

Quantum  
Computing

A Hands-on  
Experience with  
Jupyter Notebooks



University  
of Victoria

Engineering



# History

## Co-Directors

- Andrew MacLean
- Ulrike Stege

Started in 2017/18

- Out of Department of Computer Science
- First cohort of our Skills Academy in 2018
- Software development

2019

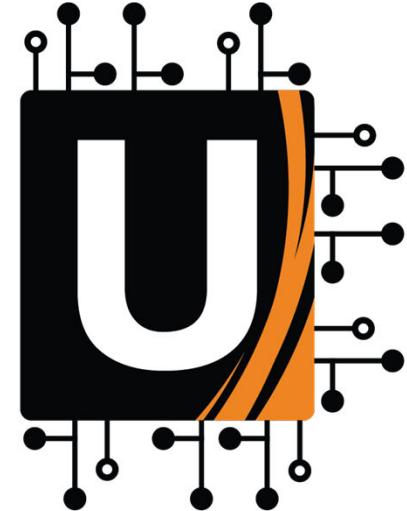
- 2 cohorts

2020

- Next cohort starts Saturday, Feb 1
- Summer skills academy—computer engineering

# HighTech

Empowering Future Innovators

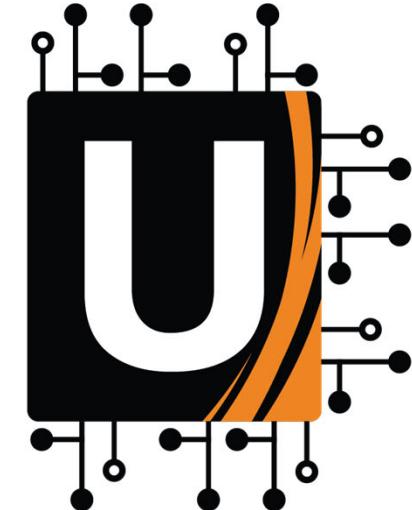


## Workshops

- Brand-new addition to HighTechU
- Plan: regular offerings of workshops
- Today: *Quantum Computing: A Hands-on Experience with Jupyter Notebooks*
- March 2020: 2-day Workshop on Quantum Computing

# HighTech

Empowering Future Innovators



## Today's HighTechU Q Team

- Priya Angara
- Hausi Müller
- Ulrike Stege
- Sunil Kumar
- Andrew MacLean
- Ivan Martell



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An initiative of

Engineering

WE ARE CURIOUS

<https://hightechu.ca>

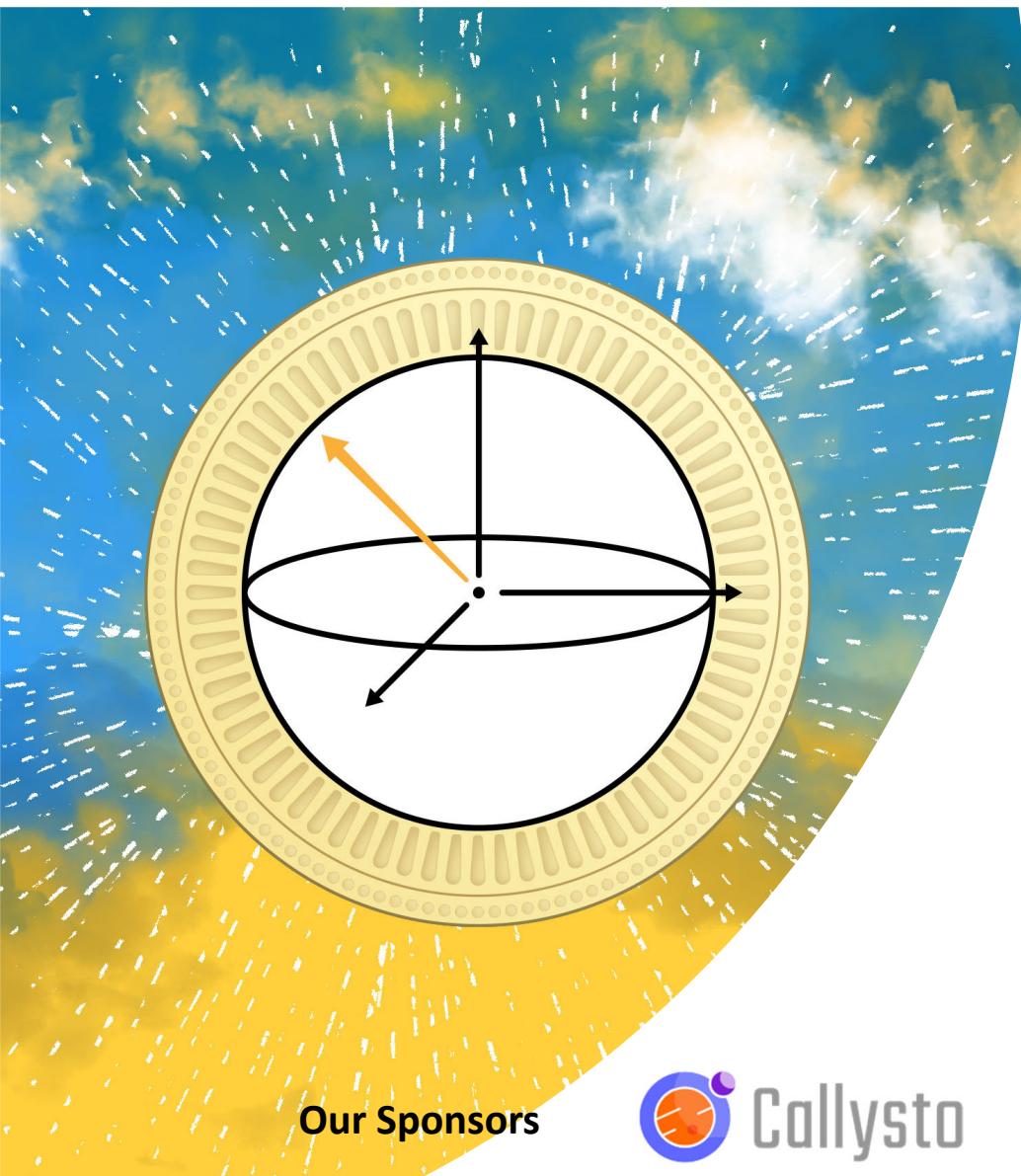


Introduce  
yourself

# Today's Agenda



Starting Time Approximate	Topic
9:00	Introduction and Motivation
9:30	Account setup on IBM Q Experience
10:00	Break
10:15	Introduction to Jupyter Notebooks, Python, Qiskit
11:00	Qubits, gates, superposition and measurements
12:30	Lunch
1:00	Hands-on programming
2:30	2-qubit systems and entanglement
3:30	Break
3:45	Entanglion
4:45	Closing & Feedback



