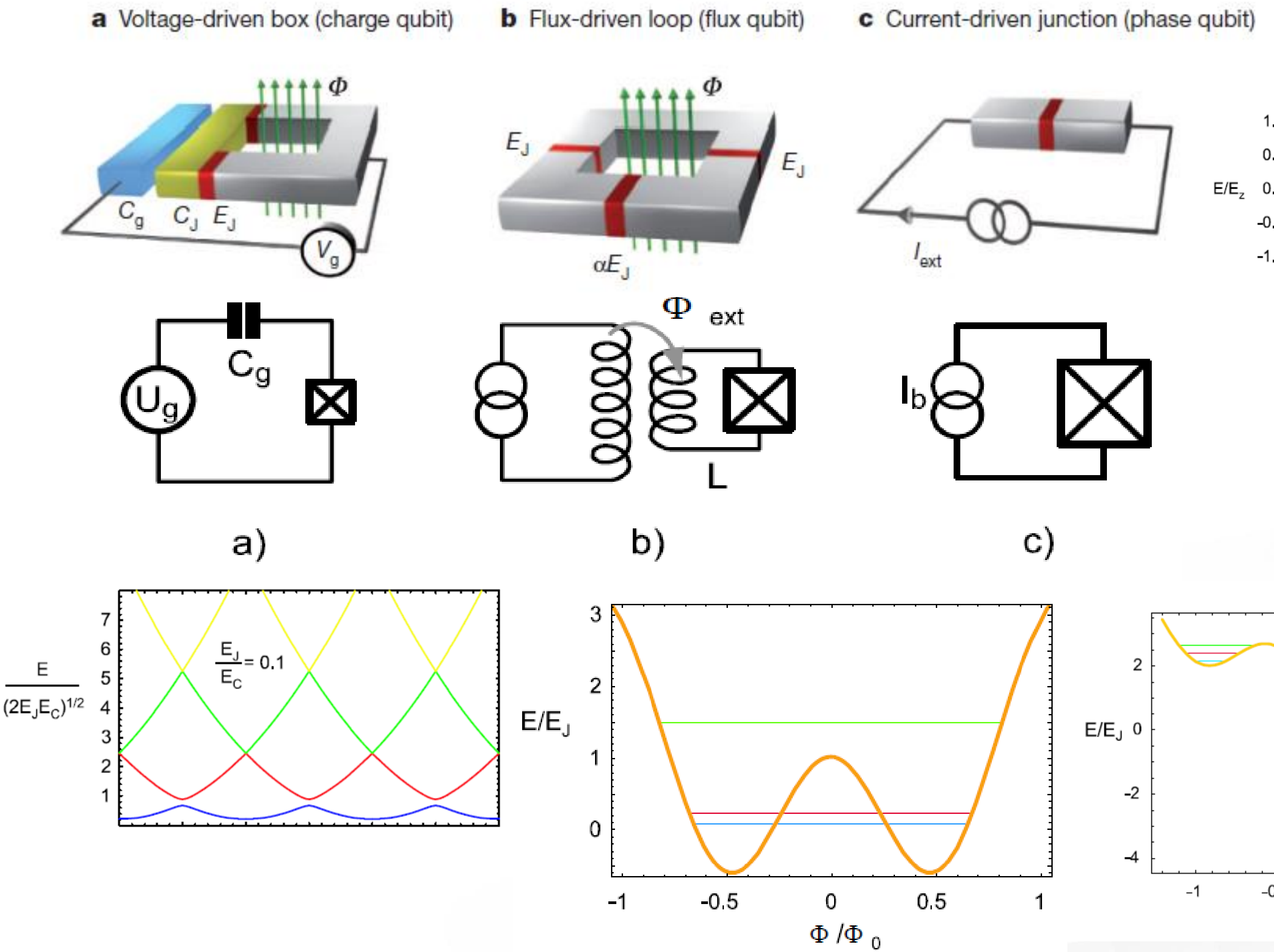
SC Qubit = “Electronics Circuit”

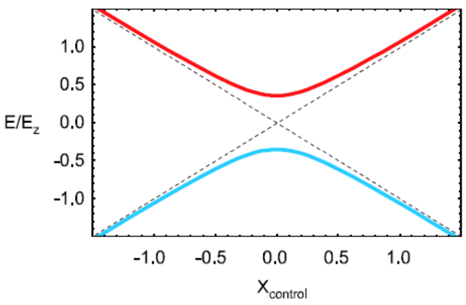
You design your Circuit = You design your Atom
= You design your Hamiltonian



Qubit with electrons? - “interact, but be isolated”

→ Named after the control force

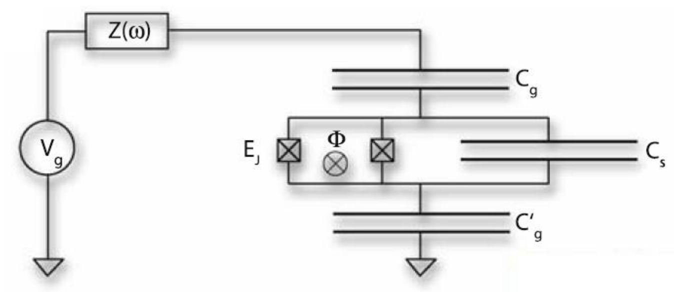


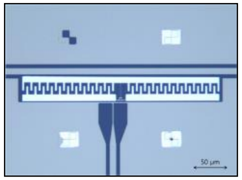


Sweet Spot

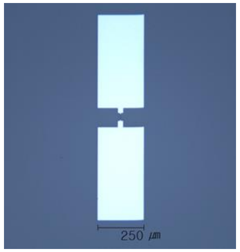
Transmon

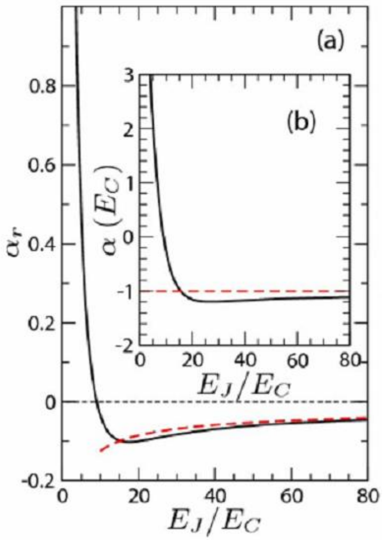
Shunted with a Capacitor

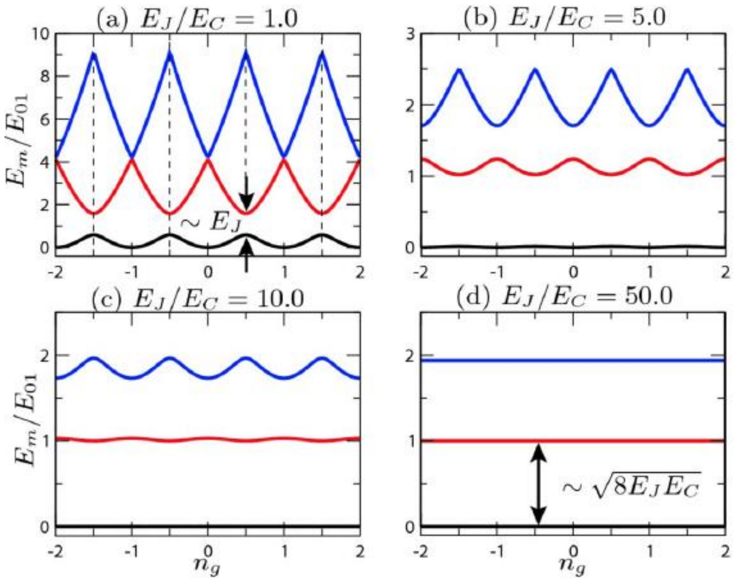




or





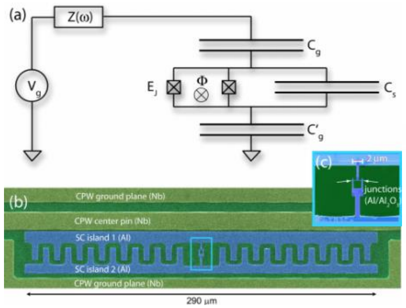


$$E_m \simeq -E_J + \sqrt{8E_CE_J}\left(m+\frac{1}{2}\right) - \frac{E_C}{12}(6m^2+6m+3)$$

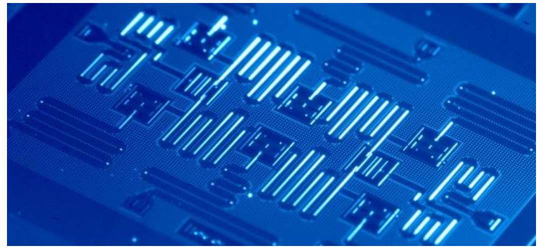
$$\alpha \equiv E_{12} - E_{01}, \quad \alpha_r \equiv \alpha/E_{01}$$

$$\alpha \simeq -E_C \qquad \alpha_r \simeq -(8E_J/E_C)^{-1/2}$$

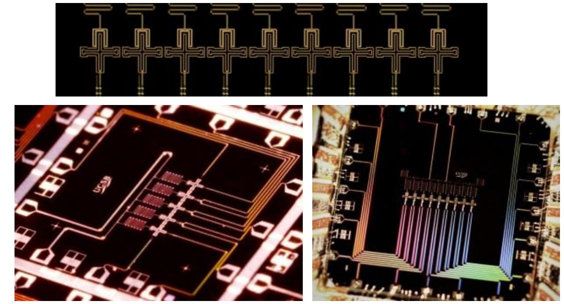
Transmon



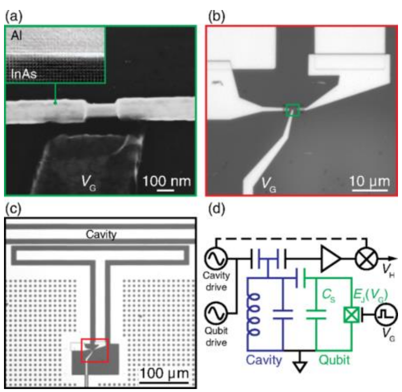
Transmon (Yale)



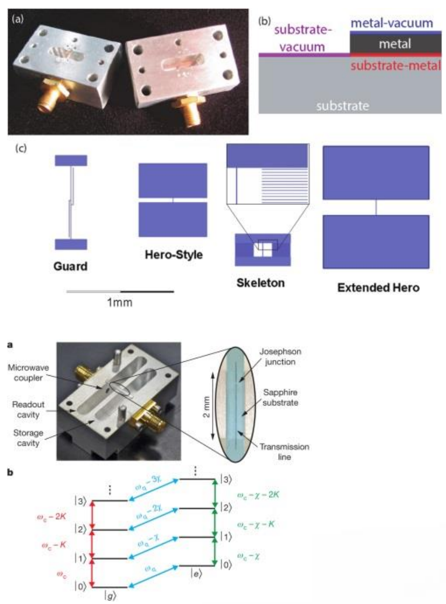
Transmon (IBM)



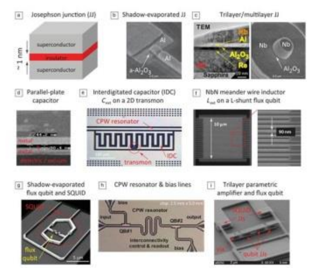
Xmon (Google-UCSB)



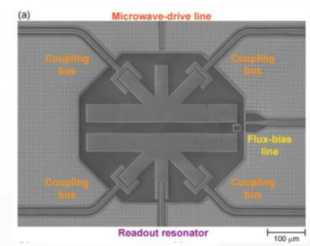
Gatemon (Niels Bohr Inst.)



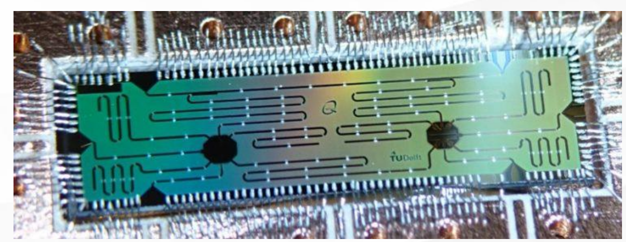
3D-transmon (Yale, IBM)



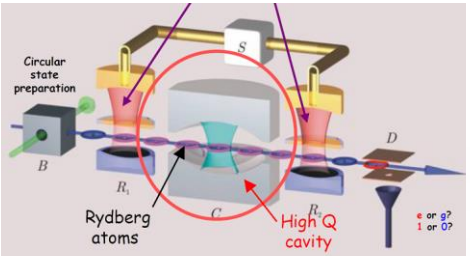
MIT-LL



Starmon (Delft-QUTech)



Circuit QED

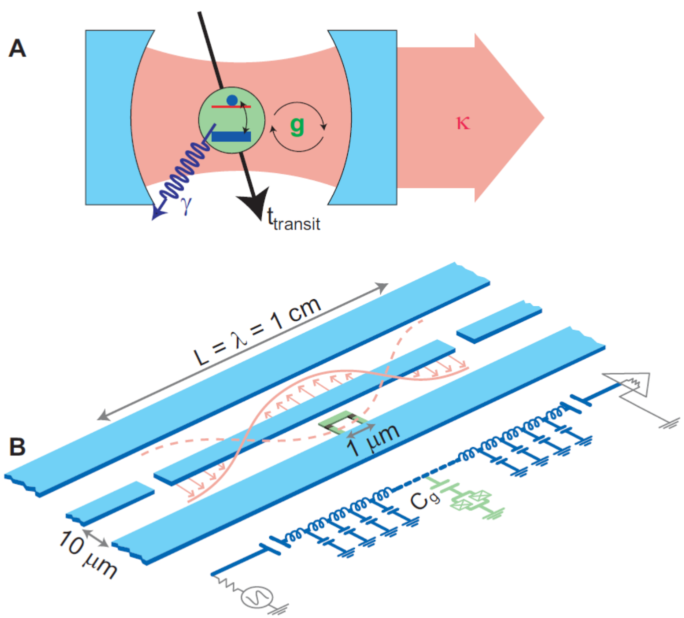


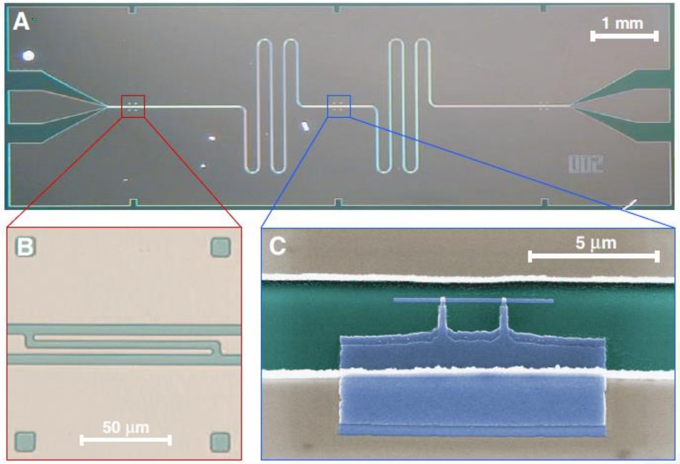
Nature 2004

Strong coupling of a single photon to a superconducting qubit using circuit quantum electrodynamics

A. Wallraff[1], D. I. Schuster[1], A. Blais[1], L. Frunzio[1], R.- S. Huang[1,2], J. Majer[1], S. Kumar[1], S. M. Girvin[1] & R. J. Schoelkopf[1]

[1]*Departments of Applied Physics and Physics, Yale University, New Haven, Connecticut 06520, USA*
[2]*Department of Physics, Indiana University, Bloomington, Indiana 47405, USA*



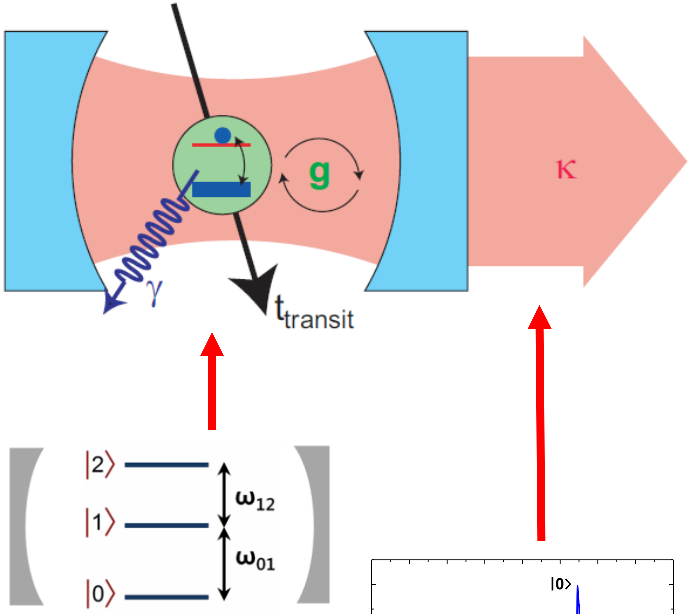


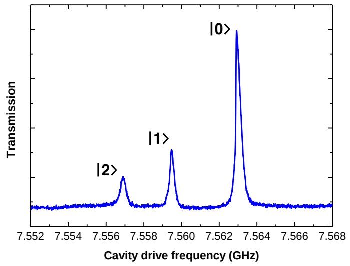
***Jaynes-Cummings* Hamiltonian**

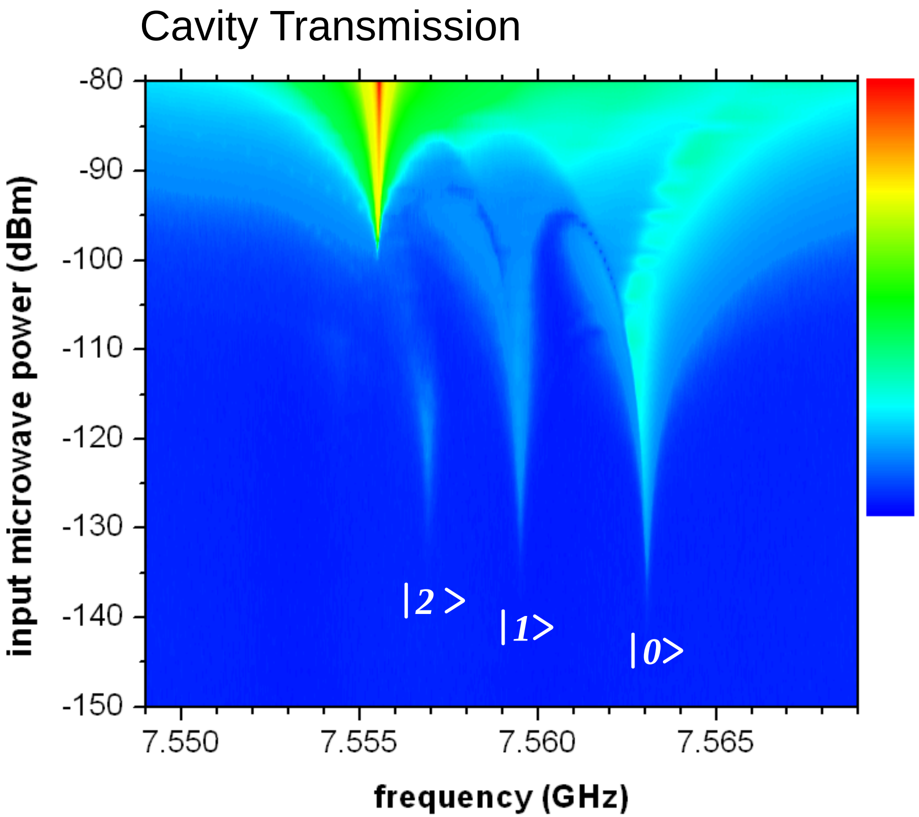
$$H = \hbar\omega_r\left(a^\dagger a + \frac{1}{2}\right) + \frac{\hbar\omega_a}{2}\sigma^z + \hbar g\left(a^\dagger\sigma^- + a\sigma^+\right) + H_\kappa + H_\gamma$$

Circuit QED

Qubit in a Resonator







Circuit QED

Dispersive Shift

If qubit and cavity are well off resonance

$$\Delta \equiv \left|\omega_r - \omega_a\right| >> g \qquad \chi \equiv \frac{g^2}{\Delta} << g$$

$$H = \hbar\omega_r\left(a^\dagger a + \frac{1}{2}\right) + \frac{\hbar\omega_a}{2}\sigma^z + \hbar g\left(a^\dagger\sigma^- + a\sigma^+\right) + H_\kappa + H_\gamma$$

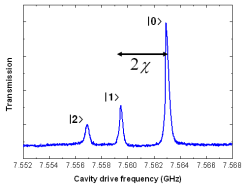
$$\Rightarrow \quad H = \hbar\omega_r\left(a^+ a + \frac{1}{2}\right) + \hbar\omega_a\frac{\sigma_z}{2} + 2\hbar\chi\left(a^+ a + \frac{1}{2}\right)\frac{\sigma_z}{2}$$

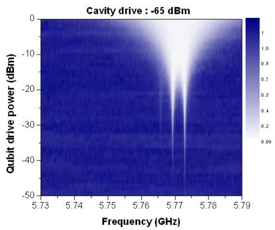
$$= \hbar\left(\omega_r + \chi\sigma_z\right)\left(a^+ a + \frac{1}{2}\right) + +\hbar\left(\omega_a + \chi\right)\frac{\sigma_z}{2}$$

qubit-state dependent cavity frequency shift

$$= \hbar\omega_r\left(a^+ a + \frac{1}{2}\right) + \hbar\left(\omega_a + 2\chi\left(a^+ a + \frac{1}{2}\right)\right)\frac{\sigma_z}{2}$$

cavity photon-number dependent qubit energy shift





Universal Quantum Gate Set

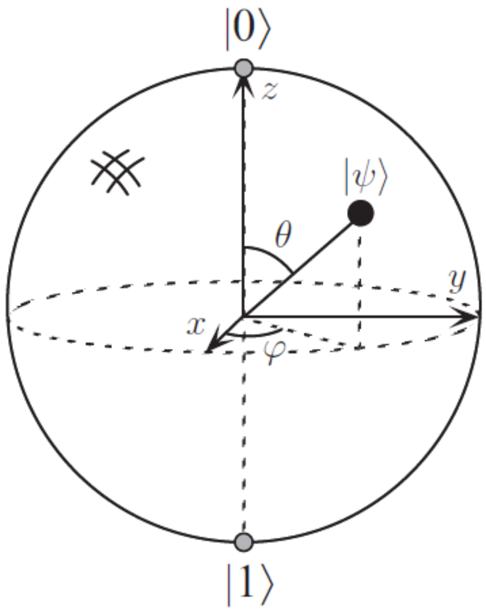


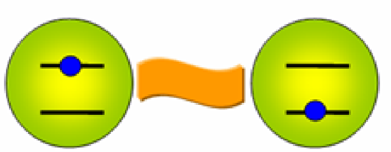
Figure 1.3. Bloch sphere representation of a qubit.

