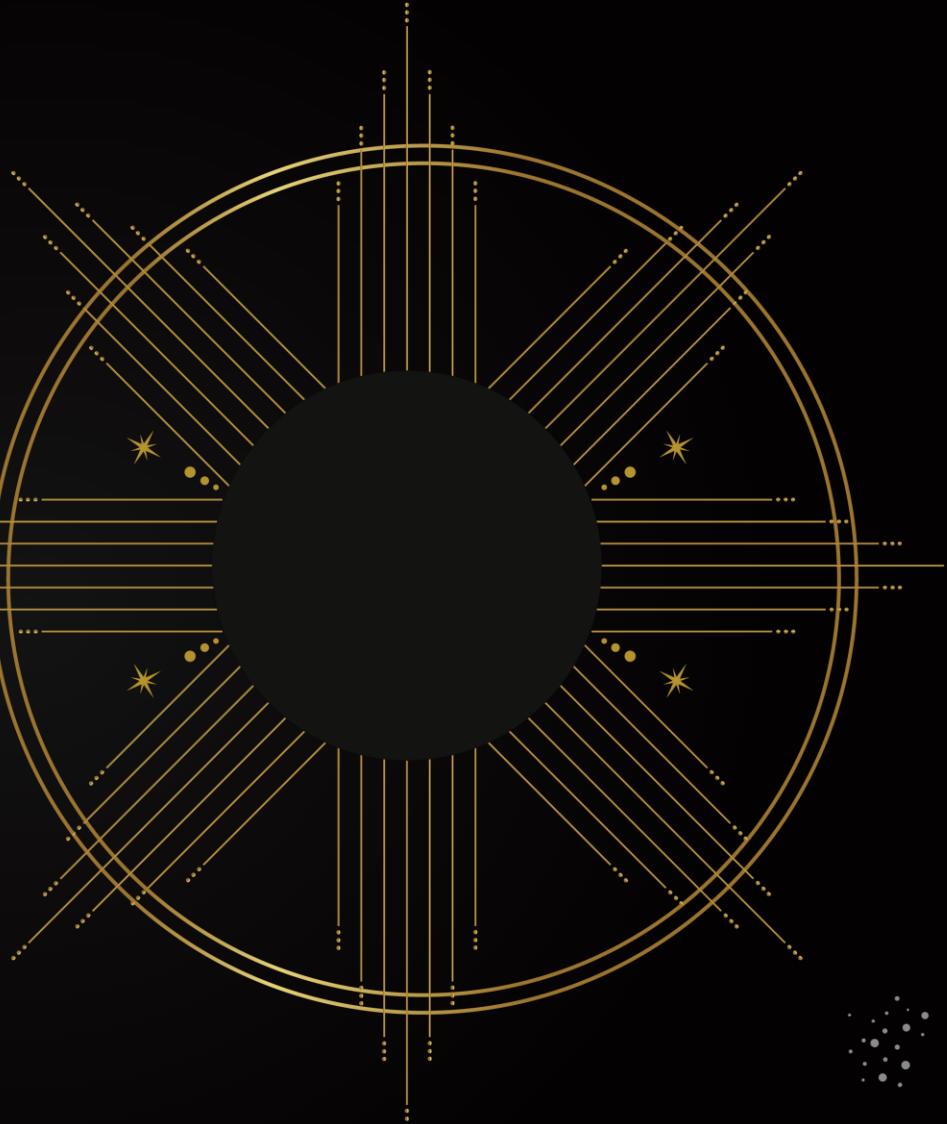




EQUINOX

AI&DATA LAB





Applications & Big Players

Bringing QC to business



Big Players & Applications

Contents

1. Applications

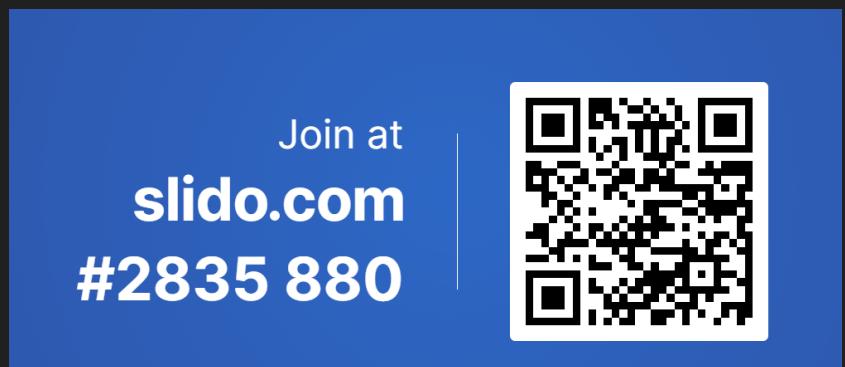
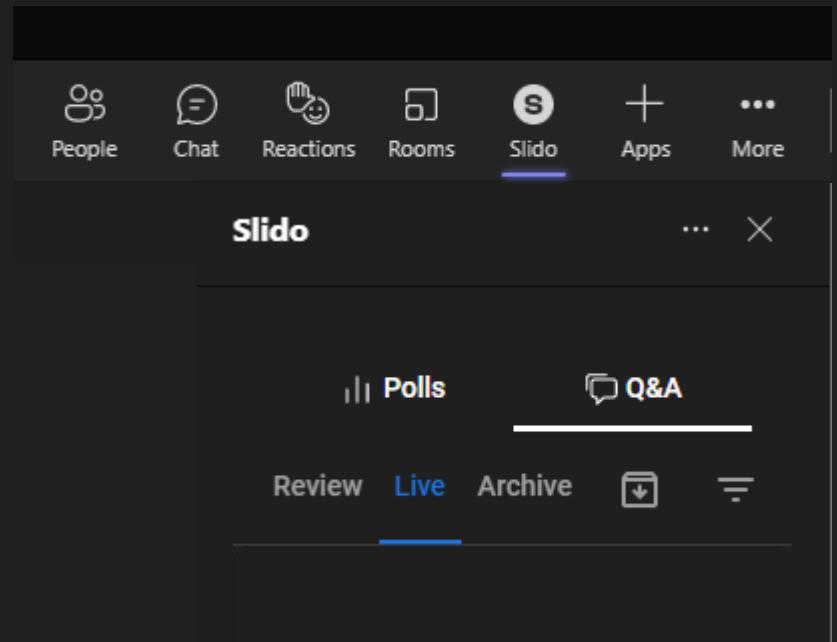
- a) Drug discovery
- b) Energy optimisation
- c) Vehicle routing
- d) Finance

2. The highest profile QC companies



QnA

- We use Slido for Q&As and polls
- Teams app users can see Slido at the bottom of the meeting
- Web users can go to slido.com and enter the number **#2835880**



