Quantum Computing @ INFN

A Containerized Quantum Application Software Architecture Framework

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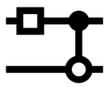
Introduction

Why

- Quantum algorithms can be run on different platforms, where the user needs to **write algorithms using the available tools**
- API access can be done using Software Development Kits (SDKs)
- Urgent to find methods to **fill the gap between a low-level approach and the high-level general user experience and programming**



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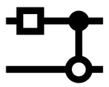

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- The framework proposed provides developers, UI designers and researchers with a generalizable system that
  - **enables and speeds up** the creation and the deployment of applications with a hybrid classical-quantum backend
  - creates a **custom user experience** based on the problem to be solved
  - **spreads out the usage** of quantum computing

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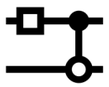

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How

- This method has been reflected into a **well defined framework** leveraging the following technologies
  - Red Hat OpenShift
  - Kafka
  - Knative
  - IBM Cloudant
  - IBM Quantum / Qiskit
- New approach on asynchronous job submission method specially created

Initiative summary and objectives

Creation of a **microservices-based framework** to easily deploy applications with a **hybrid classical-quantum backend**

- **Extreme portability of the framework**
  - Deployment on both Cloud and On-premises
  - Multi-cloud enabled
  - Containerisation of all components
- **IaaC** (Infrastructure-as-Code) enablement

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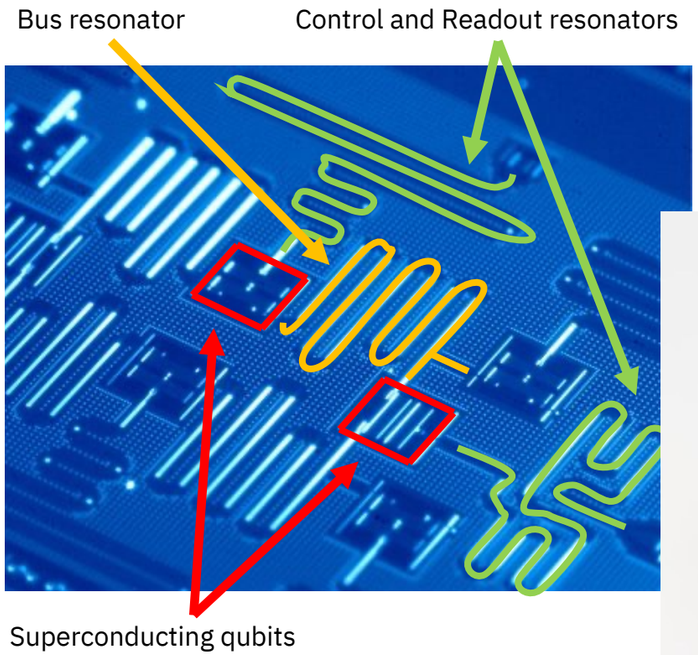
  - Multi-cloud enabled
  - Containerisation of all components
- **IaaC** (Infrastructure-as-Code) enablement
- **MVP implementation on Red Hat OpenShift on IBM Cloud**
- **Integration with IBM Quantum**

IBM Quantum

- **Journey started in 1981** at “Physics of Computation Conference”, hosted by IBM and the MIT
- IBM Quantum devices available in IBM Cloud **since 2016**
- Based on superconducting transmon technology



433 qubits Osprey chip just announced (IBM Quantum Summit 2022)

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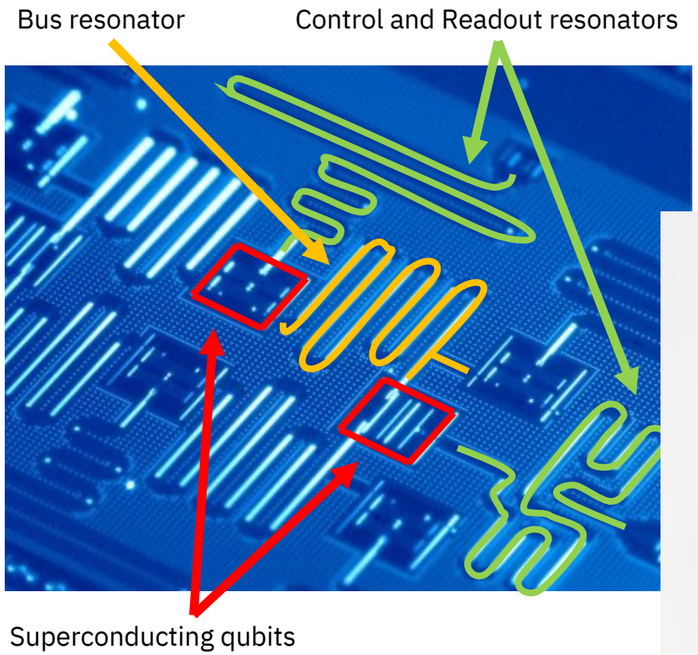

