Analog Quantum Computing: from the lab to the industry

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The importance of quantum and its impact

Quantum logic
New computational logic based on the laws of quantum mechanics that allows for exponential resources

+

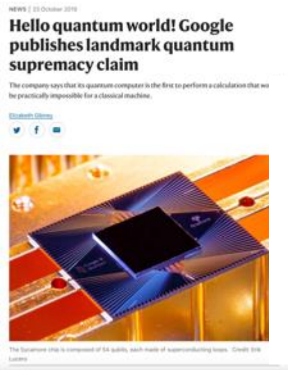
Qubit
Basic unit of quantum information analog to the classical bit. Lower energy resources.

+

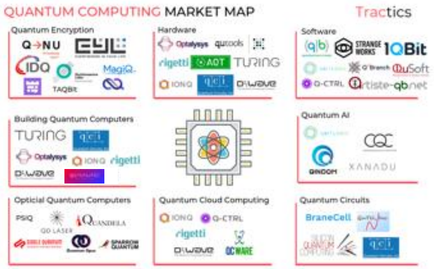
Quantum effects
Superposition and entanglement to simultaneously access candidate solutions

Efficient solutions to otherwise intractable problems

- Bypass the end of Moore's law of integrated circuits
- Accelerate heavy computing problems in chemistry, optimisation, cryptography, etc.
- More sustainable and with improved accuracy - less approximations, better results



Rapidly growing excitement and development of the technology



"Conservatively, we estimate that the value at stake in pharmaceuticals, automotive and finance use cases could be up to nearly **700B$"**
McKinsey, December 2021

The error correction barrier: a long road ahead

Practical applications of **digital quantum computers** are not expected to be a reality for the next decade.

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CIO JOURNAL

Google Aims for Commercial-Grade Quantum Computer by 2029

- While so far it has been one of the preferred quantum computing proposals by big tech companies, it faces a big challenge: **errors**
- Due to the intricate nature of quantum mechanics, **correcting from errors is not easy** and requires **two important technological achievements**:

Logical qubits ▶ A single unit of quantum information now needs to be encoded in ~1000 qubits in order to allow for quantum error correction protocols to be effective. Largest chips so far are of the order of 100

Low-error gates ▶ Quantum error correction protocols will only work if the errors introduce per gate reach a certain threshold, not been achieved yet.

Analog: a different way of doing quantum computing

Our Mission

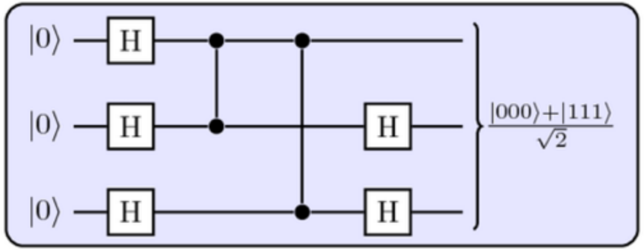
- Bring practical applications of quantum computing in a shorter timeframe than digital quantum computers

How

- Using a different but complementary model of quantum computation: **the analog model**

Digital quantum computer

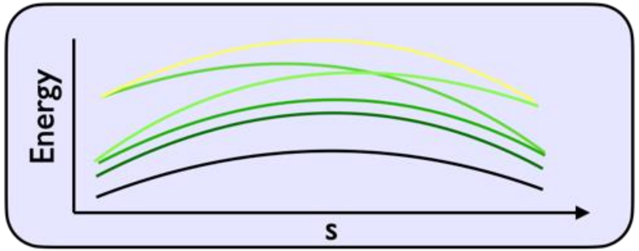
- Encoding: sequence of gates
- Control: discrete
- Universal general-purpose model
- Need for error-correction codes (no available yet)



Google IQM rigetti IBM

Analog quantum computer

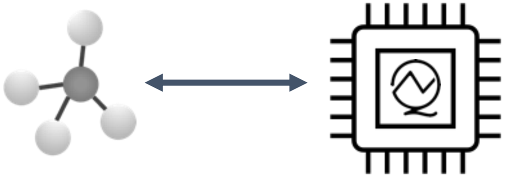
- Encoding: Hamiltonian
- Control: continuous
- Focuses on **specific tasks** (can be universal)
- Bypasses error-correction needs (**available now**)