QnA- Chemicals companies using QC

- Bayer
- Boehringer Ingelheim
- Roche

Startups using QC for chemistry problems

Phasecraft

Rahko

Qubit pharmaceuticals

Quantinuum

Zapata Computing

Netramark

Molecular Quantum Solutions

HQS Quantum Simulations

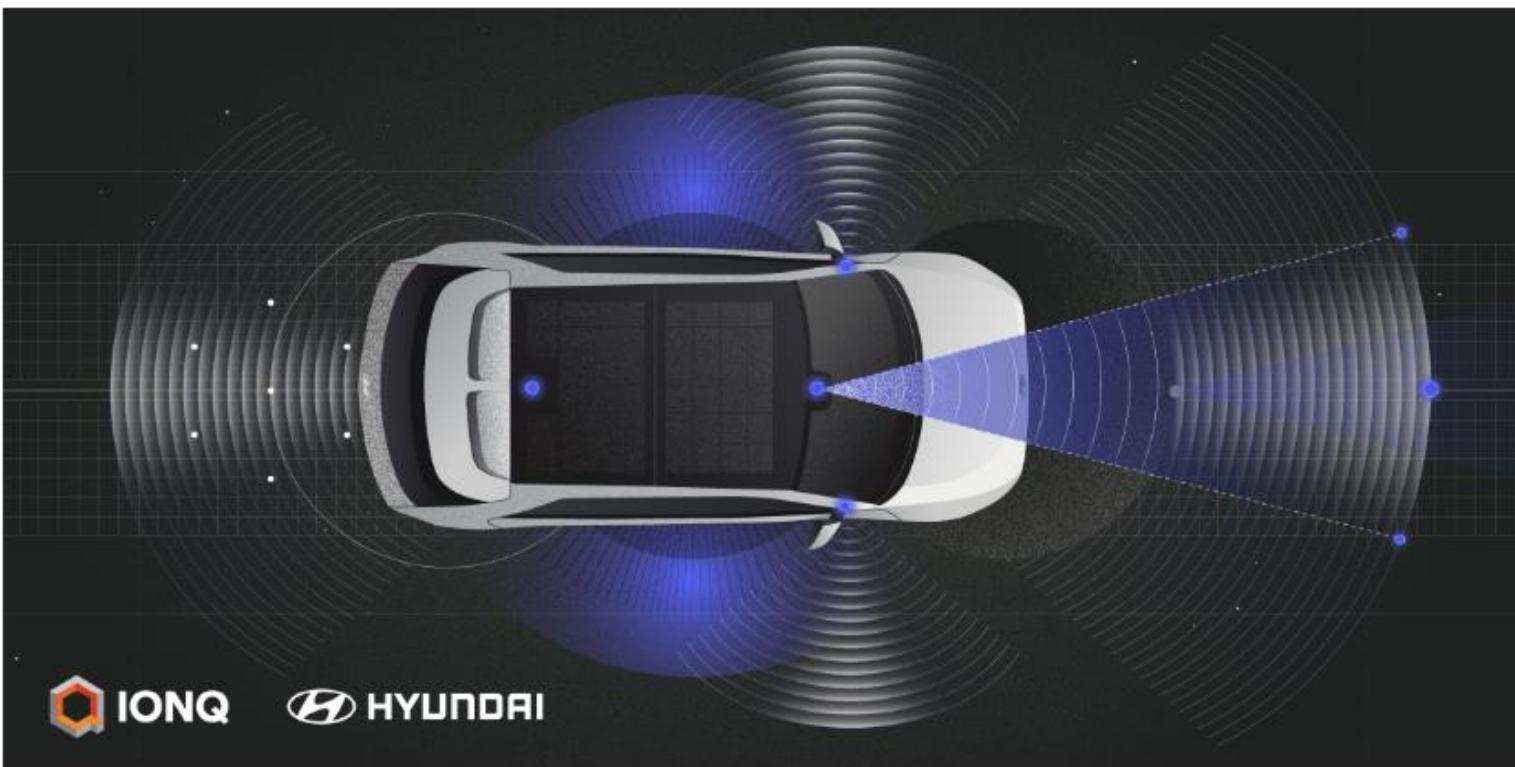
AQEMIA

[11 Companies Using Quantum Technologies To Determine The Properties & Reactions of Chemical Substances, Optimizing R&D For Chemistry & Pharma \(thequantuminsider.com\)](https://thequantuminsider.com/companies-using-quantum-technology-chemistry-pharma/)



Which advan

- a) Reduced
- b) Processing
- c) Improved
- d) Running
- e) Solving p
- f) Solving t



IonQ (NYSE: IONQ), a leader in quantum computing, and Hyundai Motor Company today announced a new project designed to apply quantum machine learning to image classification and 3D object detection for future mobilities.

Image classification and 3D object detection are foundational steps toward the next generation of mobilities, including autonomous vehicles. Together, IonQ and Hyundai will look to improve computational functionality through more efficient machine learning on quantum computers, as they can process enormous amounts of data faster and more accurately than classical systems.

NOPE



Web users c



Business expectations

- Focus on optimisation, simulation & cybersecurity for early applications
- Last year, BCG estimated **\$450-\$850 billion** in value creation, with 80% of that going to end users

In a recent Capgemini report,

- 23% of surveyed organisations are either working or planning to work with quantum technologies
- 85% of those planning to increase investment in the next year
- EY study found “81% of senior UK executives expect quantum computing to play a significant role in their industry by 2030”



Exhibit 1 - More Than Two-Thirds of Equity Investments in Quantum Computing Have Been Made Since 2018



Sources: PitchBook (as of June 7, 2021), BCG analysis.

¹E=estimate for full year.

"What Happens When 'If' Turns to 'When' in Quantum Computing?.. BCG Digital Transformation (2021).

Distinguishing hype from science



The business course will cover how to distinguish product marketing from technical achievements



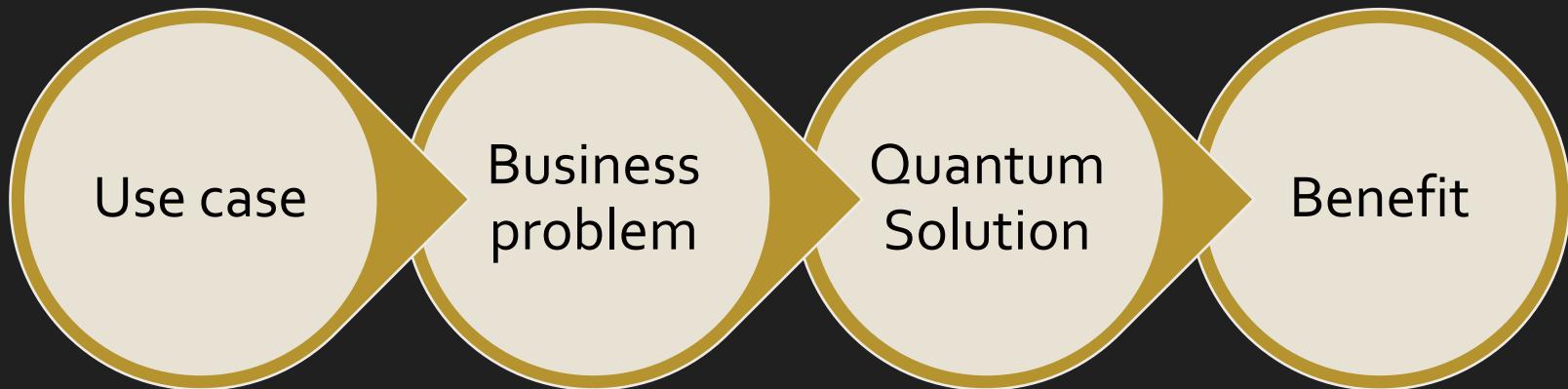
Marketing uses buzzwords, lacks detail about the implementation and doesn't reference scientific publications



Real technical progress is measured and usually comes with scientific publishing



Framework for quantum advantage



What should a quantum solution provide?

