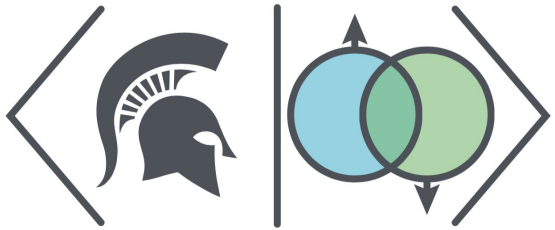
Quantum Revolution II

QuIC Seminar
Fall 2019

Welcome to the

Quantum Information and Computation seminar

v2.0



This is a weekly reading group/seminar about the rapidly emerging field of quantum technologies.

The QuIC Seminar

Structure and Organization

When and where?

Friday 11:00 - 12:00 pm in BPS 1300 (unless otherwise noted)

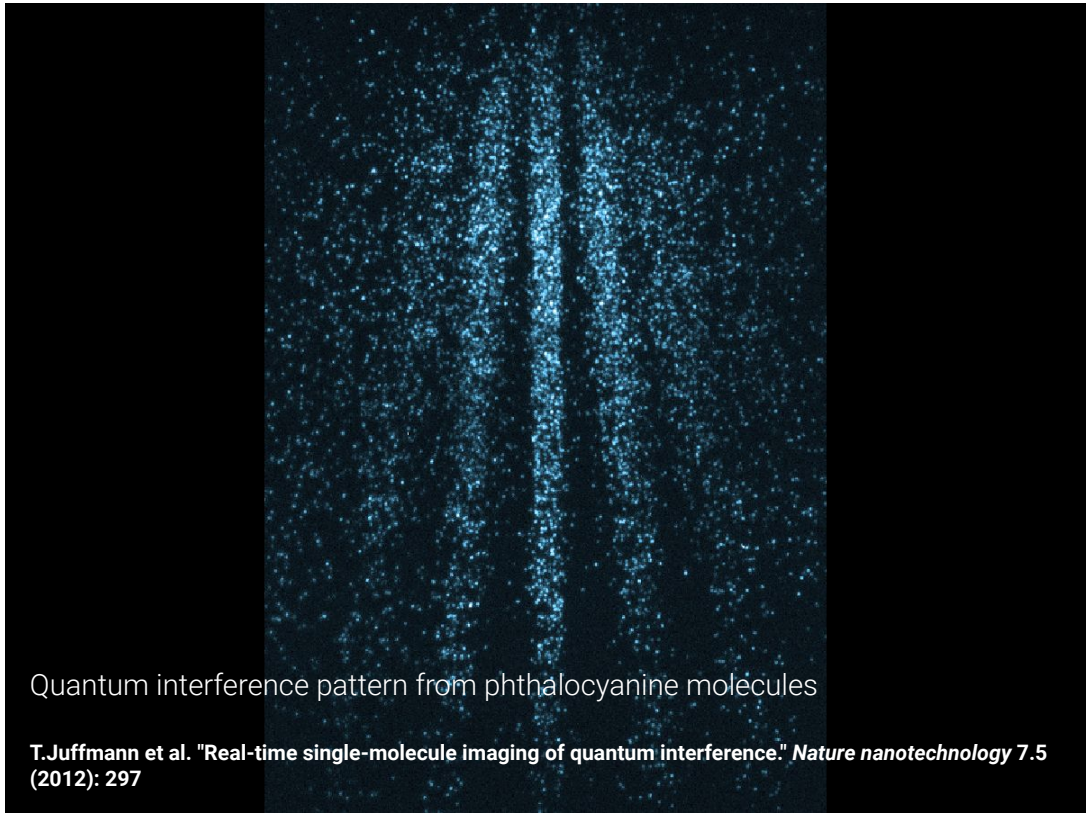
What and How?

Topics:

- Quantum computing/quantum information fundamentals
- Programming quantum computers/quantum algorithms
- Various experimental implementations

Format:

- mostly hands on learning (programming using Qiskit/Simulations using qutip?)
- Maybe lecture-like sessions later?