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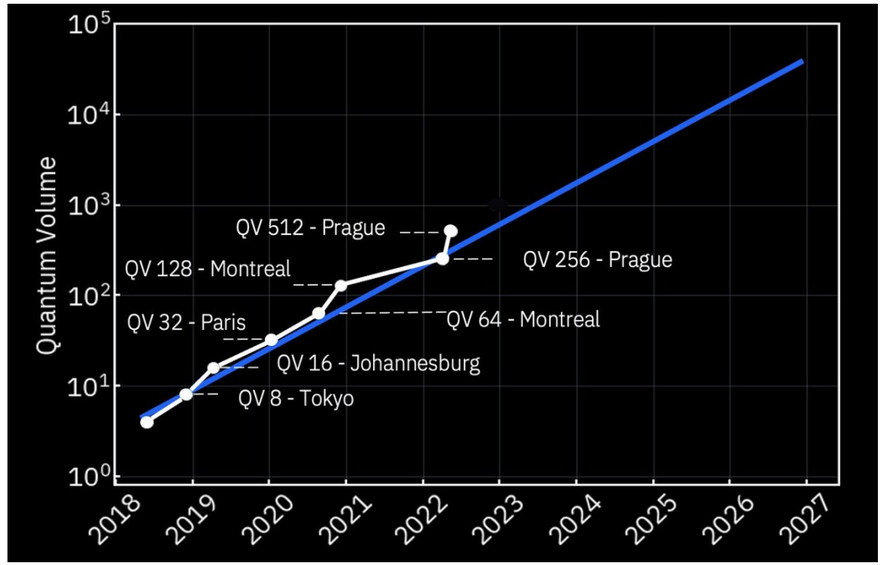


Quantum Volume

- IBM Proposed metric (2019) to define the **quality and computational power of NISQ devices** [1a]
- Largest square circuit of random two-qubit gates that a processor can successfully run

[1a] https://research.ibm.com/blog/quantum-volume-256

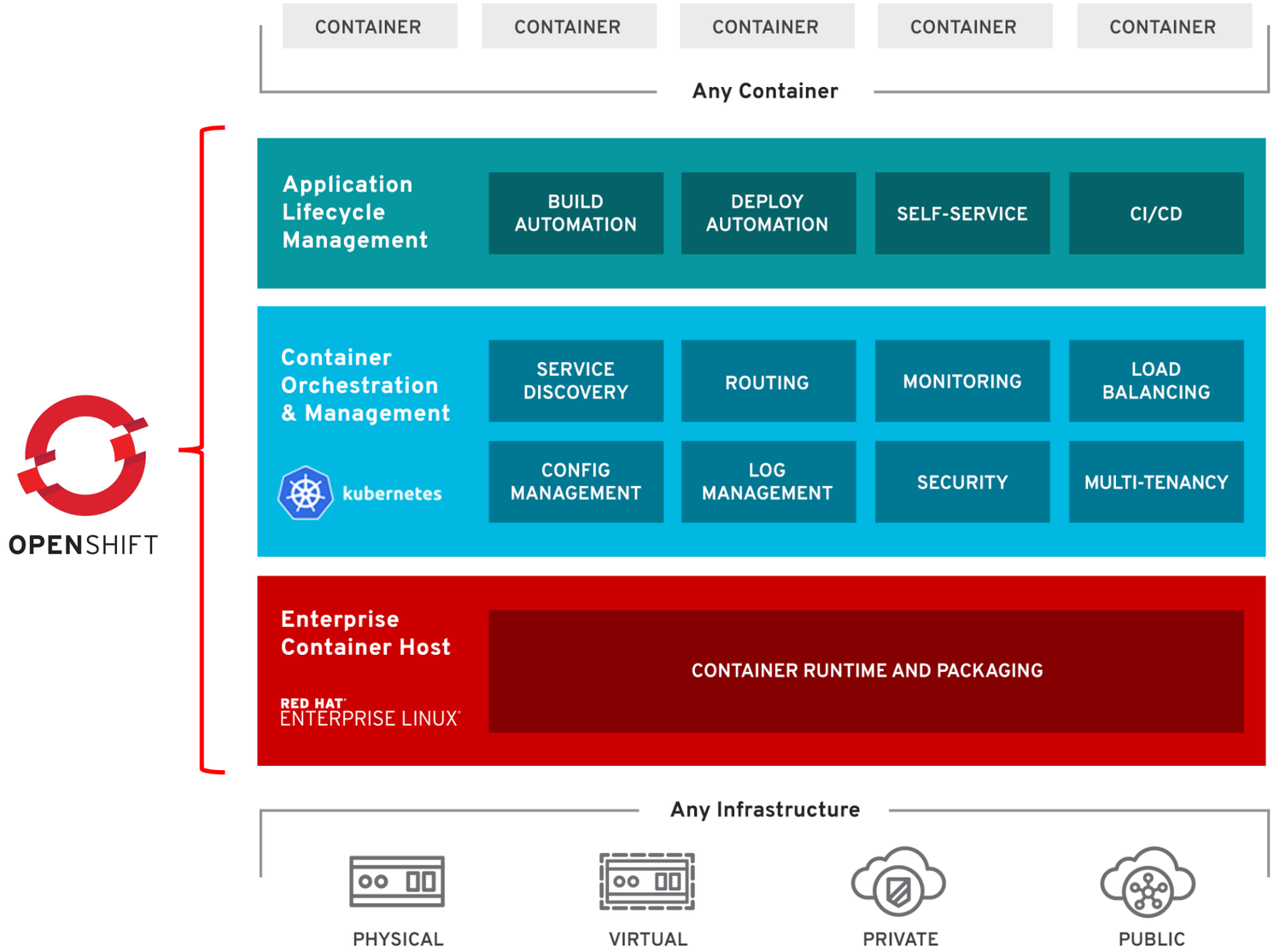
Qiskit

- Open-Source Quantum Development Software Development Kit [1b]

[1b] https://qiskit.org

Red Hat OpenShift

- OpenShift is a family of containerization softwares
- Developed by Red Hat and owned by IBM since 2018



