

The Noisy Intermediate-Scale Quantum Computing Era

Alba Cervera-Lierta

JURES'21

September 17th, 2021



UNIVERSITY OF
TORONTO

Outlook

1. Recap: what is Quantum Computation?
2. Quantum computing in the NISQ era
3. Applications
4. NISQ horizon

The basics of Quantum Computation

What

How

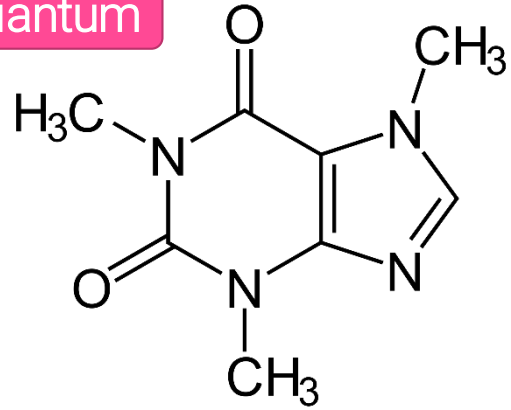
Where

Why

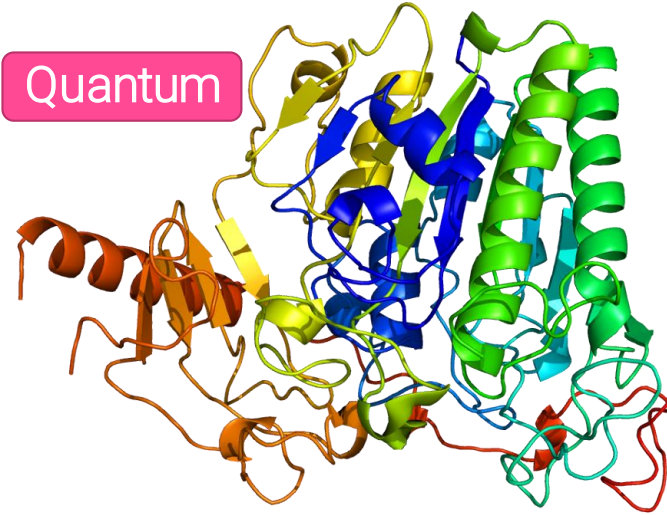
Who

Why do we need a quantum computer

Quantum



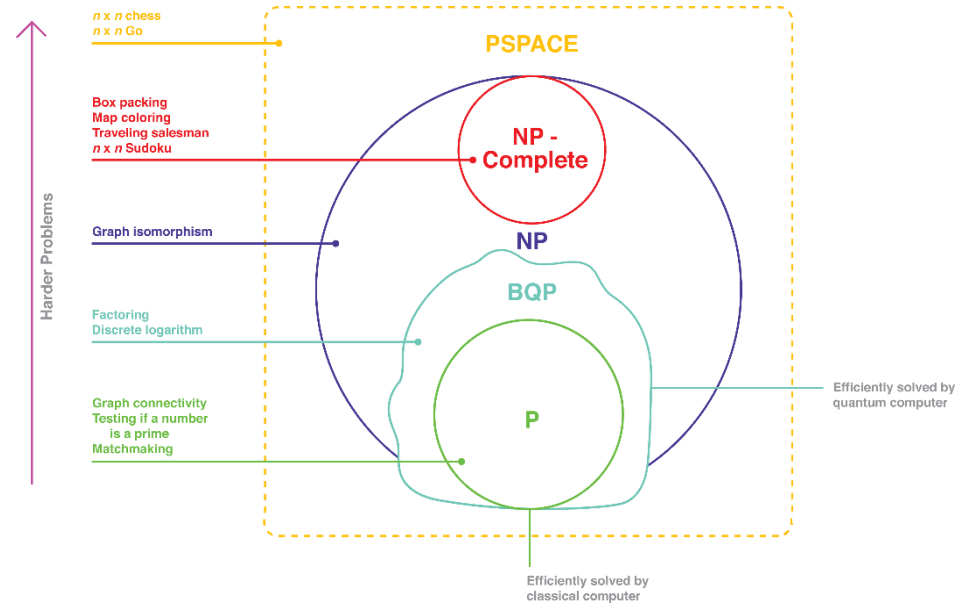
Quantum



Not Quantum



Quantum



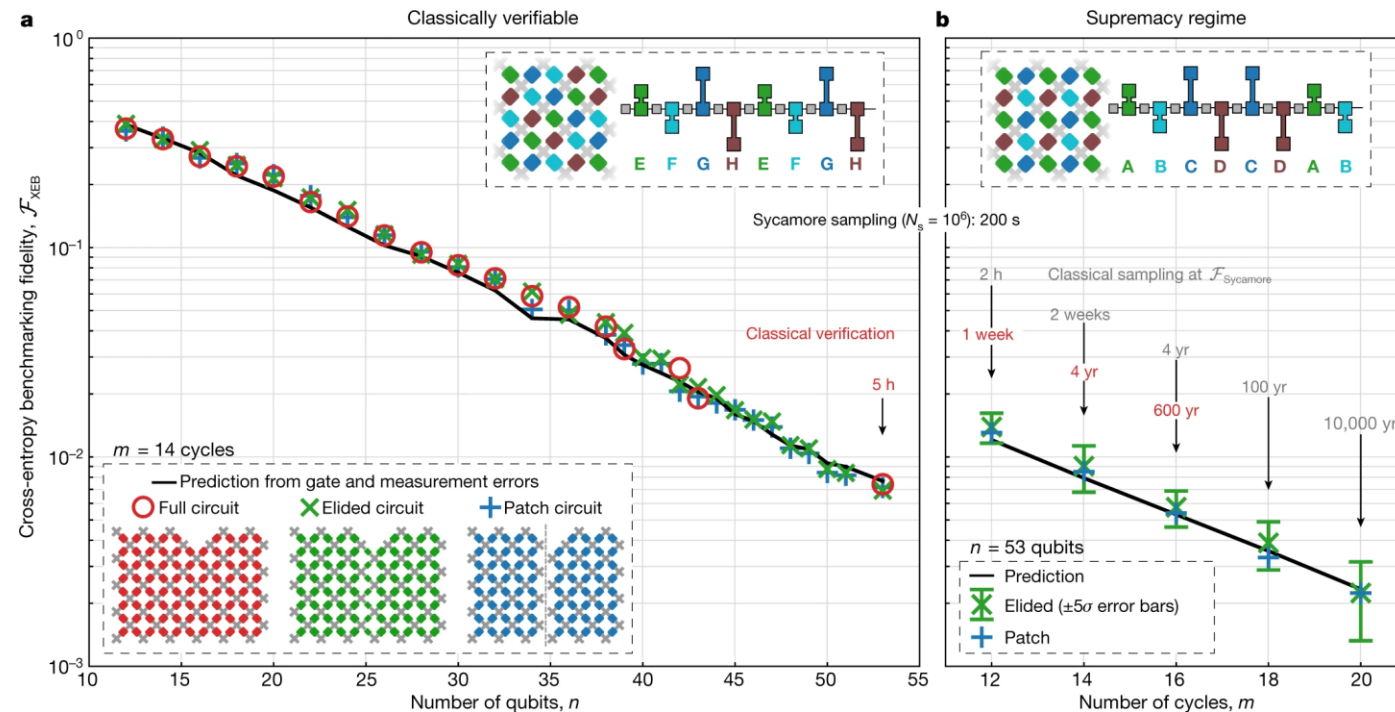
Powerful, but Not Quantum