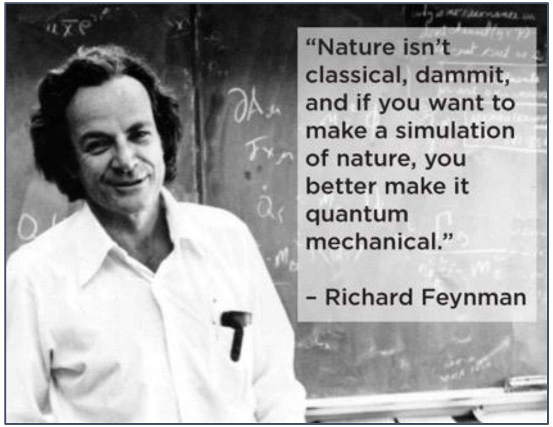


D-Wave The Quantum Computing Company QILIMANJARO QUANTUM TECH

Nature isn't classical, nor digital

At the microscopic level, nature is quantum and it evolves in an analog manner. Thus the **embedding of the quantum description of physical systems into the quantum description of Qilimanjaro analog processor is straightforward.**





Digital quantum computers discretize the continuous processes of nature, which induces errors.

With Qilimanjaro's analog quantum processors we can pursue Nobel Prize Richard Feynman's idea, precursor of quantum computing, on simulating nature and its processes to better understand our universe.

Targeted applications

Examples from our current ongoing projects

Applications of Analog Quantum Computing

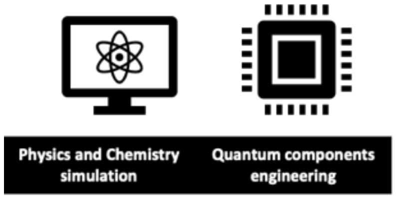
- **Adiabatic Quantum Computation and Annealing**
- **Analog Simulation**

Optimisation

- Logistics, energy and defense

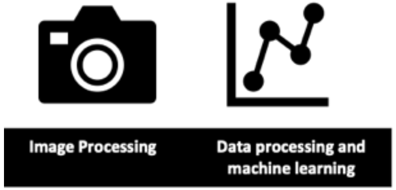
Chemistry, Physics and Engineering

- Evaluation of inaccessible chemical reaction paths
- Molecules geometry optimisation
- Quantum buses, sensors and dedicated quantum processing units
- Particle detection and high energy physics



Quantum Machine Learning

- Classification of data and regression analysis
- Image processing, neural networks

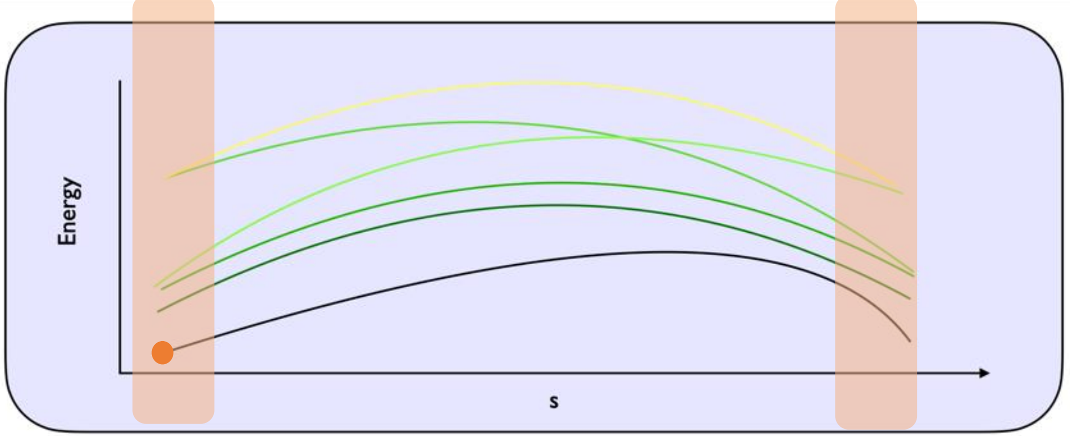


AQC: the basic idea

$$H(s) = (1-s)H_0 + sH_f$$

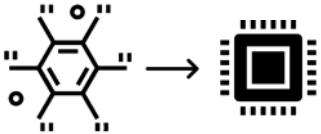
Initial Hamiltonian: with an easy-to-prepare ground state