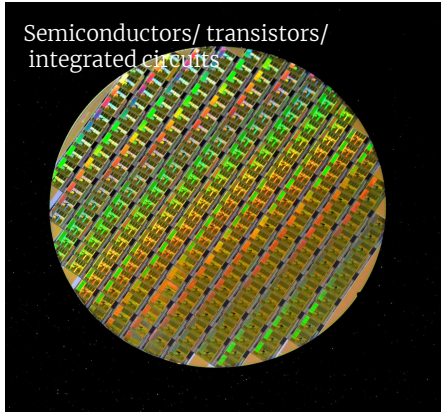
Quantum interference pattern from phthalocyanine molecules

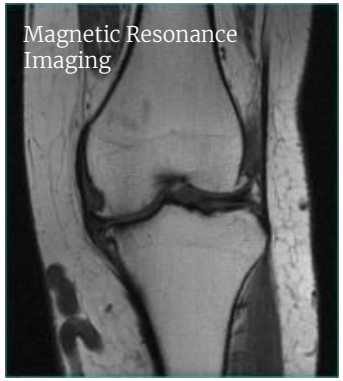
T.Juffmann et al. "Real-time single-molecule imaging of quantum interference." ***Nature nanotechnology*** **7.5 (2012): 297**

Quantum Revolution I

Wave-particle duality

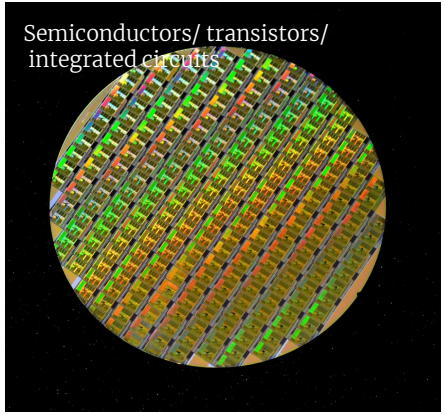
The first quantum revolution gave us new rules that govern physical reality





Quantum Revolution I leads to...

...basically the modern world



Quantum Revolution I leads to...

...basically the modern world

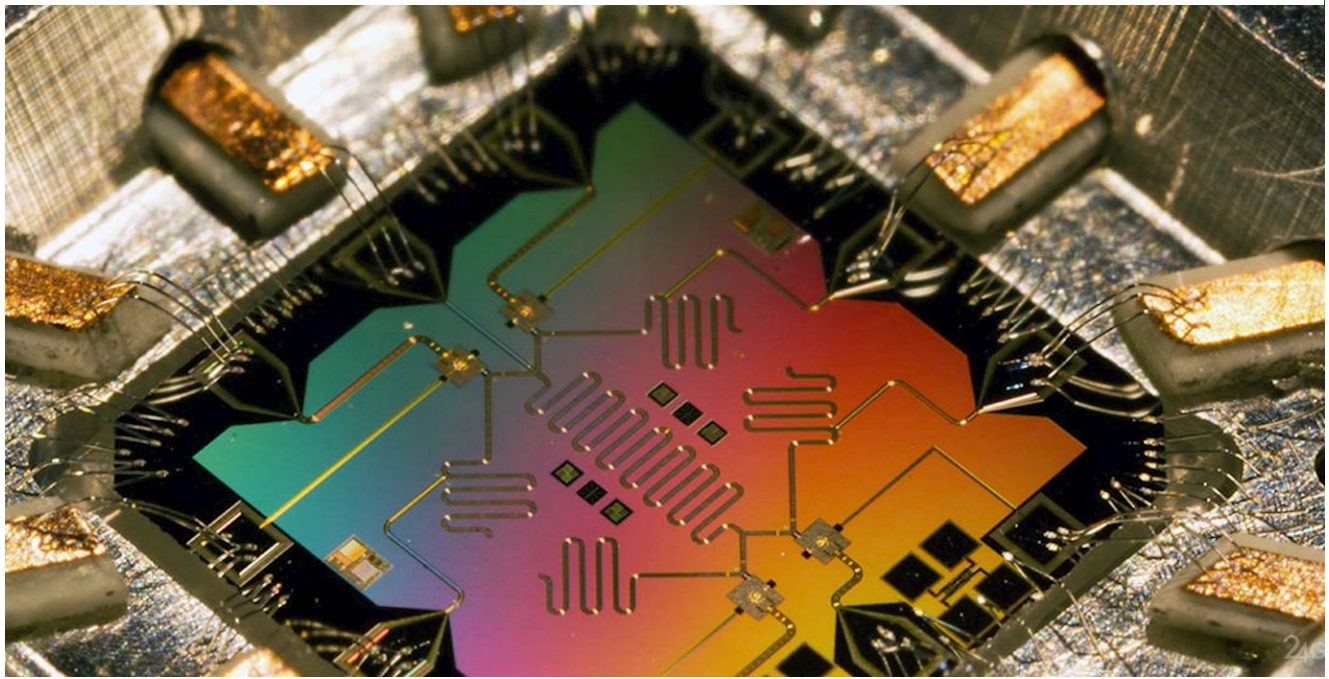
All these technologies use quantum physics to understand and design devices...

