EDF R&D : Quantum @each point of the value chain

Quantum Team
Teams of experts cumulating more than 20 000 citations
PhD students, 20 papers published on Quantum

Production

- Material Simulation of internals
- Safety Risk Assesment
- Partial Differential Equations
- Metrology

Networks

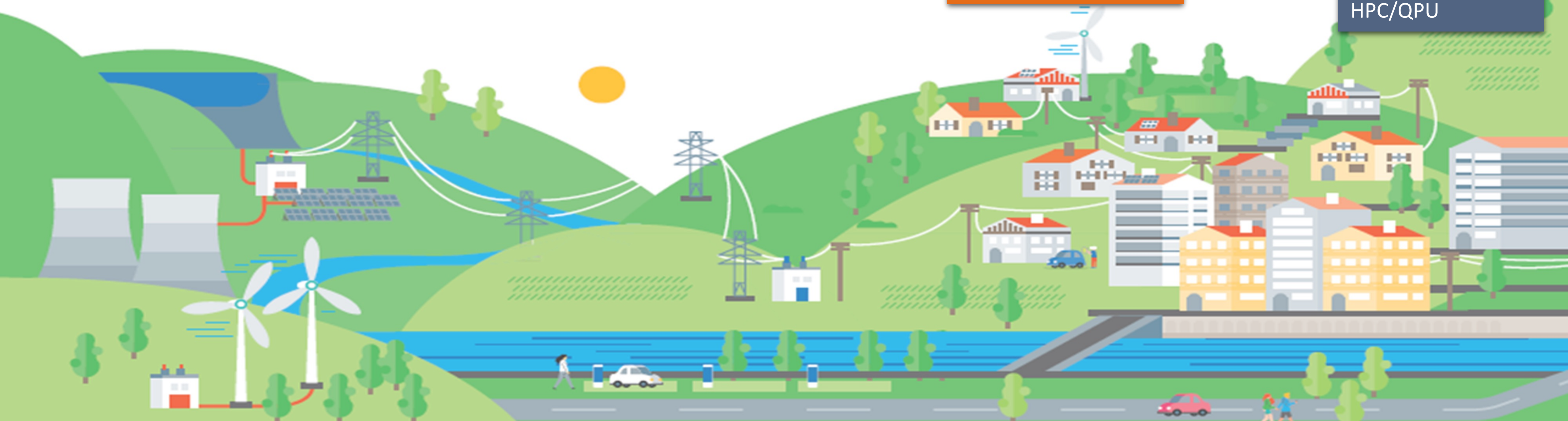
- Optimal Power Flow

Energy management

- Optimisation
  Scheduling
  Smart Charging
  V2G
- Machine Learning
  Forecasting

IT

- Post-quantum Cryptography
- Integration HPC/QPU



FRANCE
HYBRID
HPCQUANTUM
INITIATIVE

cea

- HQI, The French Hybrid Quantum Initiative
  - Aims to integrate the QC systems in the HPC environment
  - Strong focus on the HPC/QC hybridation
  - Builds future systems running codes with steps on QPU and CPU/GPU

- Philippe DENIEL: your HQI ambassador Today
  - Has been working with CEA since 1998 in CEA's computer centers teams
  - Fellow Expert at CEA with a focus on HPC
  - Point of contact for the TGCC computer center inside HQI

- The HPC has a strong background using benchmarks
  - The Top500 is nothing but an award associated with a large benchmark
  - Each technology comes with probe and metrics to expose their benefits
  - Probe and metrics help building KPIs (Key Performance Indicators)
    - KPIs are useful to expose the performances of a machine / device / algorithm
    - KPIs are used to evaluate the compliancy of delivered hardware and software in procurements

- Benchmarks are tools, they should be handled carefully
  - It’s easy to misinterpret a benchmark result
  - It’s not difficult to cheat on benchmark (http://fsbench.filesystem.org/papers/cheating.pdf)

❑Benchmarking is useful

- It highlights the point of interest
- They describe the key points of interest to final users
- Benchmark helps “classifying” the items they evaluate
- As a consequence, benchmark helps establishing standard : most of the time, an benchmark evaluates the compliancy of something to a explicit standard

❑Benchmarks structure communities

- Many examples in the HPC ecosystems
- Many opensource initiatives, independent from vendors and industrials It highlights

- Benchmarking and QC
  - Many different technologies exists in QC (qubits/qugates, annealers, quantum simulators, …)
  - Not all problems addressed by HPC can be handled efficiently with QC (QC won't replace HPC)
  - … but QC may brings huge improvements when applied for the right problems
  - Benchmark will help identify the area of interest and quantify the improvements made in those area
- One benchmark to rule them all ?
  - Probably not. But there clearly will be one dedicated and "official" benchmark for each identify application / domain of interest

HPC simulation of quantum Computer

230511

Nobuyasu Ito
Unit Leader
Quantum Computing Simulation Unit
RIKEN Center for Computational Science

collaboration with Naoki Yoshioka

braket: A open-source quantum computer simulator for parallel computer coded using C++
https://github.com/naoki-yoshioka/braket

RIKEN R-CCS and supercomputers

K 10PFLOPS, 2011-2019

Fugaku 442PFLOPS, 2020-

Fugaku NEXT ～2030?

with quantum-hybrid architecture?