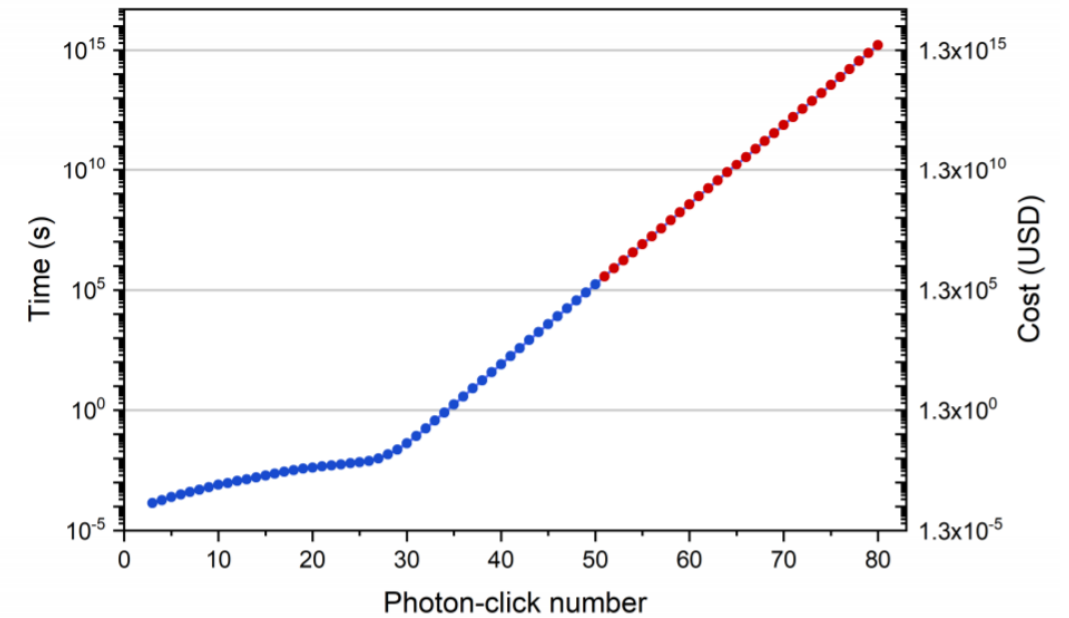
MareNostrum supercomputer (BSC)

Why do we need a quantum computer

Less time... and less energy!



“Quantum supremacy using a programmable superconducting processor”, Nature **574**, 505–510(2019)

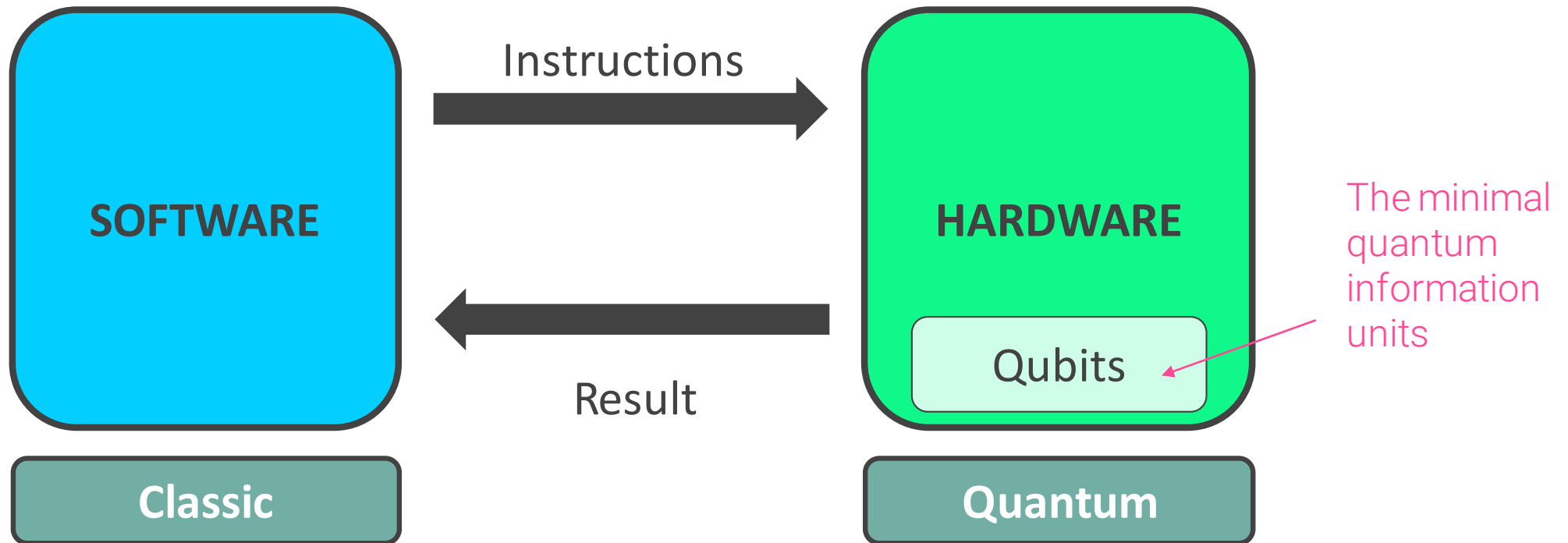


“Quantum computational advantage using photons”, Science eabe8770 (2020)

What is a quantum computer



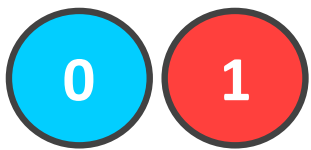
A device capable of processing data in a quantum mechanical form.
A device that uses the properties of quantum mechanics to process data.