Scalable: can be deployed in industry in a relevant time period

Measurable: Or qualitative benefits over current (classical) solution

Achievable: Be realistic on near-term quantum hardware

Relevant: Solve a problem that really exists

Value: Net gain to justify the investment

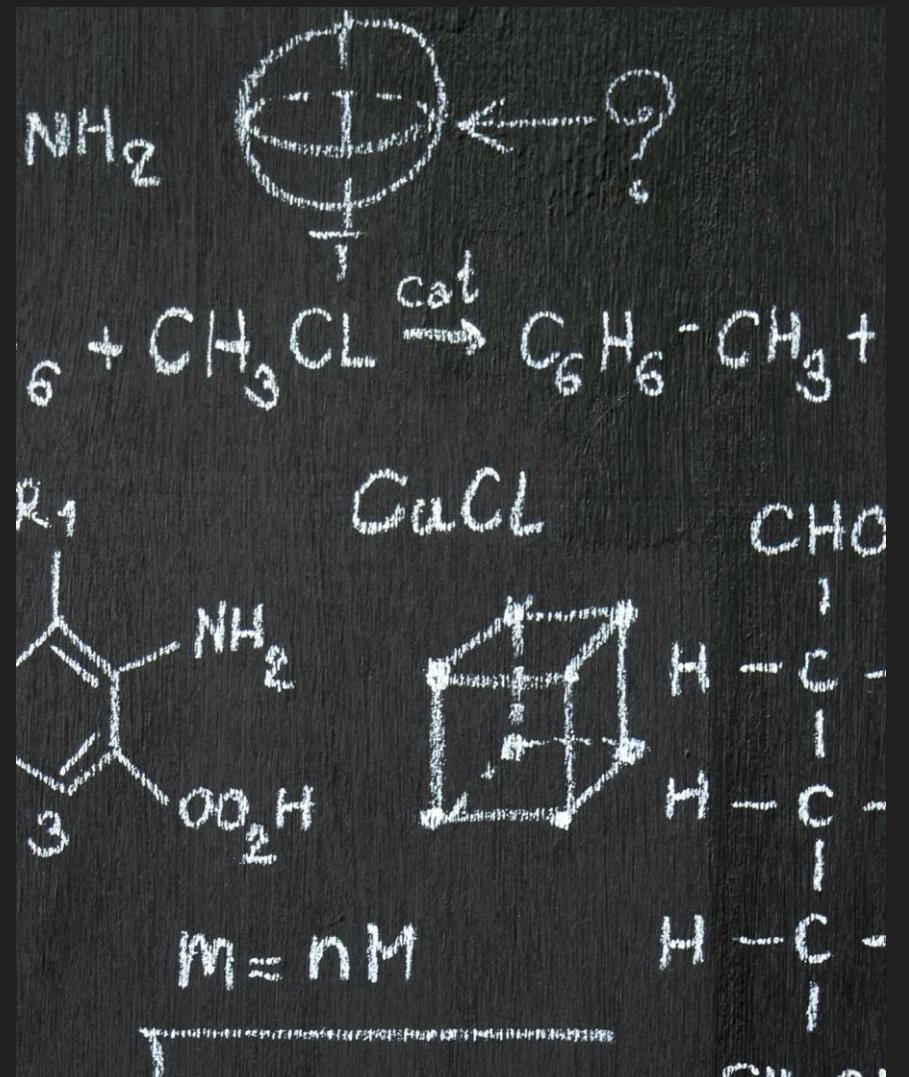


Application: Drug discovery

- Bayer
- Boehringer Ingelheim
- Roche

Quantum simulation

- Use case: Developing new medicines
- Problem: Modelling complex chemicals is difficult because they are inherently quantum systems
- Quantum Solution: Simulate the chemistry using a quantum computer
- Advantage: Improved accuracy, better understanding of chemistry



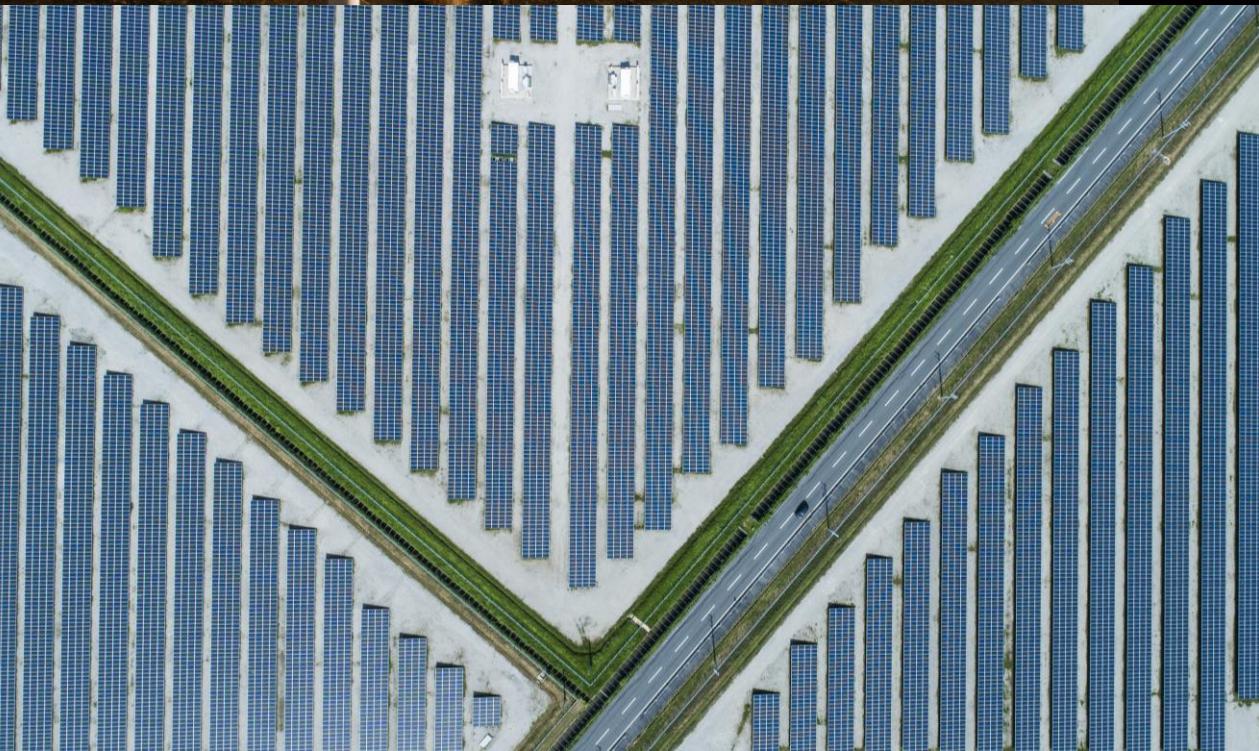
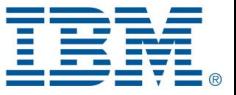
Considered the most promising application of QC, BCG estimate Q simulation to generate \$175-\$330 Bn



Pharmaceutical use case

- Modelling how drugs undergo chemical reactions is difficult
- Drug must be developed and undergoes long and expensive clinical trials
- High failure-rate at late stages make costs of development very high
- QC could shorten development times and cost substantially