Red Hat OpenShift

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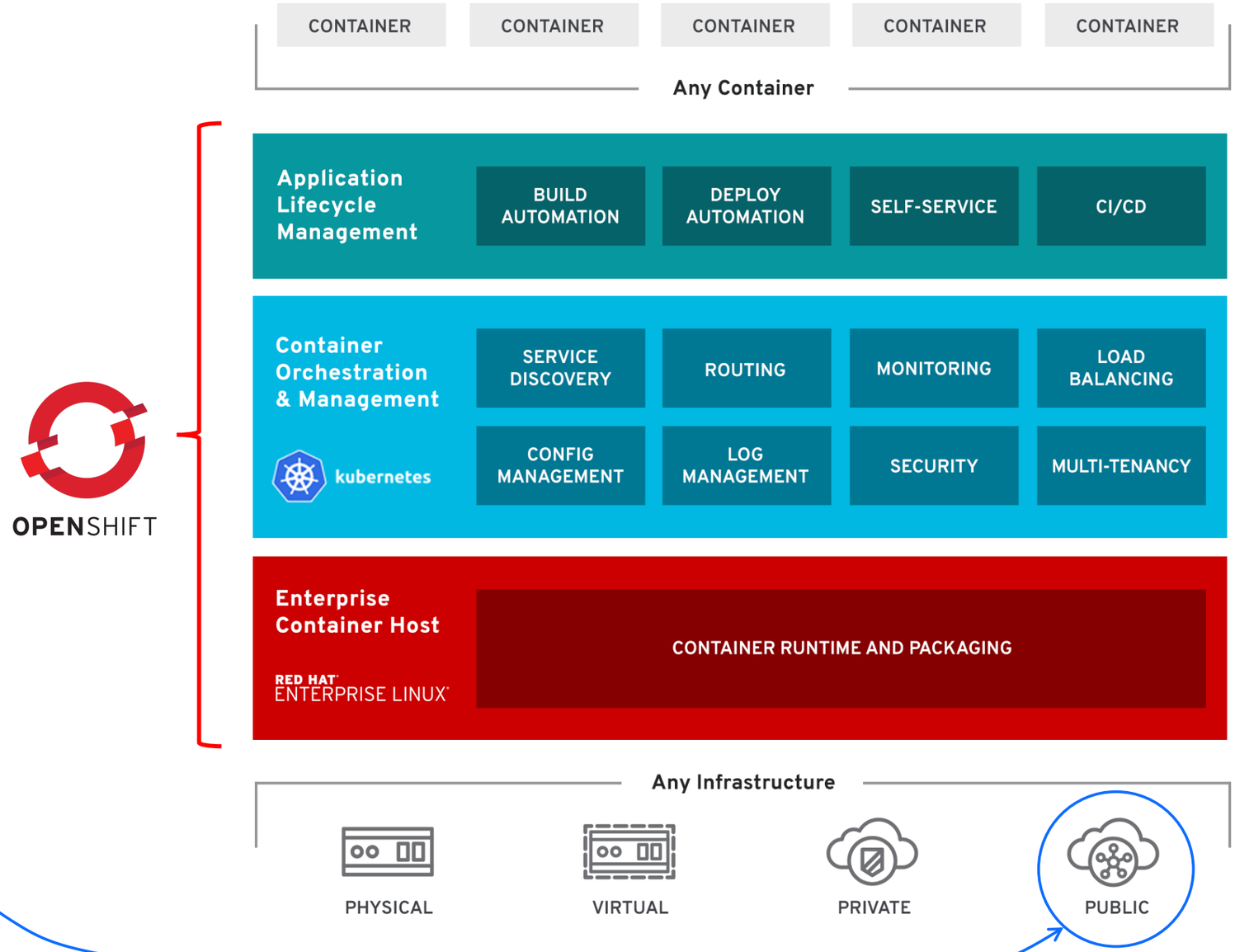
- Developed by Red Hat and owned by IBM since 2018

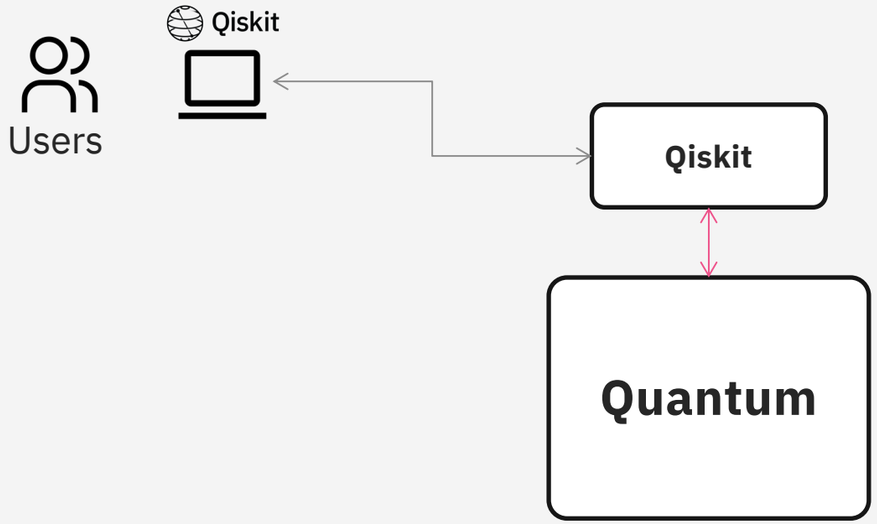
- This MVP has been deployed on IBM Cloud