Hadamard	H	$\frac{1}{\sqrt{2}}\begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}$
Pauli-X	X	$\begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}$
Pauli-Y	Y	$\begin{bmatrix} 0 & -i \\ i & 0 \end{bmatrix}$
Pauli-Z	Z	$\begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix}$
Phase	S	$\begin{bmatrix} 1 & 0 \\ 0 & i \end{bmatrix}$
$\pi/8$	T	$\begin{bmatrix} 1 & 0 \\ 0 & e^{i\pi/4} \end{bmatrix}$

single-qubit gates

+

two-qubit (entangling) gate

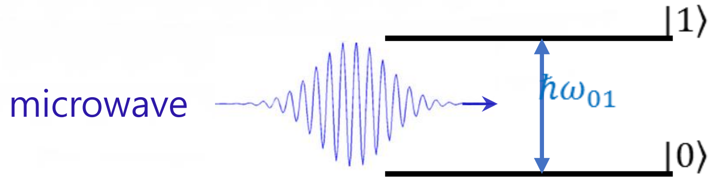


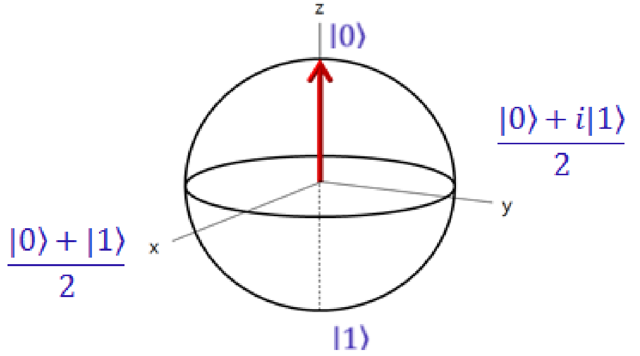
controlled-NOT

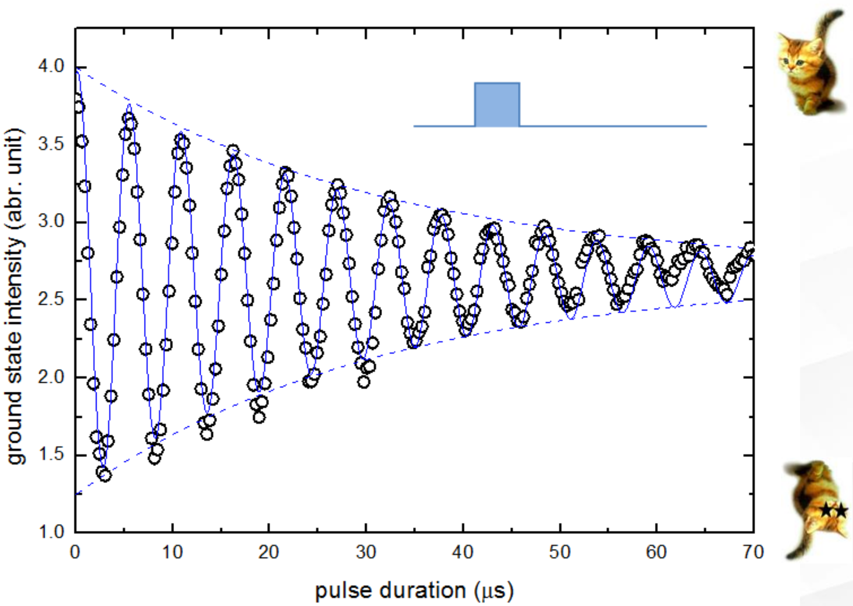
$$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{bmatrix}$$

큐비트 제어 및 결맞음

Coherent rotation of qubit states is controlled by microwave pulses





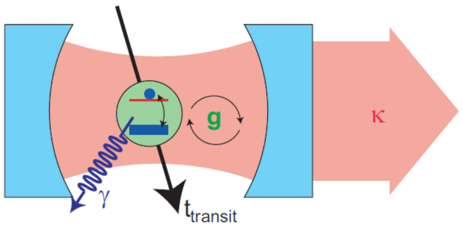


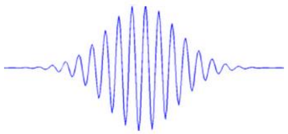
$$R_x(\theta) \equiv e^{-i\frac{\theta}{2}X} = \cos\frac{\theta}{2}I - i\sin\frac{\theta}{2}X = \begin{bmatrix} \cos\frac{\theta}{2} & -i\sin\frac{\theta}{2} \\ -i\sin\frac{\theta}{2} & \cos\frac{\theta}{2} \end{bmatrix}$$

$$R_y(\theta) \equiv e^{-i\frac{\theta}{2}Y} = \cos\frac{\theta}{2}I - i\sin\frac{\theta}{2}Y = \begin{bmatrix} \cos\frac{\theta}{2} & -\sin\frac{\theta}{2} \\ \sin\frac{\theta}{2} & \cos\frac{\theta}{2} \end{bmatrix}$$

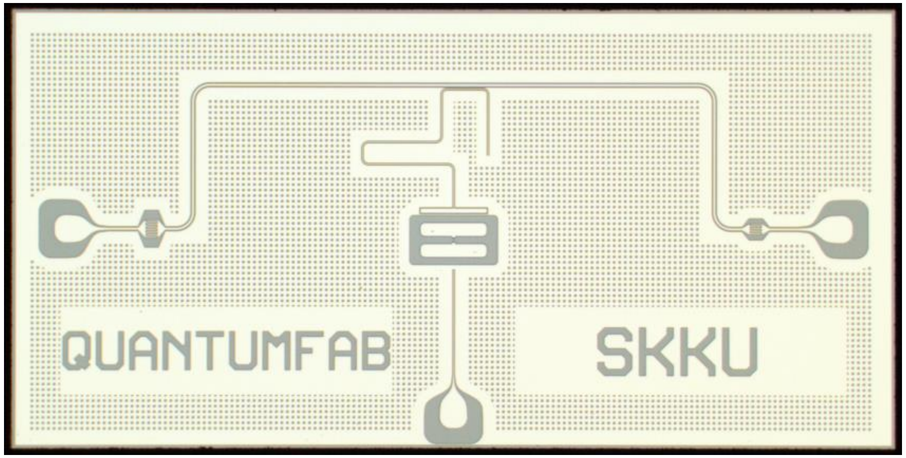
$$R_z(\theta) \equiv e^{-i\frac{\theta}{2}Z} = \cos\frac{\theta}{2}I - i\sin\frac{\theta}{2}Z = \begin{bmatrix} e^{-i\theta/2} & 0 \\ 0 & e^{i\theta/2} \end{bmatrix}$$

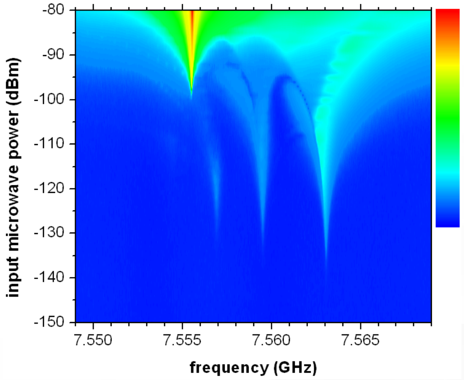
큐비트 제어 및 측정



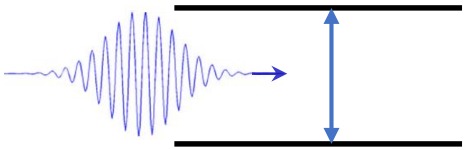


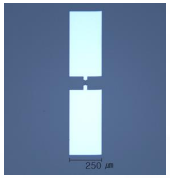
microwave





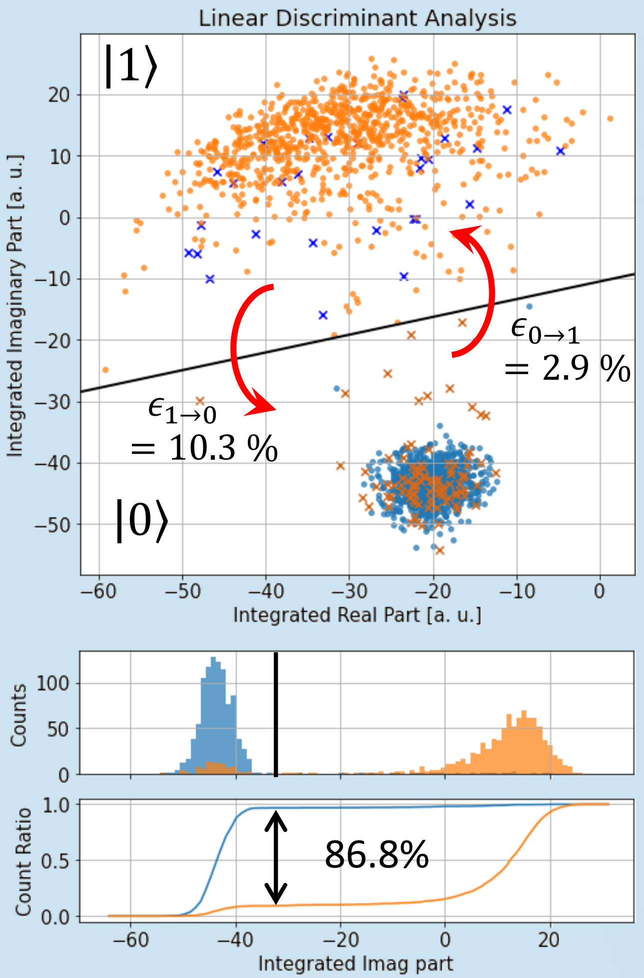
microwave



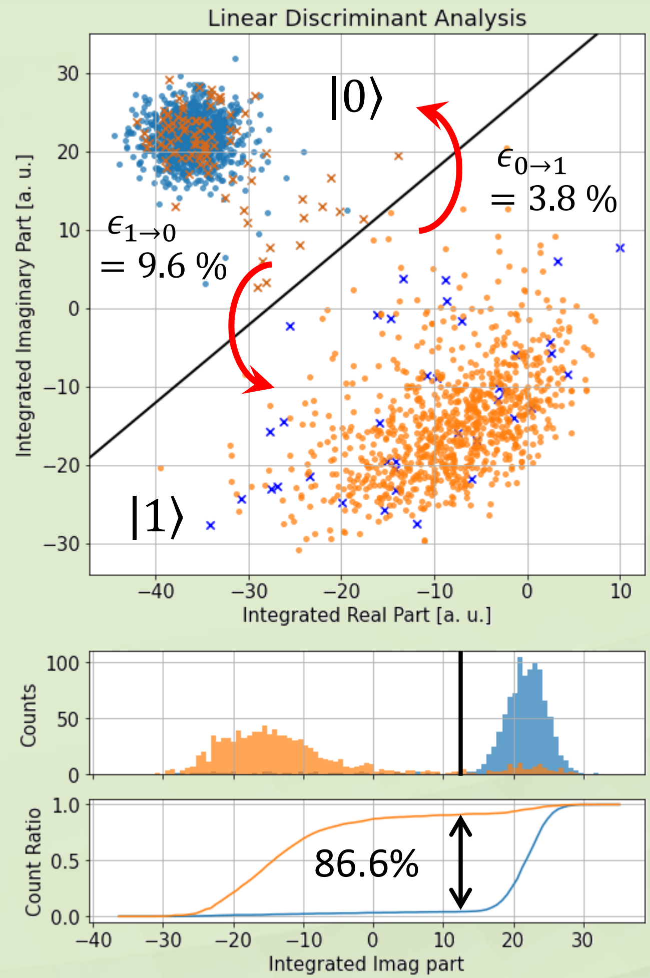


Single Shot Readout

Q0



Q1



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D-wave Cloud

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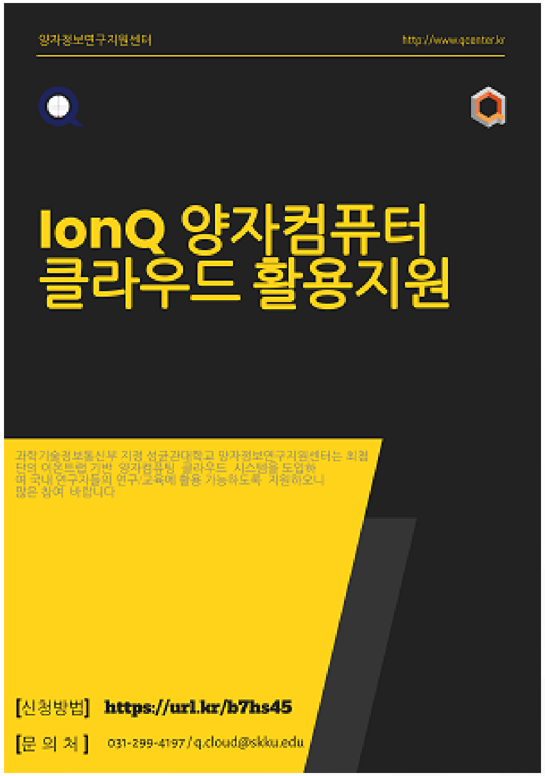
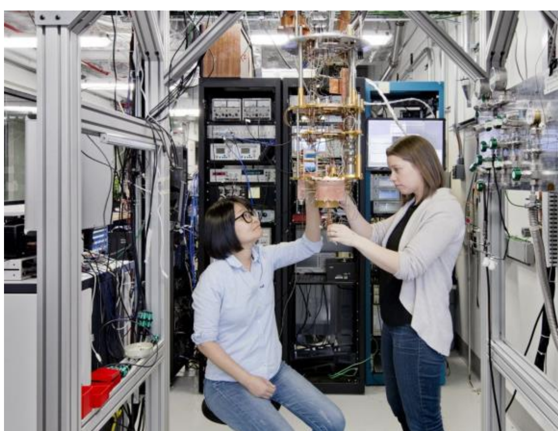


IBM



IBM Cloud


2022
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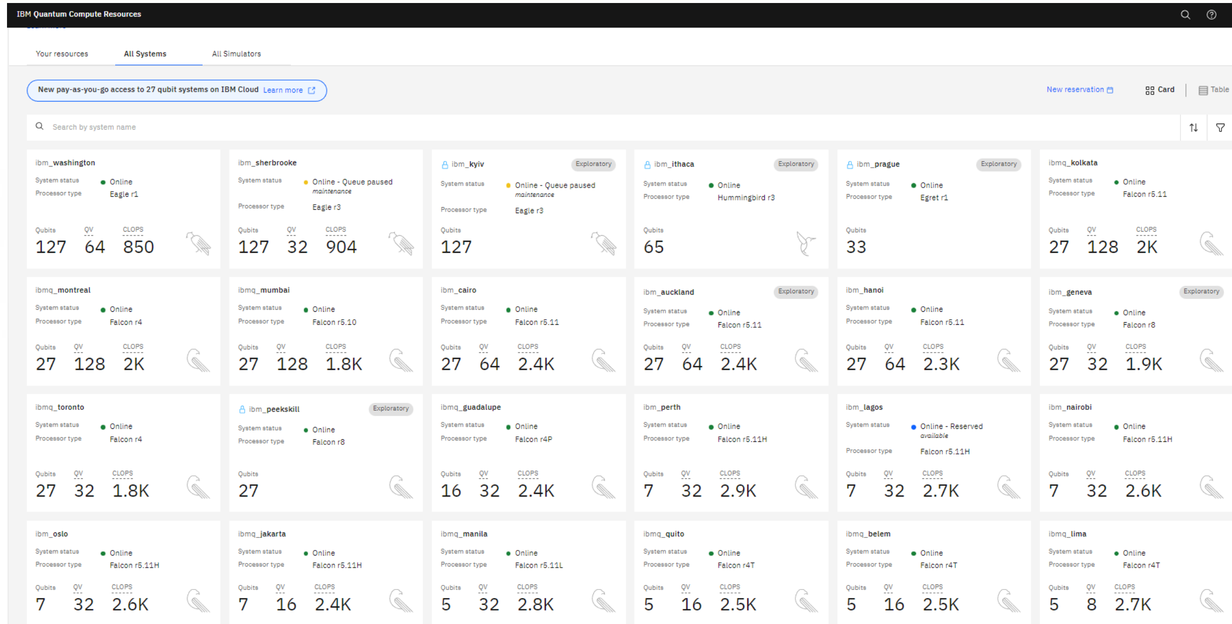
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Search by system name
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ibm_sherbrooke 127 32 904
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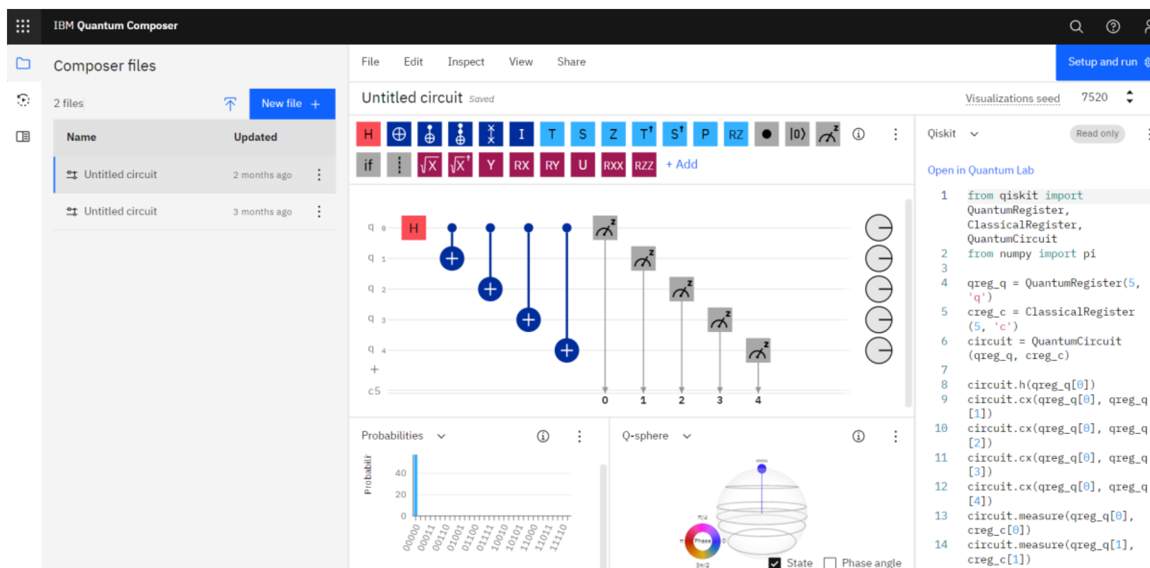
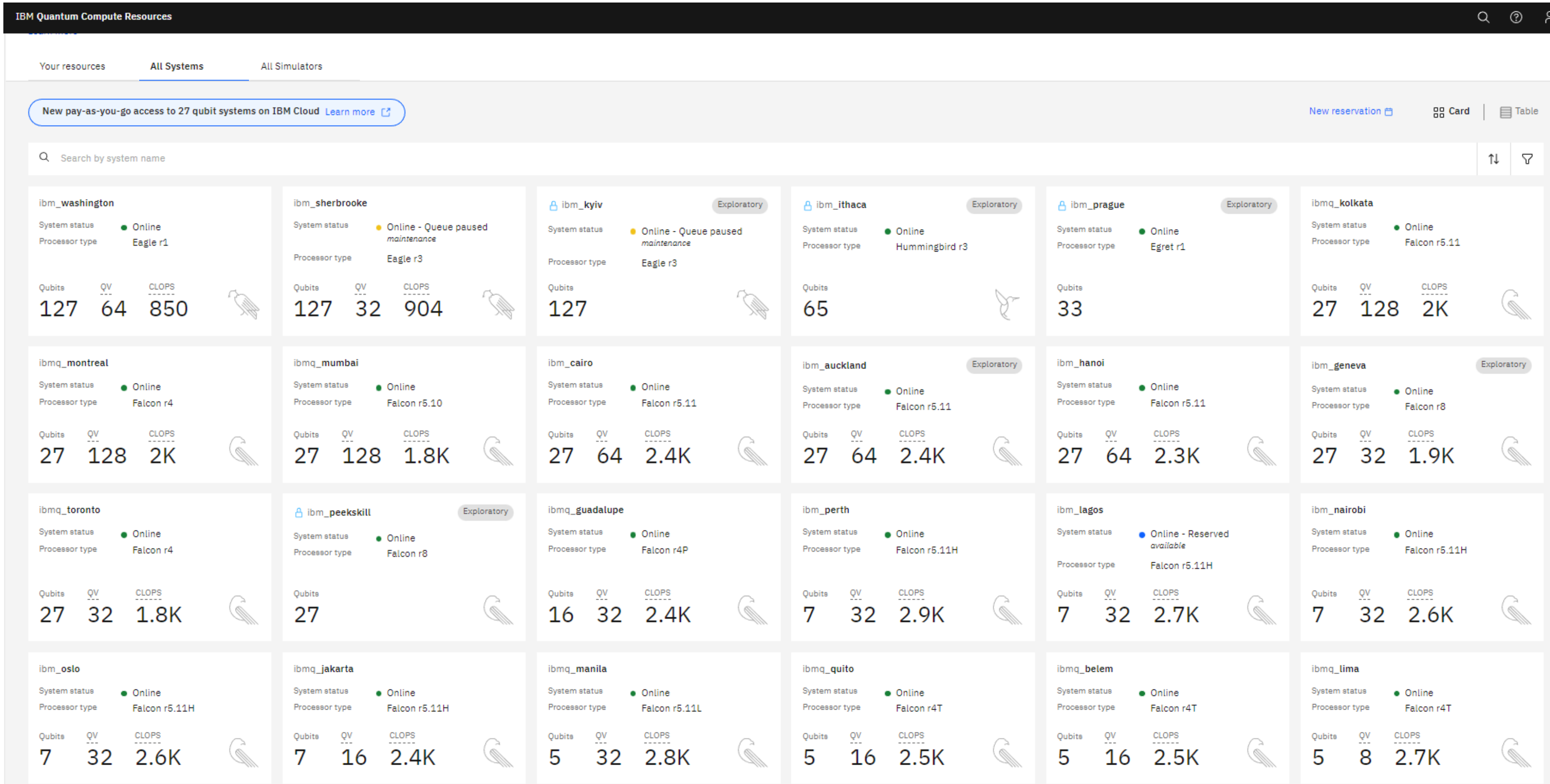
ibm_ithaca 65
ibm_prague 33
ibmq_kolkata 27 128 2K
ibmq_montreal 27 128 2K
ibmq_mumbai 27 128 1.8K
ibm_cairo 27 64 2.4K
ibm_auckland 27 64 2.4K
ibm_hanoi 27 64 2.3K
ibm_geneva 27 32 1.9K
ibmq_toronto 27 32 1.8K
ibm_peekskill 27
ibmq_guadalupe 16 32 2.4K
ibm_perth 7 32 2.9K
ibm_lagos 7 32 2.7K
ibm_nairobi 7 32 2.6K
ibm_oslo 7 32 2.6K
ibmq_jakarta 7 16 2.4K
ibmq_manila 5 32 2.8K
ibmq_quito 5 16 2.5K
ibmq_belem 5 16 2.5K
ibmq_lima 5 8 2.7K