Application: Energy Optimisation



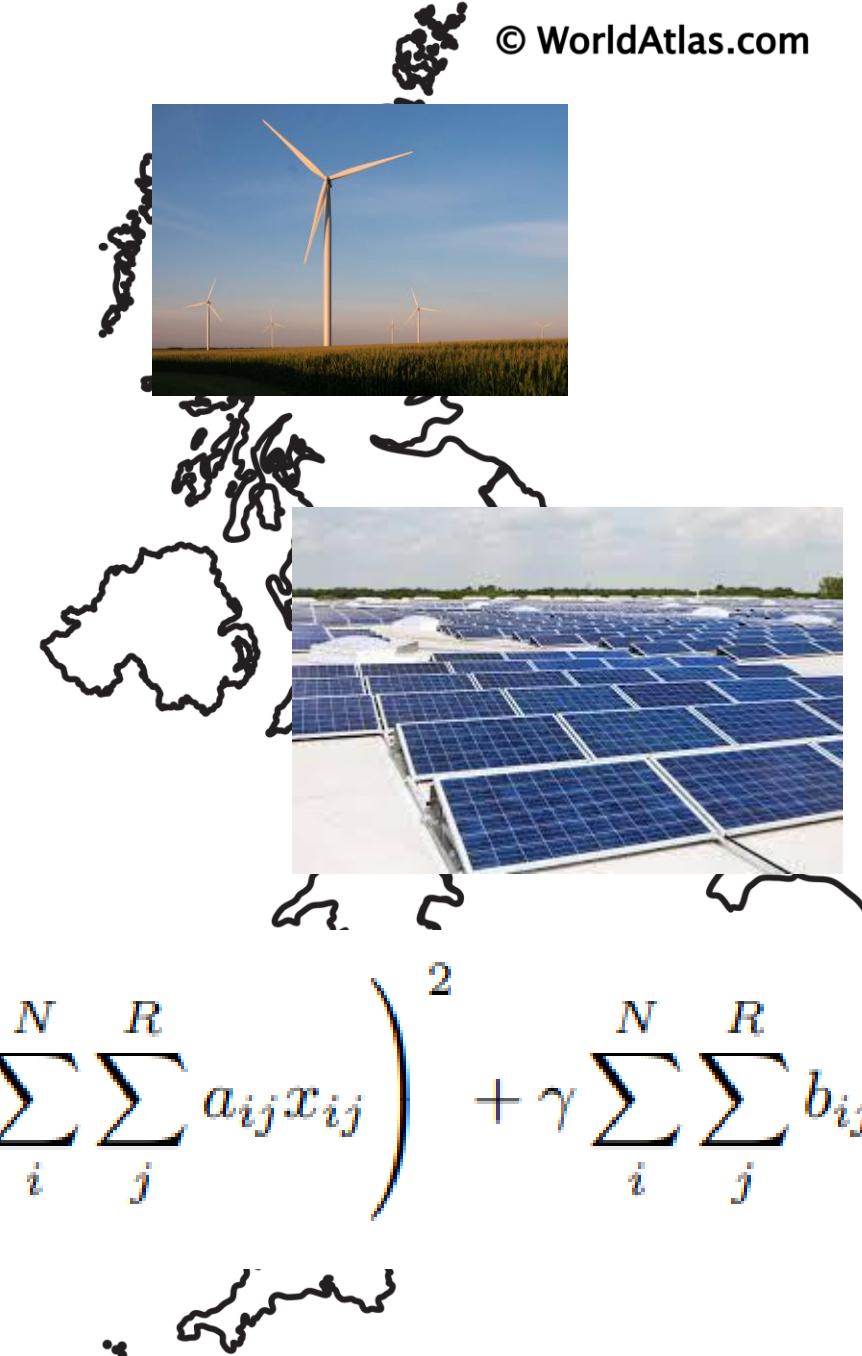
Energy Optimisation

- **Use Case:** Governments wish to increase energy production from renewable sources
- **Problems:** Finding the optimum set of energy sources is difficult
- **Quantum Solution:** Quantum optimisation algorithm to find the best set of energy sources
- **Advantage:** A range of suggested solutions in case one doesn't work



An optimisation problem

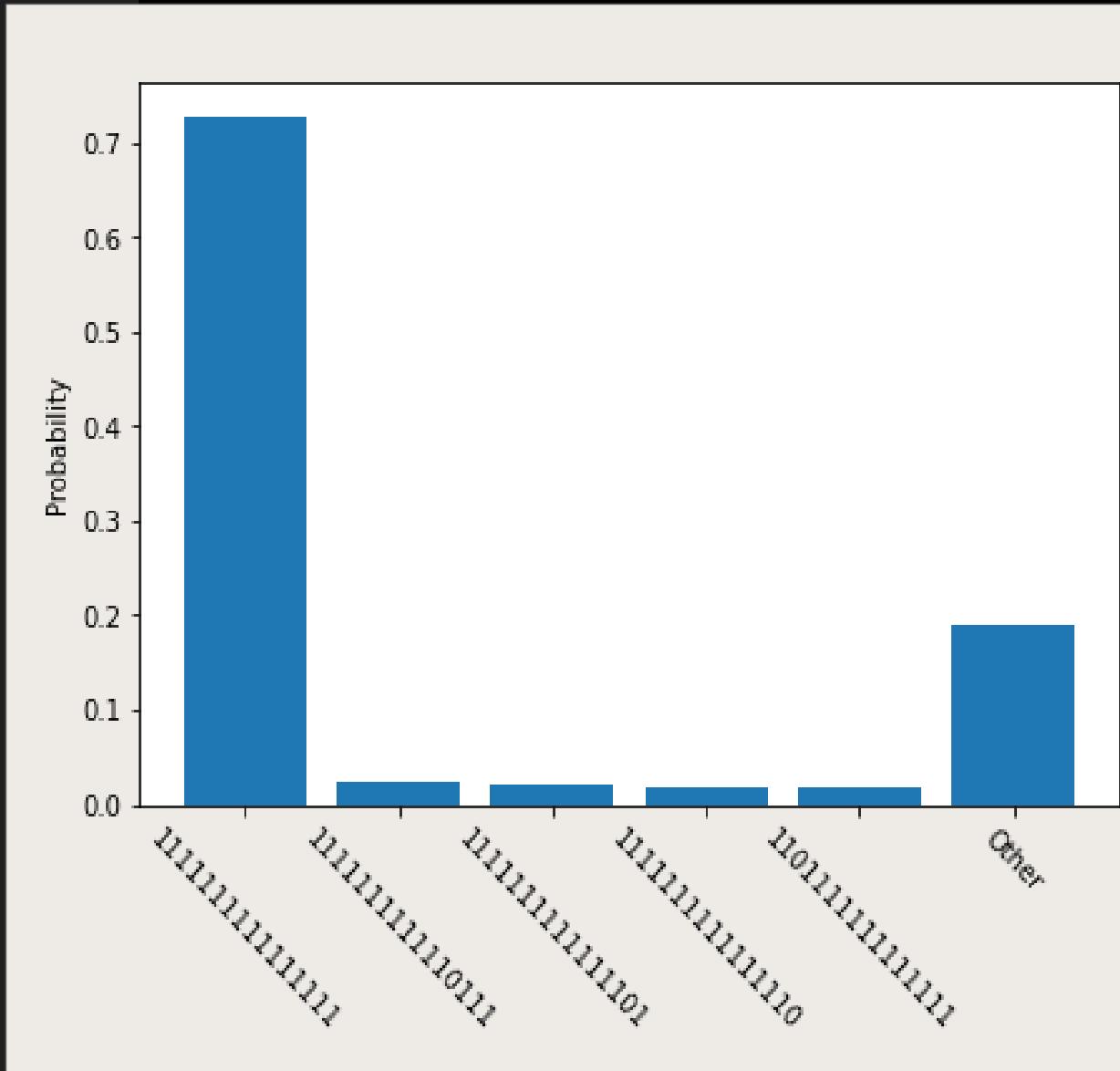
- The problem was to maximise the total renewable energy production whilst minimising the cost
- For R regions and N power sources, there are N*R possible positions to place a power station



$$\min_{X \in \{0,1\}^{N \times R}} f(X = x_{11}, \dots, x_{nn}) = \lambda \left(C - \sum_i^N \sum_j^R a_{ij} x_{ij} \right)^2 + \gamma \sum_i^N \sum_j^R b_{ij} x_{ij}.$$

Result

- These are bad results
- Nobody else was able to get this far in the 24 hours we had to solve the problem
- Likely caused by a regularization issue

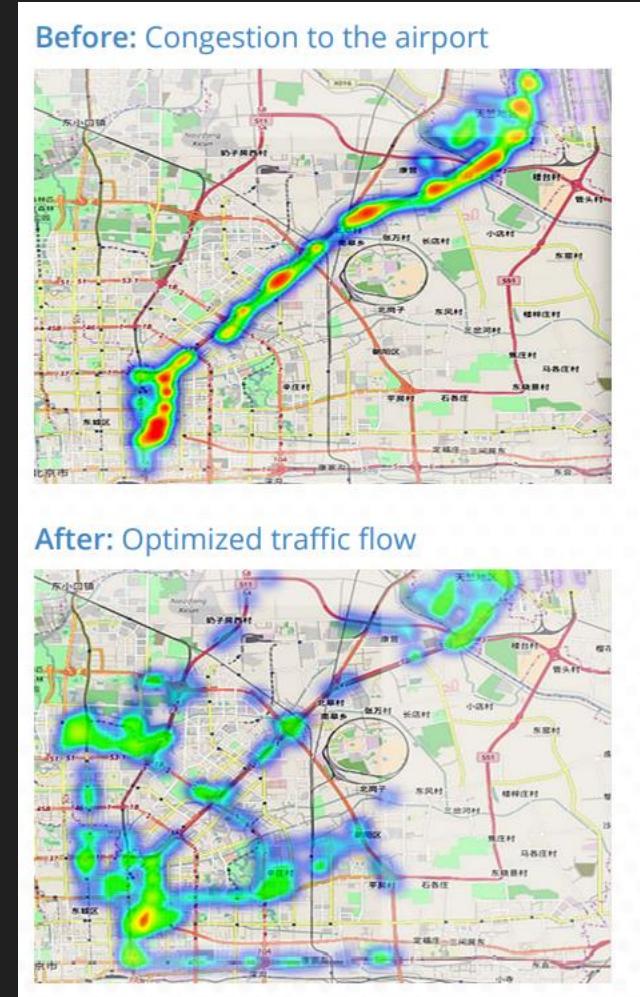


Application: Vehicle Routing

- D-Wave & Volkswagen (2019)