...none of them actually *manipulate* and *measure* quantum systems

Quantum Revolution II

The second quantum revolution will take these rules and use them to develop new technologies that **directly manipulate** and measure quantum systems

We want to "use the wavefunction"



Applications of Quantum Technologies

Quantum Communication
- Internet
- Cryptography

Quantum Simulations
- Strong correlated systems

Quantum computer Chemistry
- Designing new chemical processes and molecules

Optical metrology, imaging & Quantum sensing

Big Data boosting
- Optimization
- AI

Clock & Network Synchronization

Applications of Quantum Technologies

Quantum Communication

Internet

Cryptography

- Speed of light communication that is provably secure by the laws of quantum mechanics

 - Uses quantum teleportation, no-cloning theorem

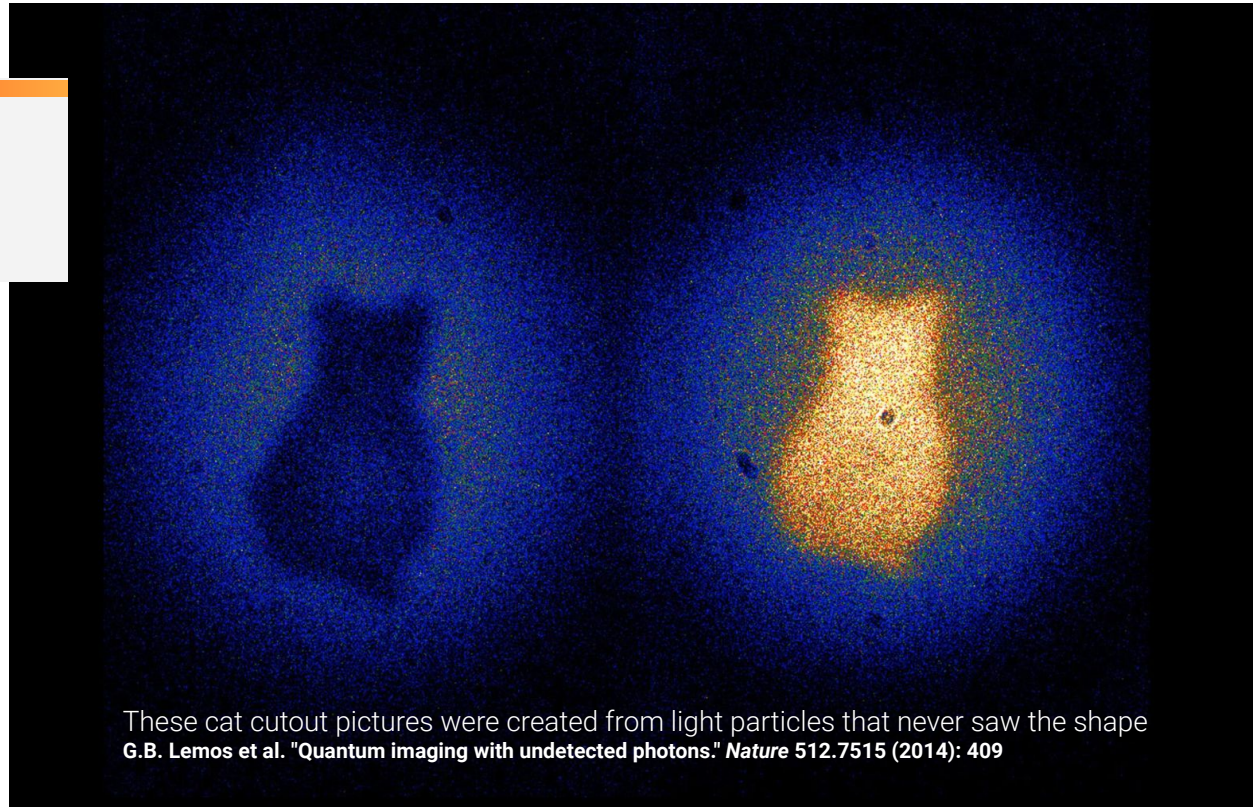
- Quantum key distribution and post-quantum cryptography