IBM Quantum Composer
Composer files
2 files
New file
Name
Updated
Untitled circuit
2 months ago
Untitled circuit
3 months ago
File
Edit
Inspect
View
Share
Setup and run
Untitled circuit
Saved
Visualizations seed
7520
Qiskit
Read only
Open in Quantum Lab
from qiskit import QuantumRegister, ClassicalRegister, QuantumCircuit
from numpy import pi
qreg_q = QuantumRegister(5, 'q')
creg_c = ClassicalRegister(5, 'c')
circuit = QuantumCircuit(qreg_q, creg_c)
circuit.h(qreg_q[0])
circuit.cx(qreg_q[0], qreg_q[1])
circuit.cx(qreg_q[0], qreg_q[2])
circuit.cx(qreg_q[0], qreg_q[3])
circuit.cx(qreg_q[0], qreg_q[4])
circuit.measure(qreg_q[0], creg_c[0])
circuit.measure(qreg_q[1], creg_c[1])
circuit.measure(qreg_q[2],
Probabilities
Q-sphere
State
Phase angle

IBM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All Systems
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New pay-as-you-go access to 27 qubit systems on IBM Cloud
Learn more
New reservation
Card
Table
Search by system name
ibm_washington
System status Online
Processor type Eagle r1
Qubits 127 QV 64 CLOPS 850
ibm_sherbrooke
System status Online - Queue paused
maintenance
Processor type Eagle r3
Qubits 127 QV 32 CLOPS 904
ibm_kyiv
Exploratory
System status Online - Queue paused
maintenance
Processor type Eagle r3
Qubits 127
ibm_ithaca
Exploratory
System status Online
Processor type Hummingbird r3
Qubits 65
ibm_prague
Exploratory
System status Online
Processor type Egret r1
Qubits 33
ibmq_kolkata
System status Online
Processor type Falcon r5.11
Qubits 27 QV 128 CLOPS 2K
ibmq_montreal
System status Online
Processor type Falcon r4
Qubits 27 QV 128 CLOPS 2K
ibmq_mumbai
System status Online
Processor type Falcon r5.10
Qubits 27 QV 128 CLOPS 1.8K
ibm_cairo
System status Online
Processor type Falcon r5.11
Qubits 27 QV 64 CLOPS 2.4K
ibm_auckland
Exploratory
System status Online
Processor type Falcon r5.11
Qubits 27 QV 64 CLOPS 2.4K
ibm_hanoi
System status Online
Processor type Falcon r5.11
Qubits 27 QV 64 CLOPS 2.3K
ibm_geneva
Exploratory
System status Online
Processor type Falcon r8
Qubits 27 QV 32 CLOPS 1.9K
ibmq_toronto
System status Online
Processor type Falcon r4
Qubits 27 QV 32 CLOPS 1.8K
ibm_peekskill
Exploratory
System status Online
Processor type Falcon r8
Qubits 27
ibmq_guadalupe
System status Online
Processor type Falcon r4P
Qubits 16 QV 32 CLOPS 2.4K
ibm_perth
System status Online
Processor type Falcon r5.11H
Qubits 7 QV 32 CLOPS 2.9K
ibm_lagos
System status Online - Reserved
available
Processor type Falcon r5.11H
Qubits 7 QV 32 CLOPS 2.7K
ibm_nairobi
System status Online
Processor type Falcon r5.11H
Qubits 7 QV 32 CLOPS 2.6K
ibm_oslo
System status Online
Processor type Falcon r5.11H
Qubits 7 QV 32 CLOPS 2.6K
ibmq_jakarta
System status Online
Processor type Falcon r5.11H
Qubits 7 QV 16 CLOPS 2.4K
ibmq_manila
System status Online
Processor type Falcon r5.11L
Qubits 5 QV 32 CLOPS 2.8K
ibmq_quito
System status Online
Processor type Falcon r4T
Qubits 5 QV 16 CLOPS 2.5K
ibmq_belem
System status Online
Processor type Falcon r4T
Qubits 5 QV 16 CLOPS 2.5K
ibmq_lima
System status Online
Processor type Falcon r4T
Qubits 5 QV 8 CLOPS 2.7K

IBM

ibmq_kolkata

OpenQASM 3

Details

27 Qubits	Status:	Online	Median CNOT Error:	6.730e-3
128 QV	Total pending jobs:	836 jobs	Median Readout Error:	1.210e-2
2K CLOPS	Processor type:	Falcon r5.11	Median T1:	117 us
	Version:	1.11.22	Median T2:	87.87 us
	Basis gates:	CX, ID, IF_ELSE, RZ, SX, X	Providers with access:	5 Providers
	Your usage:	0 jobs		

Your upcoming reservations 0 New reservation +

Calibration data Last calibrated: 3 minutes ago

Map view | Graph view | Table view

Qubit:

Readout assignment error

Median 1.210e-2

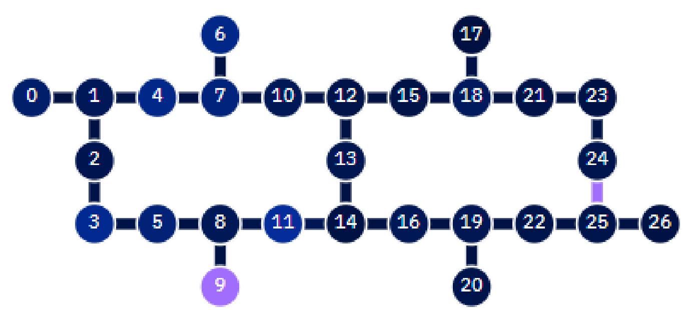
min 5.300e-3 max 1.467e-1

Connection:

CNOT error

Median 6.730e-3

min 4.053e-3 max 1.000e+0



양자컴퓨터의 계층구조

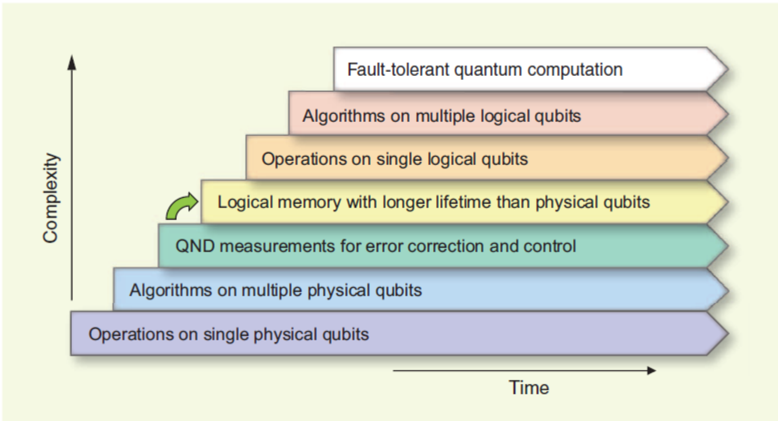


Fig. 1. Seven stages in the development of quantum information processing. Each advancement requires mastery of the preceding stages, but each also represents a continuing task that must be perfected in parallel with the others. Superconducting qubits are the only solid-state implementation at the third stage, and they now aim at reaching the fourth stage (green arrow). In the domain of atomic physics and quantum optics, the third stage had been previously attained by trapped ions and by Rydberg atoms. No implementation has yet reached the fourth stage, where a logical qubit can be stored, via error correction, for a time substantially longer than the decoherence time of its physical qubit components.

Devoret, Schoelkopf, Science 2013

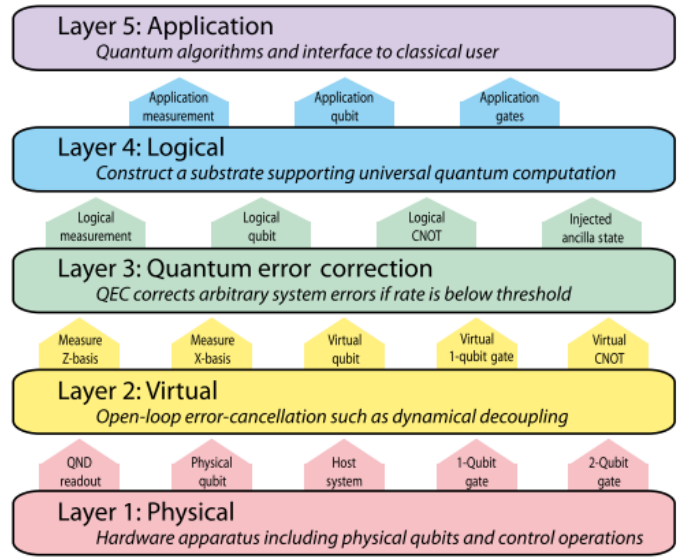
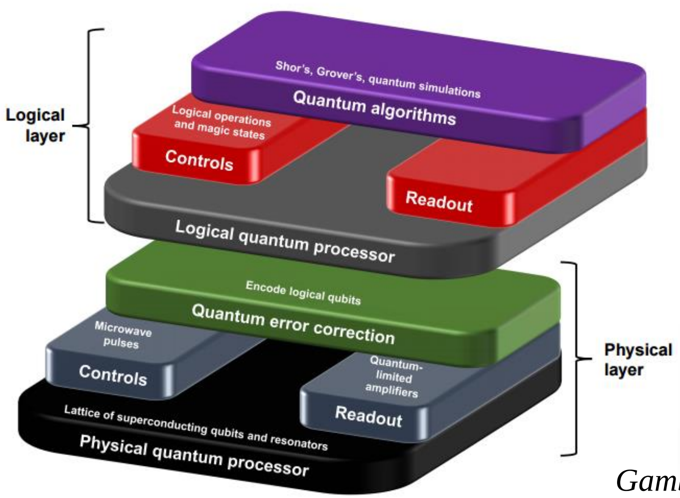


FIG. 1. Layered control stack that forms the framework of a quantum-computer architecture. Vertical arrows indicate services provided to a higher layer.

Jones, Yamamoto, PRX 2012

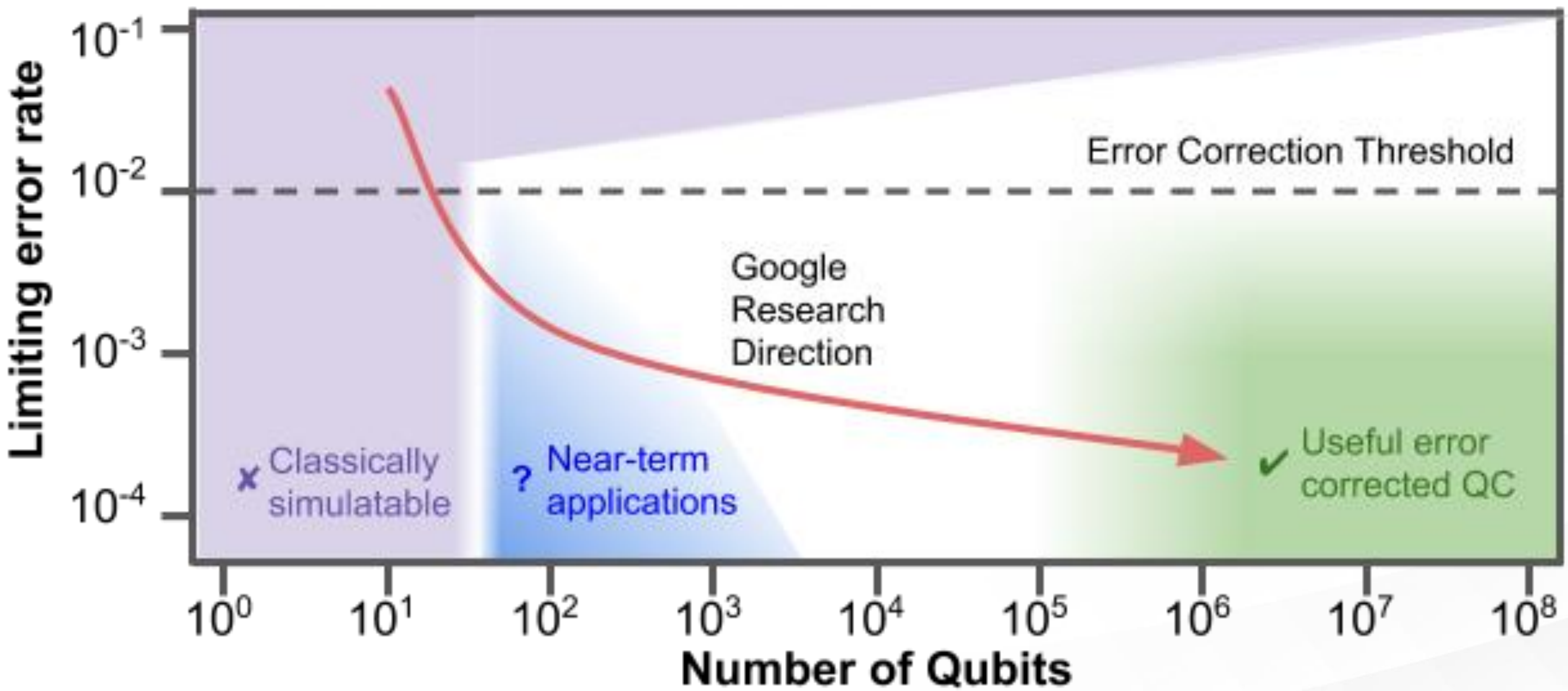


Gambetta, ArXiv 2015

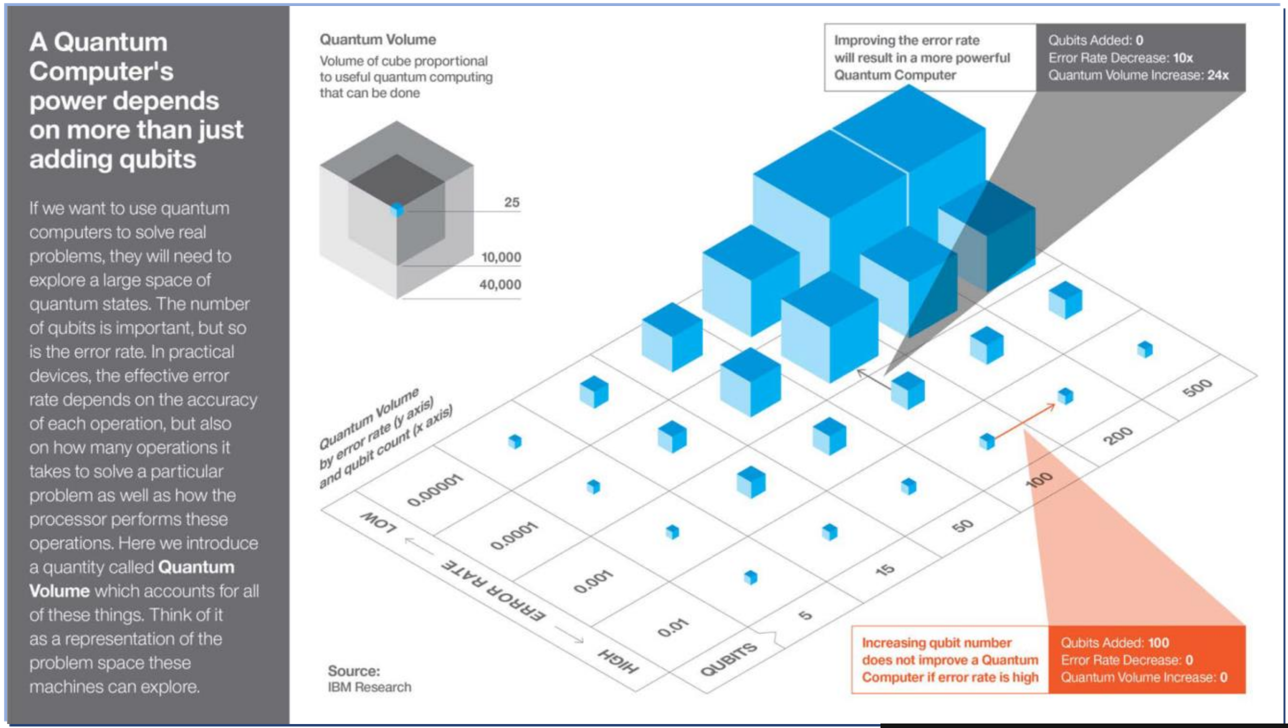
신뢰도 (Fidelity)

Don’t be fooled by the number

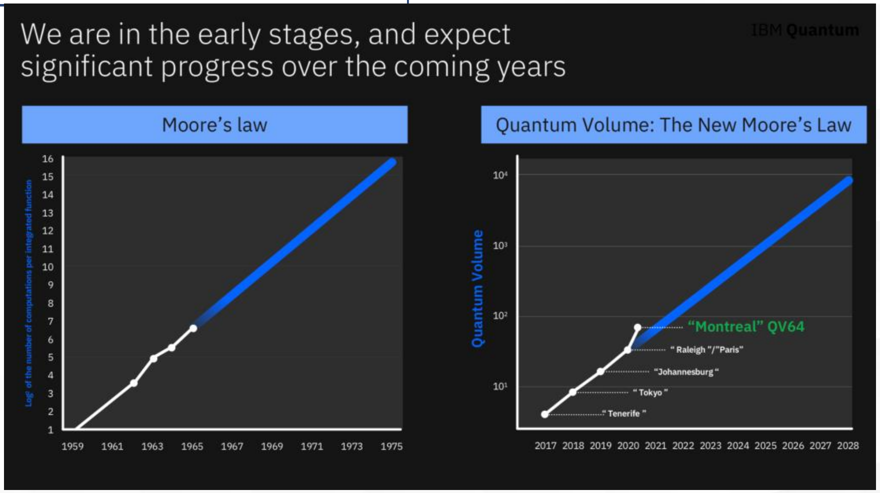
Google



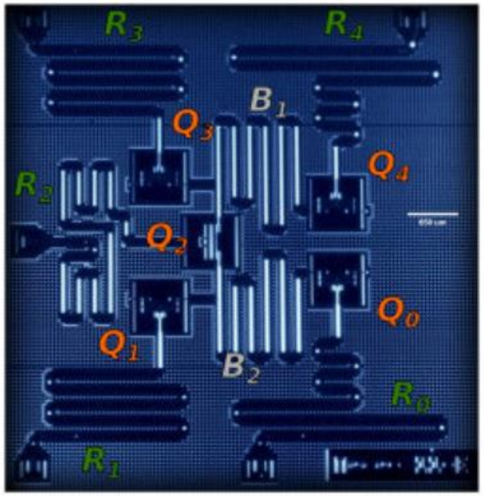
성능지표: Quantum Volume (IBM)



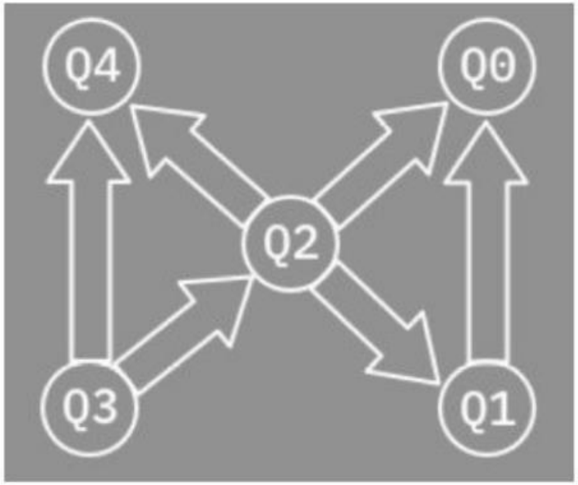
다른 성능지표도 있음
예) Algorithmic Qubit (IonQ)

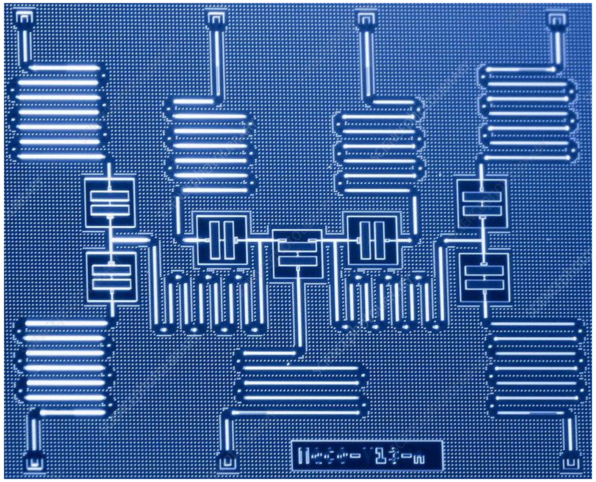


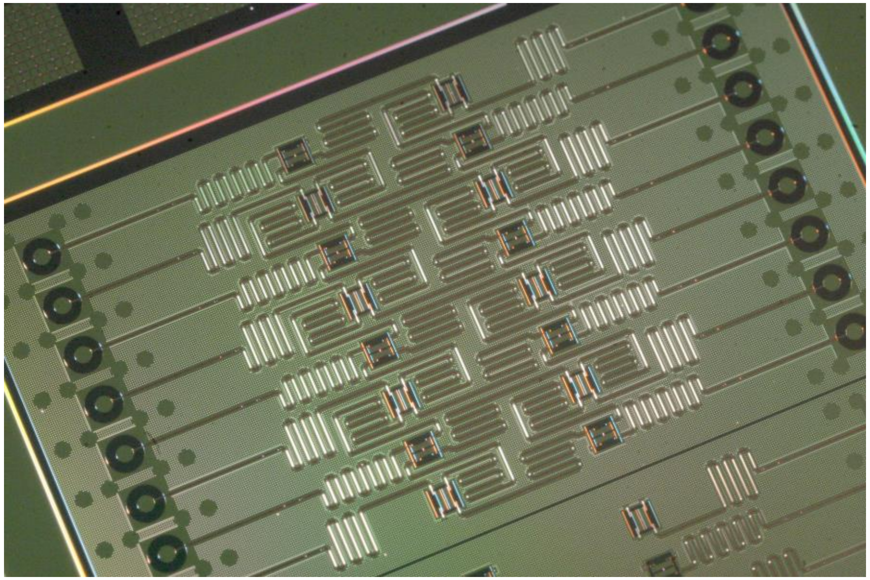
IBM Chips Old Days

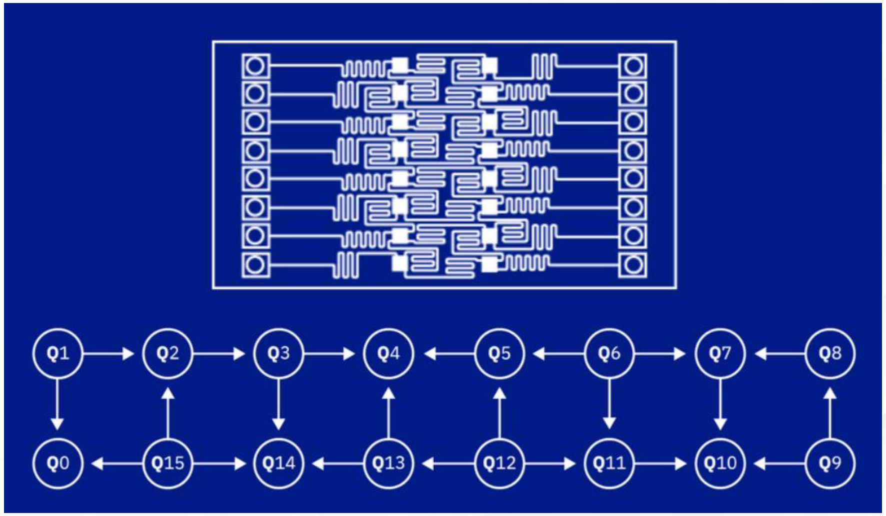


b









IBM Chips : How the qubits are connected?