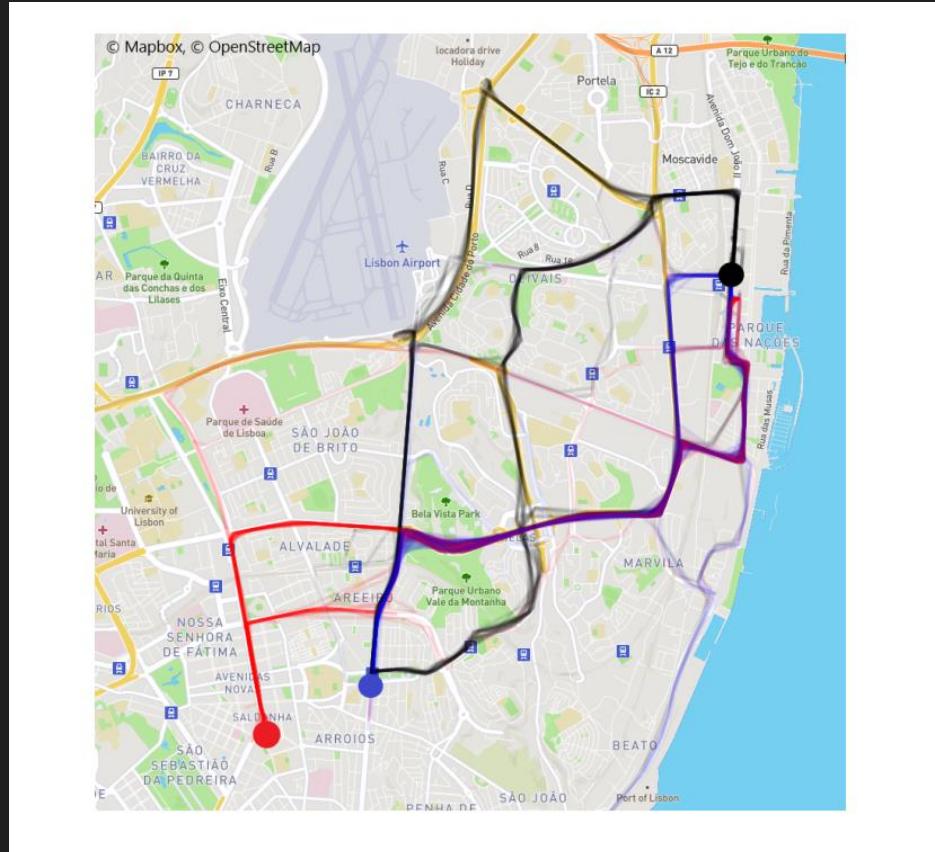
Vehicle Routing

- **Use Case:** Delivery companies, Uber, City planners
- **Problems:** Finding the optimum routing in changing traffic conditions whilst meeting a set of requirements is computationally difficult
- **Quantum Solution:** Quantum annealing to optimise routes quickly
- **Advantage:** Less traffic, real-time adaptability



Real-time route optimisation

- For the 2019 Web Summit, VW & the city of Lisbon piloted a QC traffic optimisation project
- Goal: design bus routes to avoid traffic & integrate the system into an application for bus drivers



Real-time route optimisation

- Data Science to create routes from previous conferences
- Mapped the routing problem onto a binary optimisation problem
- Used the D-Wave QPU to suggest routes every 120 seconds

$$\text{Obj} = \sum_{p \in P} \text{cost}(p) + \lambda \sum_i \left(\sum_j q_{ij} - 1 \right)^2, \quad (1)$$

where q_{ij} are the binary decision variables associated with vehicle i taking route j , P is the set of all GPS points that overlap in the suggested routes, λ is a scaling factor ensuring only one route is



Results

- Project was implemented successfully
 - 9 busses, 162 trips over 4 days
- Mixed reactions from the bus drivers:
 - some liked the new routes
 - others didn't like having new routes suggested too frequently
- Similar case study has created immense value at the port of LA