Fugaku

up to 36 qbits in 2007

History of state-vector simulation on HPC

ELSEVIER

Available online at www.sciencedirect.com

ScienceDirect

Computer Physics Communications 176 (2007) 121–136

Computer Physics Communications

www.elsevier.com/locate/cpc

Massively parallel quantum computer simulator

K. De Raedt [a], K. Michielsen [b], H. De Raedt [b,*], B. Trieu [c], G. Arnold [c], M. Richter [c], Th. Lippert [c], H. Watanabe [d], N. Ito [e]

[a] *Department of Computer Science, University of Groningen, Blauwborgje 3, NL-9747 AC Groningen, The Netherlands*
[b] *Department of Applied Physics, Materials Science Centre, University of Groningen, Nijenborgh 4, NL-9747 AG Groningen, The Netherlands*
[c] *Zentralinstitut für Angewandte Mathematik, Forschungszentrum Jülich, D-52425 Jülich, Germany*
[d] *Department of Complex Systems Science, Graduate School of Information Science, Nagoya University, Furouchou, Chikusaku, Nagoya 464-8601, Japan*
[e] *Department of Applied Physics, School of Engineering, The University of Tokyo, Hongo 7-3-1, Bunkyo-ku, Tokyo 113-8656, Japan*

Received 21 February 2006; accepted 24 August 2006

Available online 13 October 2006

up to 48 qbits in 2019

Computer Physics Communications 237 (2019) 47–61

ELSEVIER

Contents lists available at ScienceDirect

Computer Physics Communications

journal homepage: www.elsevier.com/locate/cpc

COMPUTER PHYSICS COMMUNICATIONS

Massively parallel quantum computer simulator, eleven years later

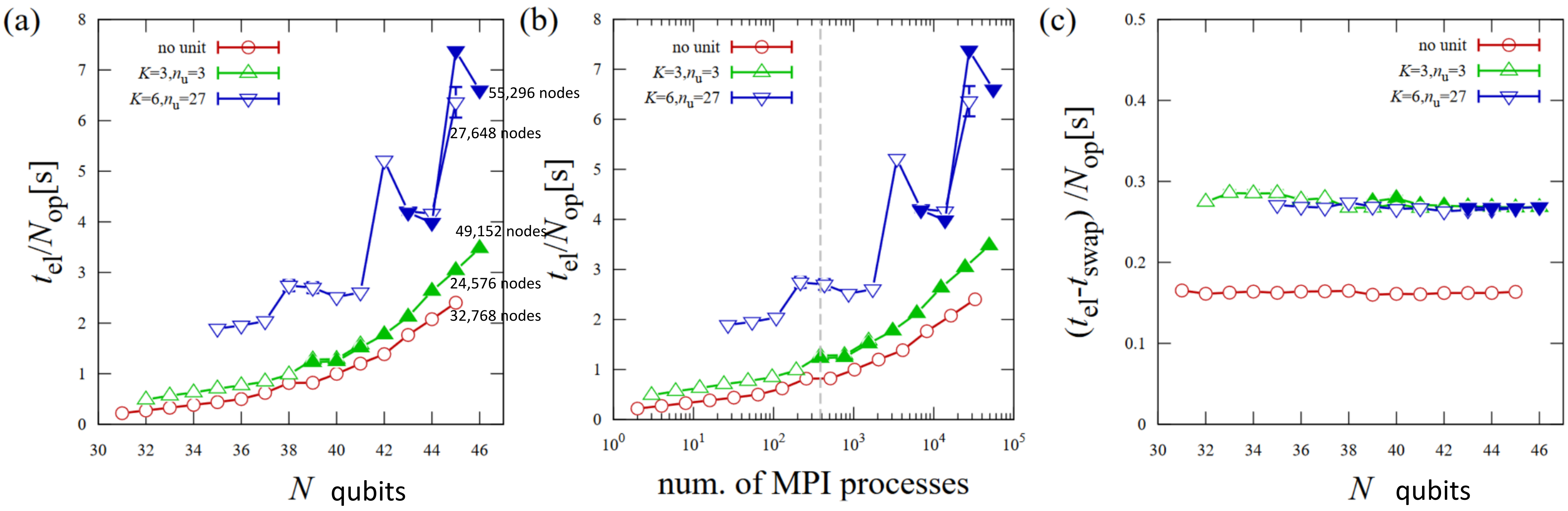
Check for updates

Hans De Raedt [a], Fengping Jin [b], Dennis Willsch [b,c], Madita Willsch [b,c], Naoki Yoshioka [d], Nobuyasu Ito [d,e], Shengjun Yuan [f,*], Kristel Michielsen [b,c,**]