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IBM Research Blog Topics Labs

Quantum Computing

Quantum computation center opens

September 18, 2019 | Written by: Doug McClure and Jay Gambetta

Categorized: Quantum Computing | Systems

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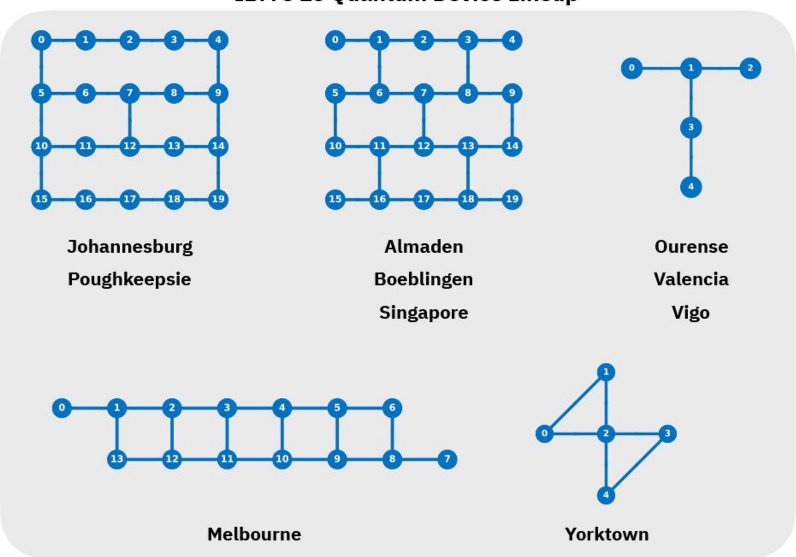
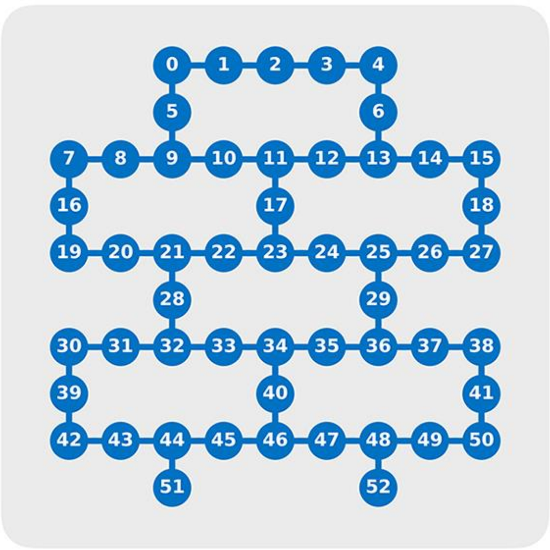
IBM continued its push toward large-scale adoption of quantum computing with the opening of the first IBM Quantum Computation Center in Poughkeepsie, NY, bringing the number of quantum computing systems available online via our IBM Q Experience platform to a total of 10. To meet growing demand, an additional four systems are scheduled to come online in the next month. This milestone represents a paradigm shift in quantum computing, marking the first large-scale deployment of quantum computing systems. One of the systems to be released next month has 53 qubits, which will make it the largest commercially available

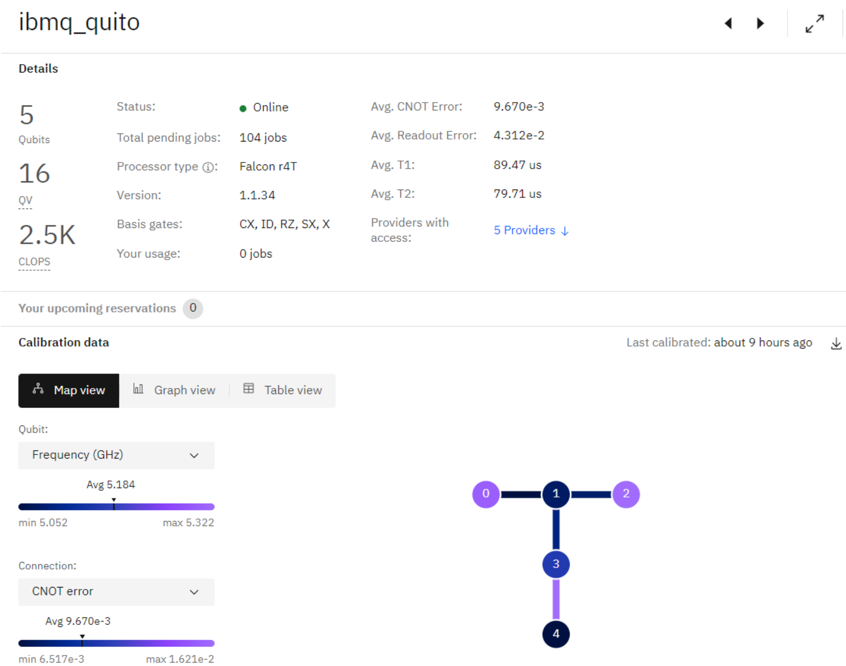
IBM's 10 Quantum Device Lineup



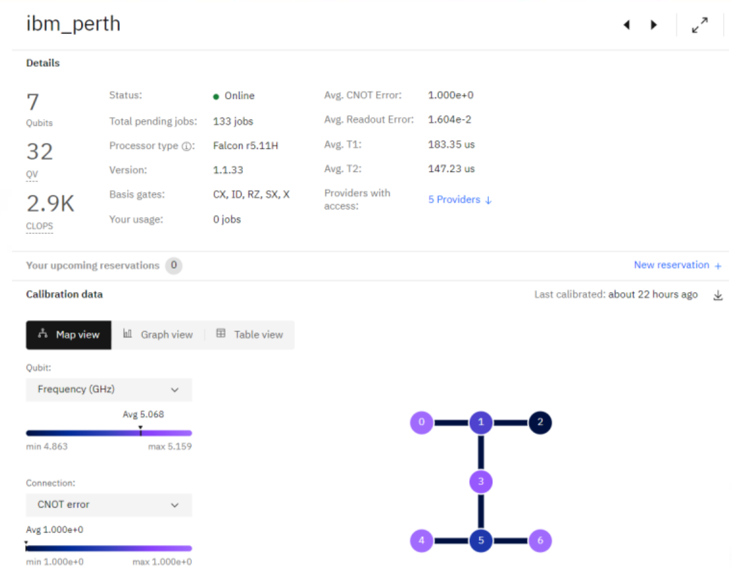
53 Qubit Rochester Device



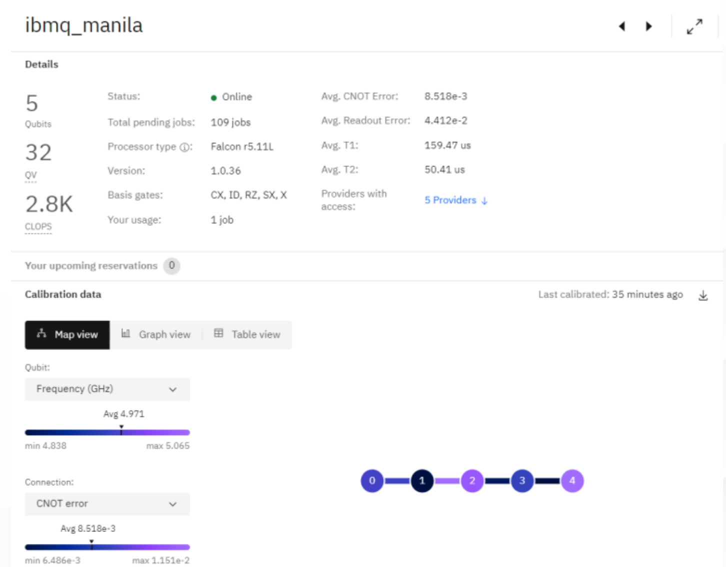
IBM Backend



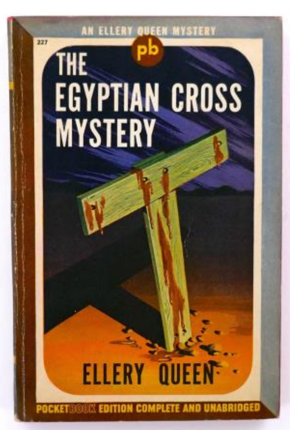
ibmq_quito
Details
5 Qubits
16 QV
2.5K CLOPS
Status: Online
Total pending jobs: 104 jobs
Processor type: Falcon r4T
Version: 1.1.34
Basis gates: CX, ID, RZ, SX, X
Your usage: 0 jobs
Avg. CNOT Error: 9.670e-3
Avg. Readout Error: 4.312e-2
Avg. T1: 89.47 us
Avg. T2: 79.71 us
Providers with access: 5 Providers
Your upcoming reservations 0
Calibration data
Last calibrated: about 9 hours ago
Map view
Graph view
Table view
Qubit:
Frequency (GHz)
Avg 5.184
min 5.052
max 5.322
Connection:
CNOT error
Avg 9.670e-3
min 6.517e-3
max 1.621e-2
0
1
2
3
4



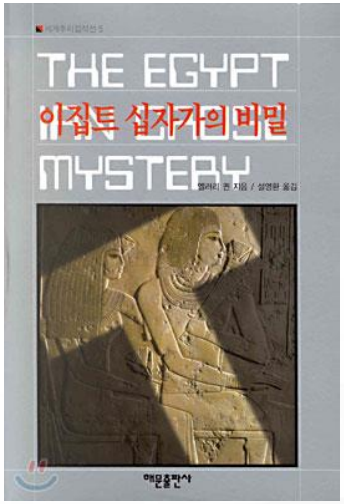
ibm_perth
Details
7 Qubits
32 QV
2.9K CLOPS
Status: Online
Total pending jobs: 133 jobs
Processor type: Falcon r5.11H
Version: 1.1.33
Basis gates: CX, ID, RZ, SX, X
Your usage: 0 jobs
Avg. CNOT Error: 1.000e+0
Avg. Readout Error: 1.604e-2
Avg. T1: 183.35 us
Avg. T2: 147.23 us
Providers with access: 5 Providers
Your upcoming reservations 0
New reservation
Calibration data
Last calibrated: about 22 hours ago
Map view
Graph view
Table view
Qubit:
Frequency (GHz)
Avg 5.068
min 4.863
max 5.159
Connection:
CNOT error
Avg 1.000e+0
min 1.000e+0
max 1.000e+0
0
1
2
3
4
5
6



ibmq_manila
Details
5 Qubits
32 QV
2.8K CLOPS
Status: Online
Total pending jobs: 109 jobs
Processor type: Falcon r5.11L
Version: 1.0.36
Basis gates: CX, ID, RZ, SX, X
Your usage: 1 job
Avg. CNOT Error: 8.518e-3
Avg. Readout Error: 4.412e-2
Avg. T1: 159.47 us
Avg. T2: 50.41 us
Providers with access: 5 Providers
Your upcoming reservations 0
Calibration data
Last calibrated: 35 minutes ago
Map view
Graph view
Table view
Qubit:
Frequency (GHz)
Avg 4.971
min 4.838
max 5.065
Connection:
CNOT error
Avg 8.518e-3
min 6.486e-3
max 1.151e-2
0
1
2
3
4

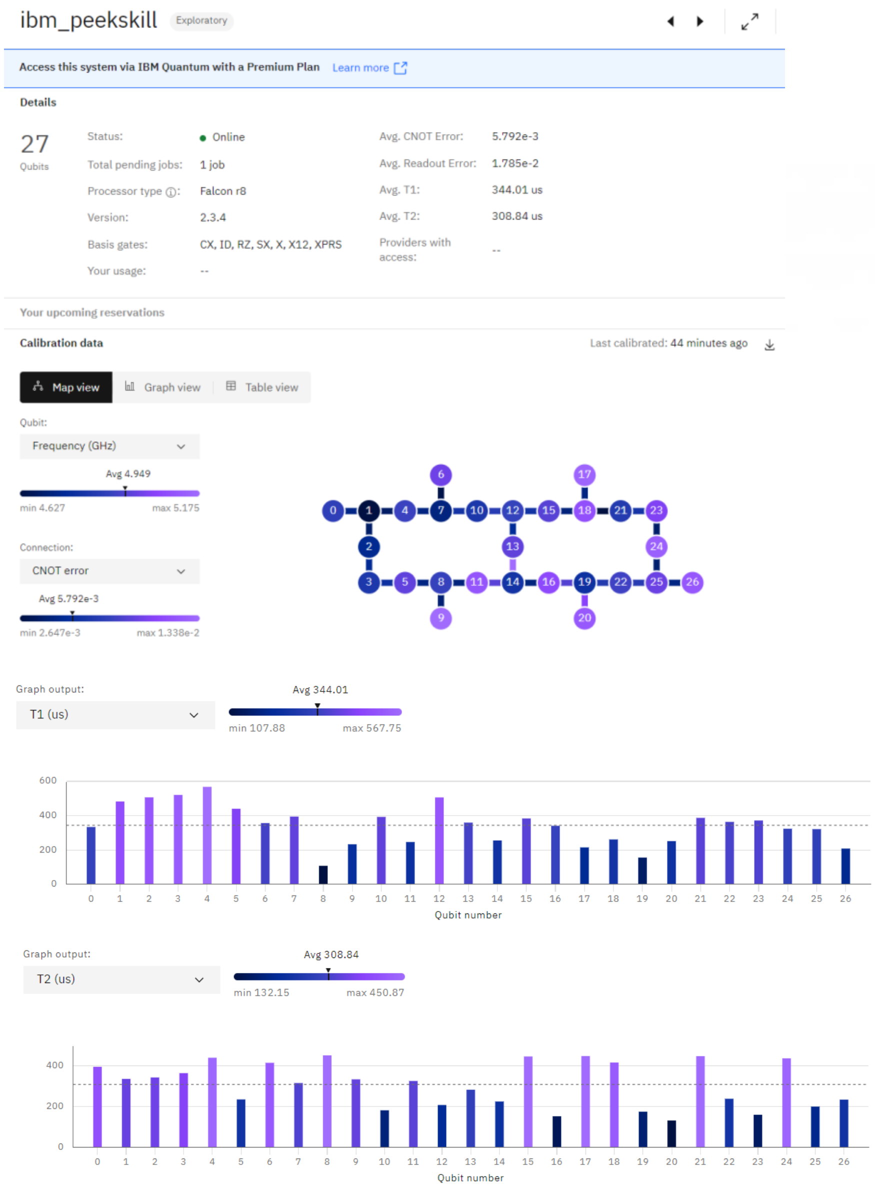


AN ELLERY QUEEN MYSTERY
THE EGYPTIAN CROSS MYSTERY
ELLERY QUEEN
POCKET BOOK EDITION COMPLETE AND UNABRIDGED

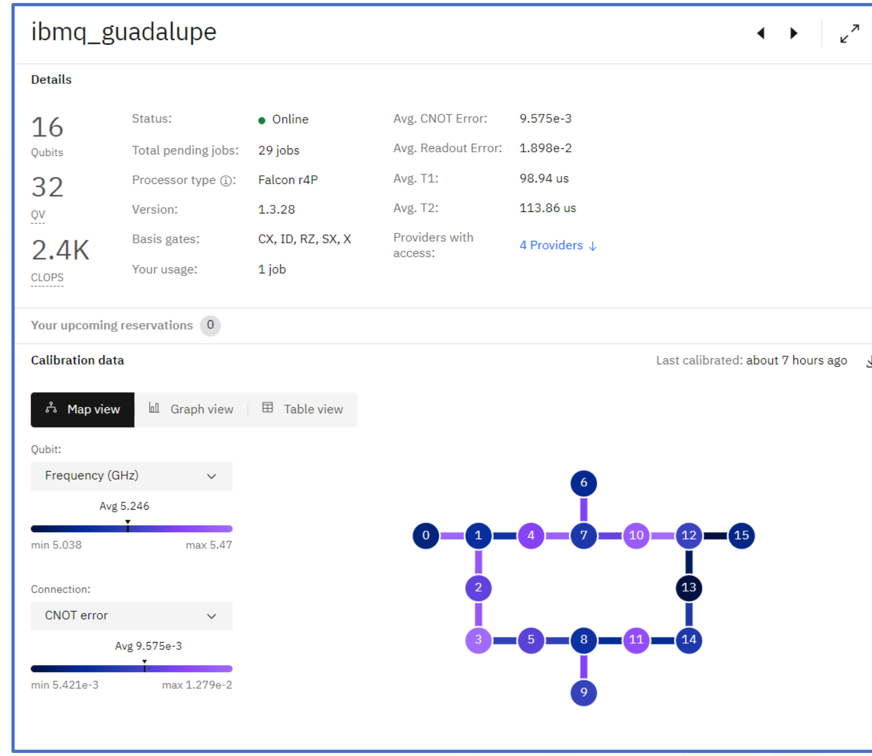


THE EGYPT
이집트 십자가의 비밀
MYSTERY
해문출판사

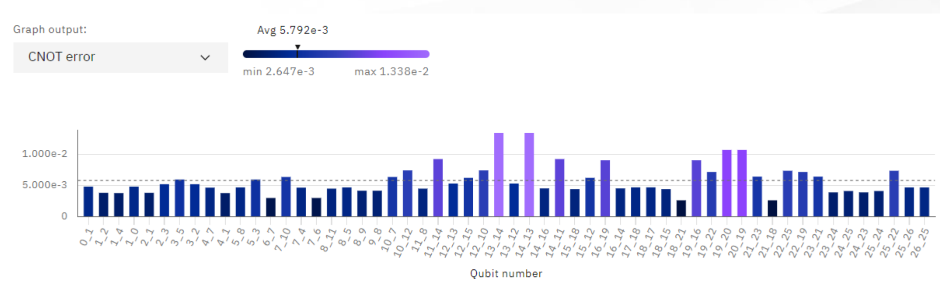
IBM Backend



ibm_peekskill
Exploratory
Access this system via IBM Quantum with a Premium Plan
Learn more
Details
27
Qubits
Status:
Online
Total pending jobs:
1 job
Processor type:
Falcon r8
Version:
2.3.4
Basis gates:
CX, ID, RZ, SX, X, X12, XPRS
Your usage:
--
Avg. CNOT Error:
5.792e-3
Avg. Readout Error:
1.785e-2
Avg. T1:
344.01 us
Avg. T2:
308.84 us
Providers with access:
--
Your upcoming reservations
Calibration data
Last calibrated: 44 minutes ago
Map view
Graph view
Table view
Qubit:
Frequency (GHz)
Avg 4.949
min 4.627
max 5.175
Connection:
CNOT error
Avg 5.792e-3
min 2.647e-3
max 1.338e-2
Graph output:
T1 (us)
Avg 344.01
min 107.88
max 567.75
Qubit number
Graph output:
T2 (us)
Avg 308.84
min 132.15
max 450.87
Qubit number