Final Hamiltonian: solution to the problem encoded in its ground state

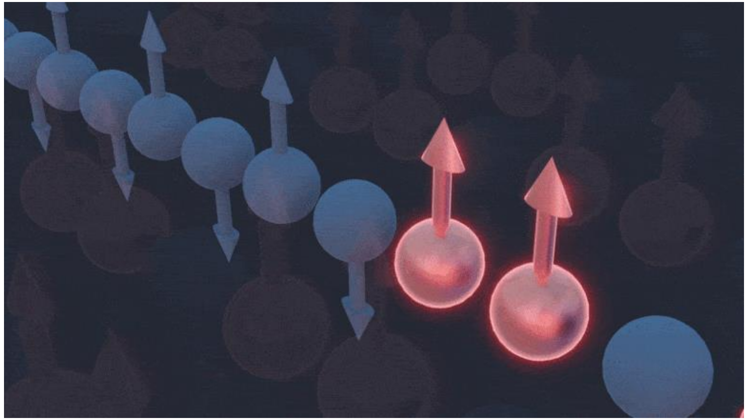


Analog simulation

Encode system of interest into the quantum device...



...and let it evolve through the **natural dynamics** of the system

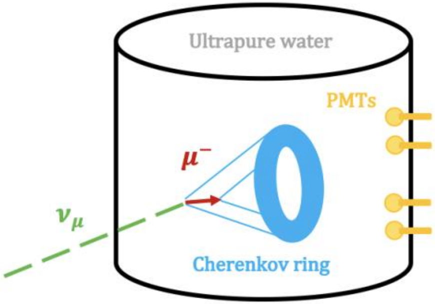


Credit: Michelle Lehman/ORNL, U.S. Dept. of Energy

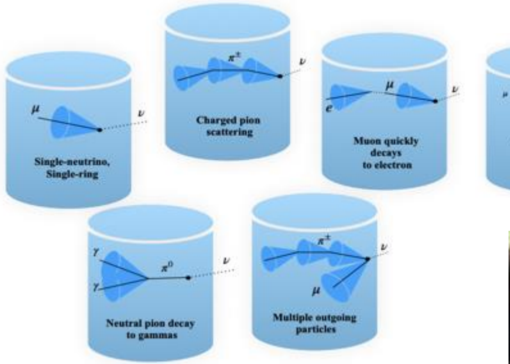
Qilimanjaro and HEP: Hyper-K detector

Largest neutrino detector, data-taking planned for 2027 in Japan

Figure: a mPMT (= 19 PMT)



Multiple event types



- Information collected from the photosensors (**PMTs**) needs to be analyzed and classified into **events**
- Investigating the use of our analog quantum devices to offer a real advantage in such a complex classification task

Limitations of Legacy Annealing quantum computers

Current annealing quantum computers are not coherent

In order to exploit quantum parallelism the quantum device needs to be **coherent**, this is qubits with enough large lifetime such that they can contain and process the quantum information until the end of the computation

Limited connectivity implies huge qubit overhead

Problems are mapped to a graph that has to be embedded in a physical device with a arbitrary qubit connectivity. Current implementations use additional qubits to mediate the required connections, supposing an important **qubit overhead** (eg 5000 qubits for problems of 62 variables)

The encoding of variables is very inefficient

Problems that are complex for classical machines are very large. Mapping of the variables to a quantum computer is efficient, but we still need the right **amount of qubits** to contain them.