[a] *Zernike Institute for Advanced Materials, University of Groningen, Nijenborgh 4, NL-9747 AG Groningen, The Netherlands*
[b] *Institute for Advanced Simulation, Jülich Supercomputing Center, Forschungszentrum Jülich, D-52425 Jülich, Germany*
[c] *RWTH Aachen University, D-52056 Aachen, Germany*
[d] *RIKEN Center for Computational Science, 7-1-26 Minatojima-minami-machi, Chuo-ku, Kobe, Hyogo 650-0047, Japan*
[e] *Department of Applied Physics, School of Engineering, The University of Tokyo, Hongo 7-3-1, Bunkyo-ku, Tokyo 113-8656, Japan*
[f] *School of Physics and Technology, Wuhan University, Wuhan 430072, China*

RIKEN Code: https://github.com/naoki-yoshioka/braket

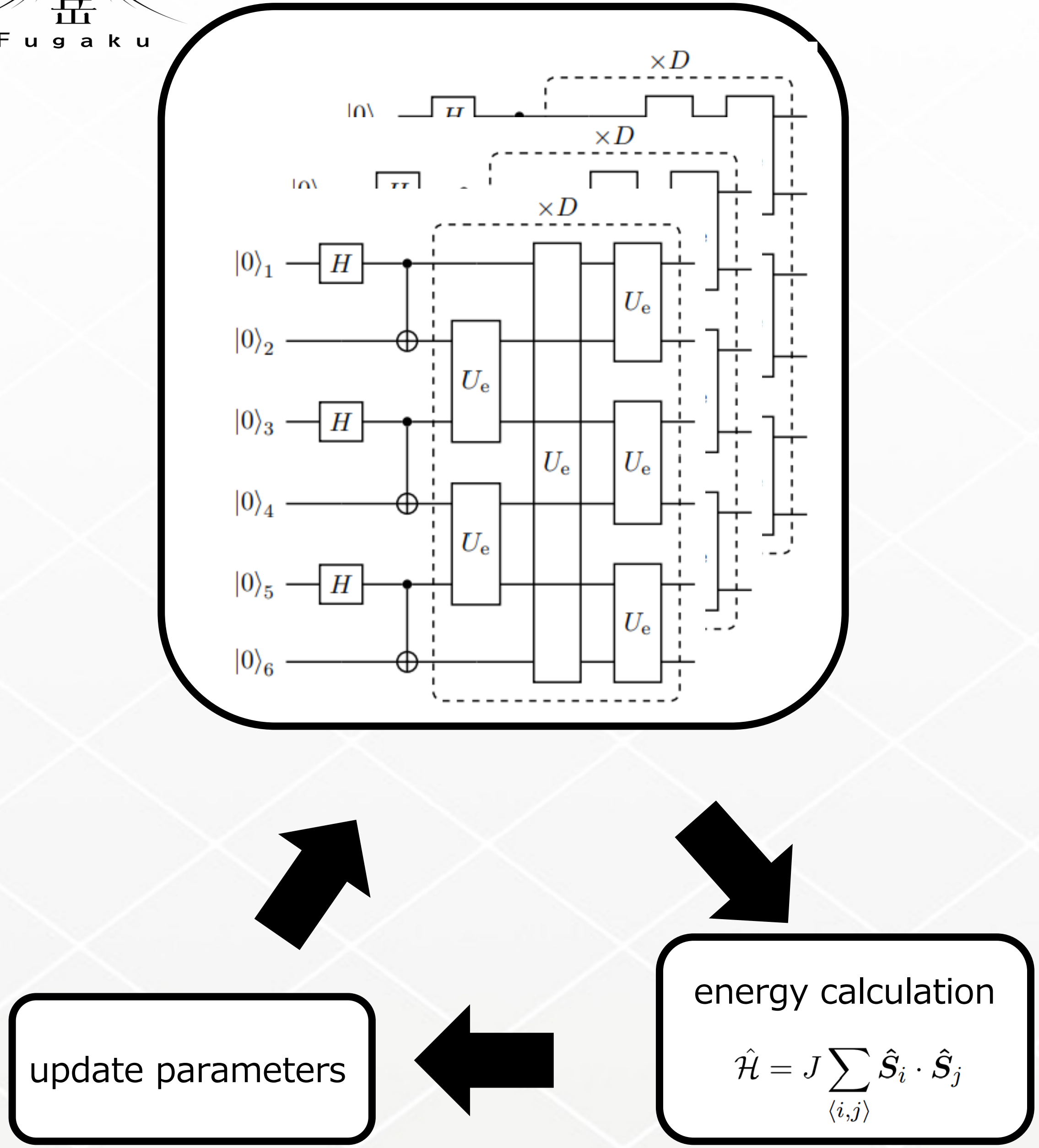
Performance of Hadamard benchmark(once) on the “Fugaku”