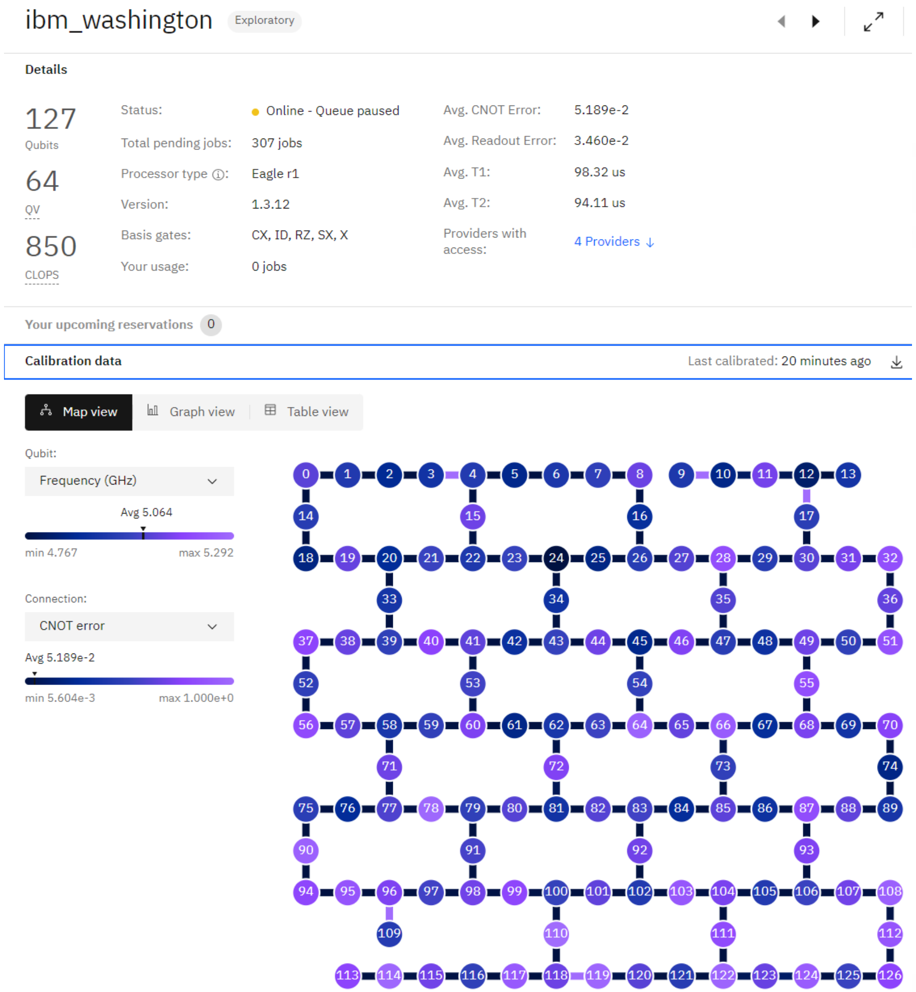


ibmq_guadalupe
Details
16
Qubits
32
QV
2.4K
CLOPS
Status:
Online
Total pending jobs:
29 jobs
Processor type:
Falcon r4P
Version:
1.3.28
Basis gates:
CX, ID, RZ, SX, X
Your usage:
1 job
Avg. CNOT Error:
9.575e-3
Avg. Readout Error:
1.898e-2
Avg. T1:
98.94 us
Avg. T2:
113.86 us
Providers with access:
4 Providers
Your upcoming reservations 0
Calibration data
Last calibrated: about 7 hours ago
Map view
Graph view
Table view
Qubit:
Frequency (GHz)
Avg 5.246
min 5.038
max 5.47
Connection:
CNOT error
Avg 9.575e-3
min 5.421e-3
max 1.279e-2

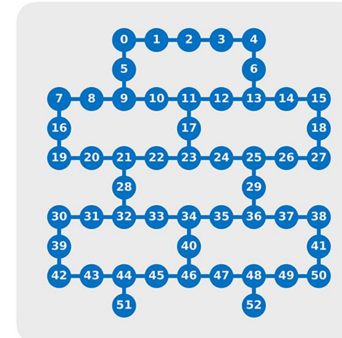


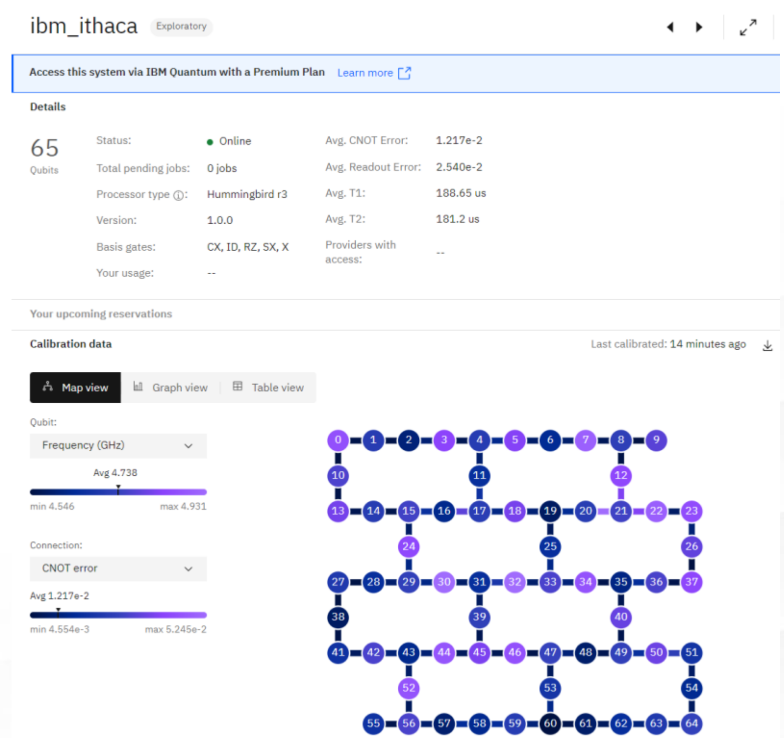
Graph output:
CNOT error
Avg 5.792e-3
min 2.647e-3
max 1.338e-2
1.000e-2
5.000e-3
0
Qubit number

IBM Backend

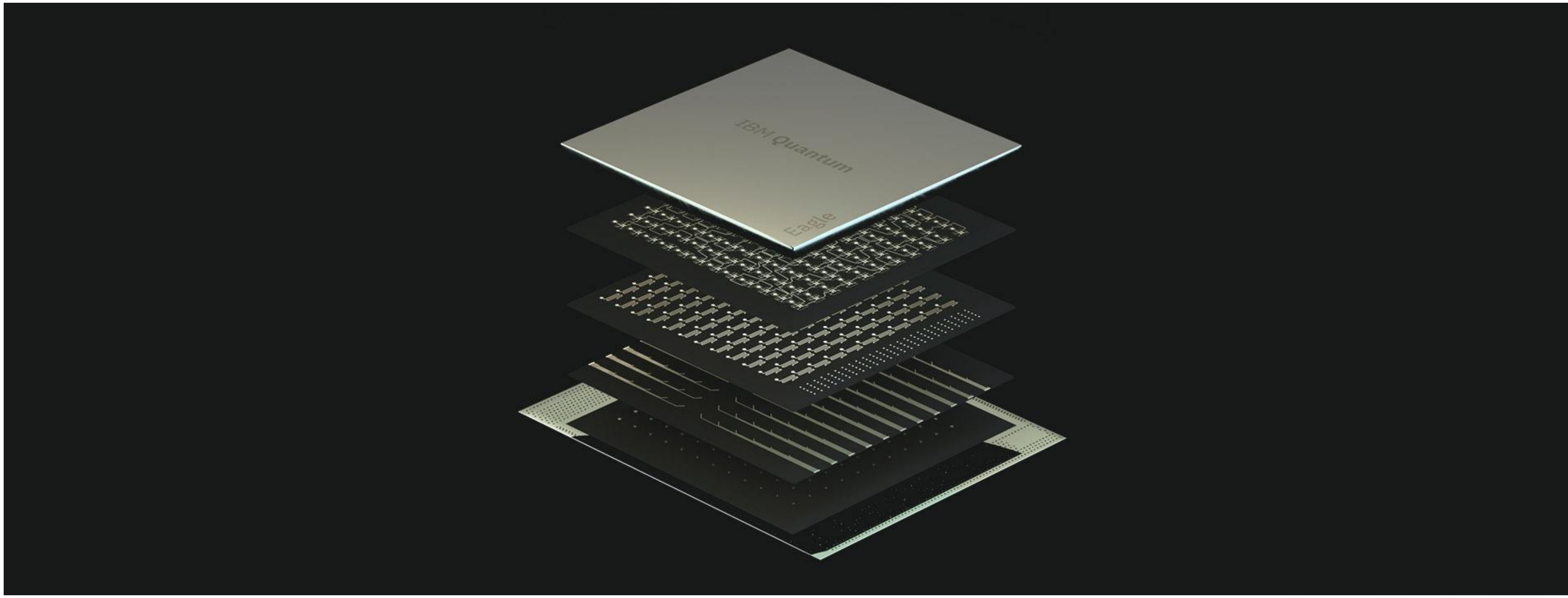


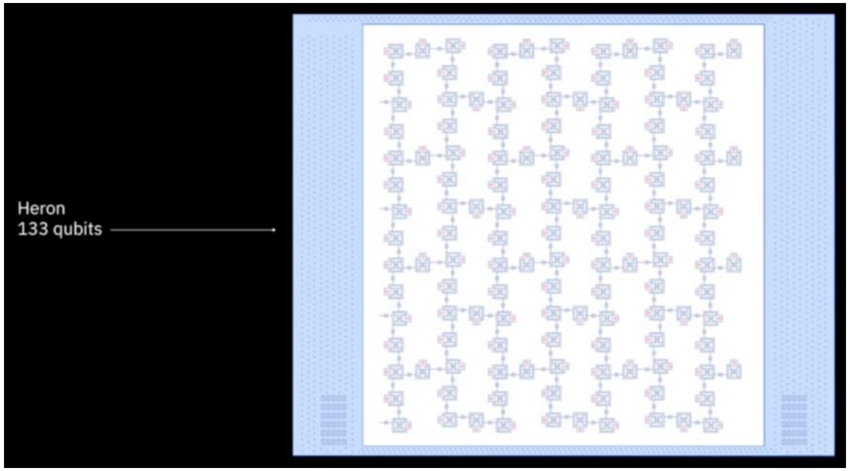
53 Qubit Rochester Device

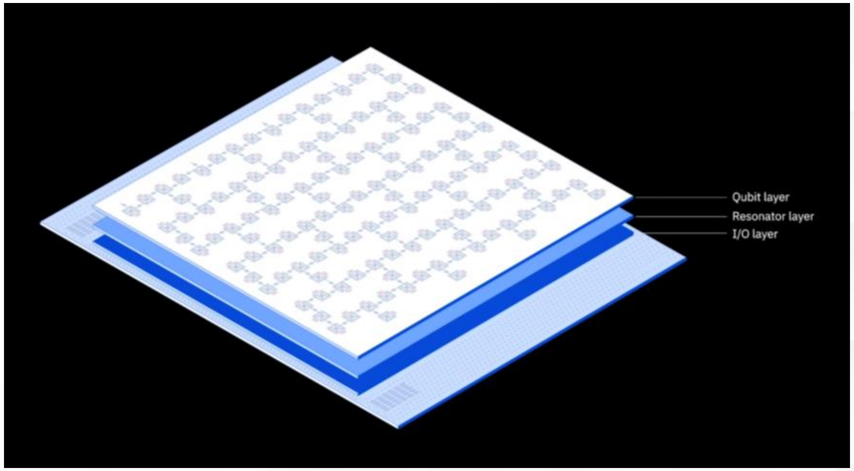




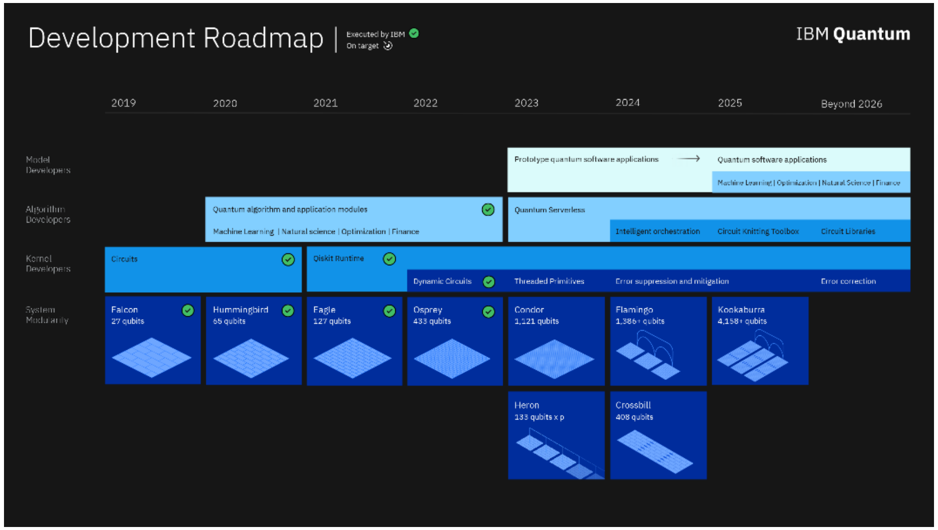
3D Stack Integration



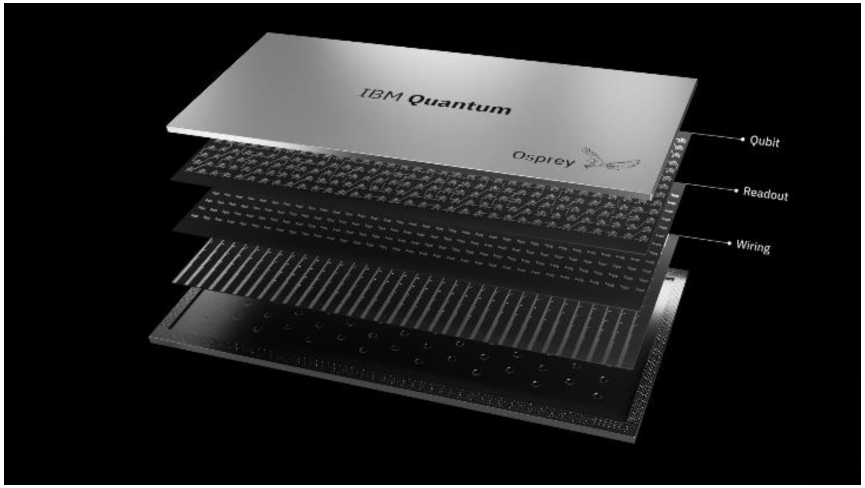




IBM

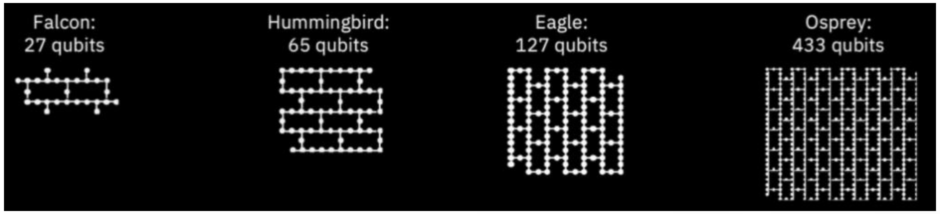


Development Roadmap
Executed by IBM
On target
IBM Quantum
2019
2020
2021
2022
2023
2024
2025
Beyond 2026
Model Developers
Algorithm Developers
Kernel Developers
System Modularity
Prototype quantum software applications
Quantum software applications
Machine Learning | Optimization | Natural Science | Finance
Quantum algorithm and application modules
Machine Learning | Natural science | Optimization | Finance
Quantum Serverless
Intelligent orchestration
Circuit Knitting Toolbox
Circuit Libraries
Circuits
Qiskit Runtime
Dynamic Circuits
Threaded Primitives
Error suppression and mitigation
Error correction
Falcon 27 qubits
Hummingbird 65 qubits
Eagle 127 qubits
Osprey 433 qubits
Condor 1,121 qubits
Flamingo 1,386+ qubits
Kookaburra 4,158+ qubits
Heron 133 qubits x p
Crossbill 408 qubits

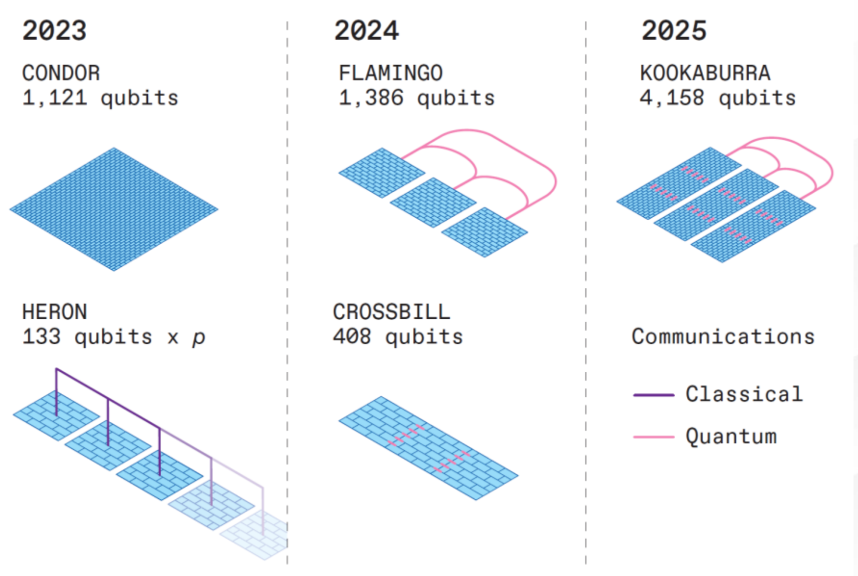


IBM Quantum
Osprey
Qubit
Readout
Wiring

2019
Falcon
27 Qubits
2020
Hummingbird
65 Qubits
2021
Eagle
127 Qubits
2022
Osprey
433 Qubits



Falcon:
27 qubits
Hummingbird:
65 qubits
Eagle:
127 qubits
Osprey:
433 qubits



2023
CONDOR
1,121 qubits
2024
FLAMINGO
1,386 qubits
2025
KOOKABURRA
4,158 qubits
HERON
133 qubits x p
CROSSBILL
408 qubits
Communications
Classical
Quantum

Error Mitigation

LETTER

https://doi.org/10.1038/s41586-019-1040-7

Error mitigation extends the computational reach of a noisy quantum processor

Abhinav Kandala[1]*, Kristan Temme[1], Antonio D. Córcoles[1], Antonio Mezzacapo[1], Jerry M. Chow[1] & Jay M. Gambetta[1]

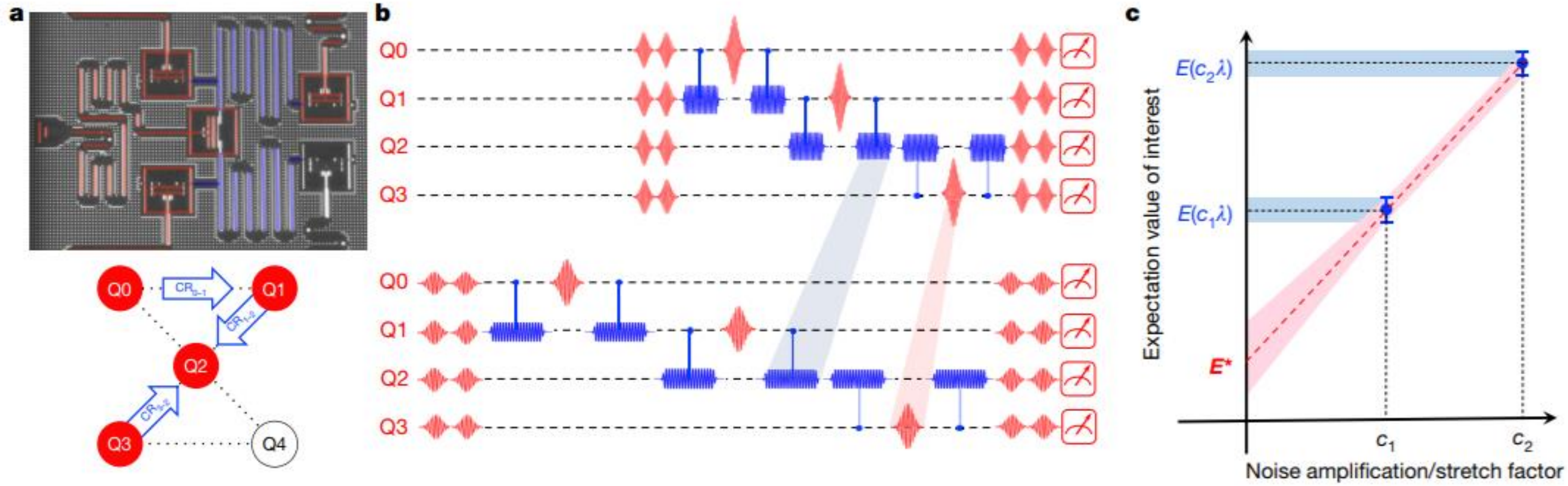
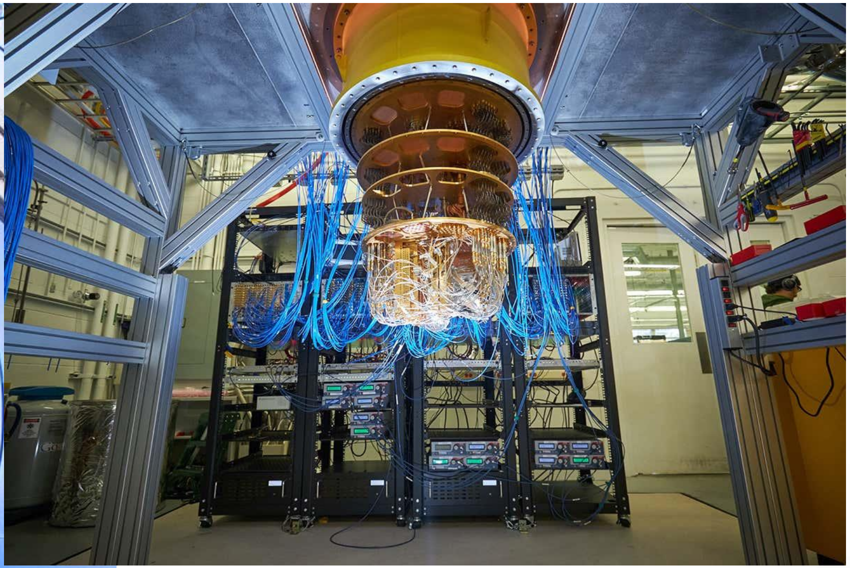
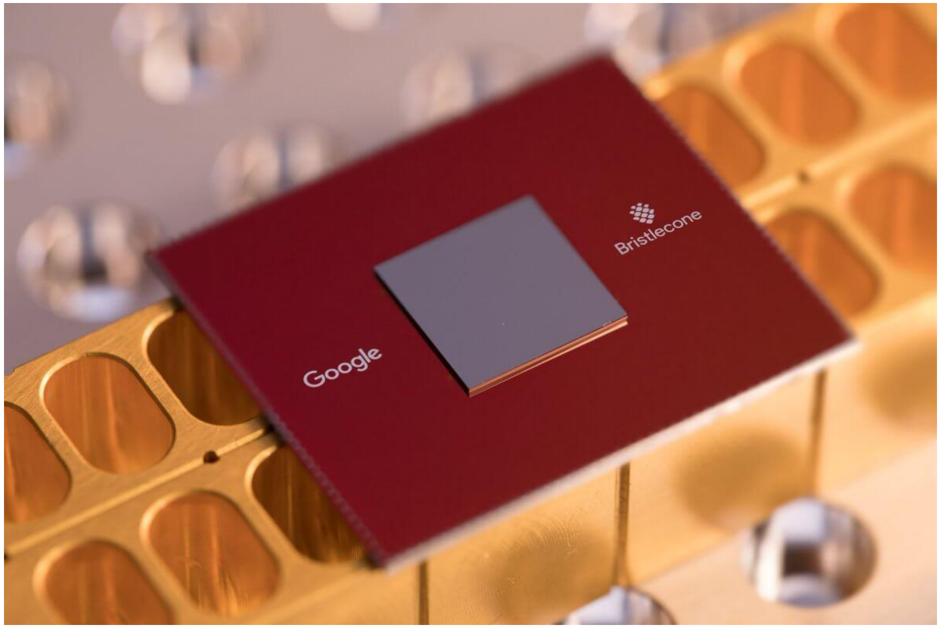


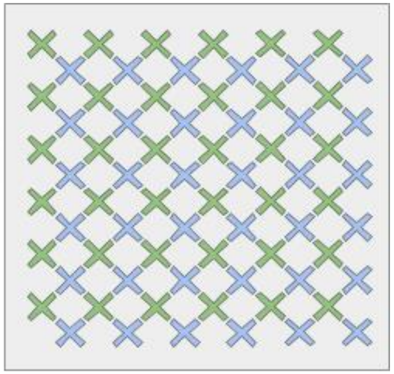
Fig. 1 | Device and experimental protocol. a, False-coloured optical micrograph (top) of the superconducting quantum processor and schematic (bottom) of the qubits (Q0, Q1, Q2, Q3) and gates ($CR_{0\text{-}1}$, $CR_{1\text{-}2}$, $CR_{3\text{-}2}$) used in the experiment. The device is composed of five transmon qubits, with the coupling provided by two superconducting co-planar waveguide resonators, in blue. **b**, A measurement of the expectation value after rescaled state preparation is equivalent to a measurement under an amplified noise strength, if the noise is time invariant. **c**, An illustration of the error mitigation method, shown here for a first-order Richardson extrapolation to the zero-noise limit, highlights that the variance of the mitigated estimate E^* is crucially dependent on the variance of the unmitigated measurements and the stretch factors c_i.