Applications of Quantum Technologies

Optical metrology, imaging & Quantum sensing

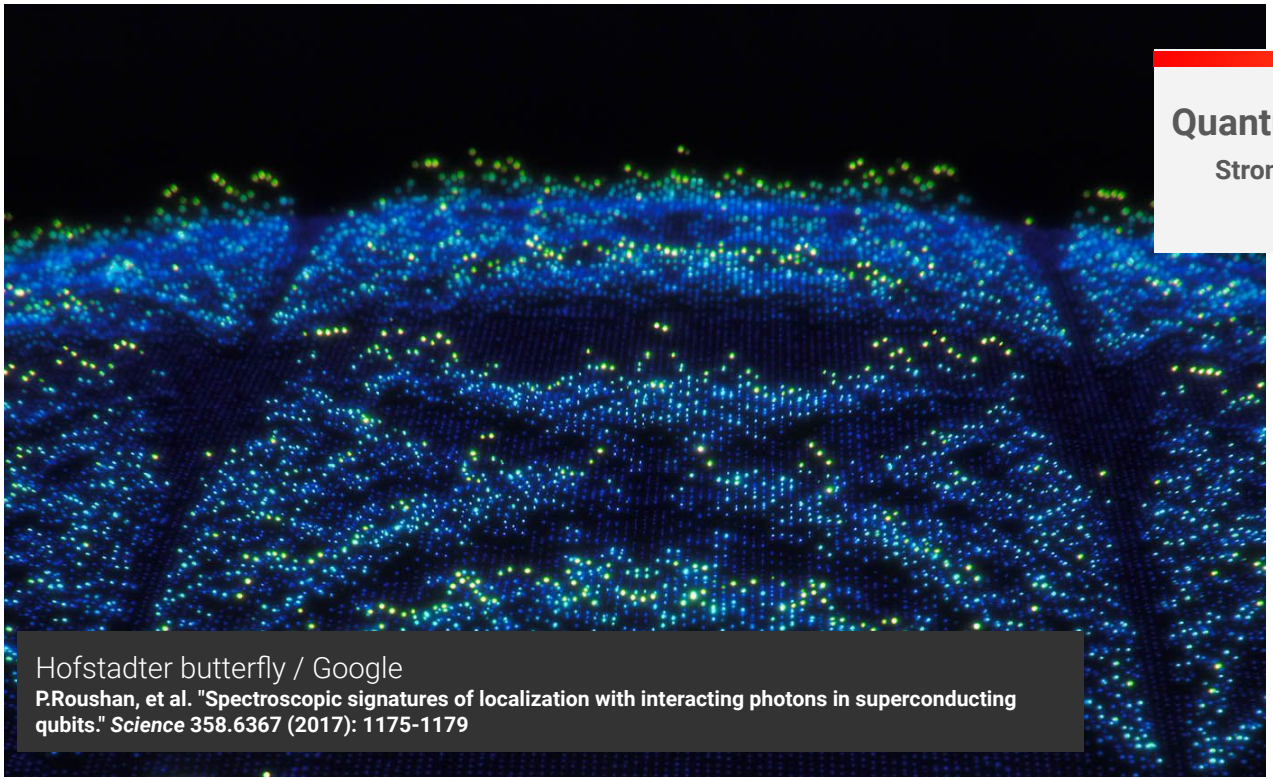
- Quantum sensors can achieve resolution better than any classical sensors