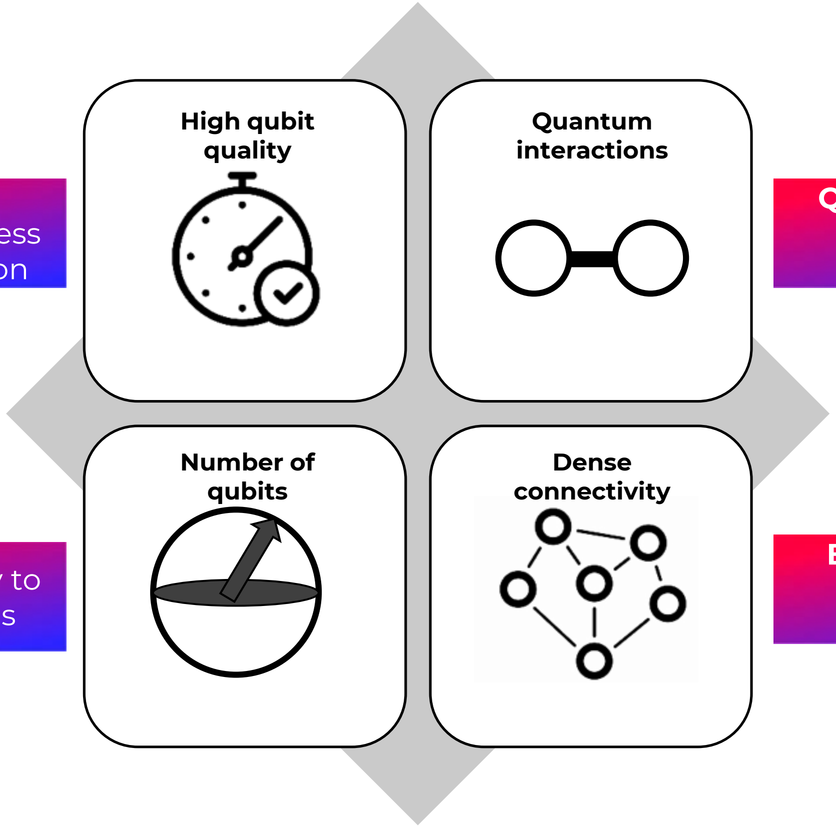
No quantum advantage is foreseen

Simulatability is the possibility to efficiently run a classical algorithm that emulates a quantum algorithm. Algorithms that run in current analog devices are simulatable, therefore no quantum advantage can be harnessed.

Qilimanjaro target ingredients for quantum advantage

Long coherence = guarantee of quantumness along entire computation

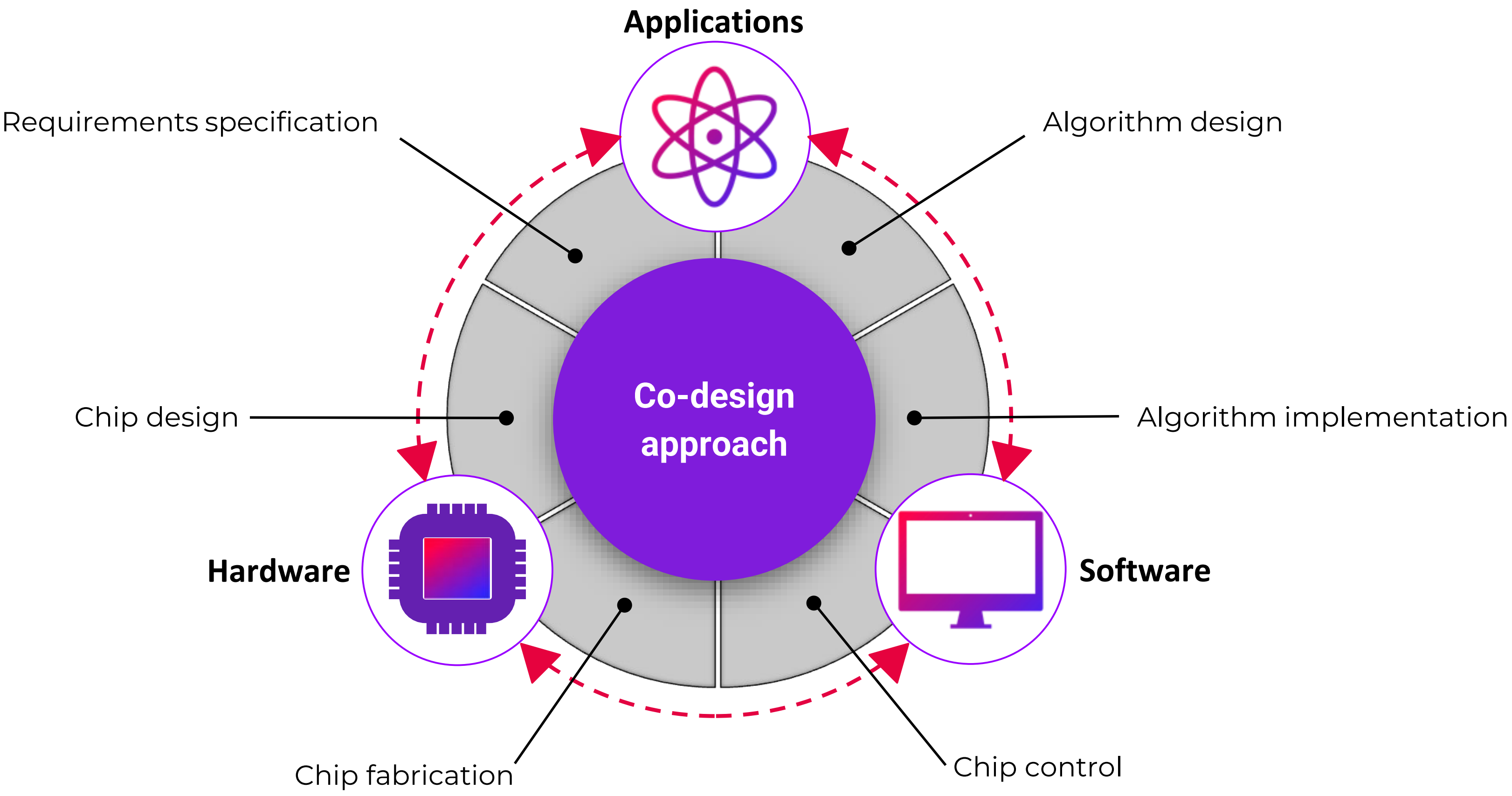
More qubits = possibility to encode larger problems