How does it work

Qubit: physical system that 1) is quantum and 2) have two well-defined states

Bit

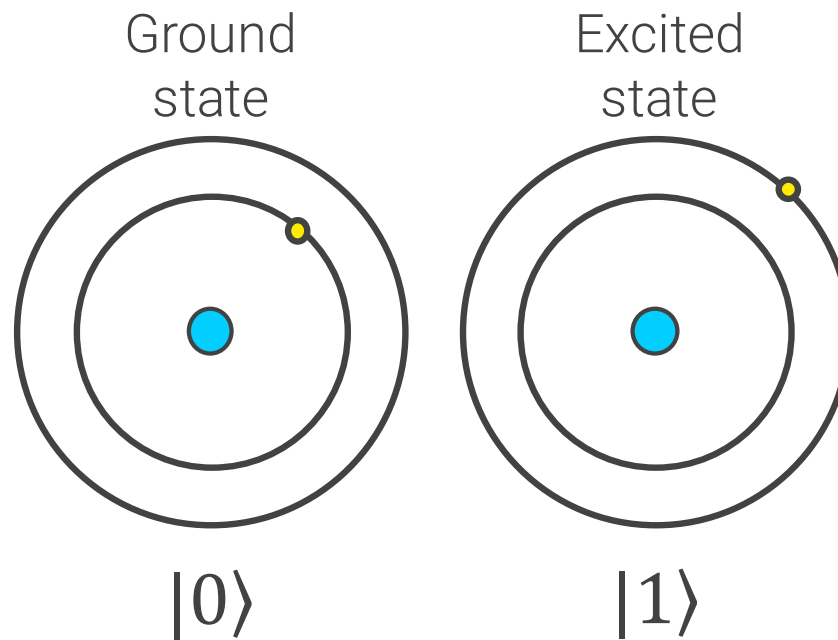


Qubit

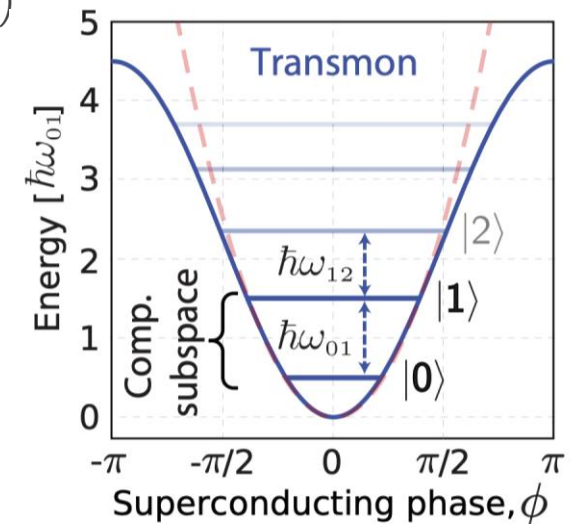
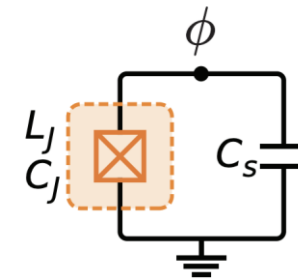


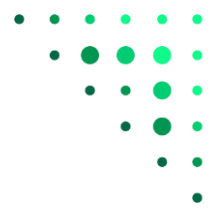
$$|\psi\rangle = \alpha|0\rangle + \beta|1\rangle$$

Example: atomic orbitals



Example:
superconducting circuit
(transmon qubit)





Who is building a quantum computer (industry)



Where are they being constructed

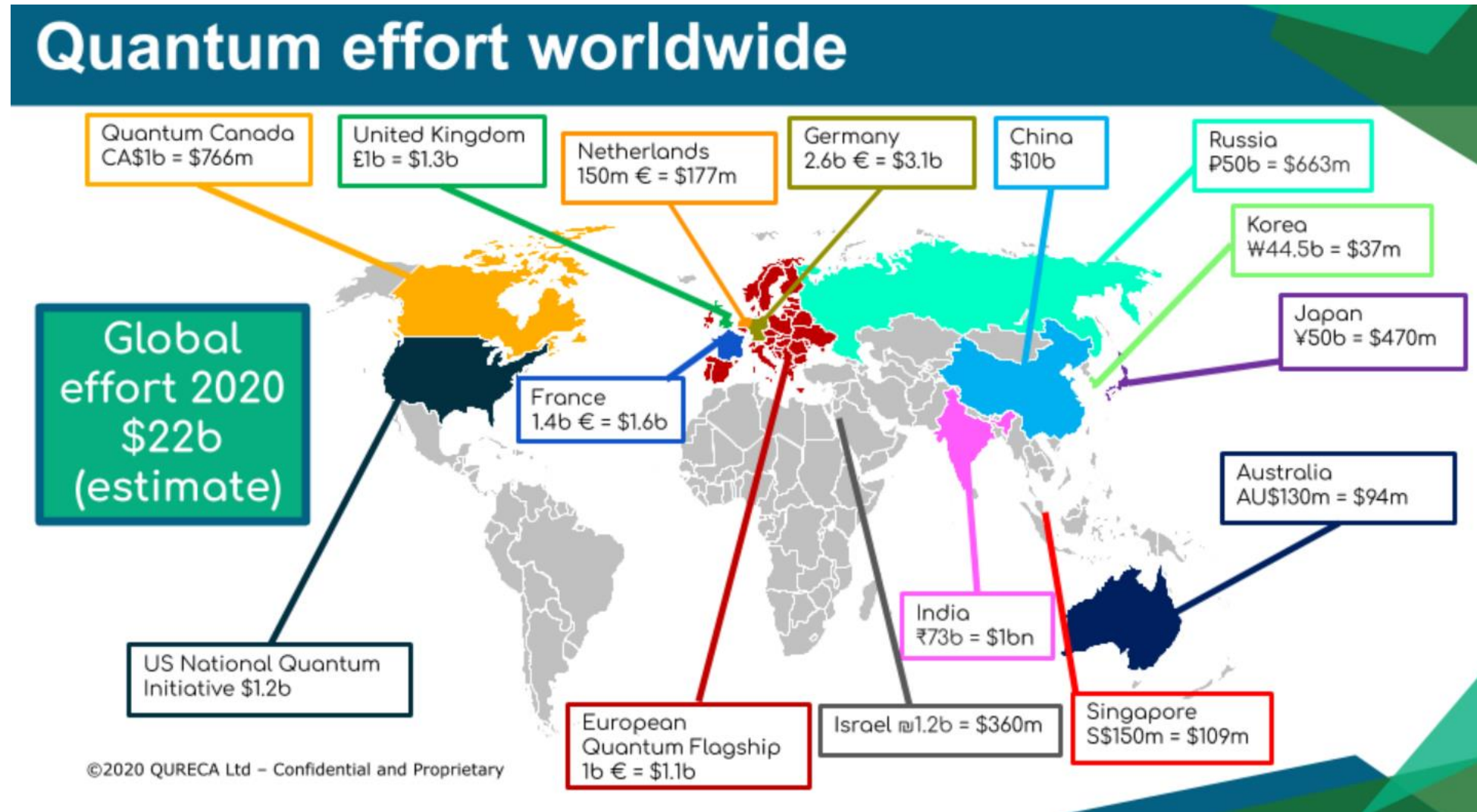


Image: "Overview on quantum initiatives worldwide", Araceli Venegas-Gomez (Qureca Ltd)