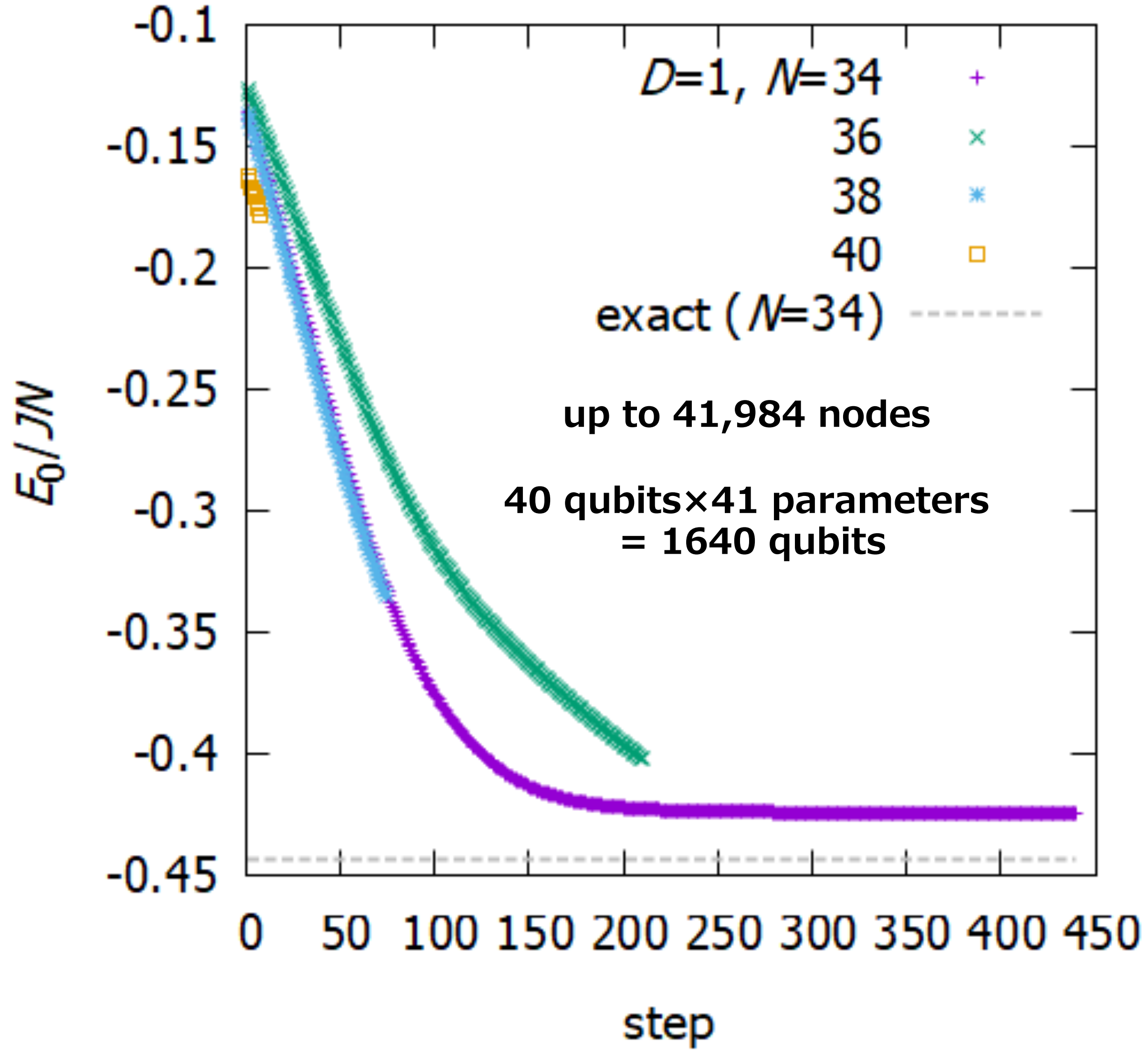


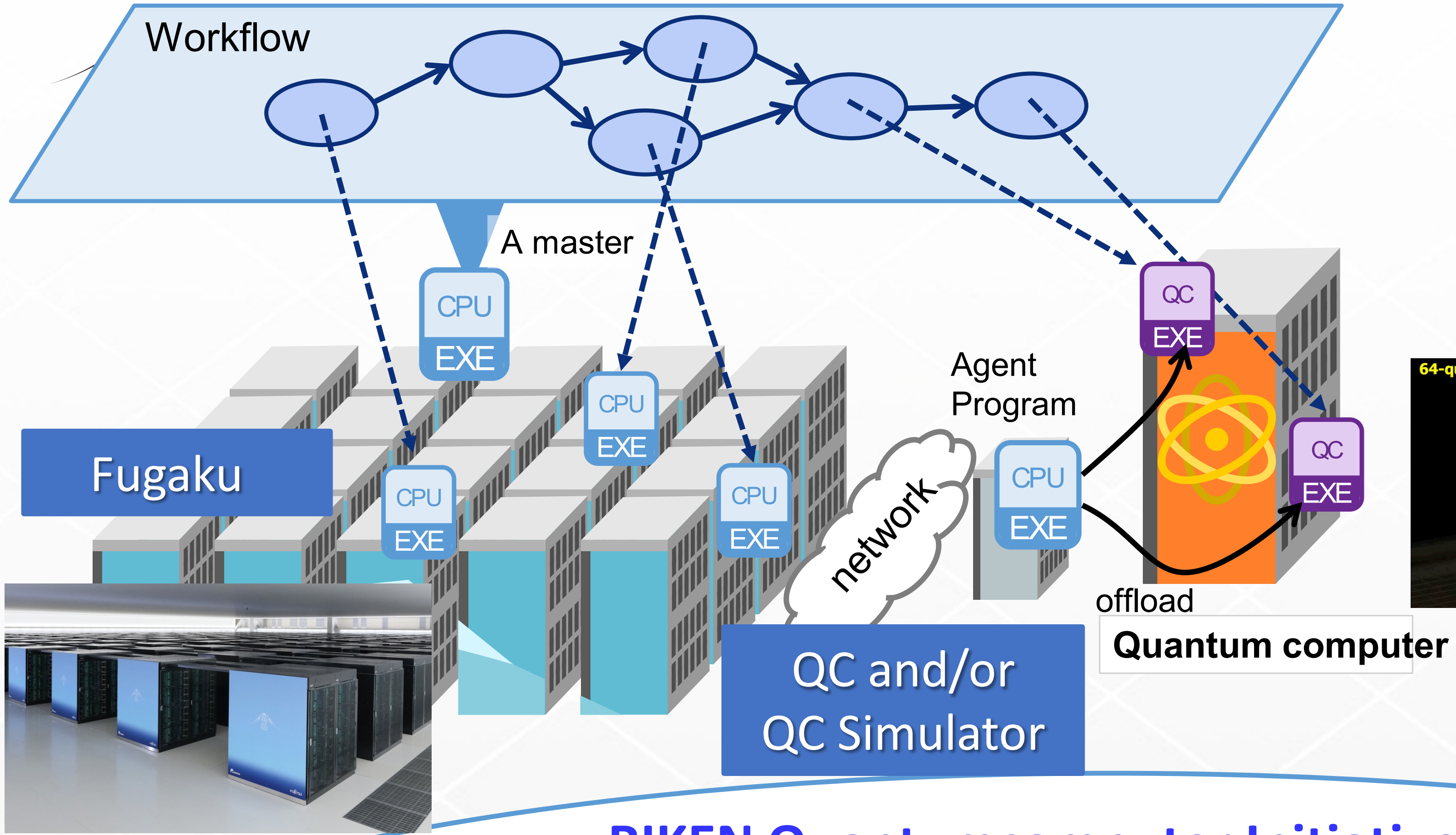
cf on K, 35 qubits: 1.2 sec
40 qubits: 2.0 sec

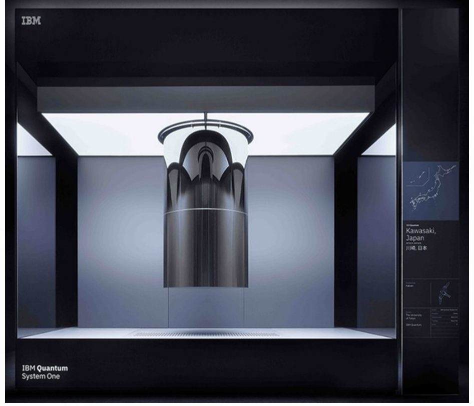
- no unit：basic parallelization using 2^M processes
- others：non 2^M parallelization

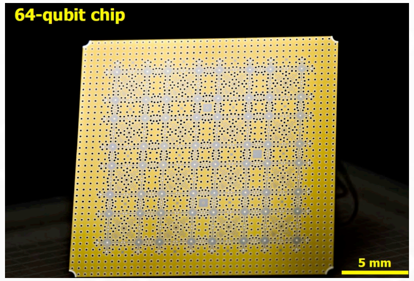
VQE simulation Heisenberg chain











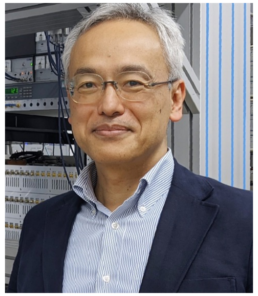
RIKEN Quantumcomputer Initiative

National Supercomputing Centre Singapore (NSCC)