Quantum interactions = possibility to run non-simulatable problems

Better connectivities = possibility to encode complex problems

Qilimanjaro: a full-stack company

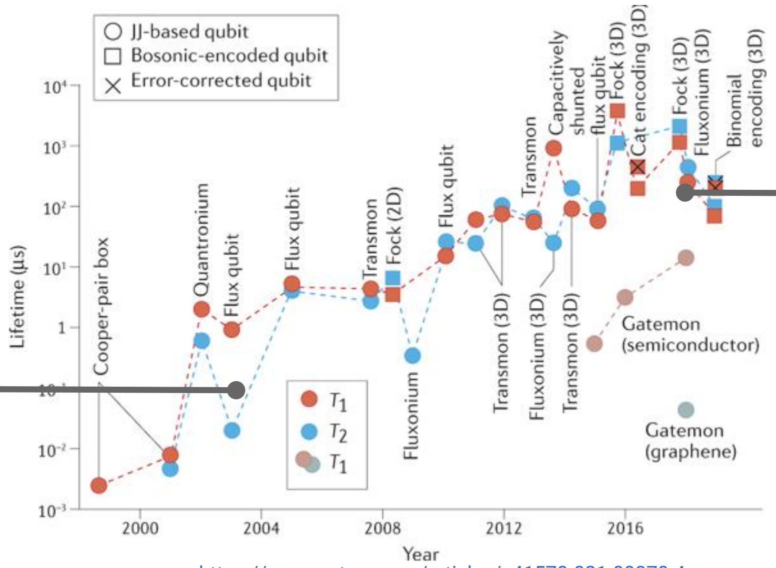


Qilimanjaro's qubit technology

We do **superconducting qubits** with high coherence lifetimes:

Superconducting qubit technology evolution

Legacy analog tech based their systems (and IP) on the state-of-the-art qubit at this point in time. Qubit changes imply redesign from scratch.

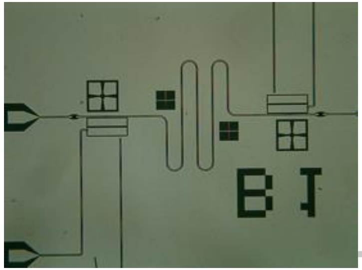


https://www.nature.com/articles/s41578-021-00370-4

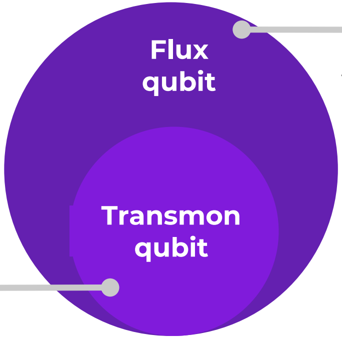
We base our qubit tech on this state-of-the-art. **Around 4 orders of magnitude better**