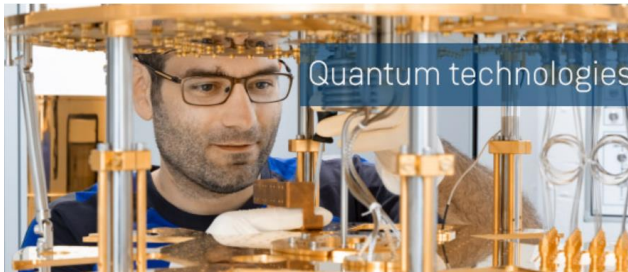
Quantum computing at Supercomputing centers

Quantum Integration Centre Opened at LRZ

GCS Newsflash 03/2021 – March 19, 2021



On March 17, 2021, Bavaria's Minister-President, Markus Söder, officially inaugurated the Quantum Integration Centre (QIC) at the Leibniz Supercomputing Centre (LRZ) in Garching near Munich. Due to the ongoing COVID-19 pandemic, the event was live streamed only.



They are building a quantum computer with the recent hiring of Rami Barends (ex-Google AI researcher and project manager)



**Barcelona
Supercomputing
Center**

Centro Nacional de Supercomputación



Institut de Física d'Altes Energies

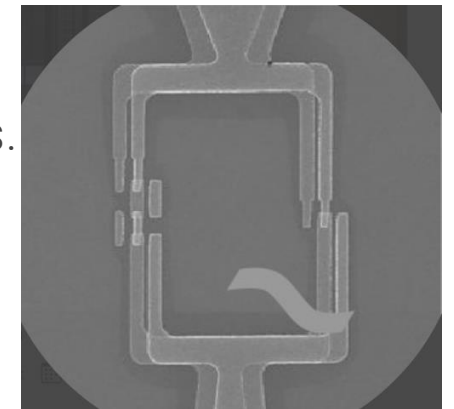


UNIVERSITAT DE
BARCELONA

QUANTIC group.
Algorithms at BSC
Quantum computer at IFAE facilities.

BSC spin-off company:

QILIMANJARO



Quantum computing in the NISQ era

Quantum Computing in the NISQ era and beyond

John Preskill

Quantum 2, 79 (2018)

Noisy intermediate-scale quantum (NISQ) algorithms

Kishor Bharti,^{1, *} Alba Cervera-Lierta,^{2, 3, *} Thi Ha Kyaw,^{2, 3, *} Tobias Haug,⁴ Sumner Alperin-Lea,³ Abhinav Anand,³ Matthias Degroote,^{2, 3, 5} Hermanni Heimonen,¹ Jakob S. Kottmann,^{2, 3} Tim Menke,^{6, 7, 8} Wai-Keong Mok,¹ Sukin Sim,⁹ Leong-Chuan Kwek,^{1, 10, 11, †} and Alán Aspuru-Guzik^{2, 3, 12, 13, ‡}

arXiv:2101.08448

Noisy Intermediate-Scale Quantum



Why is QC hard experimentally?

- Qubits have to interact strongly (by means of the quantum logic gates)...
- ...but not with the environment...
- ...except if we want to measure them.

What is the state-of-the-art in digital quantum computing?

Noisy Intermediate-Scale Quantum (NISQ) computing

- 50-100 qubits
- Low error rates
- No Quantum Error Correction

What can we do in NISQ?

- Good trial field to study physics
- Possible applications?
- A step in the path towards Fault Tolerant QC

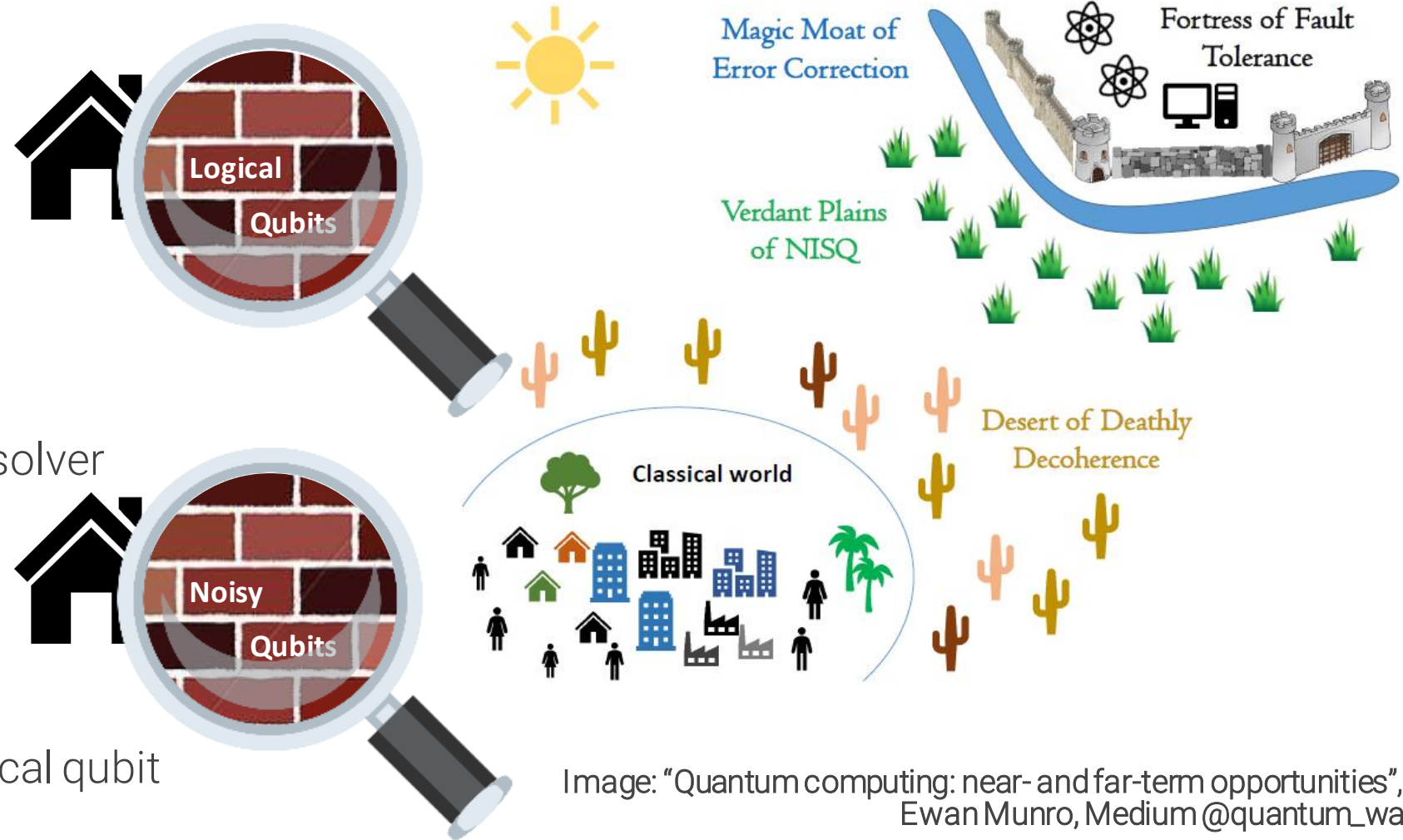
NISQ vs Fault-Tolerant

Who lives in the Fortress?