Our Sponsors



**HighTech**  
Empowering Future Innovators



# What is Quantum Computing?



Engineering

*Nature isn't classical ... and if you want to make a simulation of Nature, you'd better make it quantum ...”*

*—Richard Feynman, CalTech, 1981*

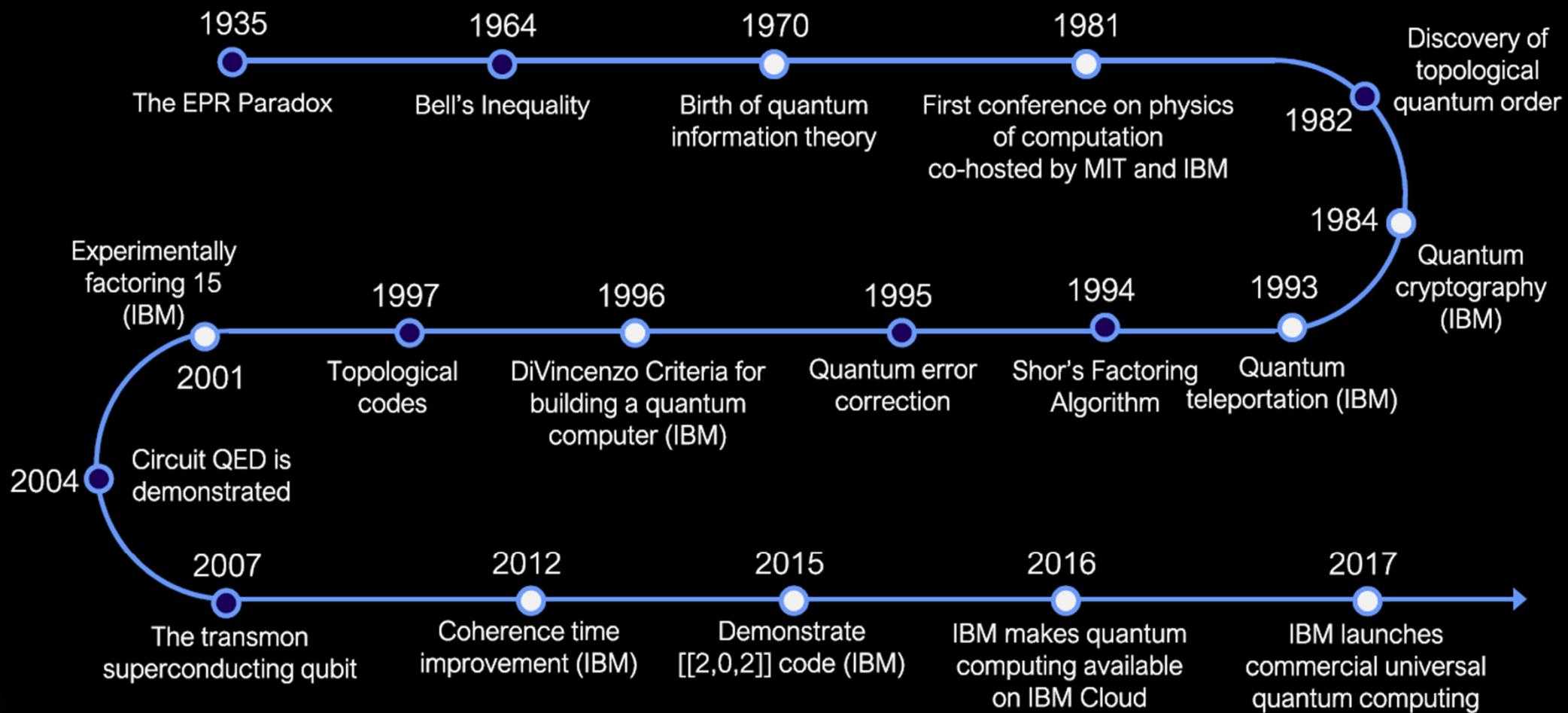
*Quantum Computing leverages nature to represent and manipulate information*



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# A history of quantum computing



# Where are we on the road to Quantum Advantage?

## Quantum Foundations

Fundamentals of quantum information science

Create and scale qubits with increasing coherence

Create error detection and mitigation schemes

## Quantum Ready

Core algorithm development

Standardize performance benchmarks

Increase quantum volume

System infrastructure and software enablement

## Quantum Advantage

Demonstrate an advantage to using QC for real problems of interest

Extract Commercial Value

Enable scientific discovery

Launch of IBM Q Experience

2016

2020s

~1900

# ONE FORM OF QUANTUM ADVANTAGE

- Quantum computers will not replace classical computers
- Hybrid quantum-classical architectures will be the norm
- Superposition & entanglement allow QC to explore an enormous set of possibilities to find answers
- QC's potential for significant speed over classical computers

Type of scaling	Time to solve problem				
Classical algorithm with exponential runtime	10 secs	2 mins	330 years	3300 years	Age of the universe
Quantum algorithm with polynomial runtime	1 min	2 mins	10 mins	11 mins	~24 mins

Coming soon to your business – Quantum computing

[www.ibm.com/thought-leadership/institute-business-value/report/quantumstrategy](http://www.ibm.com/thought-leadership/institute-business-value/report/quantumstrategy)

# A Wonderful Story of Quantum Computing Applications



Maggie Li · 1st

Biotech + Quantum Computing Enthusiast | TKS Innovator

# CATEGORIES OF QUANTUM COMPUTERS

[en.wikipedia.org/wiki/List\\_of\\_quantum\\_processors](https://en.wikipedia.org/wiki/List_of_quantum_processors)

Quantum annealing, adiabatic computing

- D-Wave Systems

Noisy intermediate-scale quantum computing (NISQ)

- IBM, Google, Rigetti, Intel

Fault-tolerant universal quantum computing

- Ultimate goal

Manufacturer	Qubits
D-Wave	512, 1024, 2048
IBM	5, 14, 20, 53
Google	53, 72
Rigetti	128
Intel	49

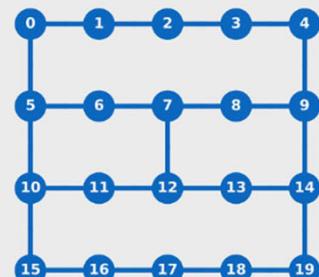


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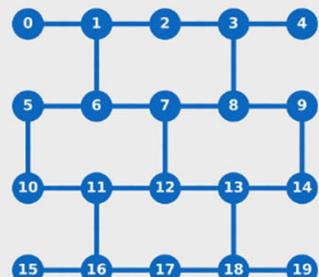
# IBM'S ONLINE QUANTUM DEVICES