One qubit to rule them all

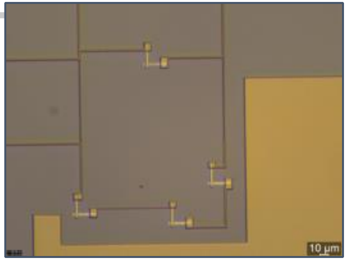
We develop two different qubit technologies: flux and transmon qubits



- State of the art for **digital quantum processors**
- Coherence times measured, on par with global competitors

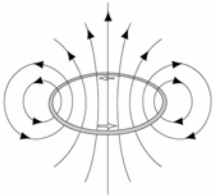


- Allows for **both gate based and analogue architecture**
- High coherence times comparable to transmon achievable

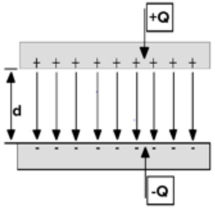


Our true innovation revolves around the **flux qubit for analog processing with dual qubit-qubit couplings:**

- **Dual coupling is necessary to achieve quantum advantage.**
- Qilimanjaro's analog inter-qubit coupling includes inductive coupling **as well as capacitive coupling**



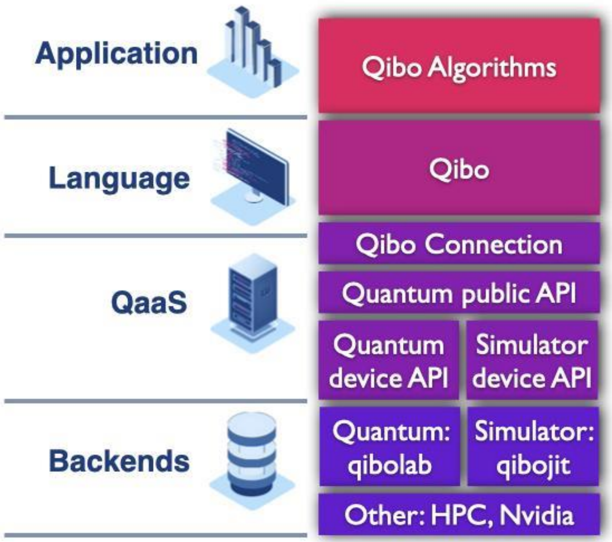
Inductive coupling
- Magnetic fields induce coupling
- Achieved via juxtaposition of qubit loops



Capacitive coupling
- Electric fields induce coupling
- Achieved via juxtaposition of qubit capacitors

A scalable and flexible, open-source full-stack software

Qilimanjaro Software Services Layout:



Qibo: https://qibo.science/

- **Full-stack software developed in partnership with several institutions** to launch algorithms to the quantum computers (or emulators)
- Options to be **in the cloud** as a Software as a Service (SaaS) **or on-premise** (client facilities)
- Using **Qibo as the open-source main** quantum programming **framework**
- **Compatible with other** quantum **frameworks** (OpenQASM) from the quantum algorithm side
- **Quantum as a Service** (QaaS) **scalable model** to **direct access** to our cloud **or via other cloud services**.
- **High Flexibility**:
  - Support for different **quantum backends**
  - And also **emulator backends**: connectors with **Nvidia and HPC**

Research and innovation leads to applications

Fundamental research and the interaction with clients is paramount not only to devise applications but also to **drive the basic development of our technology**

Fundamental research

- **Over 10 research projects** focused on the development of quantum analog techniques and algorithms
- Build the bases for the **algorithm and experiment design**
- Enhance and **keep up to date** rapidly evolving technology know-how