- Uses quantum correlations (entanglement)



These cat cutout pictures were created from light particles that never saw the shape
G.B. Lemos et al. "Quantum imaging with undetected photons." *Nature* 512.7515 (2014): 409

Applications of Quantum Technologies



Hofstadter butterfly / Google

P.Roushan, et al. "Spectroscopic signatures of localization with interacting photons in superconducting qubits." *Science* 358.6367 (2017): 1175-1179

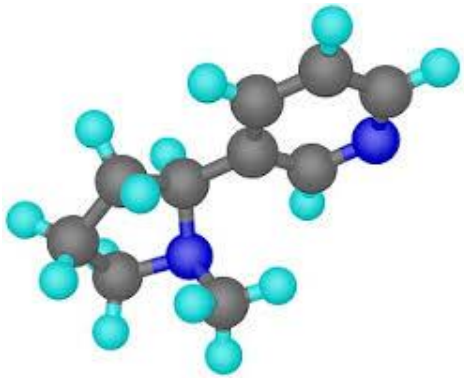
Quantum Simulations

Strong correlated systems

- Analog quantum simulators
- Digital quantum simulators
- Quantum annealers

Simulating Chemistry

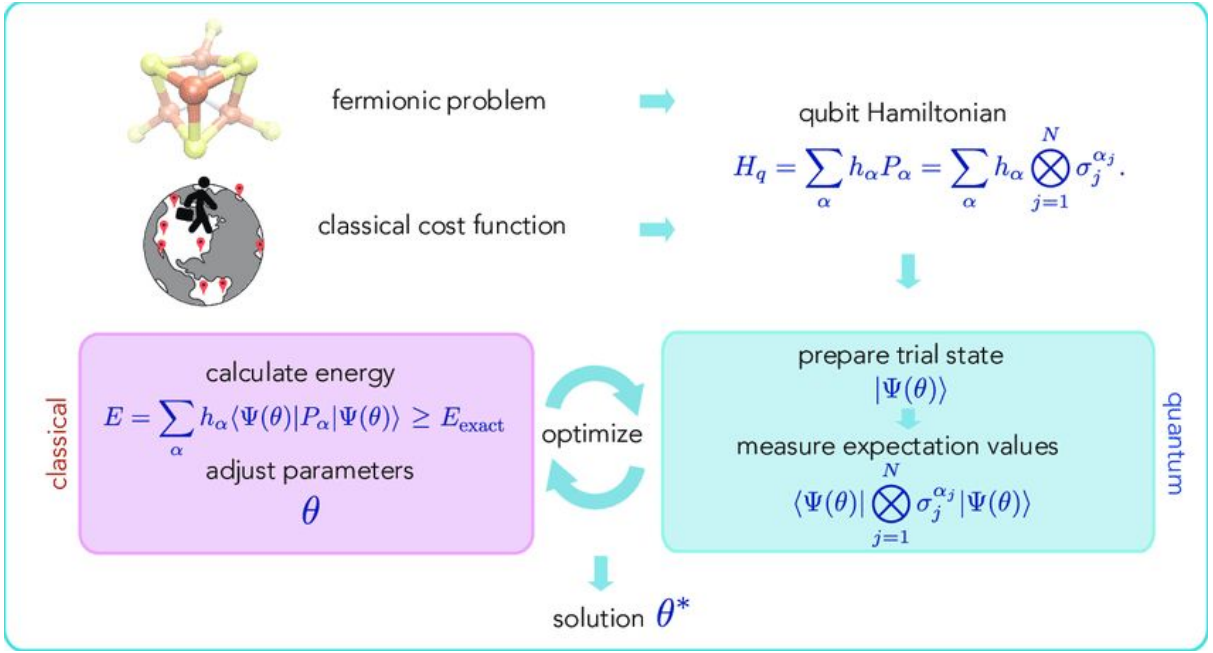
“The underlying physical laws necessary for the mathematical theory of a large part of physics and the whole of chemistry are thus completely known, and the difficulty is only that the exact application of these laws leads to equations much too complicated to be soluble.” - **Paul Dirac**