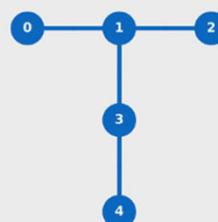
IBM's 10 Quantum Device Lineup



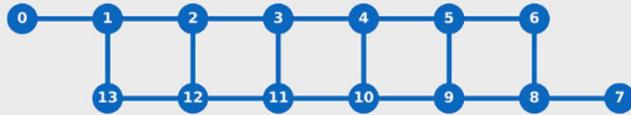
Johannesburg  
Poughkeepsie



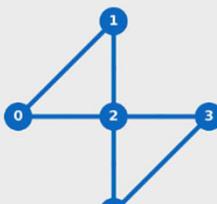
Almaden  
Boeblingen  
Singapore



Ourense  
Valencia  
Vigo

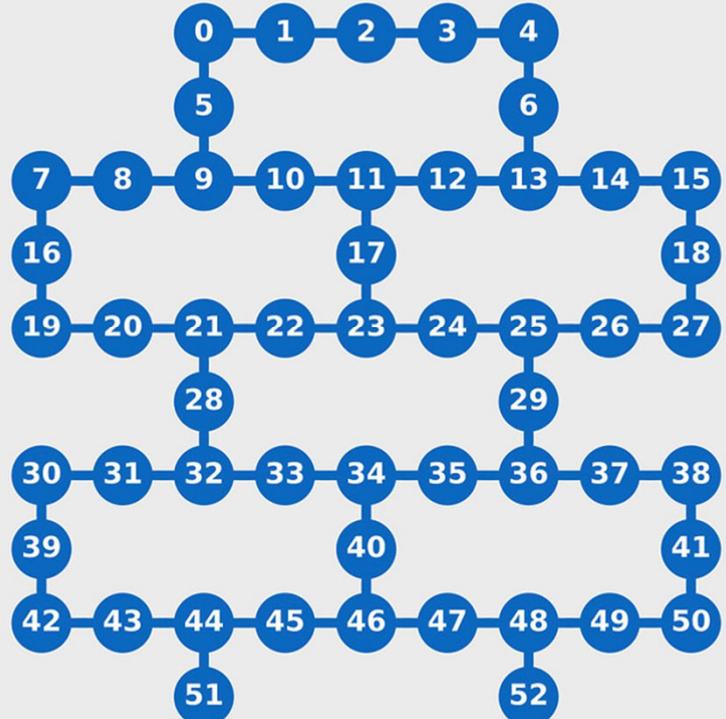


Melbourne



Yorktown

53 Qubit Rochester Device



# QUANTUM SOFTWARE DEVELOPMENT KITS

IBM

- IBM Q — [www.research.ibm.com/ibm-q/](http://www.research.ibm.com/ibm-q/)
- Qiskit—Terra, Aqua, Ter — [qiskit.org](https://qiskit.org)

Microsoft

- Q# — [www.microsoft.com/en-us/quantum/](http://www.microsoft.com/en-us/quantum/)
- Microsoft QDK — [en-us/quantum/development-kit](https://en-us/quantum/development-kit)

Google

- Google-AI — [quantum-ai/](https://quantum-ai/)
- Google Cirq — [github.com/quantumlib/Cirq](https://github.com/quantumlib/Cirq)

Rigetti

- Forest SDK — [rigetti.com/forest](https://rigetti.com/forest)

D-Wave

- Leap — [www.dwavesys.com/take-leap](https://www.dwavesys.com/take-leap)
- Ocean SDK — [ocean.dwavesys.com/](https://ocean.dwavesys.com/)

*Ready now—for you!*

Innovative digital tools are needed for developing and testing algorithms, writing software and programming the devices.

A new breed of quantum programmer is needed to study and implement quantum software

—Zheng, Rigetti: First Quantum Computers  
Need Smart Software, Nature 549(7671), 2017



# Qiskit

pypi v0.8.0

An open-source quantum computing framework for leveraging today's quantum processors in research, education, and business

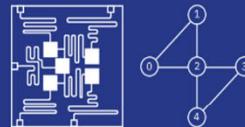
[GitHub](#)

[Join the Slack community](#)



IBM System One — 20 Qubits

## IBM Q 5 Tenerife [ibmqx4]



Last Calibration: 2019-04-03 19:04:24

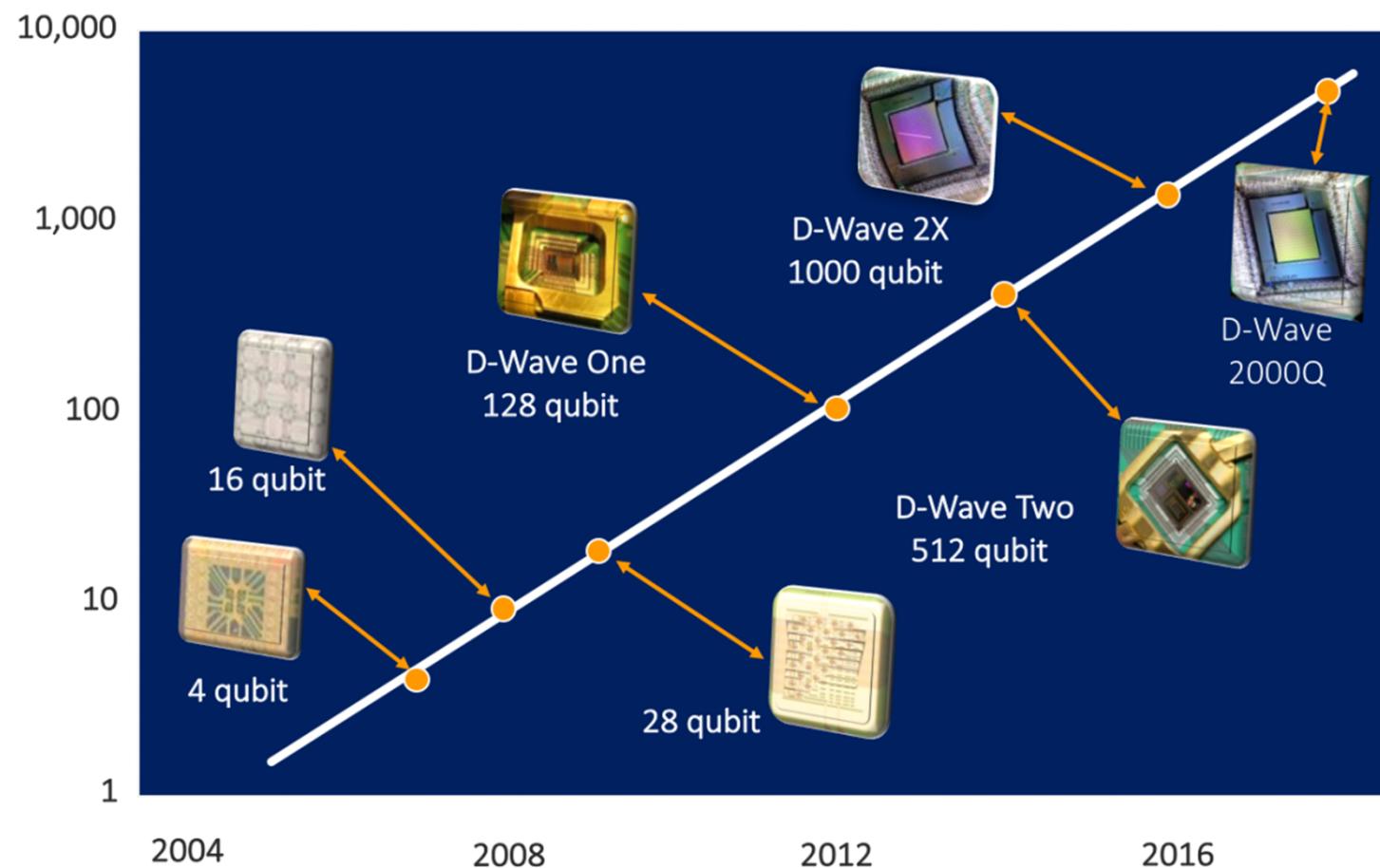
	Q0	Q1	Q2	Q3	Q4
Frequency (GHz)	5.25	5.30	5.35	5.43	5.18
T1 (μs)	51.20	51.90	30.00	49.60	68.20
T2 (μs)	33.70	19.20	25.70	15.00	9.80
Gate error (10 <sup>-3</sup> )	0.69	1.46	1.55	1.80	1.46
Readout error (10 <sup>-3</sup> )	10.50	7.10	3.40	3.10	6.30
MultiQubit gate error (10 <sup>-3</sup> )	CX1_0 3.70	CX2_0 2.95	CX3_2 6.15	CX4_2 6.22	
	CX2_1 3.78	CX3_4 3.95			