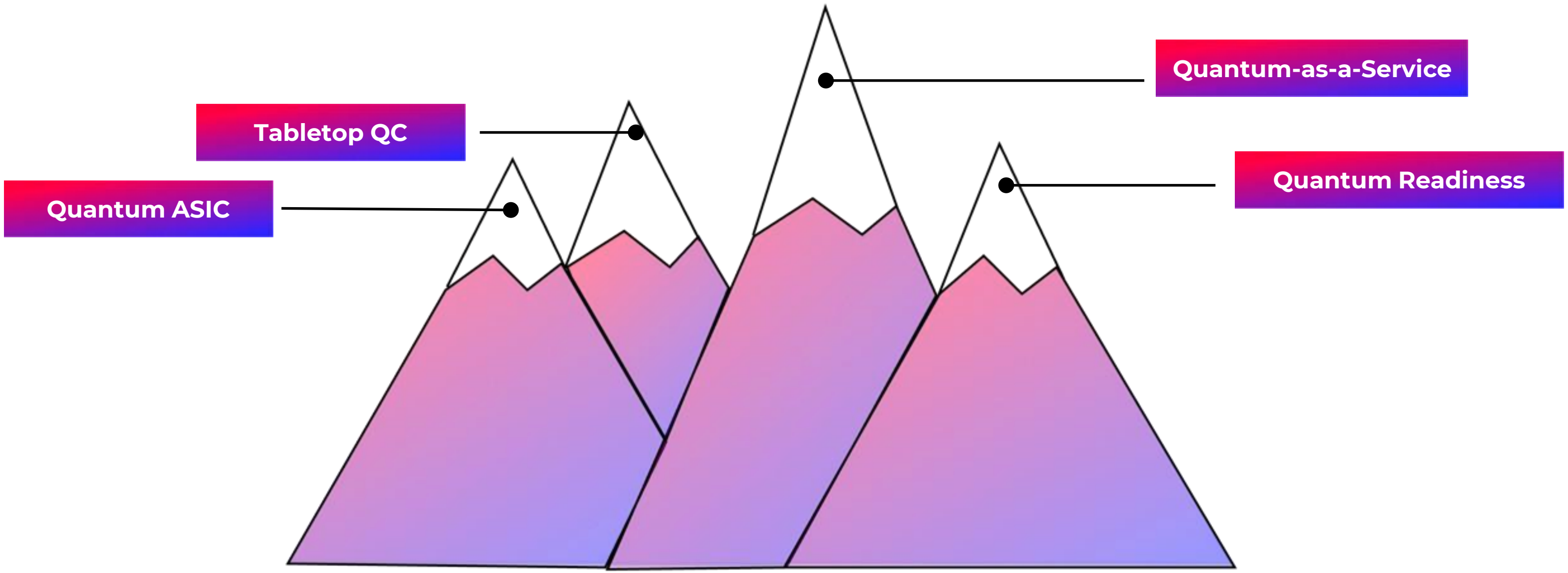
Hardware and software support

- Design and development of **qubit simulators**
- **Compilation and optimisation** of algorithms
- Co-design of **new chip architectures**

Applications

- Identify adequate **clients' use-cases**
- Develop and **implement PoCs**, enhance algorithm portfolio
- Design and run **benchmarks and metrics** to compare algorithms classical vs quantum

Business complementarity: Qilimanjaro's mountain range



Quantum readiness advisory

- Industral use-cases identification
  - Logistics
  - Finance
  - Energy
  - Chemistry
- Tailored quantum algorithm solutions and benchmarks comparing classical counterparts - **Sustainability as a quantum advantage**
- Quantum lab services for hardware development
- Traction:

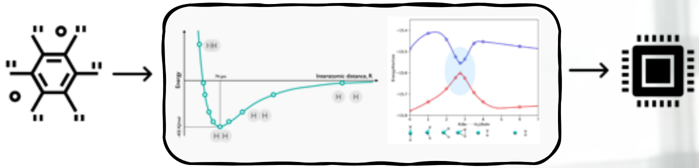
Quantum as a Service (QaaS)

Run your quantum algorithms on **Qilimanjaro cloud service to access our quantum computers and simulators**.

- With **our framework to code your quantum algorithm** an run it to our cloud service
- Compatible with other Quantum programming languages (**OpenQASM**) from the quantum algorithm side
- **Qibo as the open-source main** quantum programming **framework**

- Different backends: **quantum backends and also emulation backends** with **Nvidia** and **HPC** connectors.