$$\mathcal{H}\,|\psi\rangle = E\,|\psi\rangle$$

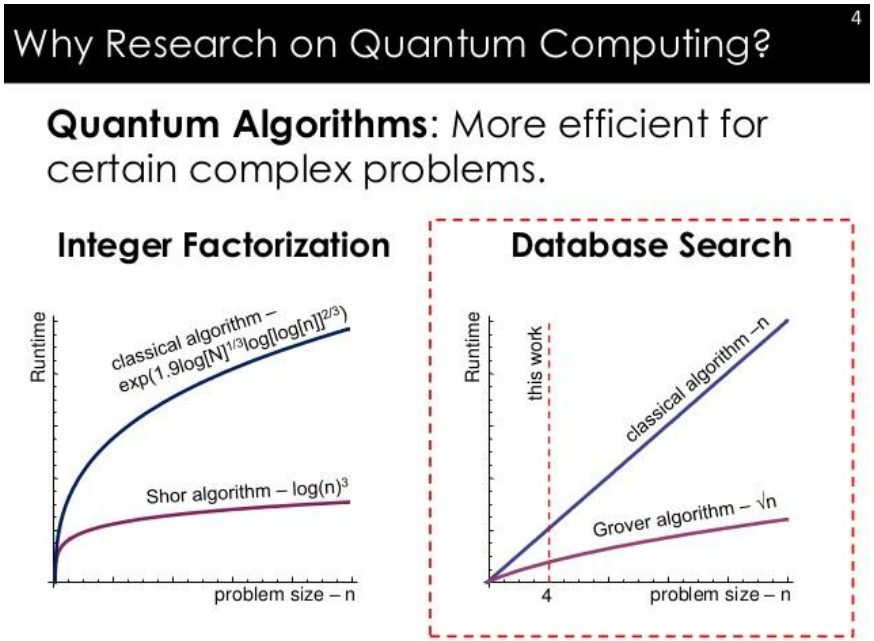
Simulating Chemistry

How it's done



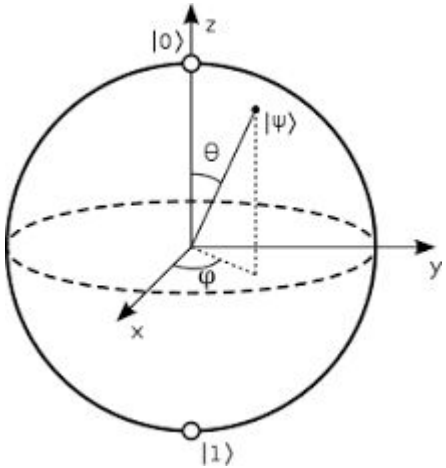
Simulating Chemistry

- Simulating atoms and molecules suffers from the “curse of dimensionality”
- Quantum algorithms promise to simulate important physical systems in practical amount of time



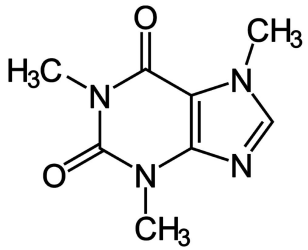
Quantum Myths

- Use exponential number of states
- Bits can be 0 and 1 at the same time
- Computes all answers in parallel



Simulating Chemistry

- We don’t understand caffeine!