## IBM Q 5 Yorktown [ibmqx2]

ACTIVE: USERS

# D-WAVE SYSTEMS & GEORDIE ROSE'S LAW

[www.dwavesys.com/resources/tutorials](http://www.dwavesys.com/resources/tutorials)

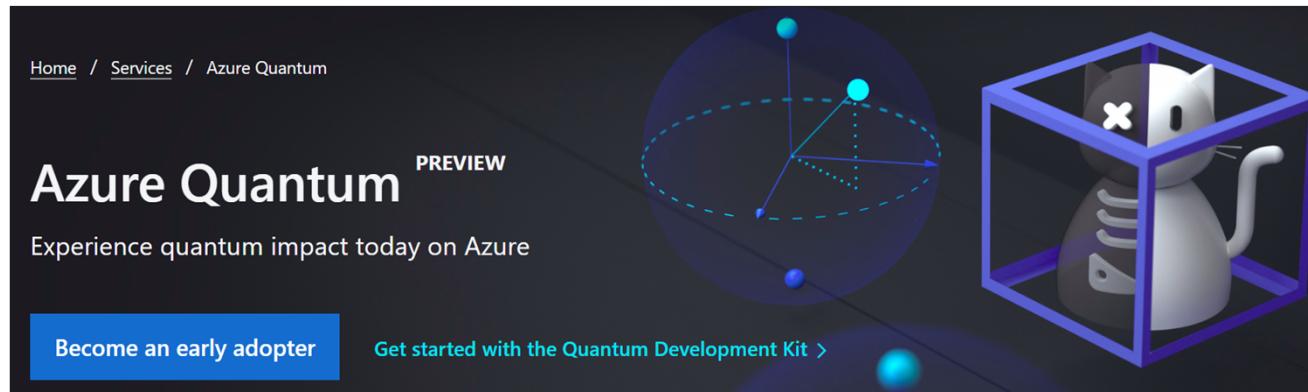


# MICROSOFT QUANTUM AZURE

[azure.microsoft.com/en-ca/services/quantum](https://azure.microsoft.com/en-ca/services/quantum)

Azure Quantum is a full-stack, open cloud ecosystem that will bring the benefits of quantum computing to people and organizations around the world.

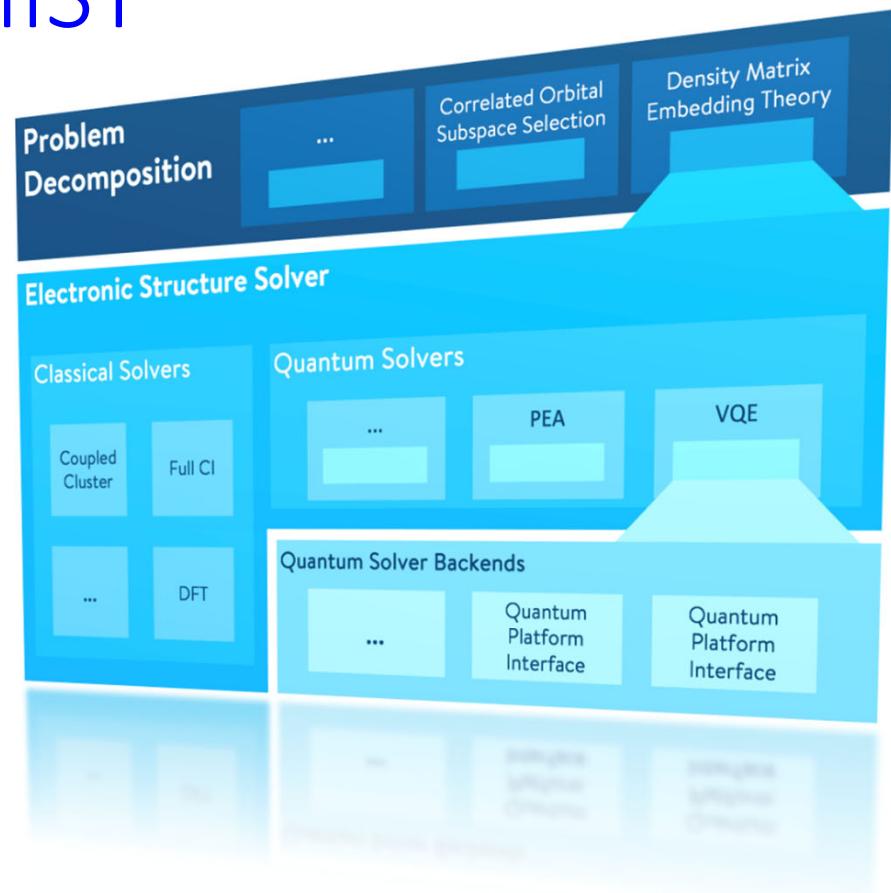
With partners [1QBit](#), [Honeywell](#), [IonQ](#), and [QCI](#), Microsoft is assembling a diverse set of quantum solutions, software, and hardware in Azure.