Agency for Science, Technology and Research Singapore

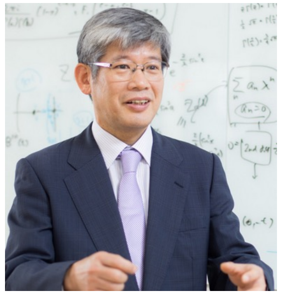
President
M. Gonokami

RQC
Y. Nakamura



R-CCS
S. Matsuoka

iTHEMS
T. Hatsuda



AIP
M. Sugiyama

FUJITSU

IBM

NVIDIA

Software environment for classical-quantum hybrid computation

Fugaku/Fugaku NEXT

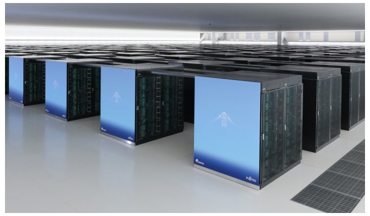
API and work-flow scheduler

cloud/network

Near-QC system （GPU & CPU)

Interface with low latency and high bandwidth

QPU



QPU simulator on Fugaku

Quantum applications

API and near-QC programming model

Quantum programming language with unified intermediate representation

Software layders necessary to test and evaluation quantum applications

Algorithms

- Hybrid
- Quantum
- NISQ

Various tools and environments

- Quantum BLAS： basic linear algebra subprogram
- Qiskit：framework by IBM
- Cirq：development tools by Google
- TensorFlow Quantum：framework for quantum machine learning
- Q#:language by Microsoft
- Qulacs, QunaSys: simulator and language by Osaka University
- Covalent: development workflow for quantum HPC environment by Agnostiq
- PyQubo：library for quantu annealing
- cuQuantum and QODA: simulator and programing language for GPU by NVIDIA
- TKET: development kit by Quantinuum

Bringing the power of Quantum Computing to Earth Observation

Bertrand Le Saux

ESA EOP-S Φ-lab

11/05/2023

The QC4EO Virtuous Circle

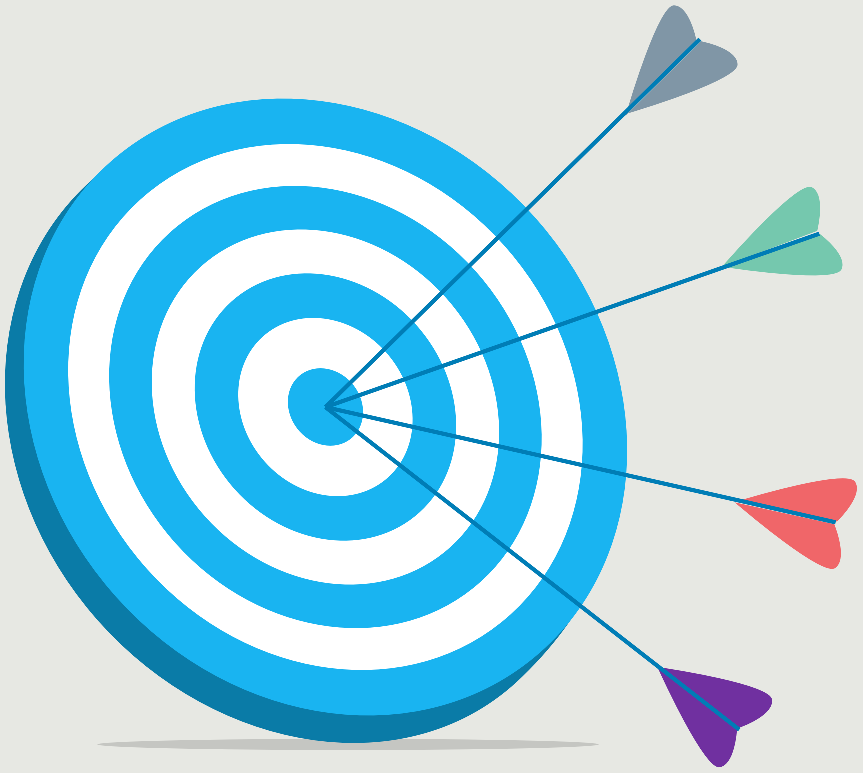
1. Roadmap definition
(QC4EO studies)

2. QML and QC
Exploratory activities

3. QC4EO Network

QC4EO Studies

2 projects during Q1 / Q2 2023 following ESA AO/1-11125/22/I-DT QUANTUM COMPUTING FOR EARTH OBSERVATION STUDY (QC4EO STUDY)