- Factorization algorithm
- Grover search algorithm
- ...

Who lives in the Plains?

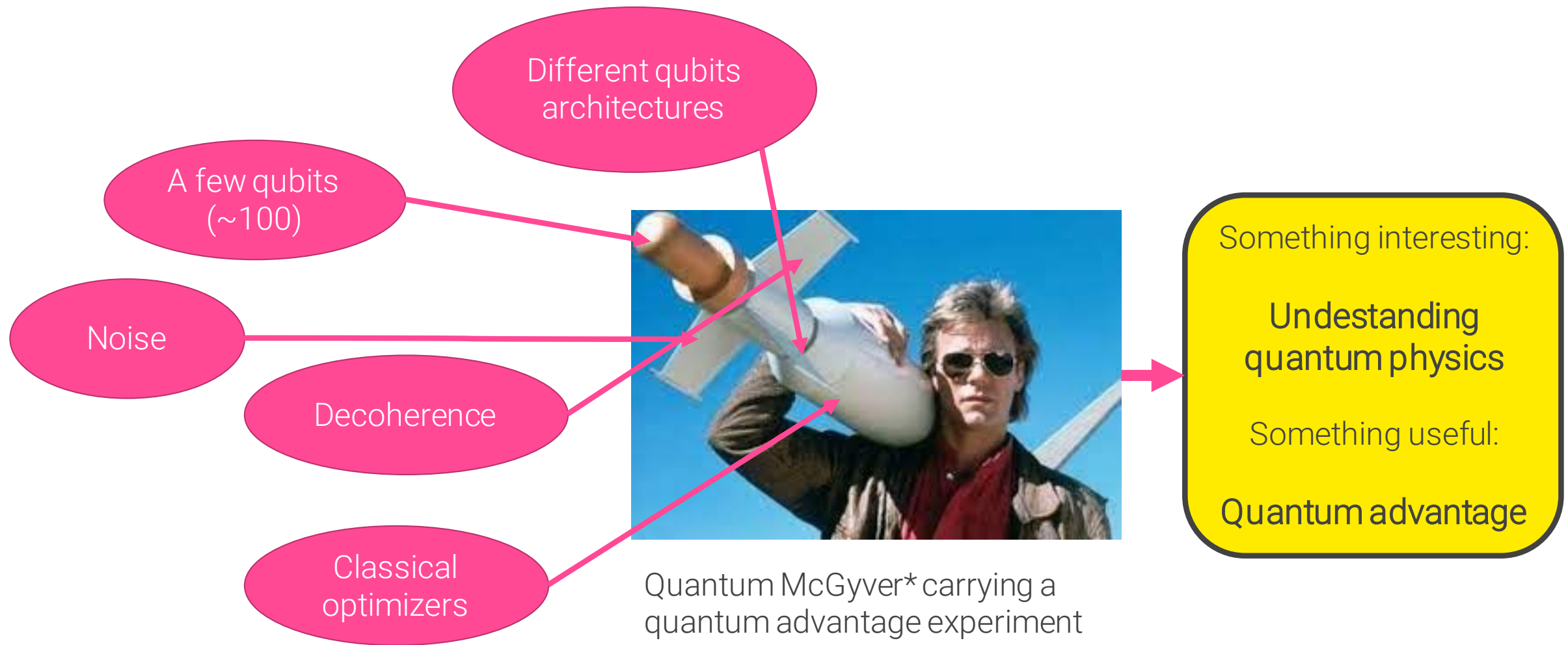
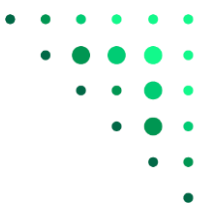
- Variational Quantum Eigensolver
- QAOA
- ...



~100 noisy qubits/logical qubit

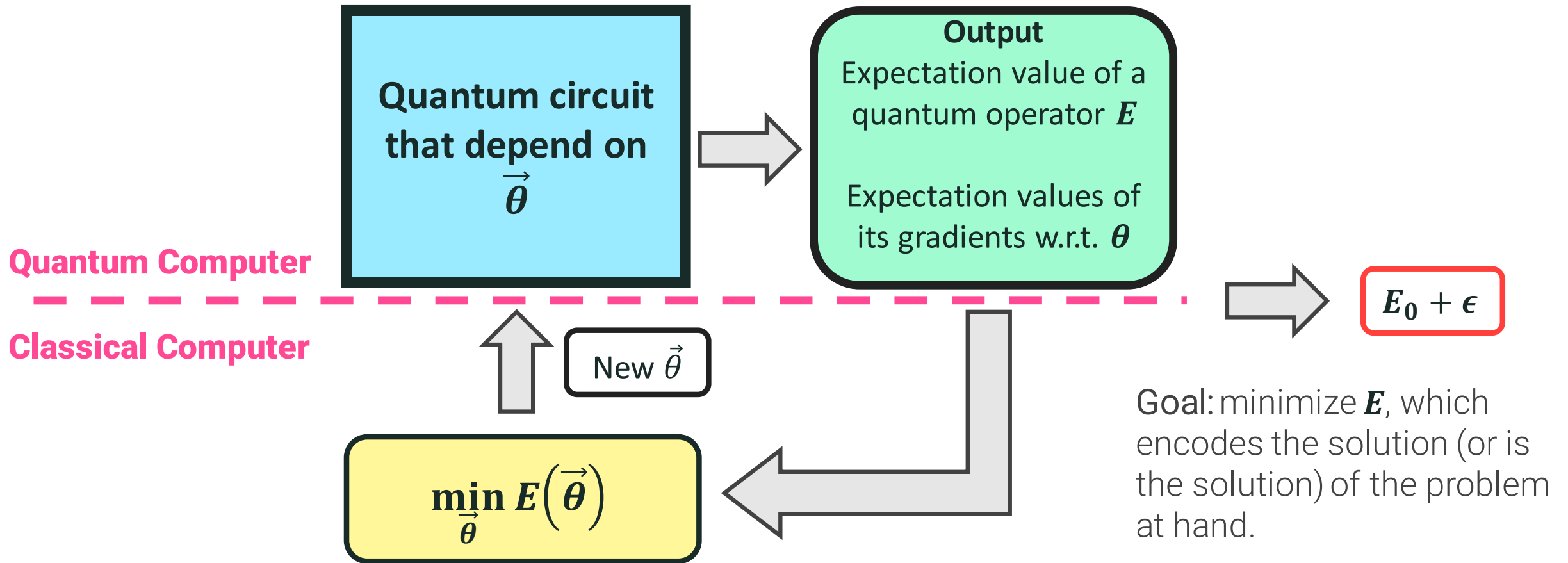
Image: "Quantum computing: near- and far-term opportunities",
Ewan Munro, Medium @quantum_wa