IBM Cloud



Architecture overview

Current integration between classical and quantum computing



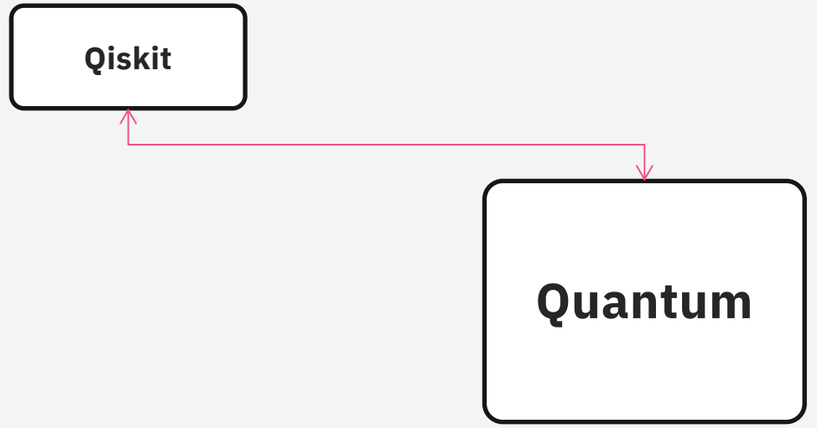
- Direct interaction with Qiskit Runtime [2] or via recently announced Quantum Serverless [3]
- Qiskit Runtime manages quantum jobs and interacts with Quantum hardware / simulators, speeding up the execution [4]
- Results are returned to User's Qiskit instance

How to deal with:

- Existing applications?
- New hybrid applications?

[2] https://quantum-computing.ibm.com/lab/docs/iql/runtime/
[3] https://research.ibm.com/blog/quantum-serverless-programming
[4] https://research.ibm.com/blog/120x-quantum-speedup

Overview of proposed architectural framework



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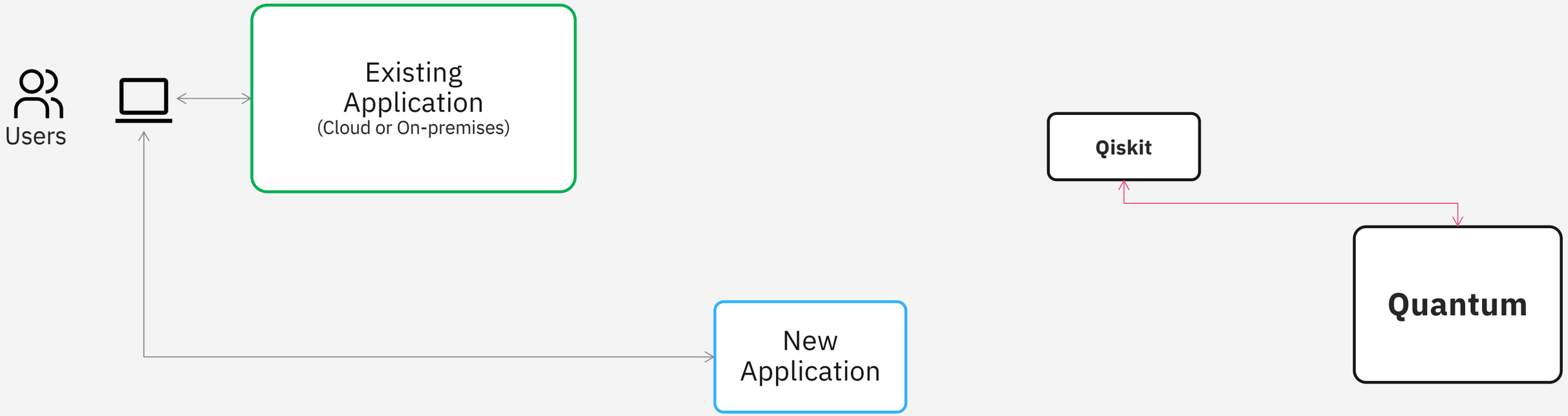