Caffeine
(coffee)

Simulating Chemistry

$$N_2 + 3\ H_2 \rightarrow 2\ NH_3$$ → Fertilizer

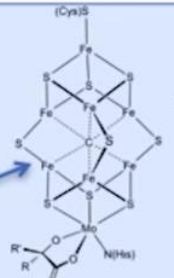
Humans: Haber Process

400° C & 200 atm

1-2% of ALL energy on earth, used on Haber process

Nature: Nitrogenase

25° C & 1 atm



"FeMoco"

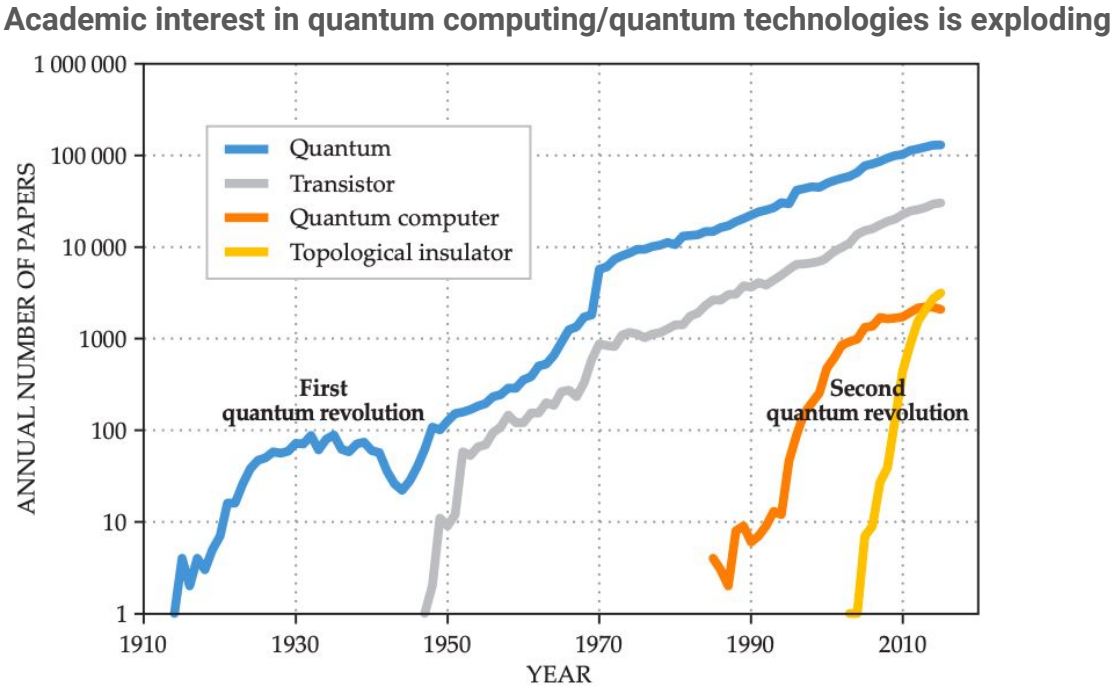
Beyond all current classical methods

Both electronic structure and substrate attachment almost totally unknown

Classically – No clear path to accurate solution
Quantum Mechanically – 150-200 logical qubits for solution