Quantum Shuttle: Traffic Navigation with Quantum Computing

Sheir Yarkoni*
sheir.yarkoni@volkswagen.de
Volkswagen Data:Lab
Munich, Germany

Florian Neukart
Volkswagen Advanced Technologies
San Francisco, California

Eliane Moreno Gomez Tagle
Volkswagen Data:Lab
Munich, Germany

Nicole Magiera
Volkswagen Data:Lab
Munich, Germany

Bharat Mehta
Hexad GmbH
Berlin, Germany

Kunal Hire
Hexad GmbH
Berlin, Germany

Swapnil Narkhede
Hexad GmbH
Berlin, Germany

Martin Hofmann
Volkswagen AG
Wolfsburg, Germany



Application: Financial modelling

- IonQ, Fidelity
- Quantinuum,
- IBM, JP Morgan, Goldman Sachs

+12,00.50

+11,00.00



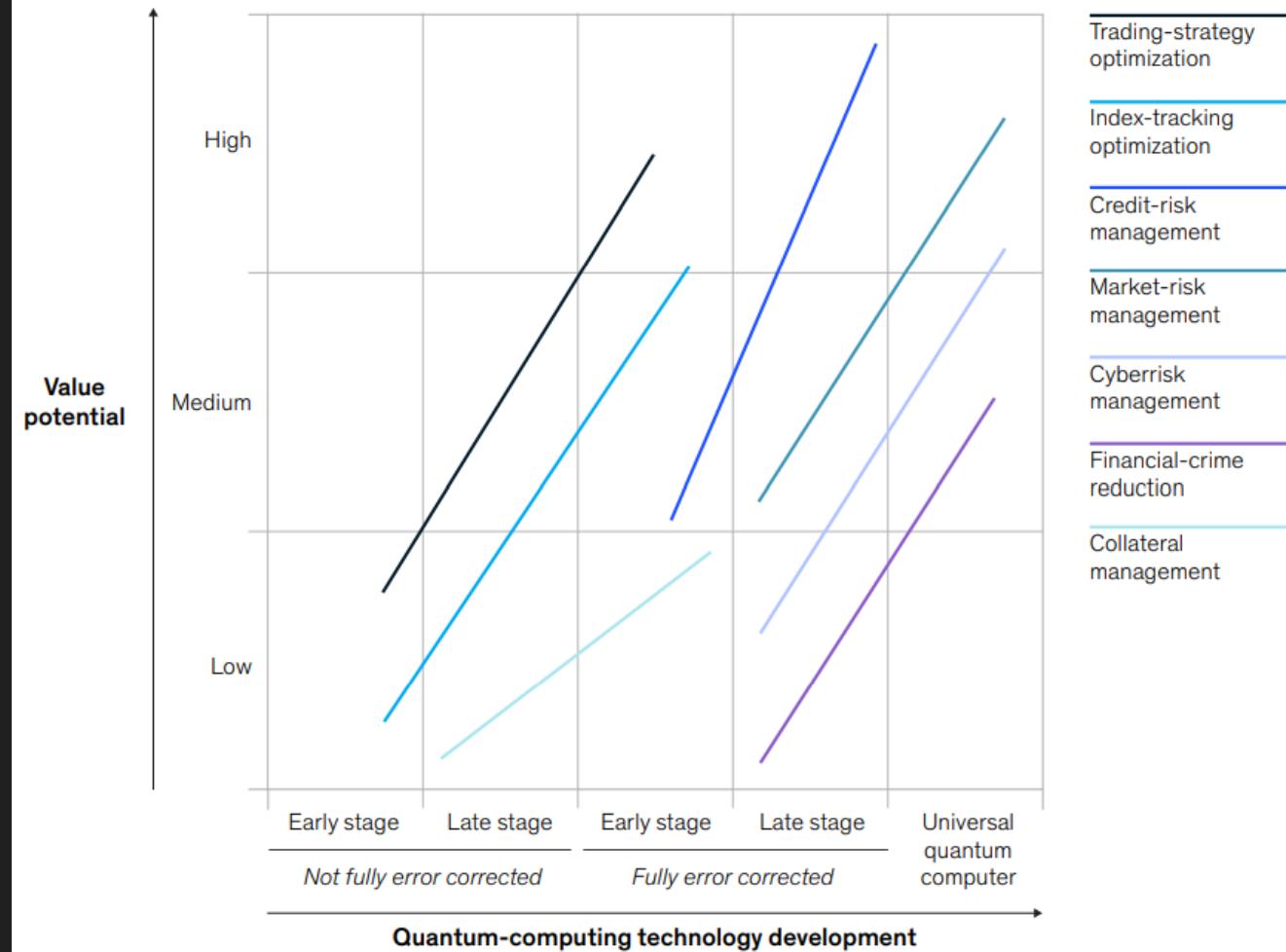
Financial Modelling

- **Use Case:**
 - Banking
 - Investment funds
 - Government policy
- **Problems:** Financial modelling requires the simulation of an exponentially large set of variables
- **Quantum Solution:** Range of quantum models, optimisation
- **Advantage:** Speed



- A marginal improvement of 1-2% could generate an additional \$36-71 billion in revenue
- Banks are big users of HPC

Finance has many computationally intense tasks that could benefit from quantum computing.



"Quantum computing: An emerging ecosystem and industry use cases"
McKinsey (2021)



How does it work?

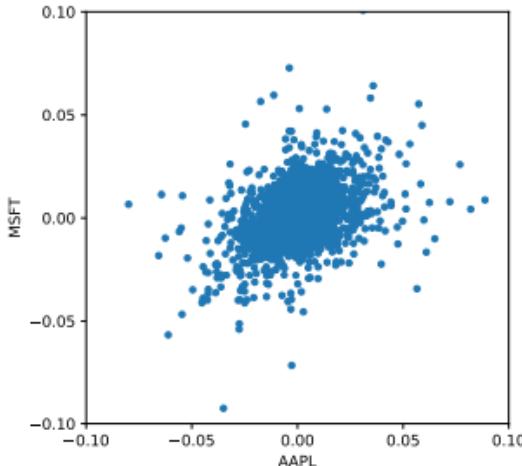
There are many proposed quantum solutions:

- Quantum Monte Carlo simulations have a theoretical quadratic improvement over classical MC
- Quantum Generative Adversarial Networks could offer better synthetic datasets for training
- Using entanglement to model joint probability distributions
- There are a large range of potential QML methods proposed
- The HHL algorithm for solving linear systems of equations (requires FSFT compute)

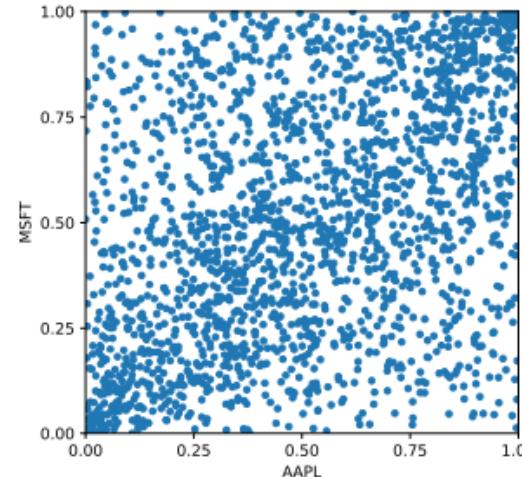




(a)



(b)



(c)

Fig. 2: (a) Hypothetical Growth of \$10,000 invested in AAPL and MSFT between 2010-2018 (b) Scatter Plot of Daily Returns (c) Scatter Plot of Data after Probability Integral Transform

Generative Quantum Learning of Joint Probability Distribution Functions

Elton Yechao Zhu^a, Sonika Johri^b, Dave Bacon^b, Mert Esencan^a, Jungsang Kim^b, Mark Muir^a, Nikhil Murgai^a, Jason Nguyen^b, Neal Pisenti^b, Adam Schouela^a, Ksenia Sosnova^b, Ken Wright^b

^a*Fidelity Center of Applied Technology,
FMR LLC, Boston, MA 02210, USA*

^b*IonQ Inc, 4505 Campus Dr, College Park, MD 20740, USA*

Additional thoughts

- Occasionally quantum advantage is given over the worst-case prediction model
- Remains unclear whether a quadratic quantum speedup will offer any value in the medium-term
- For some areas QC presents an overengineered solution
- Many of these applications require much more powerful quantum computers



The Big 6

- *“Perhaps no previous technology has generated as much enthusiasm with as little certainty around how it ultimately will be fabricated.”*-BCG Report 2021
- Important to have a software solution that can run on any type of quantum computer

There are about 40 companies working on developing quantum computers, here are some of the big ones



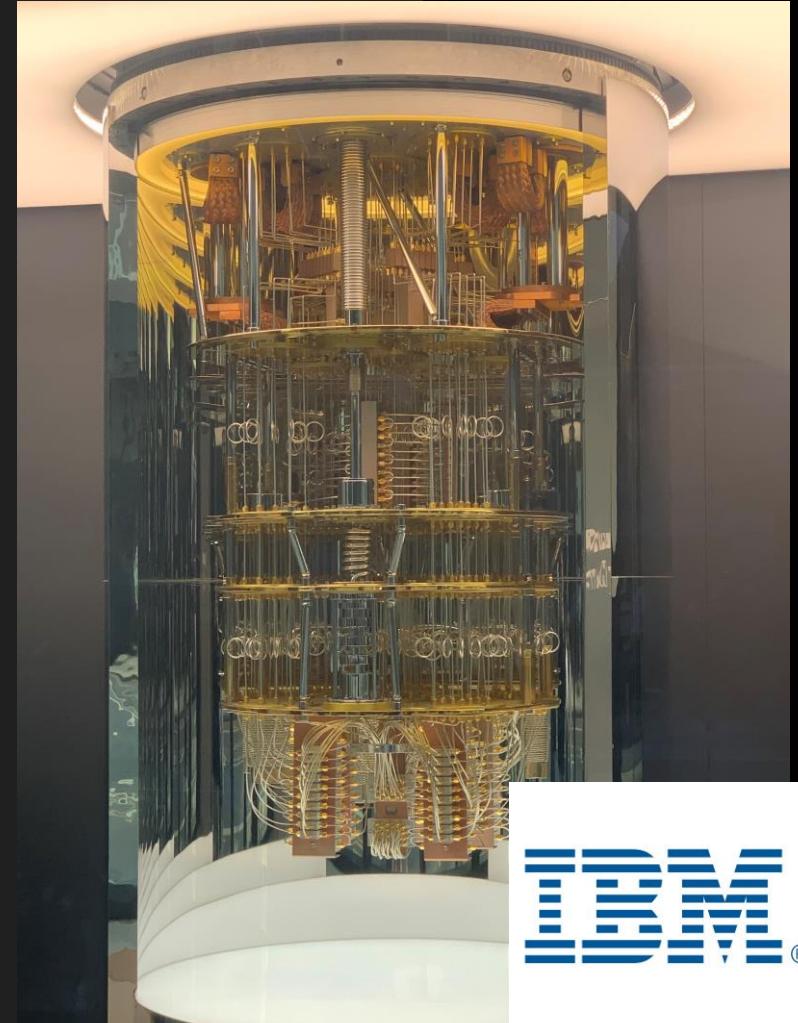
D-Wave

- First quantum computing company (1999)
- Different type of quantum computer:
quantum annealer
- Focussed on optimisation problems
- Advantage platform offers 5,000 qubits
- Offer cloud access and Ocean SDK
- Recently pivoted to the gate model of QC
- Just went public (\$1.7 Bn market cap)