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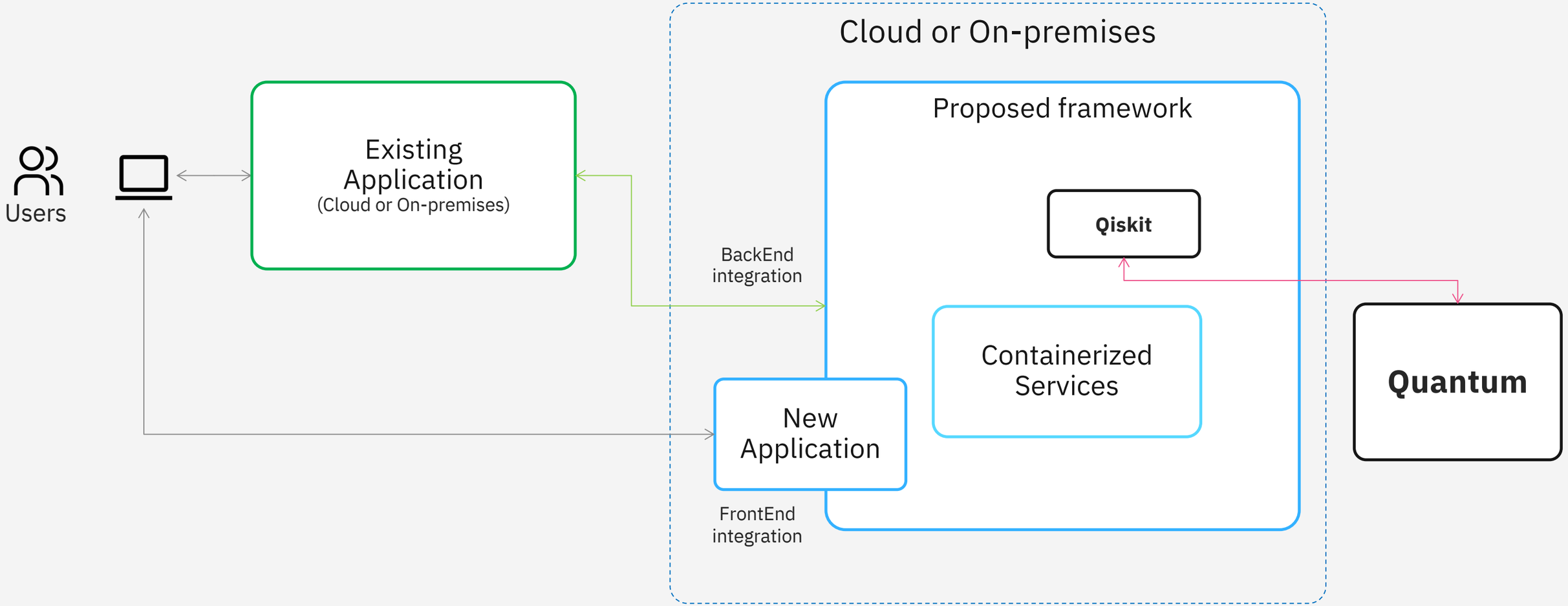
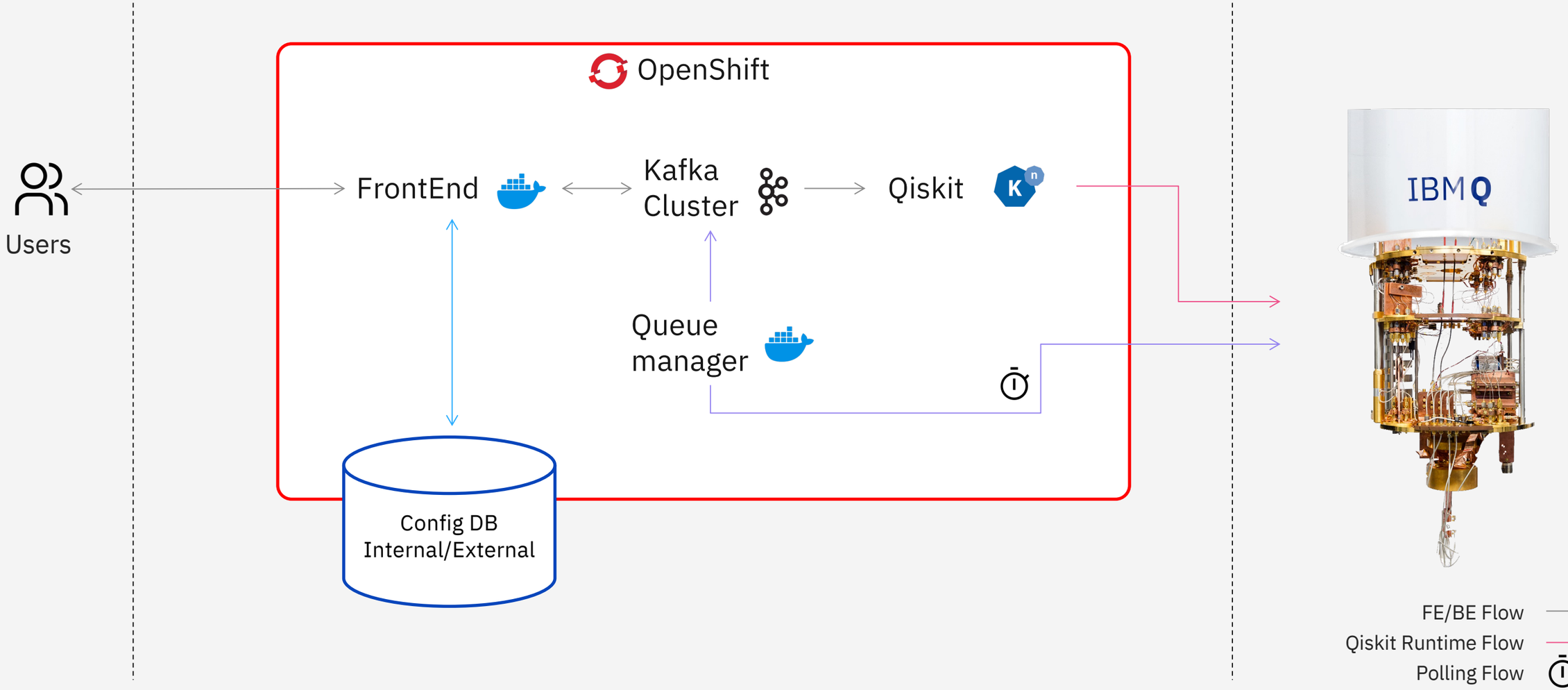


Implementation on Red Hat OpenShift



General properties

Driver	Technology approach / Cloud Services used
Extensibility	Configuration driven BackEnd (NoSQL outside or inside OpenShift)
Modularity	Microservices
Cost efficiency	Microservices
Asynchrony	Kafka on OpenShift
Scalability	Knative on OpenShift
Compatibility	OpenShift
Innovation	IBM Quantum, Qiskit
Security	OpenShift
Portability	Docker containers
Deployment	Terraform

Outcomes

Publications and IP

- Working framework based on **IBM Quantum**, **Qiskit** and **RedHat OpenShift** on **IBM Cloud**
- MVP applications implemented
- In-app documentation
- Architectural diagrams
- Deployment & installation guide
- GitHub repository with code and readme
  - Components: https://github.com/Quantum-App-Framework
  - Templates: https://github.com/vito490/Quantum-Application-Framework.git

Publications

- Grossi M. et al., https://arxiv.org/pdf/2107.02007.pdf (2021)
- Qiskit Blog in preparation