Google

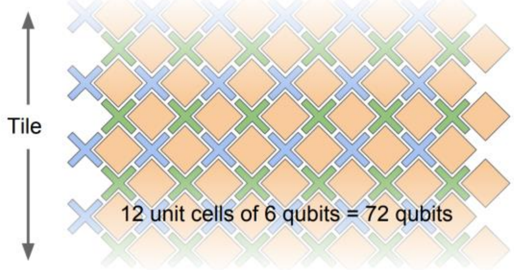


Google Bristlecone / Foxtail



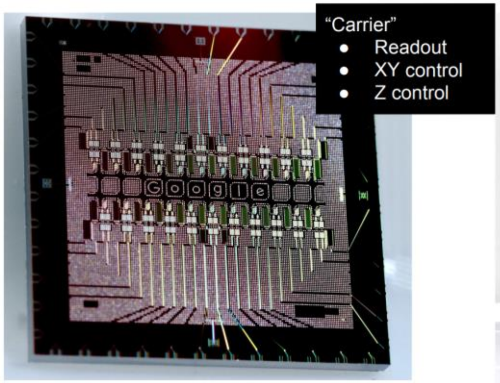


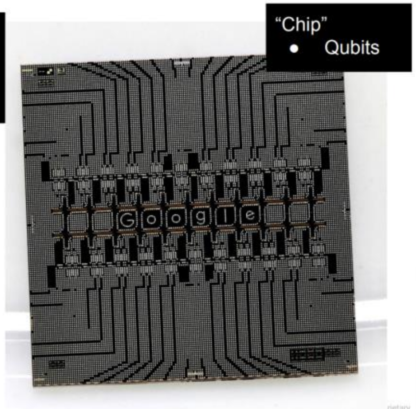
"Bristlecone" Architecture



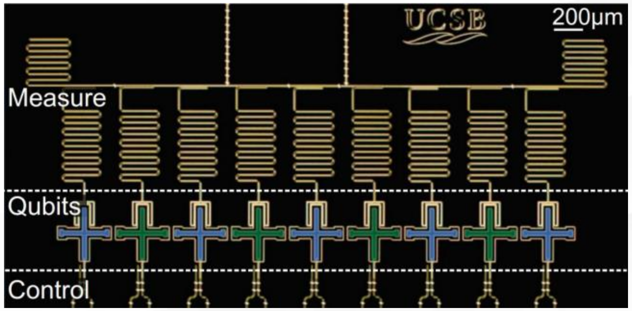
Bristlecone

"Foxtail" 22 Qubit Device





Google Cloud



Sycamore

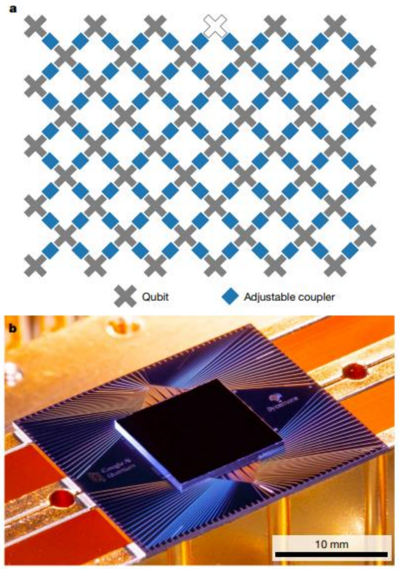


Fig. 1 | The Sycamore processor. a, Layout of processor, showing a rectangular array of 54 qubits (grey), each connected to its four nearest neighbours with couplers (blue). The inoperable qubit is outlined. **b**, Photograph of the Sycamore chip.

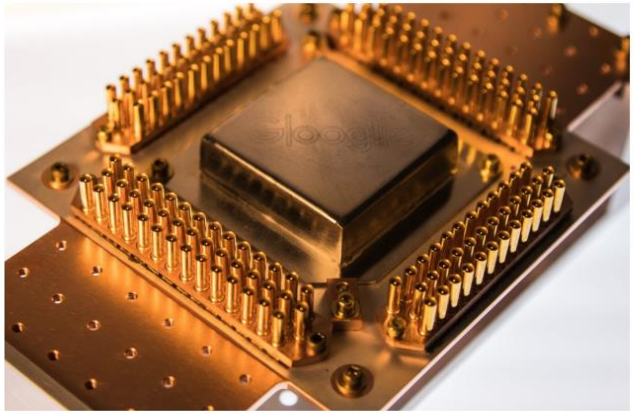
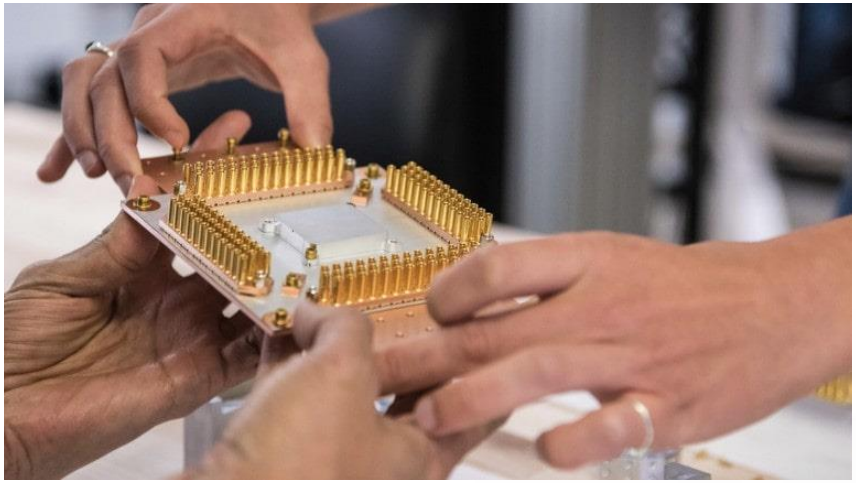


FIG. S1. **A photograph of a packaged Sycamore processor.** The processor is shielded from the electromagnetic environment by a mu-metal shield (middle) and a superconducting Aluminum cap, inside the mu-metal shield. The processor control wires are routed, through PCB circuit board, to coaxial connectors shown around the edge.

Our Sycamore quantum processor is configured as a diagonal array of qubits as seen in the schematic of Fig. 1 in the main text. The processor contains 142 transmon qubits, of which 54 qubits have individual microwave and frequency controls and are individually read out (referred to as qubits). The remaining 88 transmons are operated as adjustable couplers remaining in their ground state during the algorithms (referred to as couplers).

The qubits consist of a DC SQUID sandwiched between two metal islands, operating in the transmon



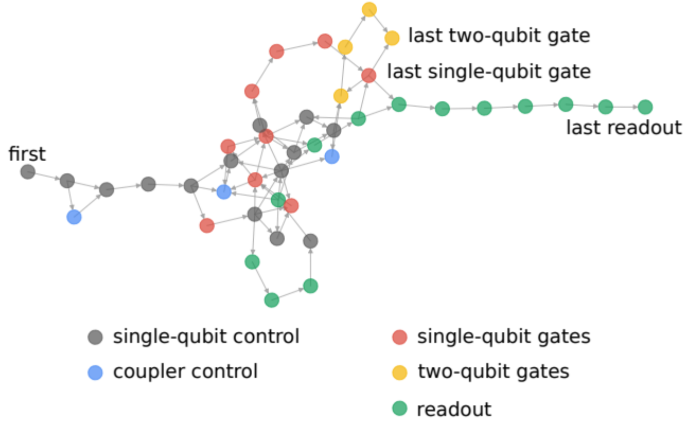


FIG. S10. **Optimus calibration graph for Sycamore.** Calibration of physical qubits is a bootstrapping procedure between different pulse sequences or "experiments" to extract control and system parameters. Initial experiments are coarse and have interplay between fundamental operations and elements such as single-qubit gates, readout, and the coupler. Final experiments involve precise metrology for each of the qubit operations: single-qubit gates, two-qubit gates, and readout.

Google Sycamore and Quantum Supremacy

단 하나의 문제에서라도 양자컴퓨터가 기존 컴퓨터를 능가할 수 있는가?

Article

Quantum supremacy using a programmable superconducting processor

https://doi.org/10.1038/s41586-019-1666-5
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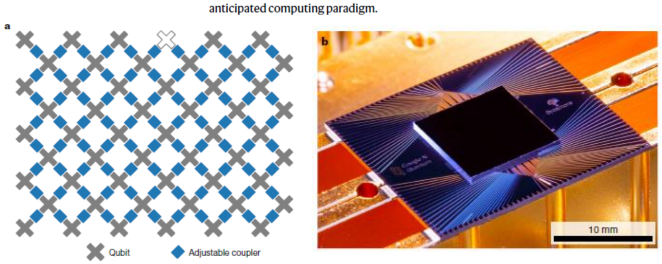
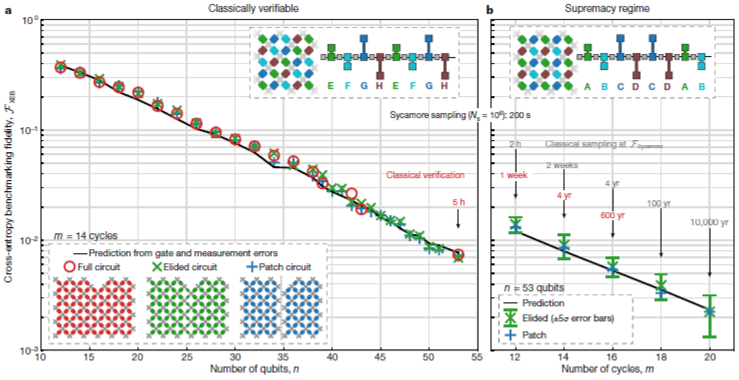
Published online: 23 October 2019

Frank Arute[1], Kunal Arya[1], Ryan Babbush[1], Dave Bacon[1], Joseph C. Bardin[1,2], Rami Barends[1], Rupak Biswas[3], Sergio Boixo[1], Fernando G. S. L. Brandao[1,4], David A. Buell[1], Brian Burkett[1], Yu Chen[1], Zijun Chen[1], Ben Chiaro[5], Roberto Collins[1], William Courtney[1], Andrew Dunsworth[1], Edward Farhi[1], Brooks Foxen[1,5], Austin Fowler[1], Craig Gidney[1], Marissa Giustina[1], Rob Graff[1], Keith Guerin[1], Steve Habegger[1], Matthew P. Harrigan[1], Michael J. Hartmann[1,6], Alan Ho[1], Markus Hoffmann[1], Trent Huang[1], Travis S. Humble[7], Sergei V. Isakov[1], Evan Jeffrey[1], Zhang Jiang[1], Dvir Kafri[1], Kostyantyn Kechedzhi[1], Julian Kelly[1], Paul V. Klimov[1], Sergey Knysh[1], Alexander Korotkov[1,8], Fedor Kostritsa[1], David Landhuis[1], Mike Lindmark[1], Erik Lucero[1], Dmitry Lyakh[9], Salvatore Mandrà[3,10], Jarrod R. McClean[1], Matthew McEwen[5], Anthony Megrant[1], Xiao Mi[1], Kristel Michielsen[11,12], Masoud Mohseni[1], Josh Mutus[1], Ofer Naaman[1], Matthew Neeley[1], Charles Neill[1], Murphy Yuezhen Niu[1], Eric Ostby[1], Andre Petukhov[1], John C. Platt[1], Chris Quintana[1], Eleanor G. Rieffel[3], Pedram Roushan[1], Nicholas C. Rubin[1], Daniel Sank[1], Kevin J. Satzinger[1], Vadim Smelyanskiy[1], Kevin J. Sung[1,13], Matthew D. Trevithick[1], Amit Vainsencher[1], Benjamin Villalonga[1,14], Theodore White[1], Z. Jamie Yao[1], Ping Yeh[1], Adam Zalcman[1], Hartmut Neven[1] & John M. Martinis[1,5]*

The promise of quantum computers is that certain computational tasks might be executed exponentially faster on a quantum processor than on a classical processor[1]. A fundamental challenge is to build a high-fidelity processor capable of running quantum algorithms in an exponentially large computational space. Here we report the use of a processor with programmable superconducting qubits[2–7] to create quantum states on 53 qubits, corresponding to a computational state-space of dimension 2^{53} (about 10^{16}). Measurements from repeated experiments sample the resulting probability distribution, which we verify using classical simulations. Our Sycamore processor takes about 200 seconds to sample one instance of a quantum circuit a million times—our benchmarks currently indicate that the equivalent task for a state-of-the-art classical supercomputer would take approximately 10,000 years. This dramatic increase in speed compared to all known classical algorithms is an experimental realization of quantum supremacy[8–14] for this specific computational task, heralding a much-anticipated computing paradigm.



Google은 초전도 양자컴퓨터를 이용하여 기존 슈퍼컴퓨터가 하기 어려운 계산을 훨씬 빨리 할 수 있음을 시연함



Quantum Advantage from Hefei

Strong quantum computational advantage using a superconducting quantum processor

Yulin Wu,[1,2,3] Wan-Su Bao,[4] Sirui Cao,[1,2,3] Fusheng Chen,[1,2,3] Ming-Cheng Chen,[1,2,3] Xiawei Chen,[2] Tung-Hsun Chung,[1,2,3] Hui Deng,[1,2,3] Yajie Du,[2] Daojin Fan,[1,2,3] Ming Gong,[1,2,3] Cheng Guo,[1,2,3] Chu Guo,[1,2,3] Shaojun Guo,[1,2,3] Lianchen Han,[1,2,3] Linyin Hong,[5] He-Liang Huang,[1,2,3,4] Yong-Heng Huo,[1,2,3] Liping Li,[2] Na Li,[1,2,3] Shaowei Li,[1,2,3] Yuan Li,[1,2,3] Futian Liang,[1,2,3] Chun Lin,[6] Jin Lin,[1,2,3] Haoran Qian,[1,2,3] Dan Qiao,[2] Hao Rong,[1,2,3] Hong Su,[1,2,3] Lihua Sun,[1,2,3] Liangyuan Wang,[2] Shiyu Wang,[1,2,3] Dachao Wu,[1,2,3] Yu Xu,[1,2,3] Kai Yan,[2] Weifeng Yang,[5] Yang Yang,[2] Yangsen Ye,[1,2,3] Jianghan Yin,[2] Chong Ying,[1,2,3] Jiale Yu,[1,2,3] Chen Zha,[1,2,3] Cha Zhang,[1,2,3] Haibin Zhang,[2] Kaili Zhang,[1,2,3] Yiming Zhang,[1,2,3] Han Zhao,[2] Youwei Zhao,[1,2,3] Liang Zhou,[5] Qingling Zhu,[1,2,3] Chao-Yang Lu,[1,2,3] Cheng-Zhi Peng,[1,2,3] Xiaobo Zhu,[1,2,3] and Jian-Wei Pan[1,2,3]

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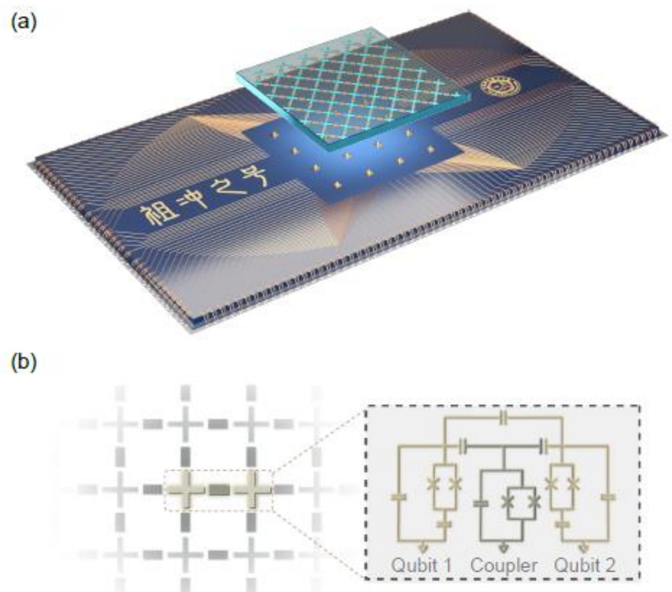
[2]*Shanghai Branch, CAS Center for Excellence in Quantum Information and Quantum Physics, University of Science and Technology of China, Shanghai 201315, China*
[3]*Shanghai Research Center for Quantum Sciences, Shanghai 201315, China*
[4]*Henan Key Laboratory of Quantum Information and Cryptography, Zhengzhou 450000, China*
[5]*QuantumCTek Co., Ltd., Hefei 230026, China*
[6]*Shanghai Institute of Technical Physics, Chinese Academy of Sciences, Shanghai 200083, China*

(Dated: June 29, 2021)



ArXiv:2106.14734

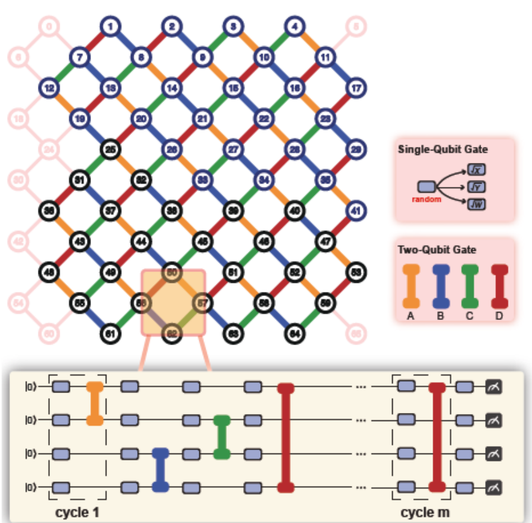
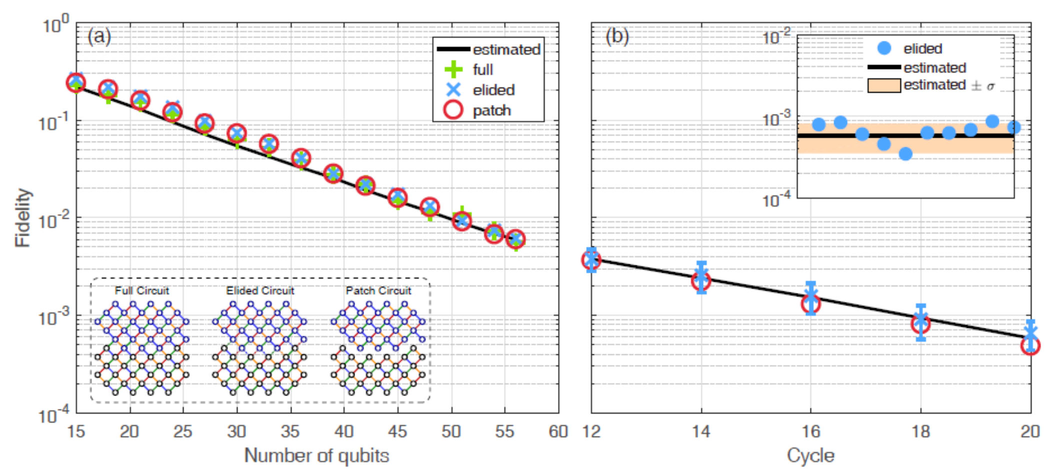