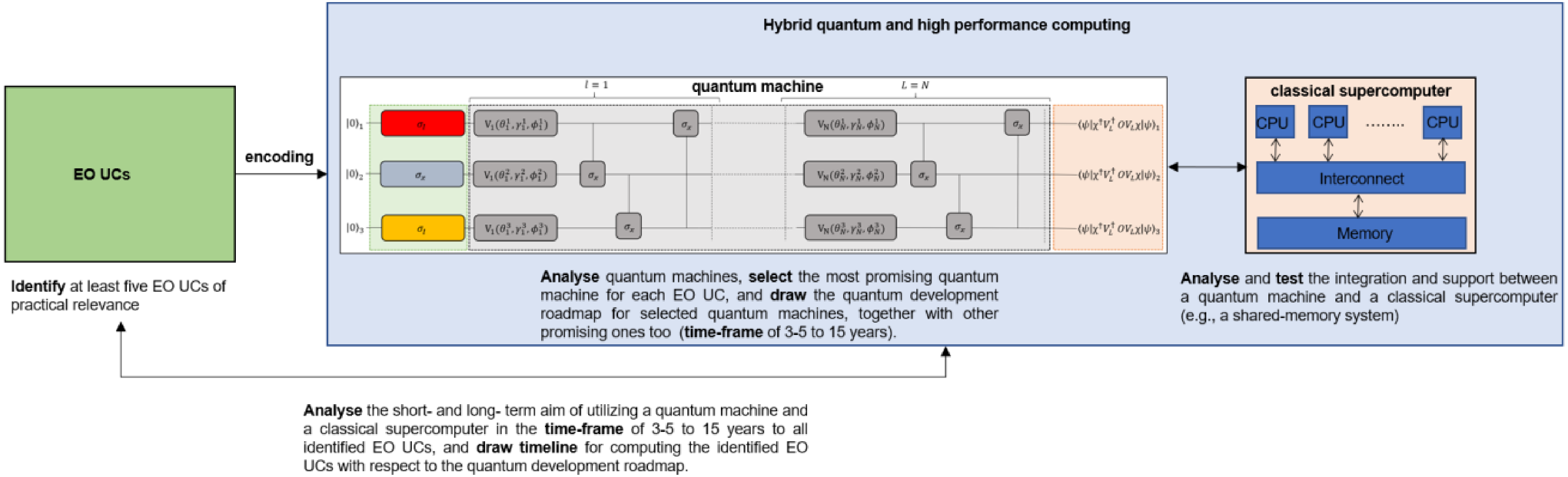
Objectives:

- ***Identify use cases relevant to the Earth Observation domain***, *for which QC is expected to dramatically enhance computational performances with respect to traditional methods.*
- ***Provide options for QC or hybrid machine architectures*** *required to solve the identified QC4EO use cases, with the relevant sizing, e.g. in term of Qubits.*
- *Perform a* ***maturity and forecast assessment of the QC machine industry roadmaps****; and*
- ***Derive a credible QC4EO timeline of use cases*** *that could take advantage of a QC approach*