State of art

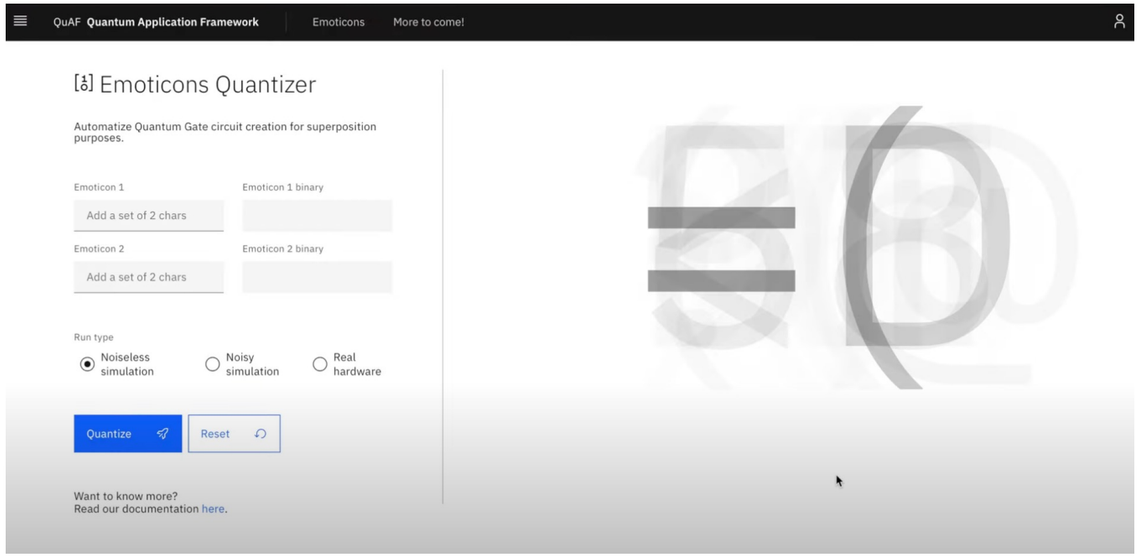
- Prior Art Database: IPCOM000258553D (2019)

Use Cases identification

- 3 sample apps currently implemented
- Could be implemented in any field
  - Research: speed up quantum jobs management
  - Business: interconnect with existing applications or creation of new hybrid applications

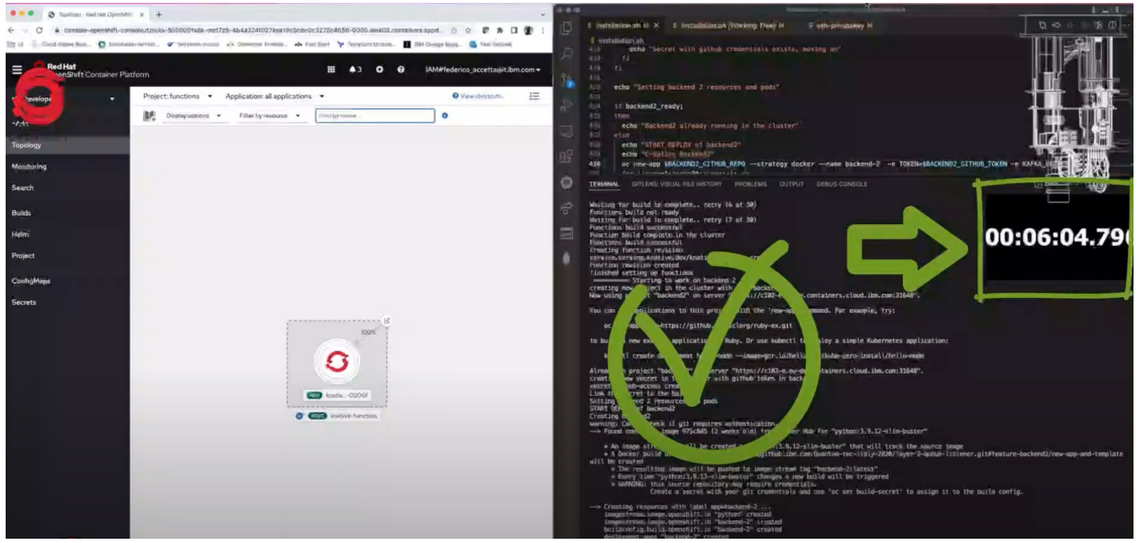
1. Sample application demo

https://www.youtube.com/watch?v=LqZZ6bhA2FA



2. One-click installation demo

https://www.youtube.com/watch?v=7wilwiUakh4



Research example

- **Manage quantum runs** and **collect results on a DB**, leveraging on multiple computing resources for simulations
- A first version has been used in this paper using **Qiskit** and **IBM Quantum** devices

Simulating Static and Dynamic Properties of Magnetic Molecules with Prototype Quantum Computers – L. Crippa et al., Magnetochemistry 7, 117 (2021) [5]

Target system: **finite-size spin ½ Heisenberg chains (4 to 6 sites)**

VQE for **static properties** (noisy simulations)

Time Evolution for **dynamic properties** (real quantum hardware runs)

Thousands of quantum runs and simulations performed, managed and stored in a DB on IBM Cloud

[5] FET-OPEN project FATMOLS (FAult Tolerant MOlecular Spin processor), Grant Agreement No. 862893, within the European Union's Horizon 2020 program

[6] A. Chiesa et al., Nature Physics 15, 455-459 (2019)