Jarrod McClean

Growth of quantum technologies



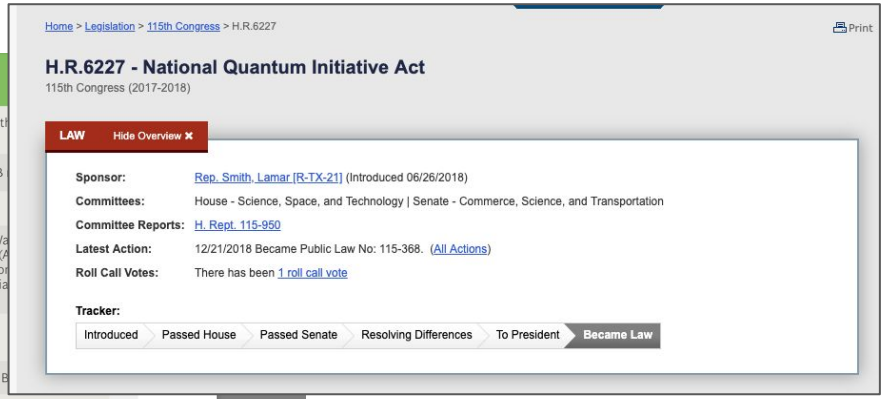
Physics Today 71, 9, 10 (2018); doi: 10.1063/PT.3.4008

Growth of quantum technologies

Corporate/government interest in quantum computing also rapidly expanding.

➔ **There is a rapidly expanding labor market for scientists familiar with quantum information and quantum computing**

Startup	Total [US$ millions]	Most recent funding	
D-Wave Systems	205	June 1, 2018	US$10 million of grant funding in a deal led by th Canadian Government
Rigetti Computing	119	March 28, 2017	Announced further US$40 million in its series B
PsiQ	65	Undisclosed	Undisclosed
Silicon Quantum Computing	60	August 2017	AU$83 million venture funded by: New South Wa (AU$9 million), University of New South Wales (A Commonwealth Bank of Australia (AU$14 millio (AU$10 million over two years), and the Australia (AU$25 million over five years)
Cambridge Quantum Computing	50	August 26, 2015	US$50 million of development capital
1QBit	35	November 28, 2017	CA$45 million of development capital in Series B
IonQ	22	February 24, 2017	US$20 million of Series B venture funding
Quantum Circuits	18	November 13, 2017	US$18 million of Series A venture funding
Alpine Quantum Computing	12	February 8, 2018	€10 million of grant funding
QC Ware	8	July 5, 2018	US$7 million of Series A venture funding
Optalysys	8	September 21, 2017	£3 million of seed funding from undisclosed investors
Nextremer	5	August 8, 2017	JP¥500 million of venture funding



Immediate future of corporate QC: Qiskit bootcamp!

- IBM is hosting a workshop at MSU on October 18-19th
- Will be introducing their quantum computing software package Qiskit
- Quantum computer programing contest (with prizes for best program)!

Our goal: familiarize ourselves with Qiskit, the physics of QC and writing and thinking about quantum algorithms for this camp!

Tentative schedule

Date	Topic
9/6	Information session + qiskit installation workshop
9/13	Quantum mechanics of quantum computing + intro to qiskit
9/20	Quantum mechanics of QC part 2+ Intro gate model
9/27	Gate model part 2
10/4	Introduction to quantum algorithms
10/11	Quantum algorithms part 2
10/18	**Qiskit workshop with IBM!**

Tentative schedule

Date	Topic
9/6	Information session + qiskit installation workshop
9/13	Quantum mechanics of quantum computing + intro to qiskit
9/20	Quantum mechanics of QC part 2+ Intro gate model
9/27	Gate model part 2
10/4	Introduction to quantum algorithms
10/11	Quantum algorithms part 2
10/18	**Qiskit workshop with IBM!**

Future: what topics would you like to see discussed? If you've got ideas or suggestions, or if want to lead a seminar, **let us know**!

Qiskit installation

Qiskit is IBM's software package for programming and simulating quantum computations, and running those computations on real, small quantum computers in IBM labs around the world.

Written in python

Installation instructions:

- https://qiskit.org/documentation/install.html
- https://www.youtube.com/watch?v=M4EkW4VwhcI (Google video search "How to install qiskit")