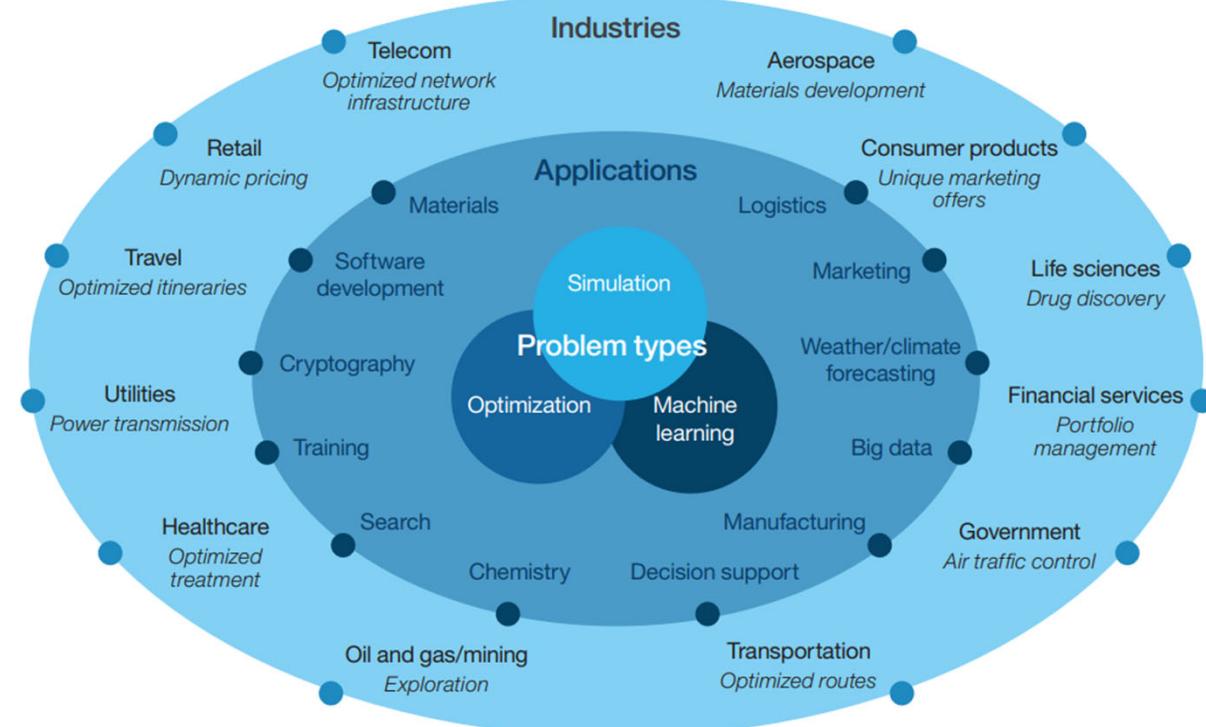
# 1QBIT QEMIST

## A Modular, Platform-Agnostic Design

QEMIST is designed to enable the accurate calculation of molecular properties by leveraging advanced problem decomposition (PD) techniques and quantum computing. The variety of PD techniques implemented in QEMIST enables massively parallel simulations by breaking down a computational chemistry task into smaller, independent subproblems. These subproblems can use a combination of interfaces to various classical and quantum solvers to achieve a higher level of accuracy for large-scale, practical molecular simulations.



# QUANTUM'S POTENTIAL IMPACT ON PROBLEM-SOLVING FOR APPLICATIONS AND INDUSTRIES



Taking the Quantum Leap – Why Now?

[www.ibm.com/thought-leadership/institute-business-value](http://www.ibm.com/thought-leadership/institute-business-value)



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# BRITISH COLUMBIA INSTITUTE FOR QUANTUM ALGORITHMS



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## NEWS RELEASE

For Immediate Release  
2019PREM0111-001892  
Oct. 2, 2019

Office of the Premier  
Ministry of Jobs, Trade and Technology

[https://archive.news.gov.bc.ca/releases/news\\_releases\\_2017-2021/2019PREM0111-001892.htm](https://archive.news.gov.bc.ca/releases/news_releases_2017-2021/2019PREM0111-001892.htm)



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# British Columbia Institute for Quantum Algorithms — Quick Facts

- **\$17 million for five years** to establish the Quantum Algorithms Institute
- Quantum Algorithms Institute (QAI) will focus on **building software and algorithms**
- Help advance QC from research through to “transformative” technology
- Universities: **SFU, UBC, UVic, Thompson Rivers University, Kwantlen University**
- Local QC companies, like D-Wave and 1Qbit
- QC world leaders like **Microsoft** and **IBM**
- Commercially active QC companies: **D-Wave, 1Qbit, IBM, Microsoft, Fujitsu**
- Physical Office at SFU to help develop **new Surrey downtown Vancouver**
- Support **Cascadia corridor** — BC, Washington, Oregon
- Connect to **Pacific Northwest Quantum Nexus** — UW, PNNL, Microsoft



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# UVic Quantum Research Cluster

- ➔ CRC in Quantum Systems — CSC & ECE, Engineering
- ➔ CRC in Quantum Computing for Simulation of Molecules and Materials— Chem & Phys-Astro, Science
- ➔ Chair in Quantum Devices — ECE/ Phys-Astro, Engr/Science

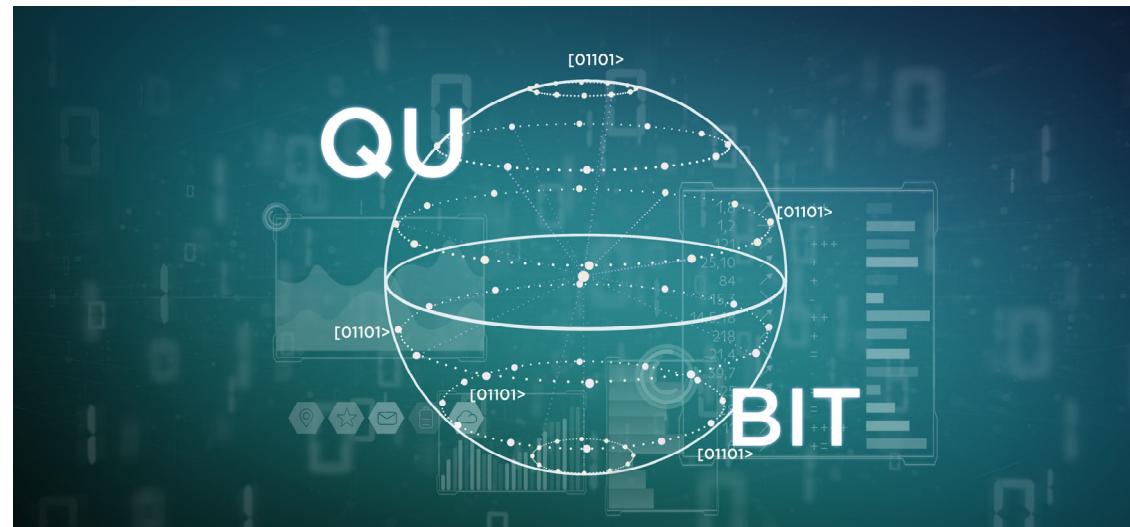


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# Quantum Problem Solving & Algorithm Design