IBM

- Unrivalled and freely available educational resources
- Free access to 5/7 qubit machines over the cloud
- Qiskit python package dominates industry & academia
- Largest network of businesses & universities working with them
- Their Eagle QPU has 127 physical qubits



Development Roadmap

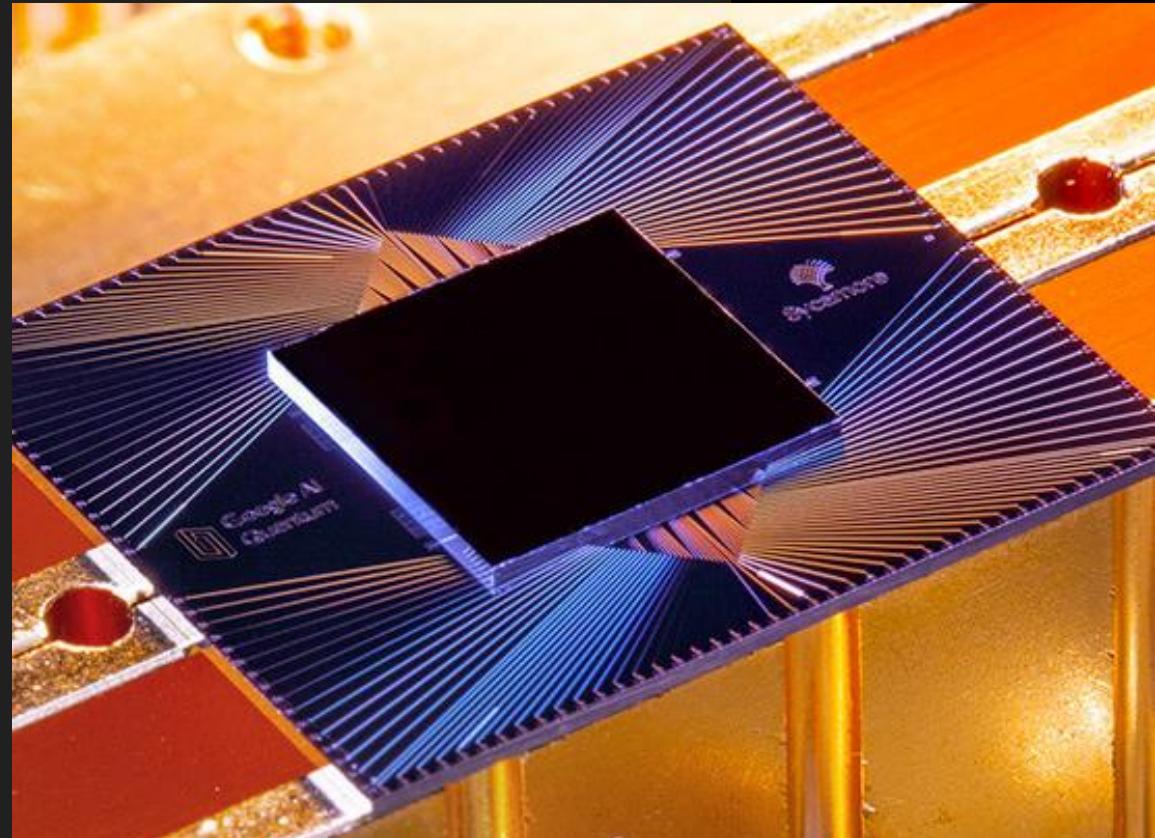
Executed by IBM ✓
On target ✅

IBM Quantum

2019 ✓	2020 ✓	2021 ✓	2022	2023	2024	2025	Beyond 2026	
Run quantum circuits on the IBM cloud	Demonstrate and prototype quantum algorithms and applications	Run quantum programs 100x faster with Qiskit Runtime	Bring dynamic circuits to Qiskit Runtime to unlock more computations	Enhancing applications with elastic computing and parallelization of Qiskit Runtime	Improve accuracy of Qiskit Runtime with scalable error mitigation	Scale quantum applications with circuit knitting toolbox controlling Qiskit Runtime	Increase accuracy and speed of quantum workflows with integration of error correction into Qiskit Runtime	
Model Developers				Prototype quantum software applications →	Quantum software applications			
Algorithm Developers	Quantum algorithm and application modules ✓				Machine learning Natural science Optimization			
Kernel Developers	Circuits	Qiskit Runtime	Dynamic circuits ↗	Threaded primitives	Error suppression and mitigation	Error correction		
System Modularity	Falcon 27 qubits ✓	Hummingbird 65 qubits ✓	Eagle 127 qubits ✓	Osprey 433 qubits ↗	Condor 1,121 qubits	Flamingo 1,386+ qubits	Kookaburra 4,158+ qubits	Scaling to 10K-100K qubits with classical and quantum communication
				Heron 133 qubits x p	Crossbill 408 qubits			

Google

- Claimed “quantum supremacy” in 2019
- Google AI launched TensorFlow Quantum to gain a foothold in QML
- Quantum virtual machine available in Collab
- Cirq python library for developing quantum circuits
- Aiming at 1M qubits by 2030