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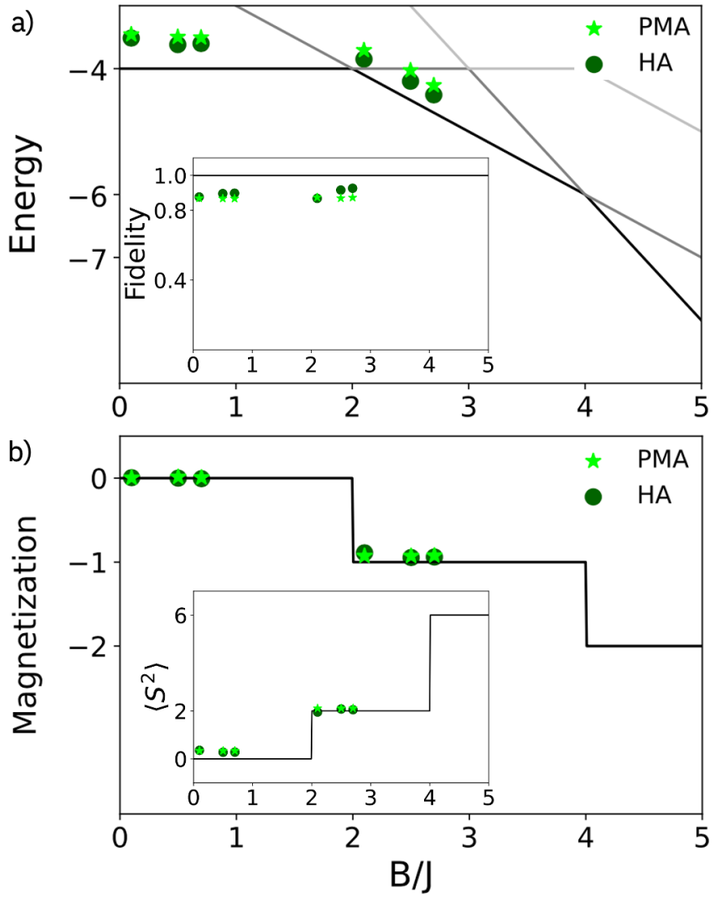
Ground State (Heuristic and Phys. Motivated Approaches)



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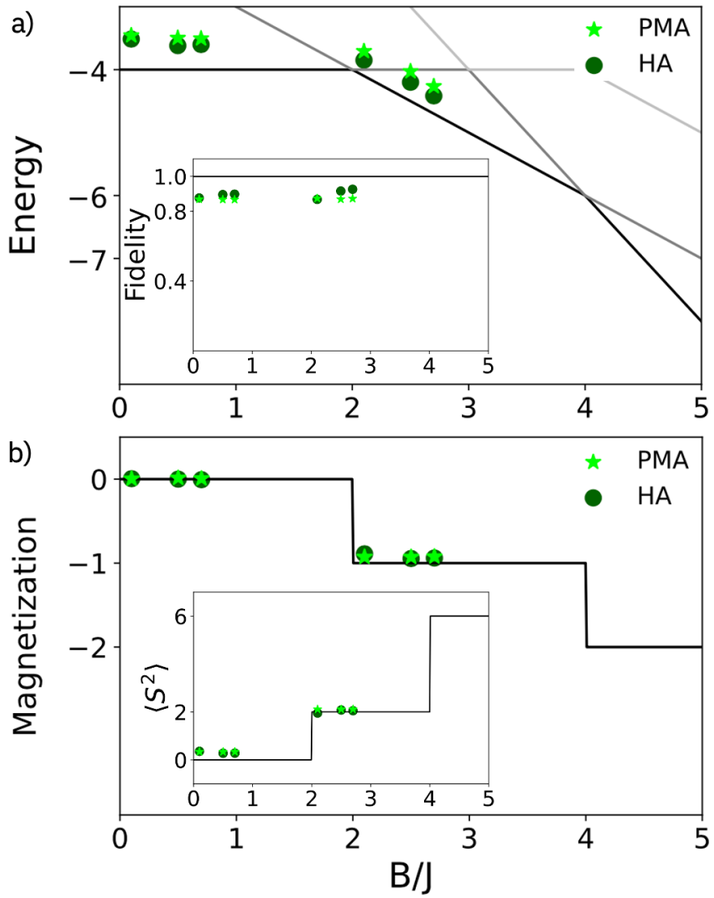
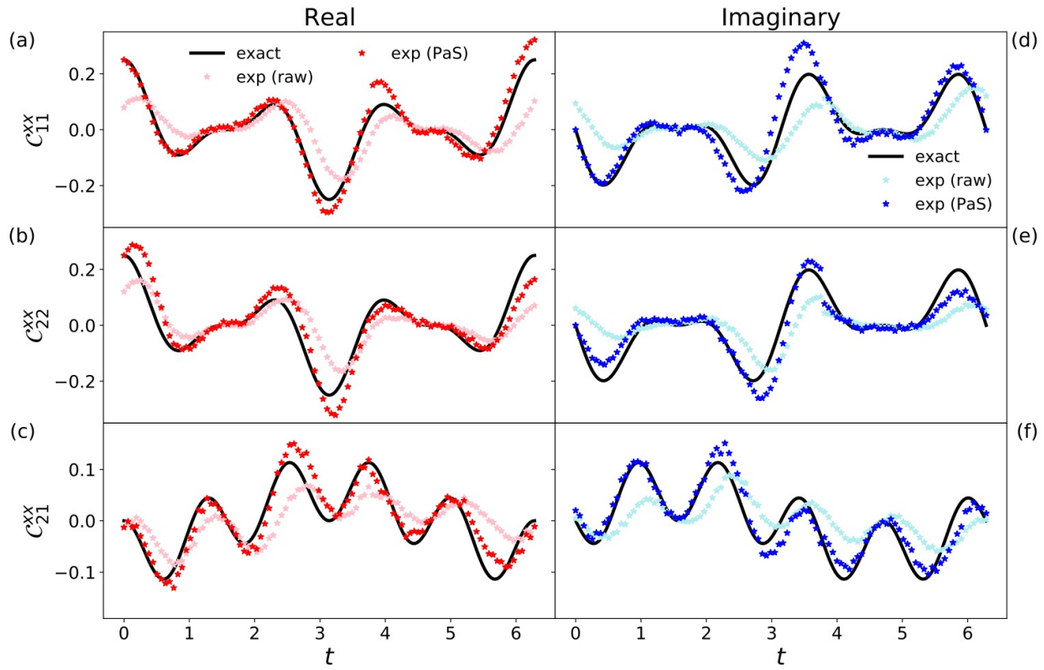