## 3-Year IBM CAS Project

- ❖ Principal investigators: Ulrike Stege, Hausi Müller, Priya Angara
- ❖ Develop a toolkit to identify quantum problems and quantum hybrid problems
- ❖ Develop quantum problem solving & algorithm design techniques for selected application domains
- ❖ Develop quantum software for selected problems using IBM Qiskit open-source quantum computing framework



# UVic Quantum Computing Training

- PHYS 280: Special Topics in Physics: Introduction to Quantum Computation Spring 2020 by Rogério de Sousa
- Directed Studies and Grad Course in Quantum Computing — Stege, Müller
- Quantum Fundamentals & Qiskit Programming — Qiskit Terra & Aqua (Fall 2020)
- Quantum Algorithms & Problem Solving — Qiskit Aqua (Spring 2021)
- Topics Courses in Quantum Applications — Quantum Molecular Chemistry — Paci
- Quantum Computing Distance Course for TRU — Tiedje
- HighTechU Quantum Computing Component — Stege
- Hands-on courses on IBM Qiskit and D-Wave D-leap development platforms as part of NSERC CREATE training program 2020



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You are cordially invited to contribute and attend  
**IEEE Quantum Week 2020**  
Oct 12-16, 2020 Denver – Broomfield, USA  
[qce.quantum.ieee.org](http://qce.quantum.ieee.org)



General Chair &  
Co-Chair IEEE FD QI  
Hausi Müller



Finance Chair & Co-  
Chair IEEE FD QI  
Candace Culhane



Technical Program  
Board Chair  
Greg Byrd



Panels & Briefings &  
Co-Chair IEEE FD QI  
Erik DeBenedictis



Workshops Co-Chair  
& Co-Chair FD QI  
Travis Humble



Posters  
Co-Chair  
Ulrike Stege



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QUANTUM COMPUTING  
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# IEEE Quantum Week 2020

Denver, Colorado — Oct 12-16, 2020

IEEE is at the center of a global conversation to understand the power and promise of quantum computing.

— Travis Humble, Co-Chair IEEE Quantum Initiative

[CALL FOR CONTRIBUTIONS](#)



Omni Interlocken Hotel & Resort  
Denver – Broomfield

## Keynote Speakers



Michelle Simmons  
University of New South Wales (UNSW)



Jerry M. Chow  
IBM Research



Anne Matsuura  
Intel Labs



Alán Aspuru-Guzik  
University of Toronto



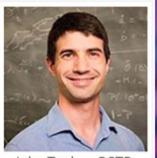
Krysta Svore,  
Microsoft Quantum,  
QuArC



John Martinis  
Google & UC Santa Barbara



Kae Nemoto, NII,  
Japan

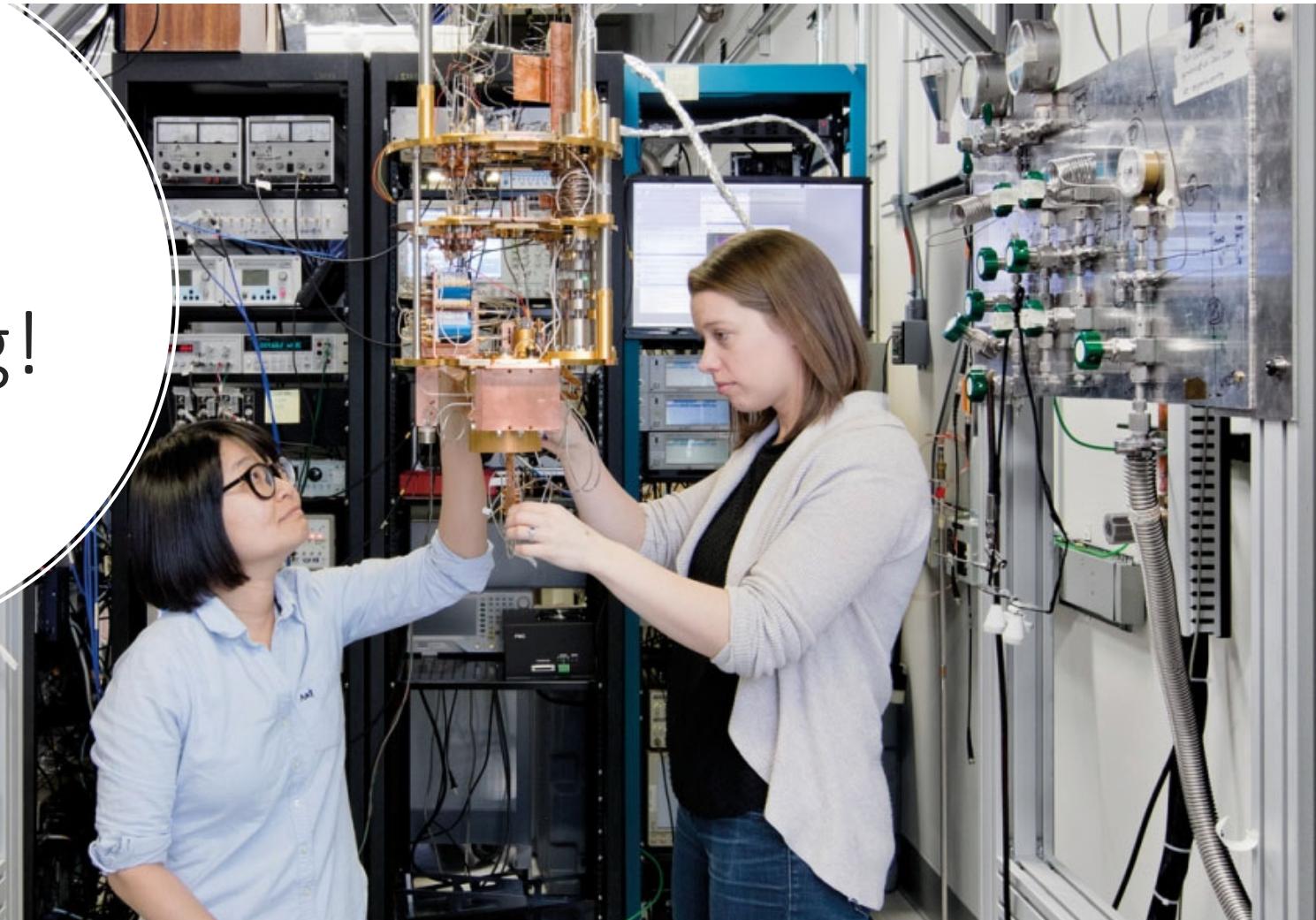


Jake Taylor, OSTP,  
QuICs, and NIST

[twitter.com/IEEEQuantumWeek](https://twitter.com/IEEEQuantumWeek)