Noisy Intermediate Scale Quantum computation



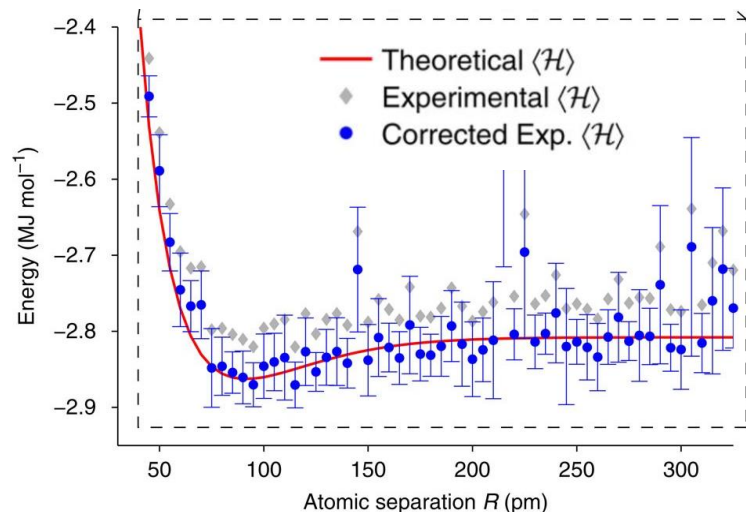
Hybrid Quantum-Classical Algorithms

Also called Variational Quantum Algorithms



Quantum Chemistry

Bond dissociation curve of the He-H⁺ molecule.



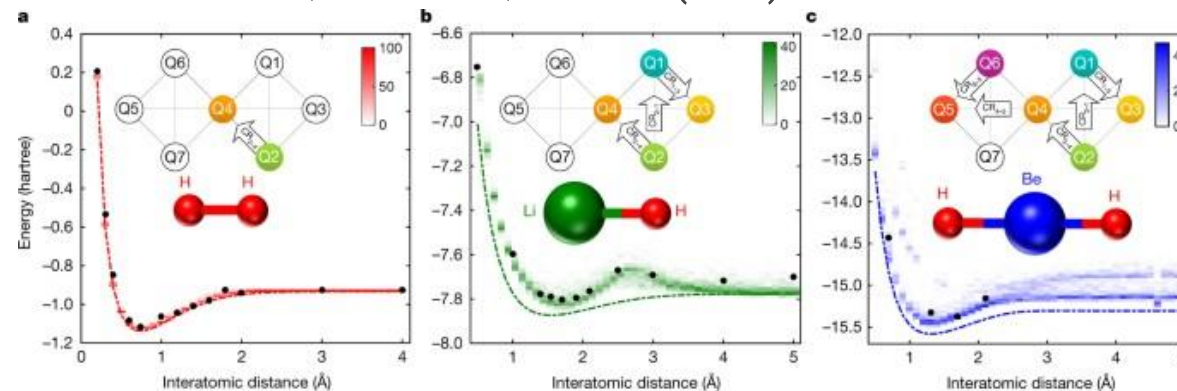
A. Peruzzo et. al., Nature Comm. 5, 4213 (2014)

Solve the electronic structure problem (obtain the minimal energy of a molecule as a function of the interatomic distance)