Sycamore chip originally developed in 2018



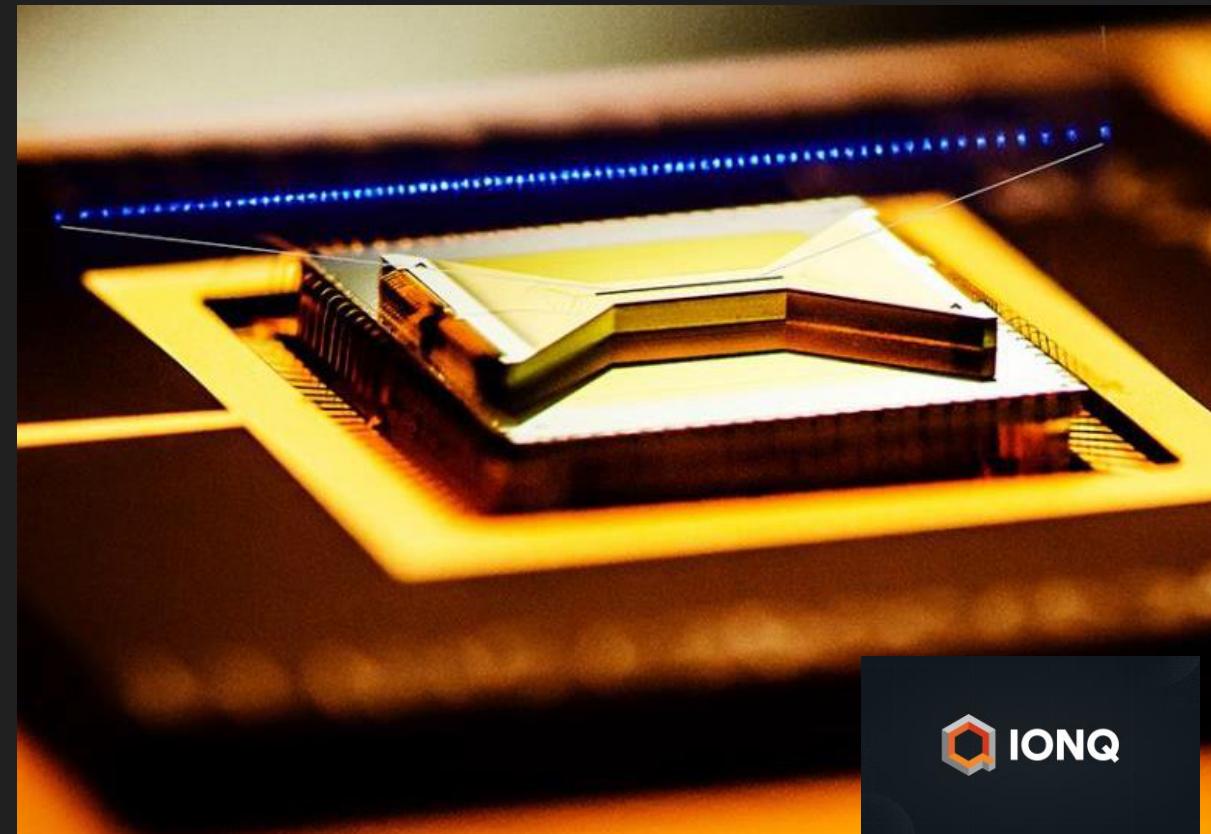
Quantium

- Merger of Honeywell QS & Cambridge Quantum Computing (CQC)
- Hardware agnostic software development kit (TKET) for optimising quantum circuits
- Research in QNLP, cybersecurity, developing quantum computers
- Recently showed “logical” qubits
- 200,000+ users of their software solutions
- IBM is an investor



IonQ

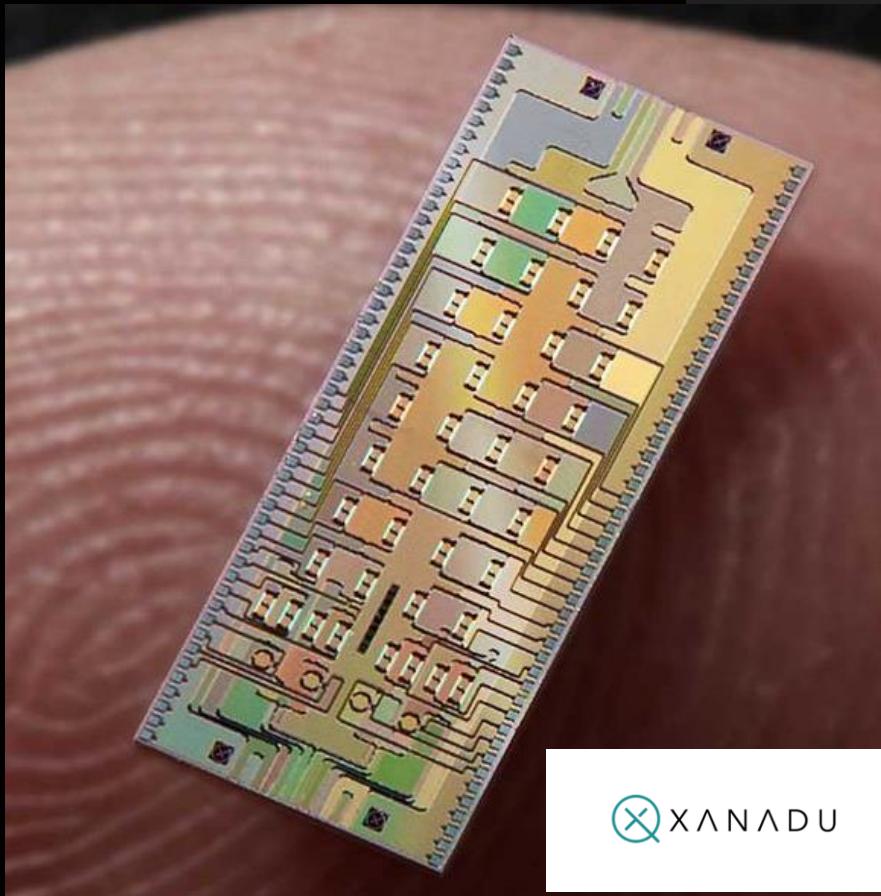
- Their QV forced IBM to redefine their benchmark for QC
- IonQ then defined their own benchmark: algorithmic qubits
- IPO this year
- Recently announced collaboration with Mitsubishi to work on computer vision & battery research



 IONQ



Xanadu



- Develop QC using integrated photonics less mature than others
- Python library has excellent documentation
- Very strong in Quantum Machine Learning
- [Xanadu Quantum codebook](#) is the closest competitor to IBMs educational
- Annual hackathons are a great way to develop QC skills



Honourable mentions

- **Microsoft**- Azure quantum is a cloud platform for QC, their exotic topological qubits may even be real
- **Intel**- they use spin qubits, which may become more competitive in the near term. It's a bit like their graphics cards...
- **Amazon**- AWS Braket offers access to QaaS through most of the main hardware providers



Assignment 2 [Due 22nd August]

Imagine you want to develop an application of QC, covered in today's class or otherwise. For each of these questions, briefly explain why:

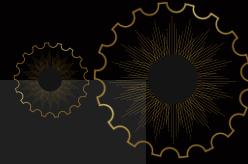
1. Which application do you choose?
2. How does QC add value to this application
3. Which QC hardware/software company do you decide to partner with for access to hardware/software
4. How do you communicate the results of your experiments?
5. [Challenge] How do you source/develop the talent needed for this application?

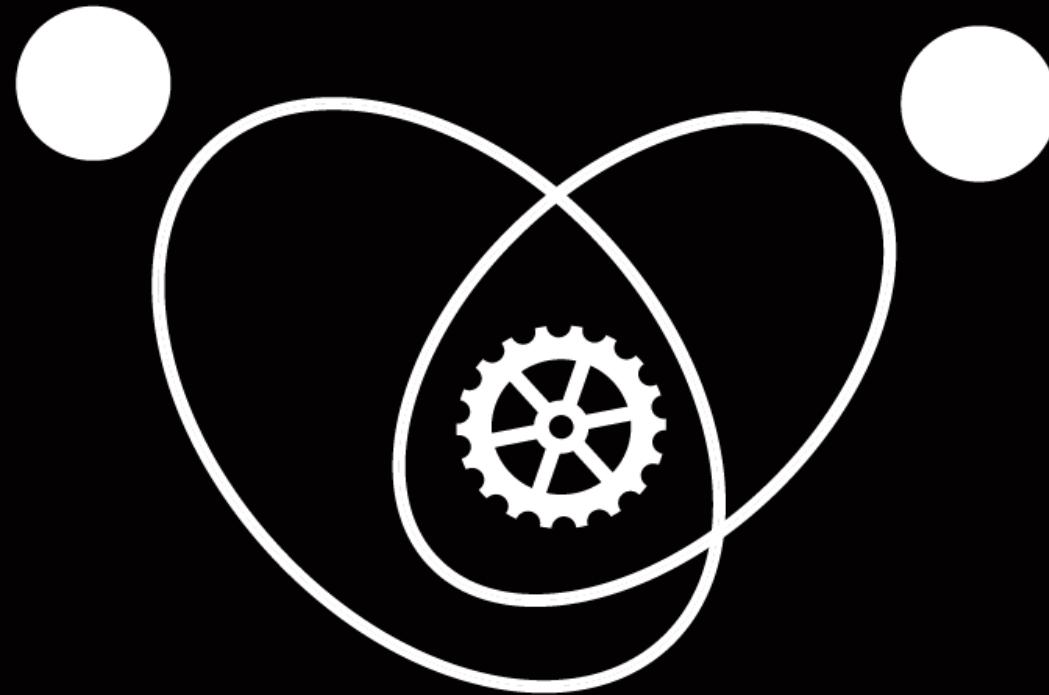
Doing additional research will help with question 2. You may also find these helpful:

[EY survey](#) (June 2022)
[Capgemini Report](#) (March 2022)
[BCG Report](#) (July 2021)
[Accenture Report](#) (Jan 2021)



GRACIAS





EQUINOX

AI & DATA LAB