[qce.quantum.ieee.org](http://qce.quantum.ieee.org)

# Quantum Computing!



IBM Quantum Computing Scientists Hanhee Paik (left) and Sarah Sheldon (right) examine the hardware inside an open dilution fridge at the IBM Q Lab at IBM's T. J. Watson Research Center in Yorktown, NY.

Quantum computing devices

<https://quantum-computing.ibm.com/>

Circuit Composer

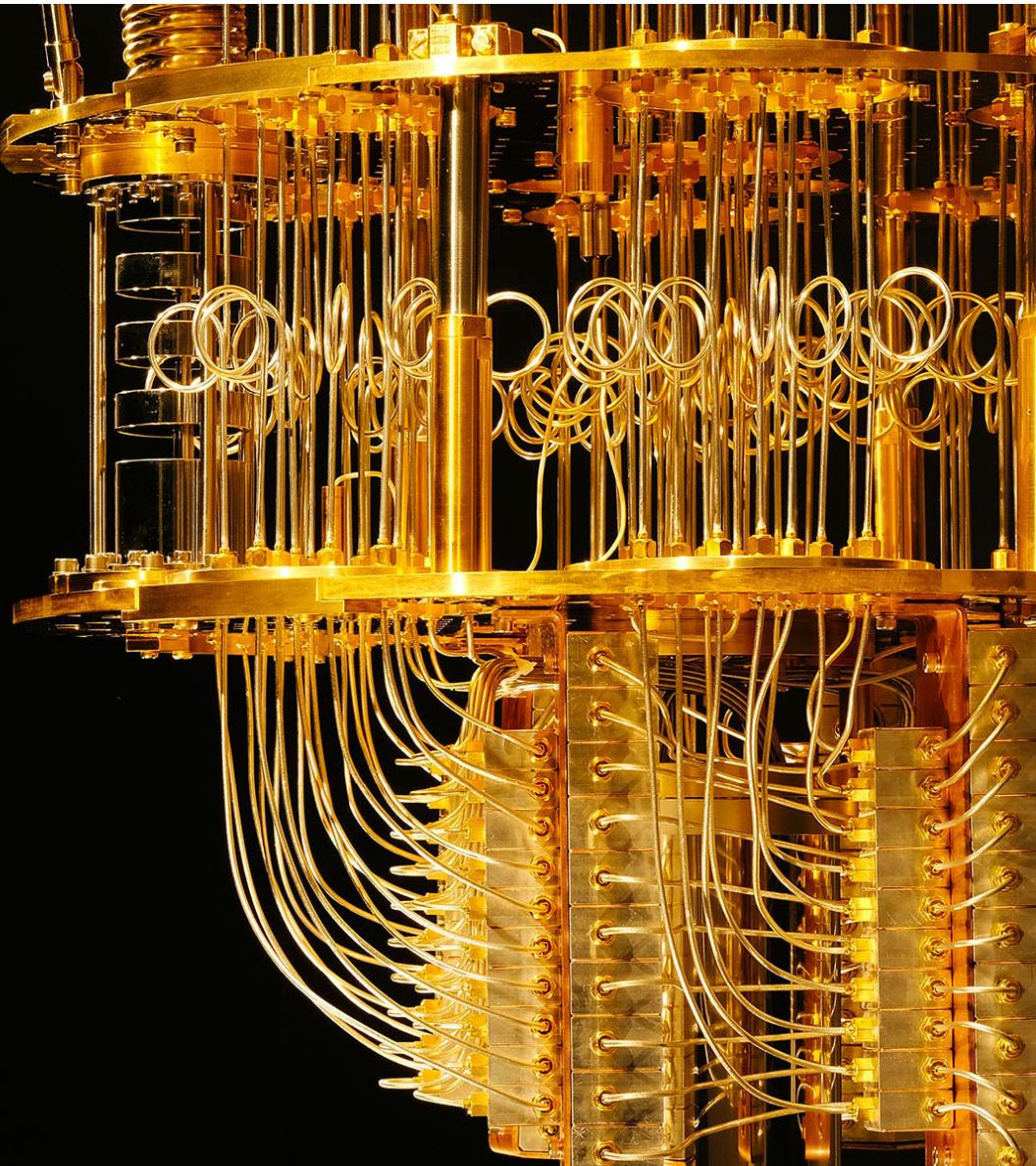
<https://quantum-computing.ibm.com/composer>