FIG. 3. **56-qubit random quantum circuit operations.** The cir-



QEC on Sycamore

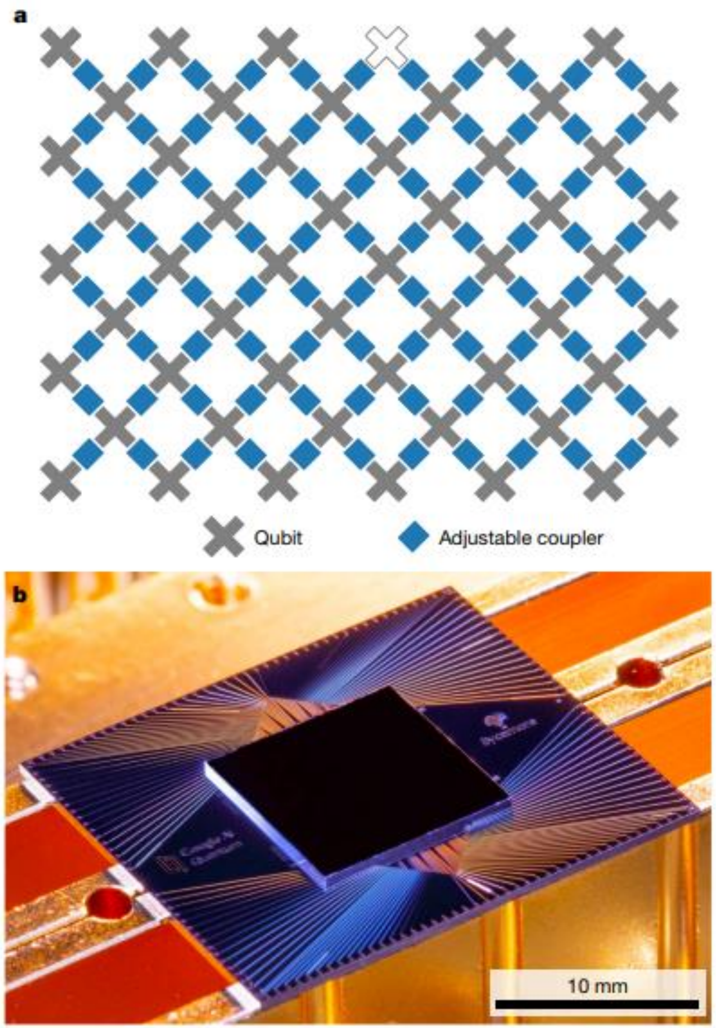
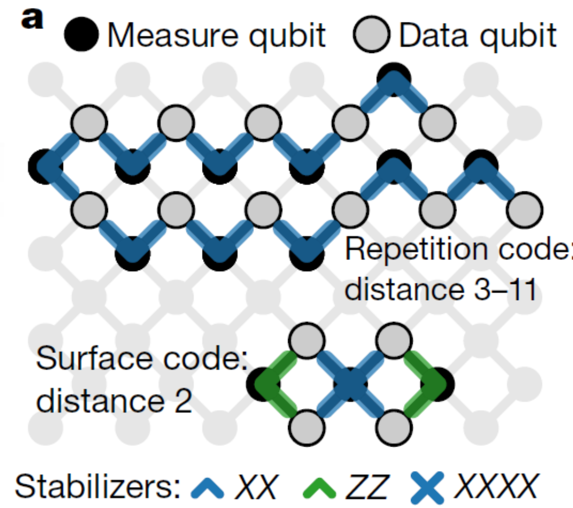
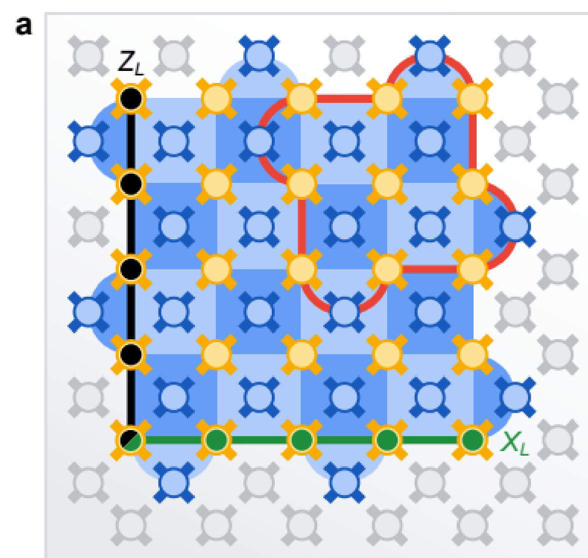


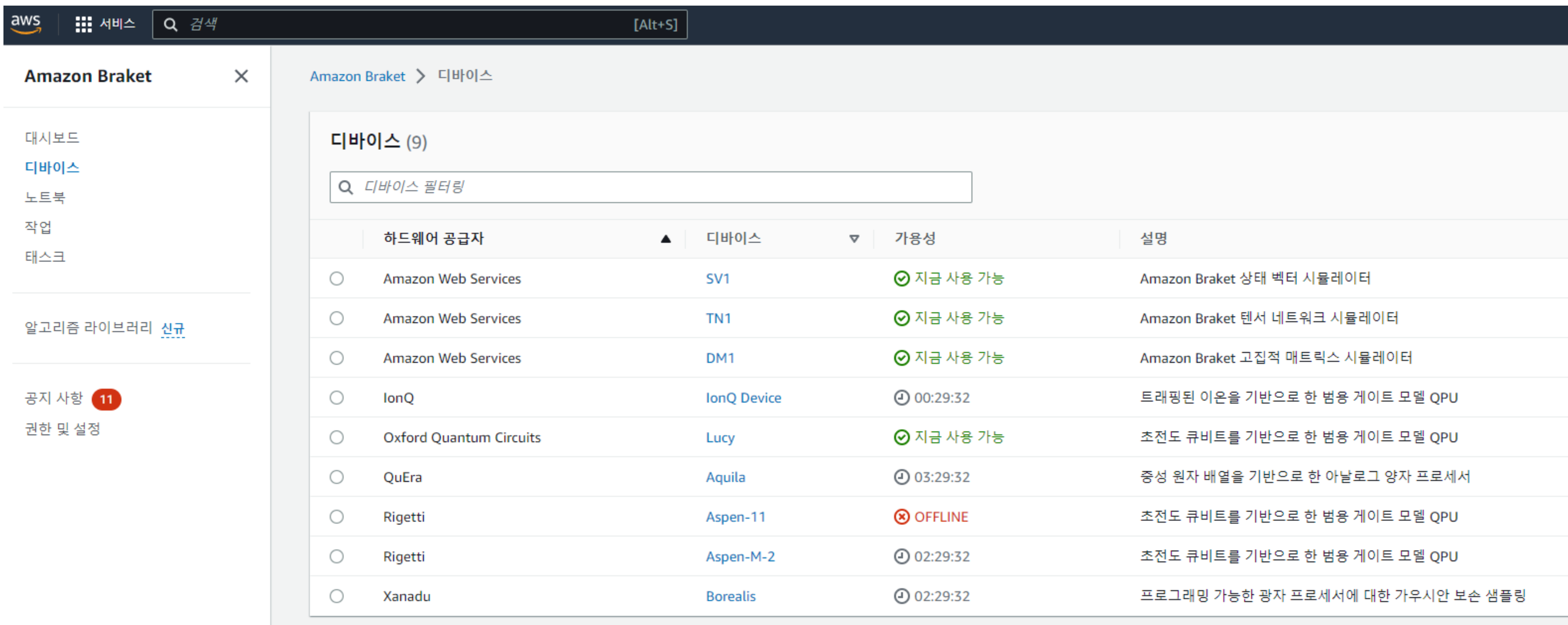
Fig. 1 | The Sycamore processor. a, Layout of processor, showing a rectangular array of 54 qubits (grey), each connected to its four nearest neighbours with couplers (blue). The inoperable qubit is outlined. **b**, Photograph of the Sycamore chip.





Amazon : AWS Braket

Amazon Braket



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Amazon Web Services	TN1	지금 사용 가능	Amazon Braket 텐서 네트워크 시뮬레이터
Amazon Web Services	DM1	지금 사용 가능	Amazon Braket 고집적 매트릭스 시뮬레이터
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Oxford Quantum Circuits	Lucy	지금 사용 가능	초전도 큐비트를 기반으로 한 범용 게이트 모델 QPU
QuEra	Aquila	03:29:32	중성 원자 배열을 기반으로 한 아날로그 양자 프로세서
Rigetti	Aspen-11	OFFLINE	초전도 큐비트를 기반으로 한 범용 게이트 모델 QPU
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Xanadu	Borealis	02:29:32	프로그래밍 가능한 광자 프로세서에 대한 가우시안 보손 샘플링

Amazon : AWS Braket

aws 서비스 검색 [Alt+S]

Amazon Braket > 디바이스

디바이스 (17)

디바이스 필터링

하드웨어 공급자	디바이스	가용성	설명
Amazon Web Services	SV1	지금 사용 가능	Amazon Braket 상태 벡터 시뮬레이터
Amazon Web Services	TN1	지금 사용 가능	Amazon Braket 텐서 네트워크 시뮬레이터
Amazon Web Services	DM1	지금 사용 가능	Amazon Braket 고집적 매트릭스 시뮬레이터
D-Wave	Advantage_system6.1	RETIRED	초전도 큐비트를 기반으로 한 양자 어닐러
D-Wave	Advantage_system4.1	RETIRED	초전도 큐비트를 기반으로 한 양자 어닐러
D-Wave	Advantage_system1.1	RETIRED	초전도 큐비트를 기반으로 한 양자 어닐러
D-Wave	DW_2000Q_6	RETIRED	초전도 큐비트를 기반으로 한 양자 어닐러
IonQ	IonQ Device	00:28:07	트래핑된 이온을 기반으로 한 범용 게이트 모델 QPU
Oxford Quantum Circuits	Lucy	지금 사용 가능	초전도 큐비트를 기반으로 한 범용 게이트 모델 QPU
QuEra	Aquila	03:28:07	중성 원자 배열을 기반으로 한 아날로그 양자 프로세서
Rigetti	Aspen-8	RETIRED	초전도 큐비트를 기반으로 한 범용 게이트 모델 QPU
Rigetti	Aspen-9	RETIRED	초전도 큐비트를 기반으로 한 범용 게이트 모델 QPU
Rigetti	Aspen-10	RETIRED	초전도 큐비트를 기반으로 한 범용 게이트 모델 QPU
Rigetti	Aspen-11	OFFLINE	초전도 큐비트를 기반으로 한 범용 게이트 모델 QPU
Rigetti	Aspen-M-1	RETIRED	초전도 큐비트를 기반으로 한 범용 게이트 모델 QPU
Rigetti	Aspen-M-2	02:28:07	초전도 큐비트를 기반으로 한 범용 게이트 모델 QPU
Xanadu	Borealis	02:28:07	프로그래밍 가능한 광자 프로세서에 대한 가우시안 보손 샘플링

Amazon : AWS Braket

D-Wave Systems — Advantage_system6.1

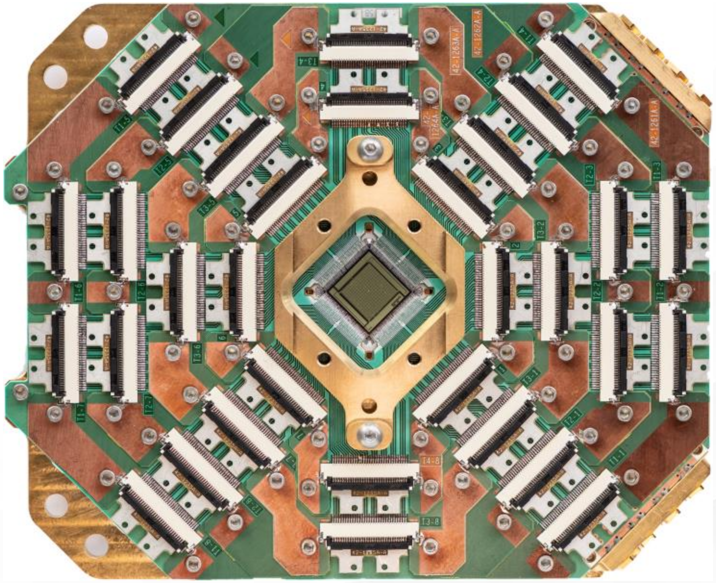
초전도 큐비트를 기반으로 한 양자 어닐러

D-Wave의 접근 방식은 양자의 상태가 자연 진화하는 현상을 활용한 양자 어닐링입니다. 각 D-Wave QPU는 작은 금속 루프의 격자로, 큐피트이거나 커플러입니다. 9.2k(켈빈)의 온도 이하에서는 이 루프가 초전도체가 되고 더 낮은 온도에서는 양자 역학적인 효과를 보이게 됩니다. Advantage6.1 양자 컴퓨터는 5,616개 이상의 큐비트와 4만 개 이상의 커플러로 이루어져 있습니다. 이 규모에 도달하기 위해 약 100만 개의 조지프슨 접합을 사용하기 때문에, Advantage QPU는 지금까지 만들어진 가장 복잡한 초전도 집적 회로 중 하나입니다. D-Wave Advantage4 시스템보다 2.5배 더 많은 연결 구조로 이루어진 Advantage QPU는 더 적은 물리적 큐비트로 더 큰 문제를 임베딩할 수 있습니다. QPU 아키텍처는 QUBO 또는 Ising 목적 함수를 D-Wave 시스템이 해결할 수 있는 형식으로 변환하는 데 있어서 매우 중요합니다. 이 이진 목적 함수는 그래프로 표현할 수 있으며, 그러한 그래프는 다시 QPU에 매핑할 수 있습니다. 이 아키텍처는 각 큐비트가 12개의 반대로 정렬된 큐비트와 3개의 비슷하게 정렬된 큐비트와 결합되는 반복 구조를 이룹니다. 기본 단위 셀에는 이러한 큐비트가 24개 있으며, 각 큐비트는 셀 내의 비슷하게 정렬된 큐비트 하나와 인접 셀의 비슷하게 정렬된 큐비트 2개와 결합됩니다. Advantage QPU는 16x16 그래프로 나타내는 2000Q 타일의 격자입니다. 글로벌 구조는 대각 배열 K_{4,4} 이분 클리크 시스템으로 볼 수 있으며, 대각 내부와 대각 사이의 반대로 정렬된 큐비트 사이에 커플러가 있는 구조입니다.

D:wave The Quantum Computing Company™

이 디바이스에 대해 자세히 알아보기

하드웨어 공급자 D-Wave	리전 us-west-2	위치 California, USA
가용성 Everyday, 00:00:00 - 23:59:59 UTC	다음 사용 가능 사용할 수 없음	비용 $0.30 / task + $0.00019 / shot
디바이스 ARN arn:aws:braket:us-west-2::device/qpu/d-wave/Advantage_system6	상태 RETIRED	큐비트 5760
펄스 제어 지원되지 않음		



Amazon : AWS Braket

D-Wave Systems — Advantage_system6.1

초전도 큐비트를 기반으로 한 양자 어닐러

D-Wave의 접근 방식은 양자의 상태가 자연 진화하는 현상을 활용한 양자 어닐링입니다. 각 D-Wave QPU는 작은
역학적인 효과를 보이게 됩니다. Advantage6.1 양자 컴퓨터는 5,616개 이상의 큐비트와 4만 개 이상의 커플러로
가장 복잡한 초전도 집적 회로 중 하나입니다. D-Wave Advantage4 시스템보다 2.5배 더 많은 연결 구조로 이루어
D-Wave 시스템이 해결할 수 있는 형식으로 변환하는 데 있어서 매우 중요합니다. 이 이진 목적 함수는 그래프로
합되는 반복 구조를 이룹니다. 기본 단위 셀에는 이러한 큐비트가 24개 있으며, 각 큐비트는 셀 내의 비슷하게 정
각 배열 K_{4,4} 이분 클리크 시스템으로 볼 수 있으며, 대각 내부와 대각 사이의 반대로 정렬된 큐비트 사이에 커

이 디바이스에 대해 자세히 알아보기

하드웨어 공급자
D-Wave

리전
us-west-2

가용성
Everyday, 00:00:00 - 23:59:59 UTC

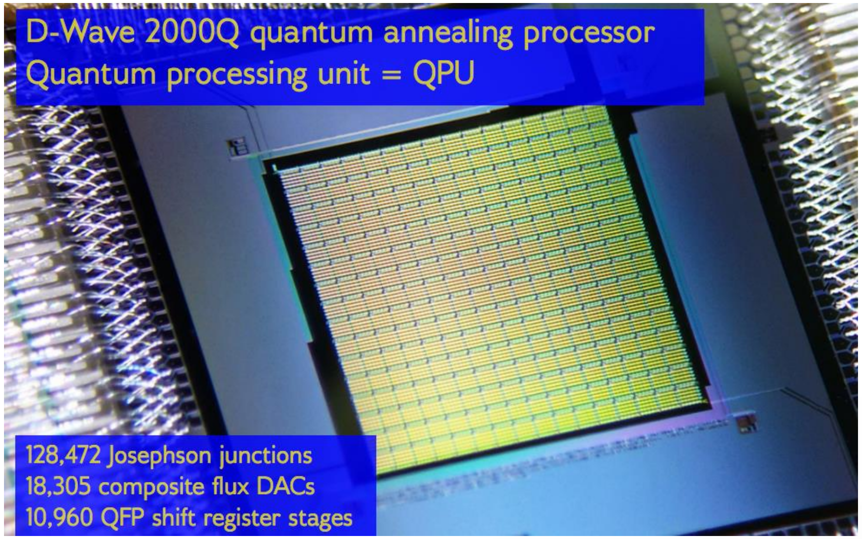
다음 사용 가능
사용할 수 없음

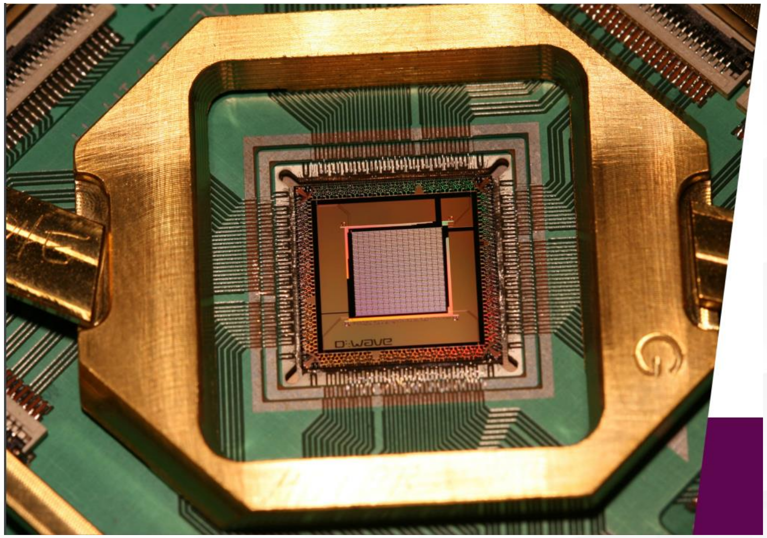
디바이스 ARN
arn:aws:braket:us-west-2::device/qpu/d-wave/Advantage_system6

상태
RETIRED

펄스 제어
지원되지 않음

	2000Q	Advantage	Advantage *performance update*
Performance			
Better Solutions (Satisfiability problems)	--	3x more often than 2000Q	23x more often than 2000Q
Time-To-Solution (3D lattice problems)	--	10x faster than 2000Q	2x faster than Advantage
Annealing Quantum Processor Design			
Qubits	2000+	5000+	5000+
Couplers	6000+	35000+	35000+
Couplers Per Qubit	6	15	15
Topology			
Graph	Chimera	Pegasus	Pegasus
Graph Size	C16	P16	P16
Connectivity	Degree 6	Degree 15	Degree 15
Lattice	8x8x8	15x15x12	15x15x12
Chain Length (for problem size n=64)	17	7	6





Amazon : AWS Braket

Rigetti — Aspen-11

초전도 큐비트를 기반으로 한 범용 게이트 모델 QPU

Rigetti 양자 프로세서는 튜닝 가능한 초전도 큐비트를 기반으로 하는 범용 게이트 모델 머신입니다. Rigetti의 최신 Aspen 칩들은 확장 가능한 40 큐비트 노드를 기반으로 하며, 깊이와 넓이에 관계없이 전반적인 회로 충실도를 높이는 향상된 판독 기능을 갖추고 있습니다. 추가적인 개선점으로는 양자 프로세스의 빠른 처리 시간, 각종 얽힘 게이트의 빠른 적용, 액티브 레지스터 재설정을 통한 빠른 샘플링, 그리고 파라메트릭 제어 기능을 들 수 있습니다. Aspen 칩 토폴로지는 큐비트를 3중(가장자리에서는 2중)으로 연결한 8각형 구조이며, 개발자가 성능 향상을 위해 프로그램을 최적화하고 회로 깊이를 최소화할 수 있도록 CPHASE 및 XY 연결 게이트를 모두 지원하고 있습니다. Rigetti의 최적화 컴파일러 quil-c는 추상적인 양자 알고리즘을 Rigetti QPU에서 동작하는 네이티브 게이트들로 재구성하고 최적화된 회로 구현을 생성합니다. 이 게이트들은 약 20µs의 큐비트 결맞음 시간 내에 프로그램을 구동할 수 있도록 빠른 1Q 및 2Q 실행 시간(각각 40ns 및 180ns)을 제공합니다. 초전도 큐비트로 구동되는 범용 게이트 기반 양자 컴퓨터는 화학 시뮬레이션, 조합 최적화, 기계 학습 분야의 문제를 탐구할 수 있도록 사용자에게 미세 제어 기능과 효율적인 변분 피드백 루프를 제공합니다.

이 디바이스에 대해 자세히 알아보기

하드웨어 공급자
Rigetti

리전
us-west-1

위치
California, USA

가용성
Everyday, 15:00:00 - 20:00:00 UTC

다음 사용 가능
사용할 수 없음

비용
$0.30 / task + $0.00035 / shot

디바이스 ARN
arn:aws:braket:::device/qpu/rigetti/Aspen-11

상태
OFFLINE

큐비트
38

펄스 제어
지원되지 않음

토폴로지

Rigetti — Aspen-M-2

초전도 큐비트를 기반으로 한 범용 게이트 모델 QPU

Rigetti 양자 프로세서는 튜닝 가능한 초전도 큐비트를 기반으로 하는 범용 게이트 모델 머신입니다. Rigetti의 최신 Aspen-M 프로세서는 확장 가능한 다중 칩 기술을 기반으로 하며, 깊이와 넓이에 관계없이 전반적인 회로 충실도를 높이는 향상된 판독 기능을 갖추고 있습니다. Aspen M 시스템은 빠른 처리 시간, 각종 얽힘 게이트의 빠른 적용, 액티브 레지스터 재설정을 통한 빠른 샘플링, 그리고 파라메트릭 제어 기능을 포함합니다. Aspen 칩 토폴로지는 큐비트를 3중(가장자리에서는 2중)으로 연결한 8각형 구조이며, 개발자가 성능 향상을 위해 프로그램을 최적화하고 회로 깊이를 최소화할 수 있도록 CPHASE 및 XY 연결 게이트를 모두 지원하고 있습니다. Rigetti의 최적화 컴파일러 quil-c는 추상적인 양자 알고리즘을 Rigetti QPU에서 동작하는 네이티브 게이트들로 재구성하고 최적화된 회로 구현을 생성합니다. 이 게이트들은 큐비트 결맞음 시간(T1은 28µs, T2는 22µs) 내에 프로그램을 구동할 수 있도록 빠른 1Q 및 2Q 실행 시간(각각 40ns 및 220ns)을 제공합니다.