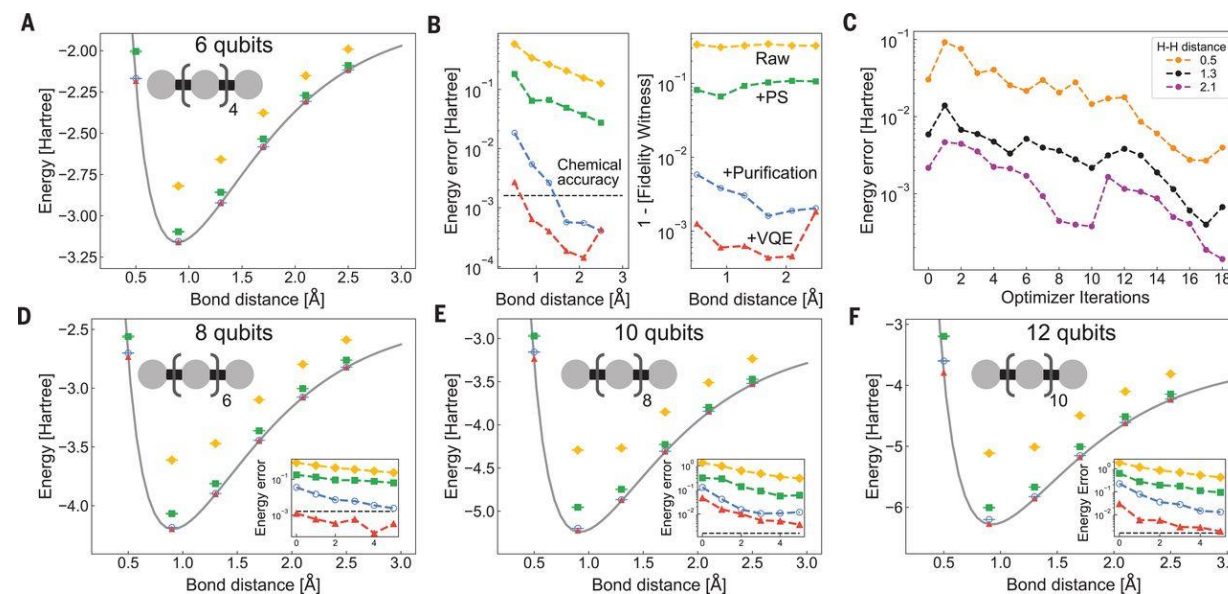
Photonic quantum computer

Superconducting circuits quantum computer

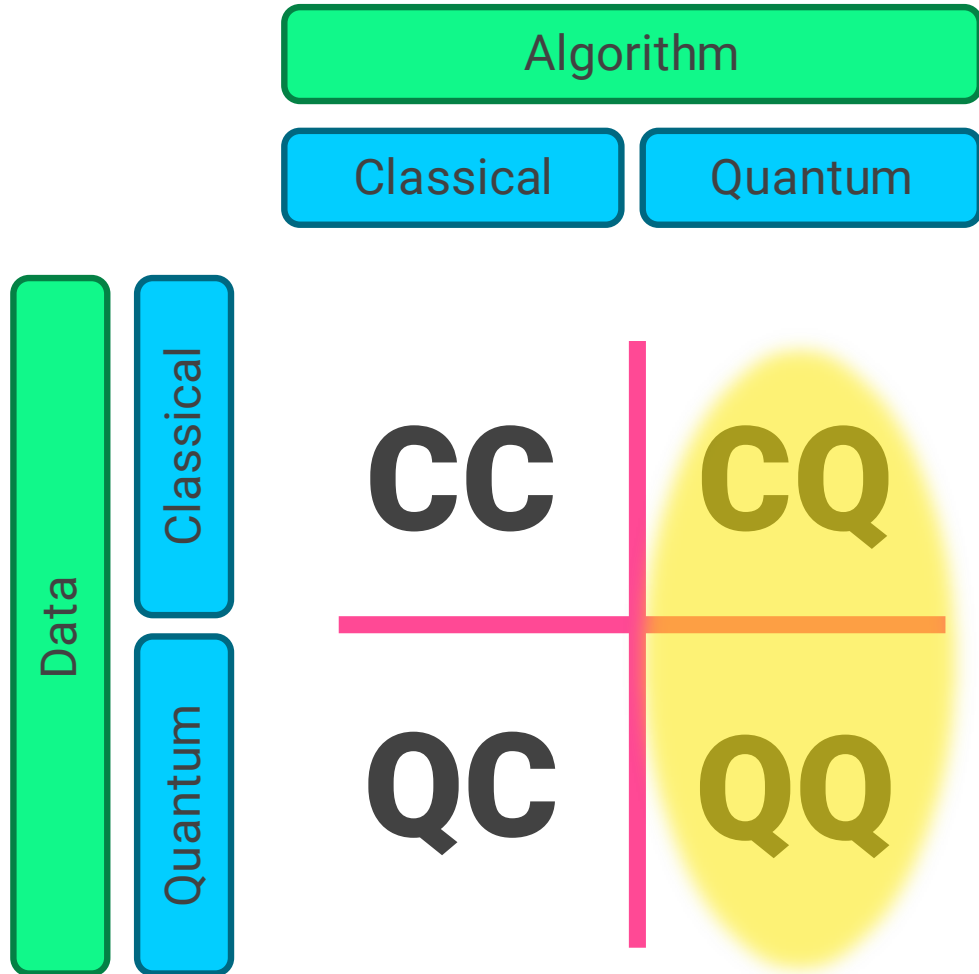
A. Kandala et. al., Nature 549, 242–246 (2017)



Google AI Quantum and Collaborators, Science 369, 6507, 1084-1089 (2020)



Quantum Machine Learning



QML

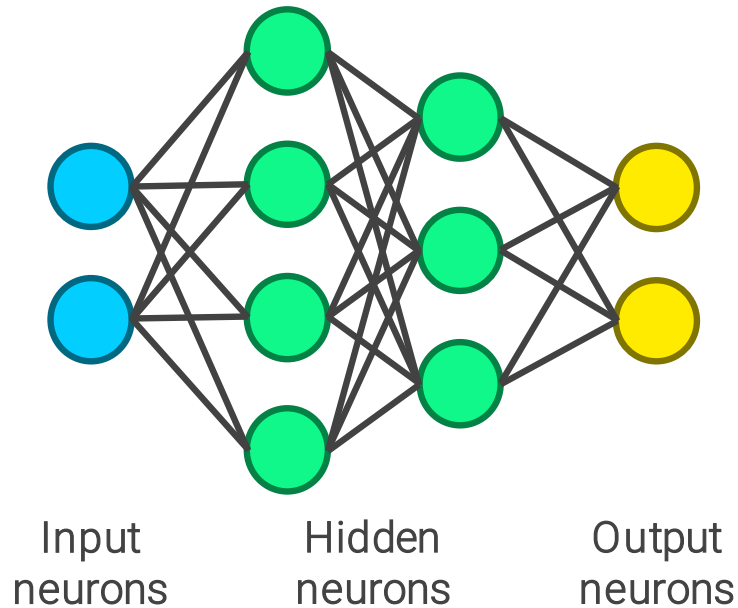
Quantum algorithms feed with classical or quantum data

- Supervised Learning
- Unsupervised Learning
- Reinforcement Learning

From classical to quantum NN



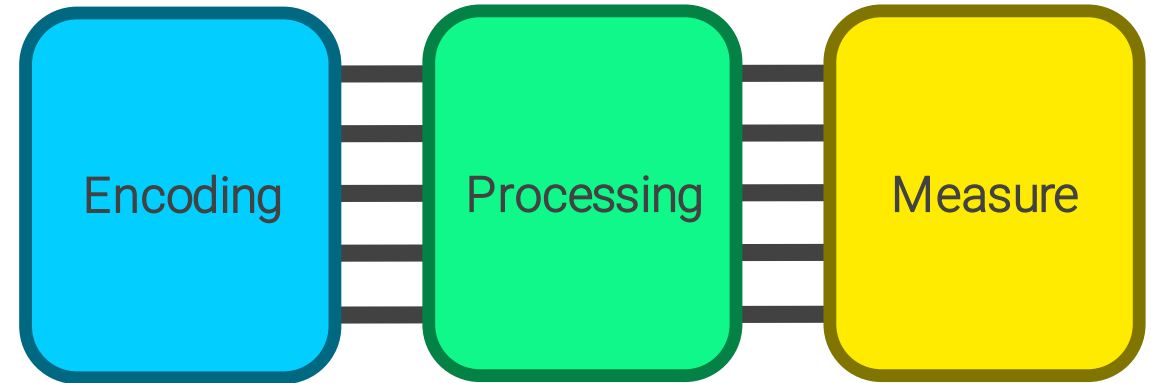
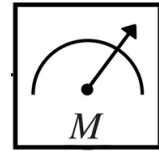
Classical



Quantum
(circuit centric)

Initial quantum state

$$|\psi_0\rangle \rightarrow |\psi(\vec{x}, \vec{\theta})\rangle \rightarrow |\psi(\vec{x}, \vec{\theta}, \vec{\phi})\rangle$$