Qiskit

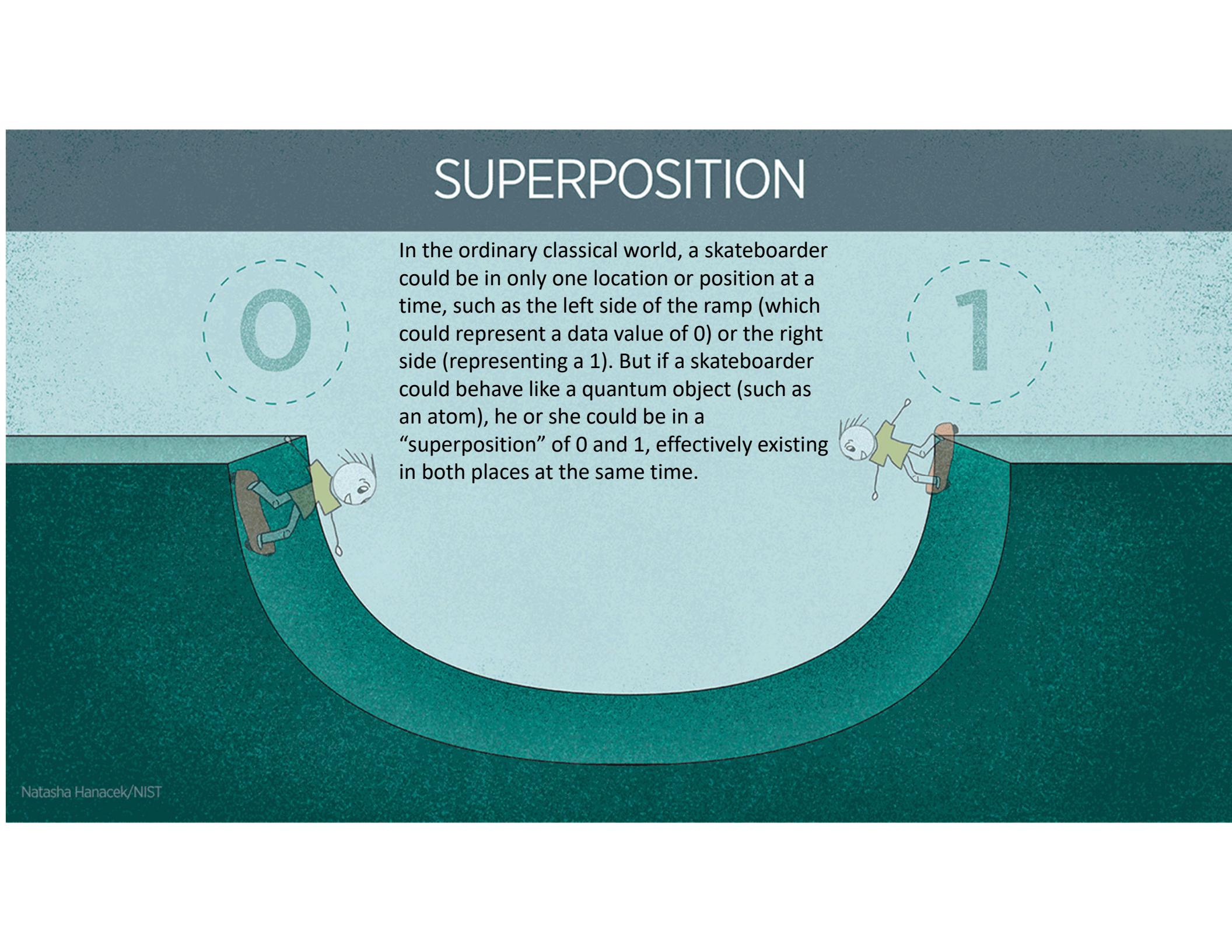
<https://qiskit.org/>

Shtetl-Optimized

<https://www.scottaaronson.com/blog/>

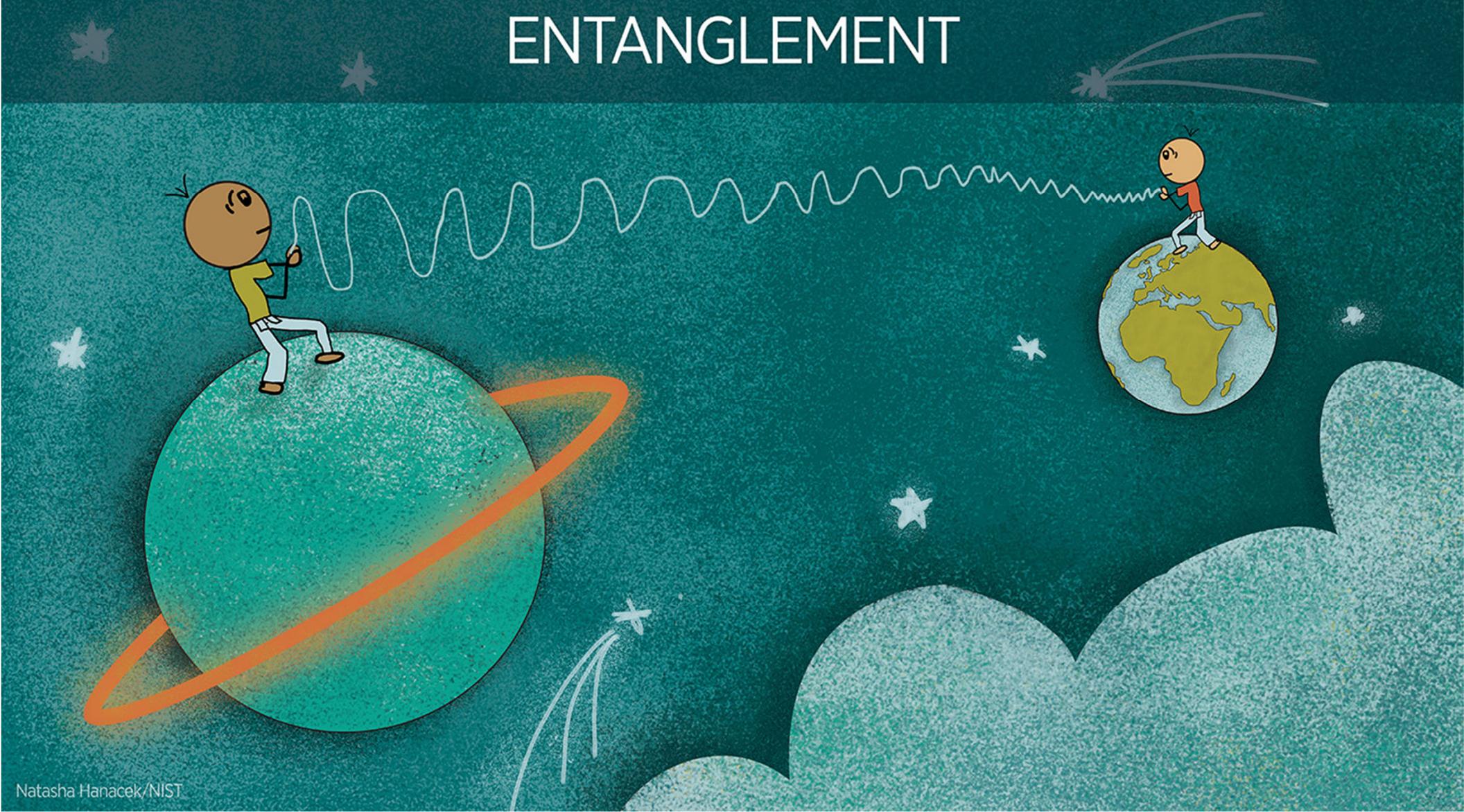


# SUPERPOSITION



In the ordinary classical world, a skateboarder could be in only one location or position at a time, such as the left side of the ramp (which could represent a data value of 0) or the right side (representing a 1). But if a skateboarder could behave like a quantum object (such as an atom), he or she could be in a “superposition” of 0 and 1, effectively existing in both places at the same time.

# ENTANGLEMENT



# Today's Agenda



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