Spin-spin dynamic correlations with 4 spins (Raw and mitigated) [6]



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Conclusions and future perspectives

- Publicly available framework with automations
- GitHub repositories:
  - Components: https://github.com/Quantum-App-Framework
  - Templates: https://github.com/vito490/Quantum-Application-Framework.git

- Possible integration with Qiskit Runtime
- Investigation of new use cases

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Federico Accetta
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Data Scientist, Advanced Analytics Consultant and Qiskit Advocate @ IBM

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PhD student @ University of Parma

Federico Mattei
Principal Account Technical Leader and Quantum Ambassador @ IBM

Thank you

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Cloud Architect and Executive PhD student

Quantum Ambassador

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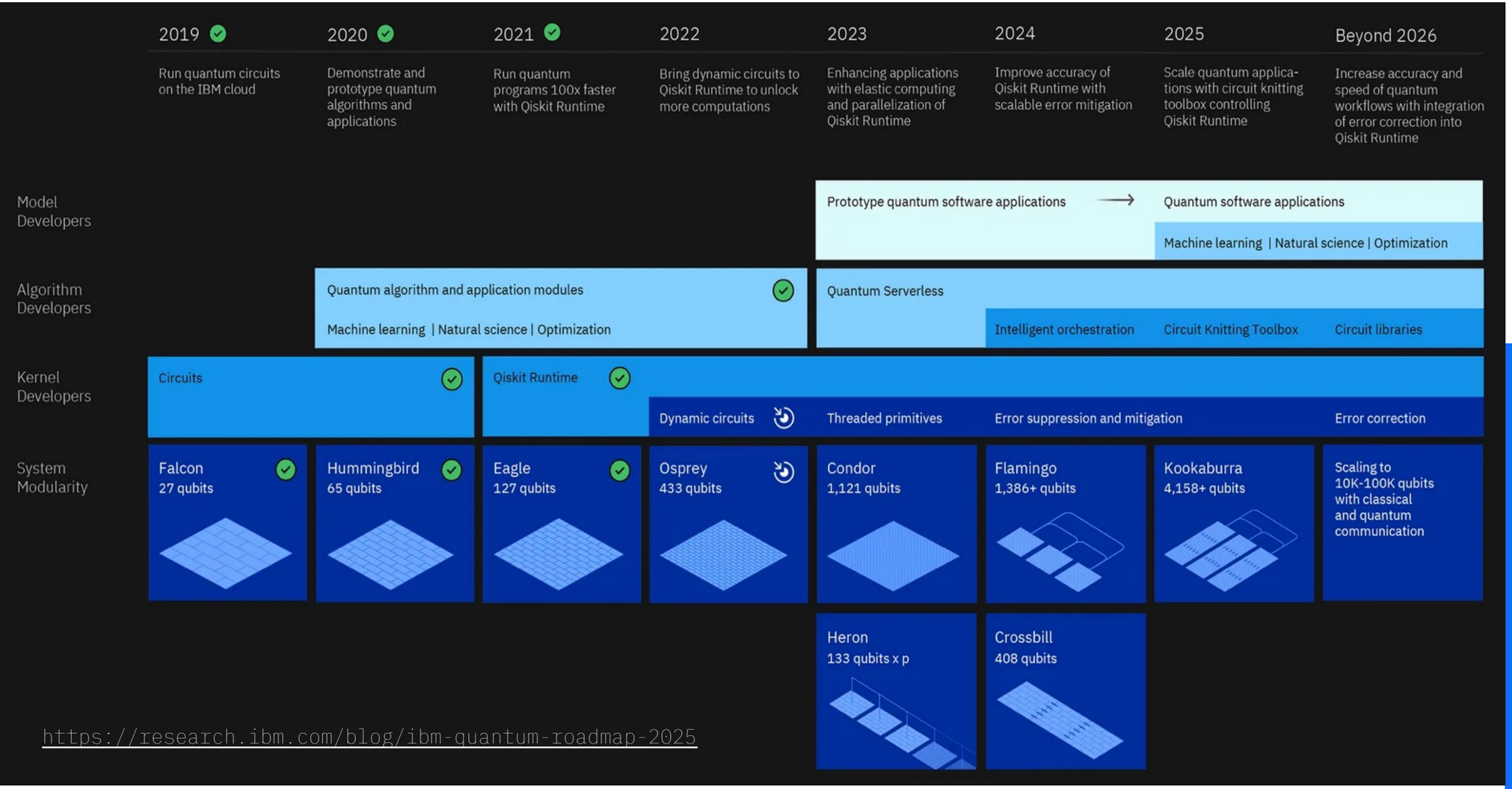
Backup

IBM Quantum roadmap



https://research.ibm.com/blog/ibm-quantum-roadmap-2025

Qiskit

Open-Source Quantum Development Software Development Kit

- **Nature**
- **Machine Learning**
- **Finance**
- **Optimization**

https://qiskit.org

IBM **Quantum**

IBM's platform, online since 2016

- Supercondicting transmon qubits, kept at 15 mK
- Almost 30 QC avaliable on Cloud