이 디바이스에 대해 자세히 알아보기

하드웨어 공급자
Rigetti

리전
us-west-1

위치
California, USA

가용성
- Everyday, 04:00:00 - 06:00:00 UTC
- Everyday, 15:00:00 - 18:00:00 UTC

다음 사용 가능
02:25:29

비용
$0.30 / task + $0.00035 / shot

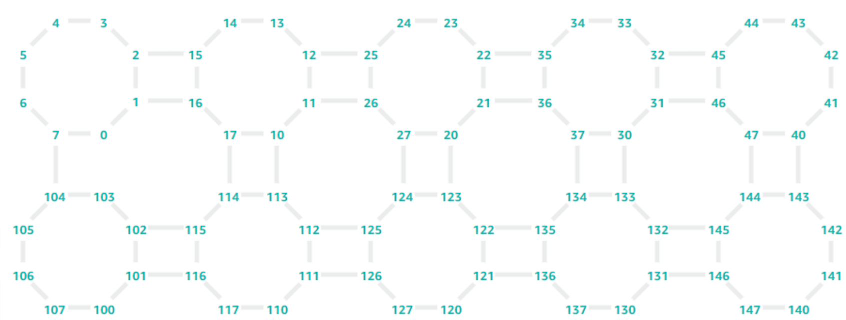
상태
ONLINE

큐비트
80

디바이스 ARN
arn:aws:braket:us-west-1::device/qpu/rigetti/Aspen-M-2

펄스 제어
지원됨

토폴로지



Amazon : AWS Braket

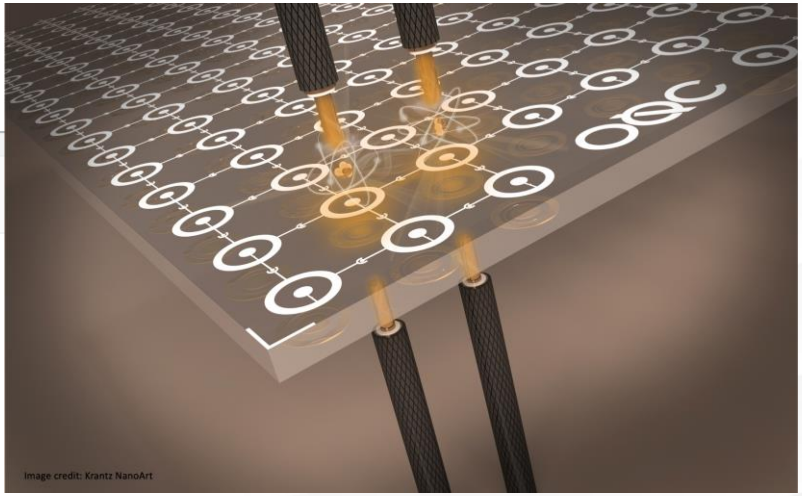
Oxford — Lucy

조전도 큐비트를 기반으로 한 범용 게이트 모델 QPU

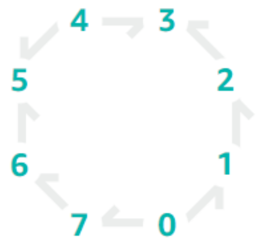
Oxford 양자 회로(OQC) 양자 컴퓨터는 독자적인 'Coaxmon' 기술을 사용하여 구축된 조전도 큐비트를 기반으로 한 범용 게이트 기반 머신입니다. Coaxmon 설계는 큐비트 평면에 수직으로 큐비트 제어 전자를 조사하는 확장 가능한 3차원 아키텍처를 사용합니다. 이 아키텍처가 단순화되면서 기존 2D 회로보다 더 많은 수의 큐비트로 손쉽게 확장할 수 있게 되었습니다. OQC 최초의 양자 컴퓨인로 Braket에서 이용 가능한 Lucy는 각 큐비트가 가장 인접한 2개의 큐비트에 연결된 링의 토폴로지를 포함하는 8큐비트 QPU를 제공합니다. 기본 컴파일러는 추상 양자 알고리즘을 프로세서에서 지원하는 기본 물리적 연결에 매핑합니다. 그러면 제어 하드웨어가 QPU에서 가장 적합한 큐비트 체인을 구동하는 최적화된 마이크로파 펄스를 생성하여 최대한 빠른 프로그램 실행 시간을 보장합니다. 이 프로세서는 1큐비트 게이트뿐만 아니라 최대 50μs의 큐비트 가간섭성 시간으로 2큐비트 RZX(pi/2) 게이트도 지원합니다.

이 디바이스에 대해 자세히 알아보기

하드웨어 공급자 Oxford Quantum Circuits	리전 eu-west-2	위치 Reading, United Kingdom
가용성 Weekdays, 10:00:00 - 13:00:00 UTC	다음 사용 가능 지금 사용 가능	비용 $0.30 / task + $0.00035 / shot
디바이스 ARN arn:aws:braket:eu-west-2::device/qpu/oqc/Lucy	상태 ONLINE	큐비트 8
펄스 제어 지원됨		



토폴로지



2 큐비트 게이트는 단방향입니다. 축어적 컴파일을 사용하려면 the verbatim compilation example notebook 을(를) 참조하세요.

국가별 양자컴퓨터 개발

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IBM to build Europe's first quantum computer in Germany

Researchers keen to use the technology without sending data to the US

The Q System One computer will be operational at a site near Stuttgart from early next year © IBM

Joe Miller in Frankfurt MARCH 13 2020

Bloomberg

Technology

Israel Allocates $60 Million to Build First Quantum Computer

By Yaacov Benmeleh

2021년 3월 3일 오후 9:07 GMT+9

TABOR NETWORK: DATANAMI ENTERPRISEAI HPCWIRE JAPAN HPC & AI WALL STREET

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GeQCoS Project to Develop German Quantum Computer Based on Superconducting Qubits

February 1, 2021

JÜLICH, Germany, Feb. 1 2021 — Building a quantum processor with novel properties based on superconducting qubits – this is the aim of the four year project GeQCoS ('German Quantum Computer based on Superconducting Qubits') funded by the German Federal Ministry of Education and Research (BMBF).

JÜLICH Forschungszentrum

In this joint project, Germany's leading scientists in the field of superconducting quantum circuits have teamed up to develop innovative concepts for the construction of an improved quantum processor. They aim to realize a quantum processor with improved quality based on new materials and manufacturing methods by the Karlsruhe Institute of Technology (KIT), tailor-made theoretical concepts of the Friedrich-Alexander University Erlangen Nürnberg (FAU), optimized control methods of the Forschungszentrum Jülichs (FZJ) and concepts for new architectures with higher connectivity at the Walther-Meißner-Institute (WMI – Bavarian Academy of Sciences and Technical University of Munich). In order to achieve this goal, semiconductor manufacturer Infineon will develop scalable manufacturing processes, while the Fraunhofer Institute for Applied Solid State Physics (IAF) in Freiburg is promoting the development of optimized chip packages. The processor performance will eventually be demonstrated using a specifically developed quantum algorithm at the WMI.

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News

French President Details €1.8b Quantum Plan

January 22, 2021 Anne-Françoise Pelé

Two years after unveiling France's roadmap in artificial intelligence, French President Emmanuel Macron presented this week a national strategy for quantum technologies. The five-year €1.8 billion plan aims to finance research in quantum computing, communications and sensing.

"Quantum strategy is of paramount importance," said Macron during a speech on January 21st at the Center for Nanoscience and Nanotechnologies (C2N) in Paris-Saclay, France. "Like artificial intelligence, microelectronics, health, energy and space technologies, quantum technologies are among the few keys to the future that France absolutely must have in hand."

The French government will invest €200 million per year over the next five years, or €1 billion in total. The remaining €800 million will come from commitments made by industrial players (€500 million), European funding (€200 million), and investors revolving around the French startup ecosystem (€100 million).

"By tripling our annual financial effort, we are already joining the leading trio of quantum nations [after the United States and China]," claimed Macron.

France's quantum strategy is based on two main axes. "The first is global and integrated technological development, from fundamental research to industrialization," said Macron. "The second is the strengthening of the French innovation ecosystem in its European environment, in particular by developing human capital and by recruiting, training and attracting the best both in public research and in industry."

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Press release

Government backs UK's first quantum computer

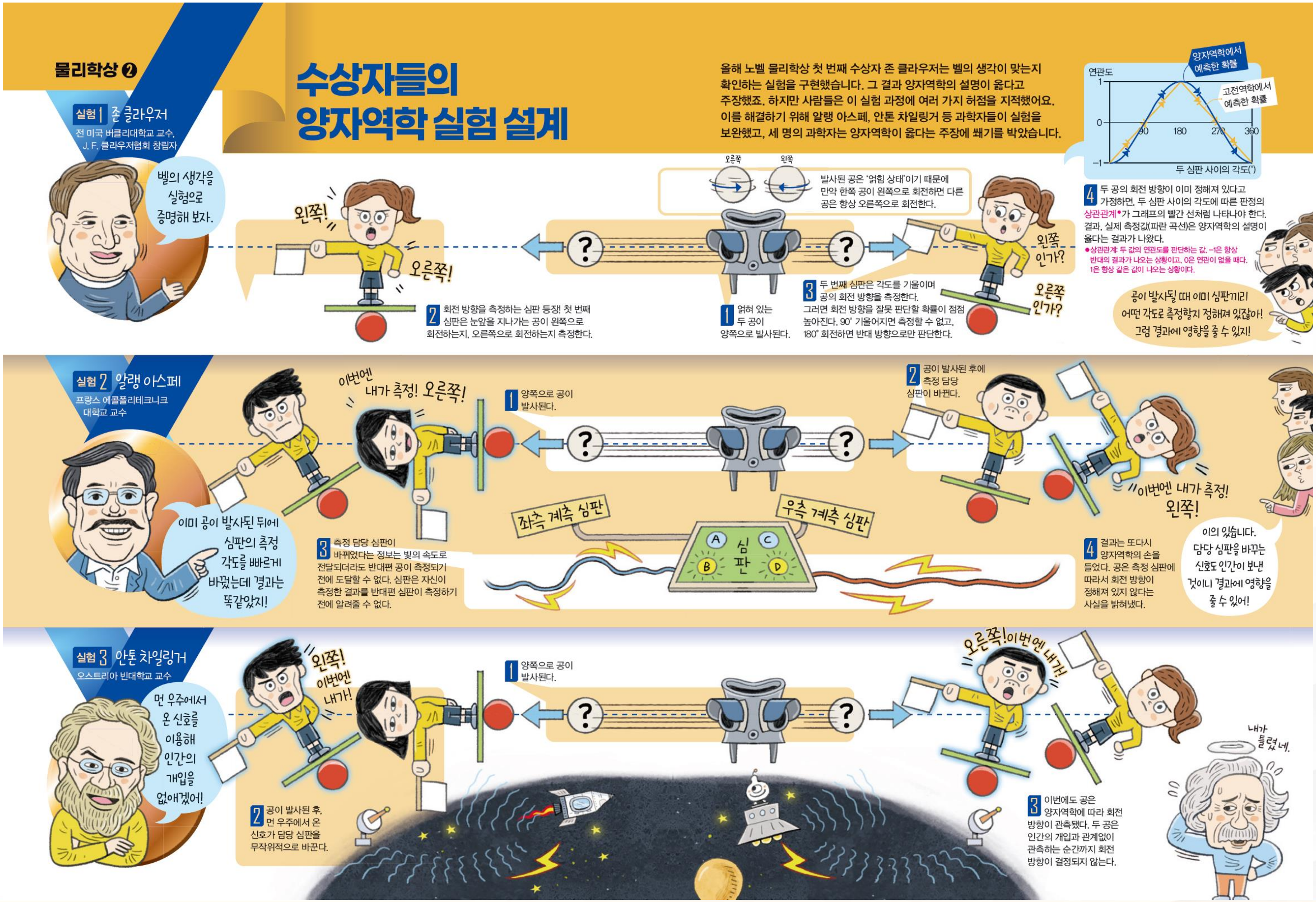
The UK's first quantum computer to be commercially available to businesses will be located in Abingdon in Oxfordshire

From: Department for Business, Energy & Industrial Strategy, UK Research and Innovation, and Amanda Solloway MP

Published: 2 September 2020

- The UK's first commercially available quantum computer to be hosted in Abingdon, backed by £10 million government and industry investment
- quantum computers could help solve issues including accelerating new drug treatments and improving traffic flow in cities and towns
- Science Minister sets out bold new vision for the UK to become the world's first quantum-ready economy and launches the new National Quantum Computer Centre in Oxfordshire

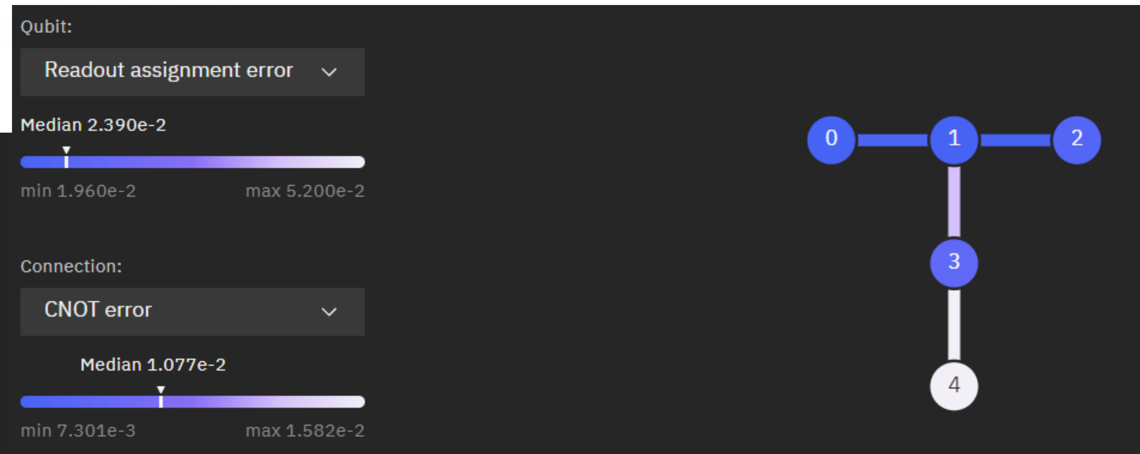
2022 노벨상 : 양자 얽힘



Bell Inequality

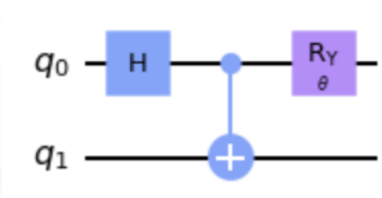
Violation experiment using qiskit runtime

CHSH inequality: $\langle AB \rangle - \langle Ab \rangle + \langle aB \rangle + \langle ab \rangle \leq 2$




```
from qiskit_ibm_runtime import Estimator, Session
from qiskit.quantum_info import SparsePauliOp
from qiskit_ibm_runtime import Options

backend_lima = "ibmq_lima"

ZZ = SparsePauliOp.from_list([("ZZ", 1)])
ZX = SparsePauliOp.from_list([("ZX", 1)])
XZ = SparsePauliOp.from_list([("XZ", 1)])
XX = SparsePauliOp.from_list([("XX", 1)])

ops = [ZZ, ZX, XZ, XX]
chsh_est_lima = []


option_nothing = Options(optimization_level = 0,resilience_level=0, transpilation=dict(initial_layout=[0,1]))
with Session(service=service, backend=backend_lima):
    estimator = Estimator(options=option_nothing)
    for op in ops:
        job = estimator.run(
            circuits=[chsh_circuits_no_meas]*len(individual_phases),
            observables=[op]*len(individual_phases),
            parameter_values=individual_phases)
        est_result = job.result()
        chsh_est_lima.append(est_result)
```

✓ 6m 48.3s

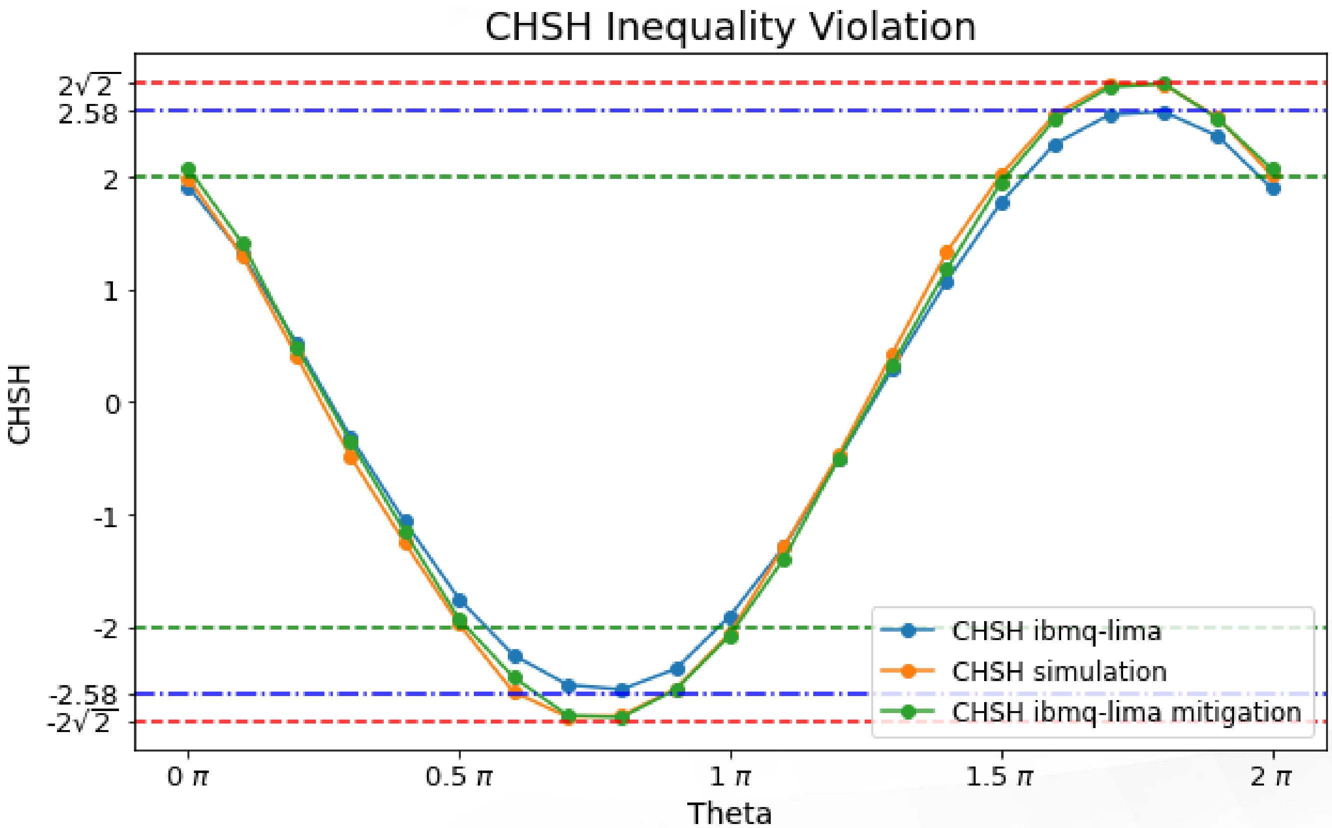


Bell Inequality

Violation experiment using Qiskit runtime

CHSH inequality: $\langle AB\rangle - \langle Ab\rangle + \langle aB\rangle + \langle ab\rangle \leq 2$

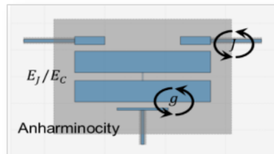
With mitigation: maximum ~ 2.825

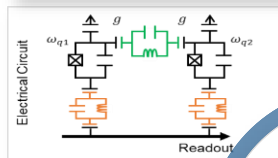


Research Excellence of SKKU

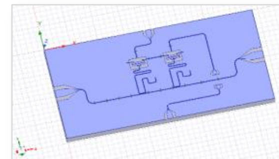
Quantum Circuit Design

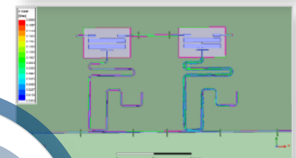
Design Qubit Properties





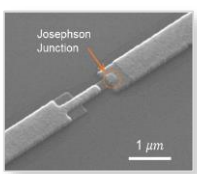
Circuit Simulation





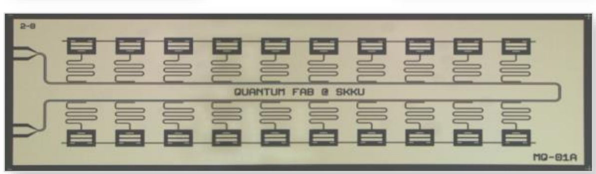
Quantum Device Fabrication

Josephson Junction

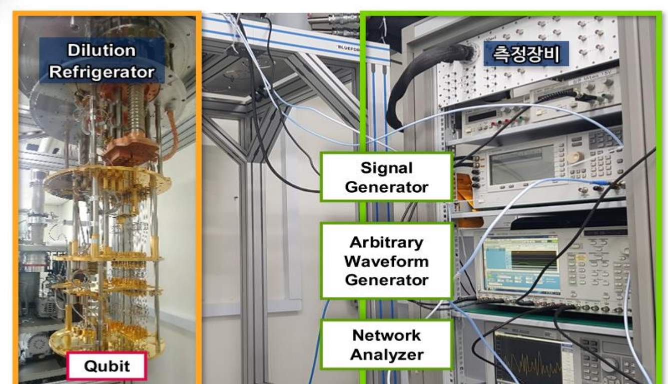


Wafer-scale Fab.

Large-scale Quantum Processor



Quantum Control & Measurement



SUNG KYUN KWAN UNIVERSITY(SKKU)

THANK YOU

정연욱 성균관대학교