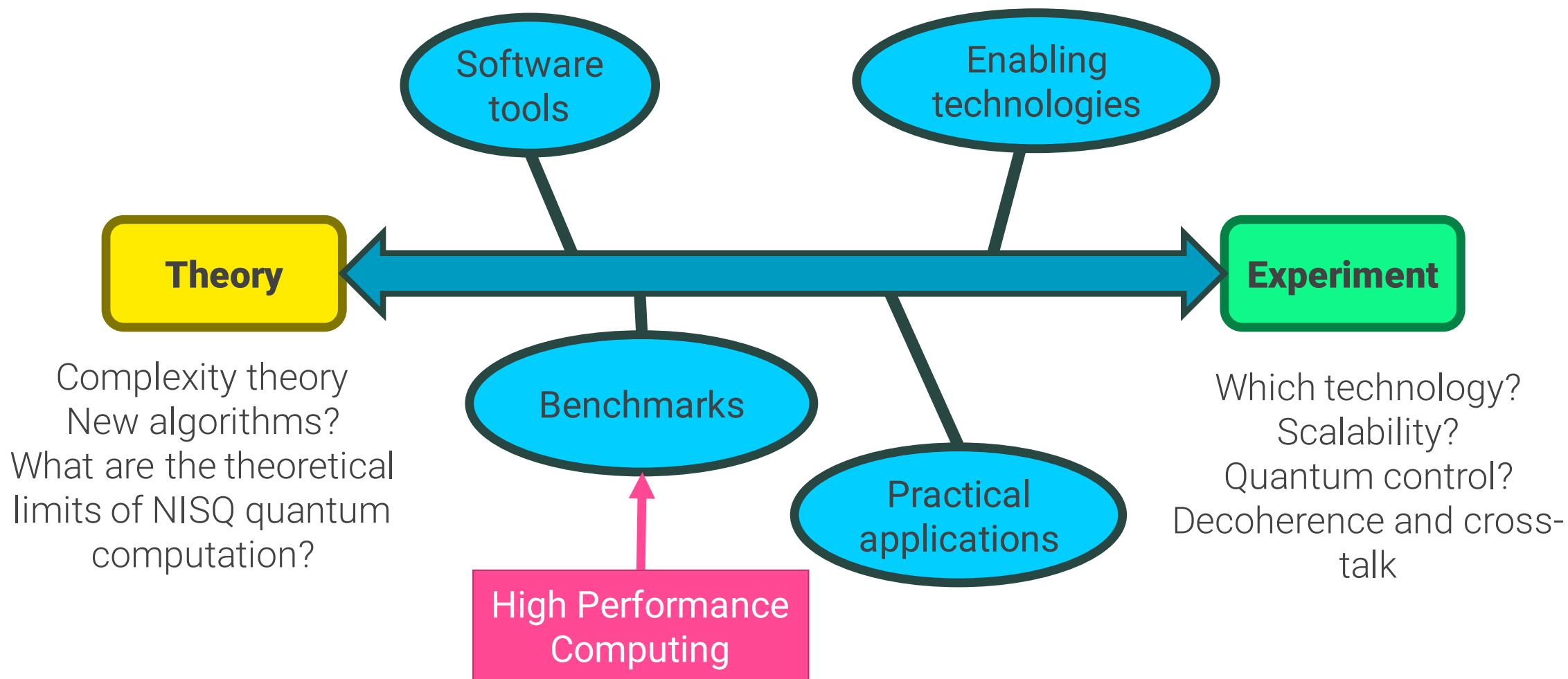
We can then compute the Kernel

$$\kappa(\mathbf{x}_i, \mathbf{x}_j) \equiv \langle \Phi(\mathbf{x}_i) | \Phi(\mathbf{x}_j) \rangle$$

Or design cost functions to minimize

$$C(\theta) = \sum_{i=1}^D (1 - |\langle y_i | \Psi(\mathbf{x}_i, \theta) \rangle|^2)$$

NISQ road



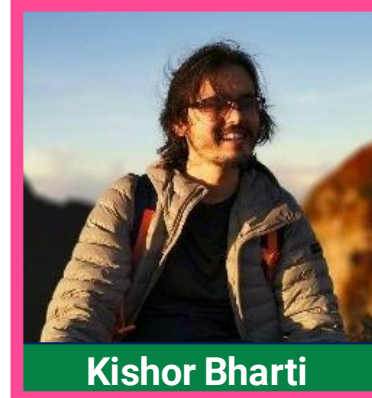
Acknowledgements



Alán Aspuru-Guzik



Leong-Chuan Kwek



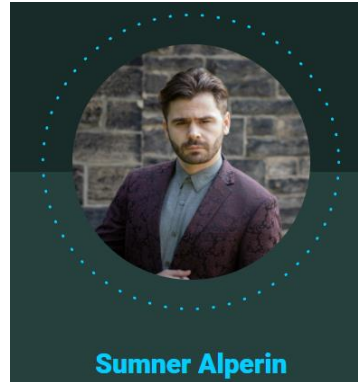
Kishor Bharti



Thi Ha Kyaw



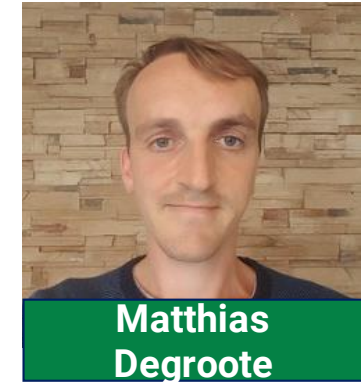
Tobias Haug



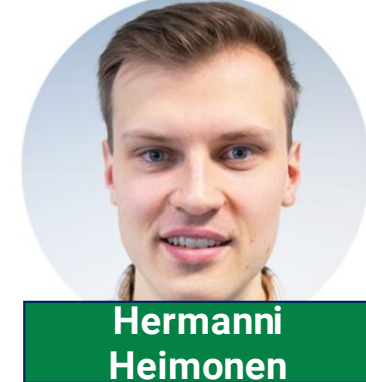
Sumner Alperin



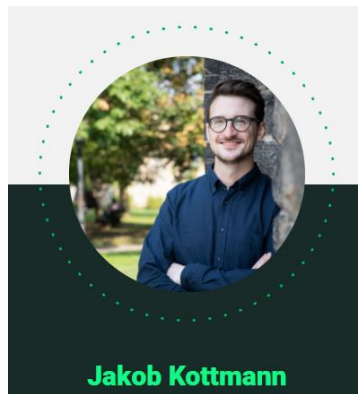
Abhinav Anand



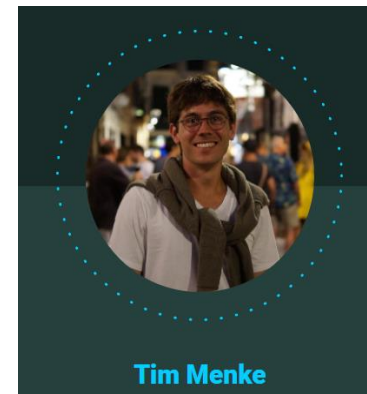
Matthias
Degroote



Hermanni
Heimonen



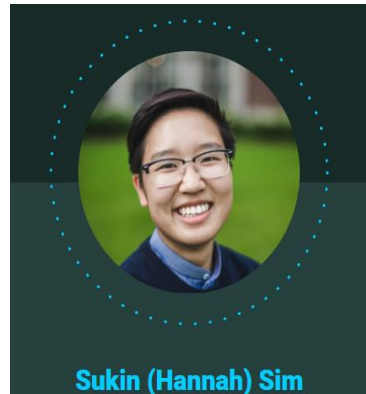
Jakob Kottmann



Tim Menke



Wai-Keong Mok



Sukin (Hannah) Sim