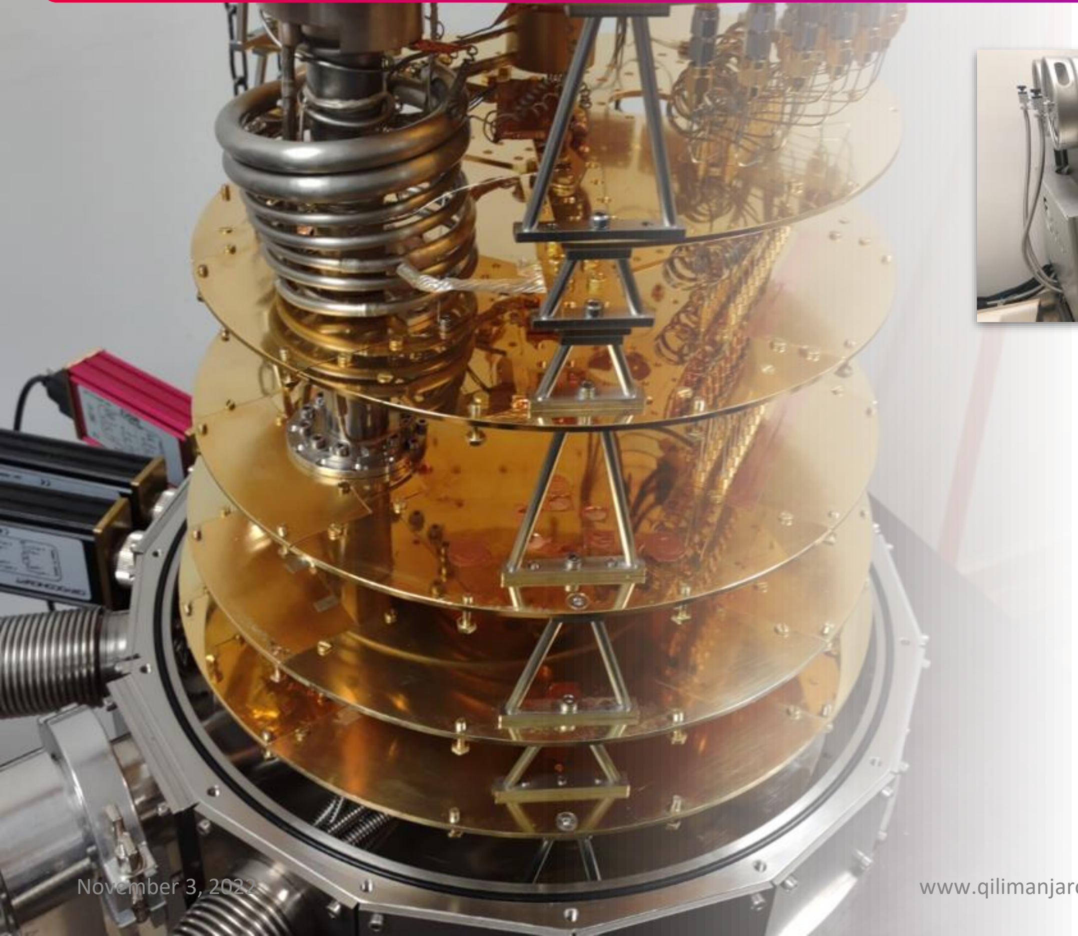
Quantum ASIC for Chemistry (and more)

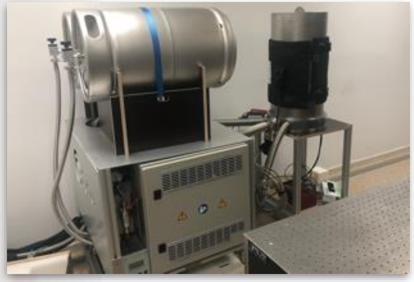


Co-development of analog **app-specific integrated quantum chips (ASIC)** for the simulation of the electronic structure of molecules:

- **Identification of quantum chemistry problems** that present challenges in their classical simulation
- **Requirement specifications** for the analog quantum hardware that go beyond current implementations
- **Development of the device** and its control for the simulation of the target problem

Tabletop Quantum Computers





VS

- Portable analog quantum computer for clients that want **in-premises access to quantum processing**
- Tight collaboration with **Qinu**, provider of unique cryogenic technology
- **Smaller volumes** of cryogenic infrastructure (about ⅓ size of a standard QC)
- Fast cycling of processors for testing, lower times and **better energy efficiencies**

Qinu

Meet the team

- **50** Years – quantum R&D experience
- **8** PhD
- **19** Physicists
- **4** Engineers and computer scientists
- **2** MBA
- **4** Avg # of interns
- **7** Women
- **7** Countries

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