ESA Contract No. 4000140122/22/I-DT

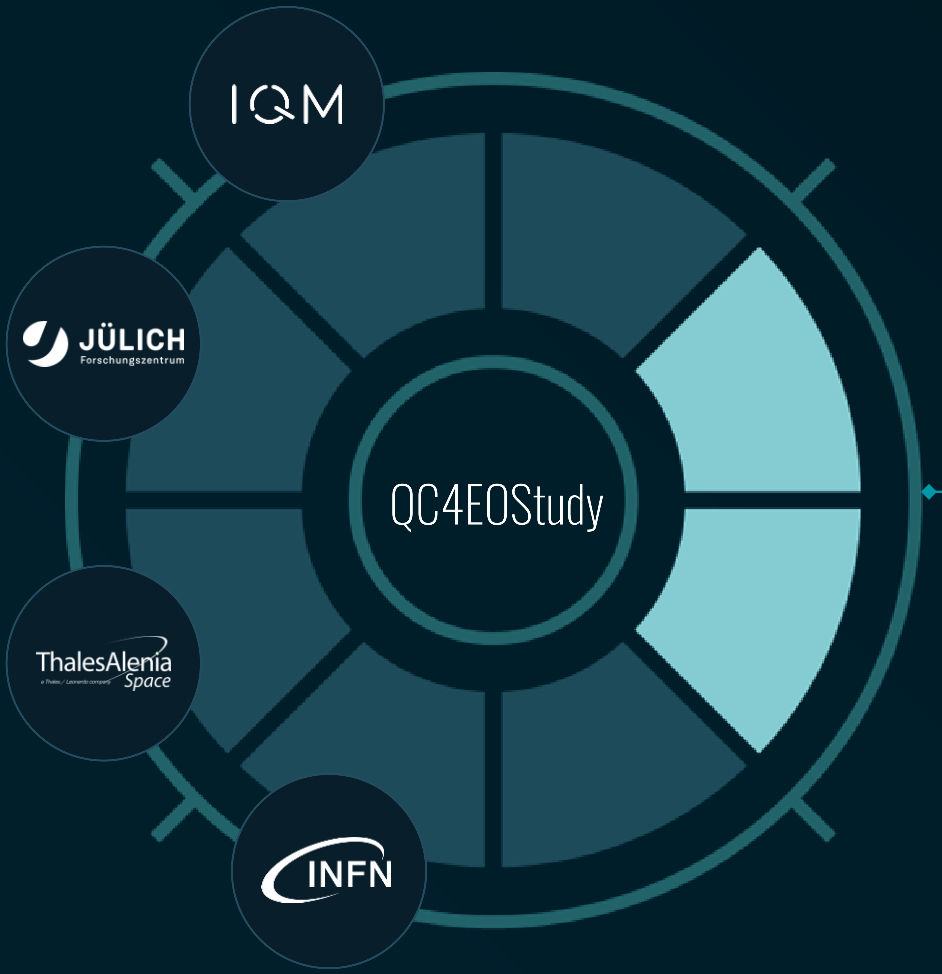
QA4EO project overview

- Identify hard Earth observation use cases (EO UCs) for quantum computers (e.g., quantum machines) or a hybrid approach
- Analyse quantum machines according to their number of qubits, errors, and so on
- Draw the roadmap of quantum computers



Quantum

COMPUTING FOR EARTH OBSERVATION



Can QC offer advantages to EO applications within a medium to long timeframe (between the next 3-5 to 15 years)? What hardware developments are necessary to achieve this quantum advantage?

- OPTIMAL SOLUTIONS
- BETTER MODELLING
- SPEED-UP
- ENERGY EFFICIENCY

Potential quantum advantages

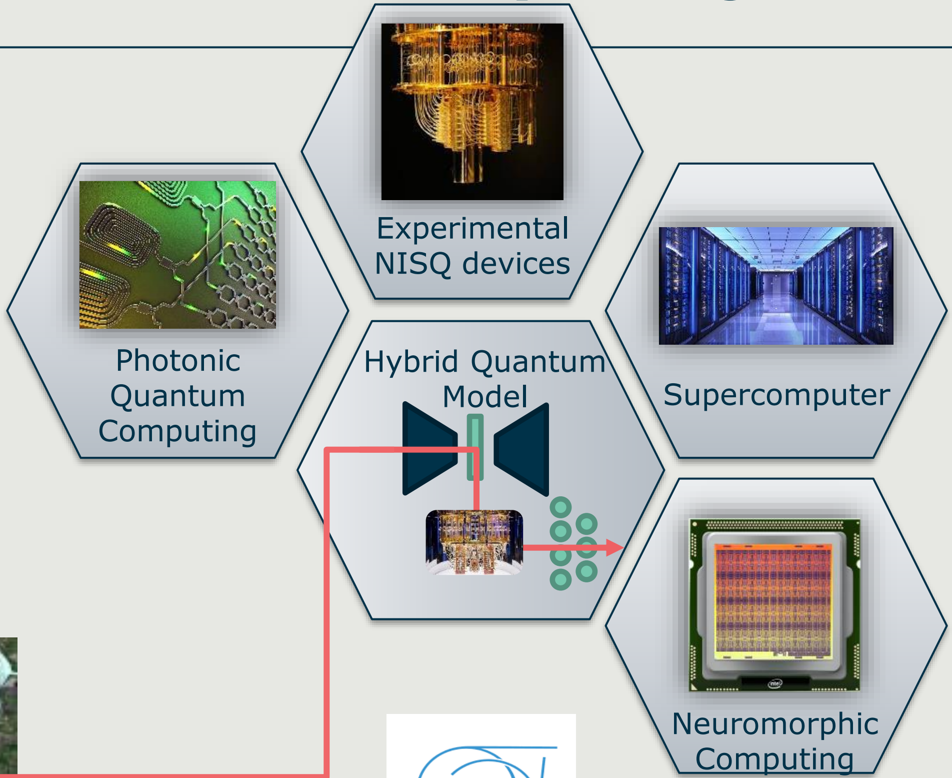
Exploratory activities in QML and Quantum Computing

esa

Explore the potential of Quantum Machine Learning for Earth Observation use cases

Devise hybrid quantum classical AI models in high performance computing environments

Build a strong community of experts in both Quantum Computing and Earth Observation



CERN

NICOLAUS COPERNICUS ASTRONOMICAL CENTER OF THE POLISH ACADEMY OF SCIENCES

UNIVERSITÀ DEGLI STUDI DI BARI ALDO MORO

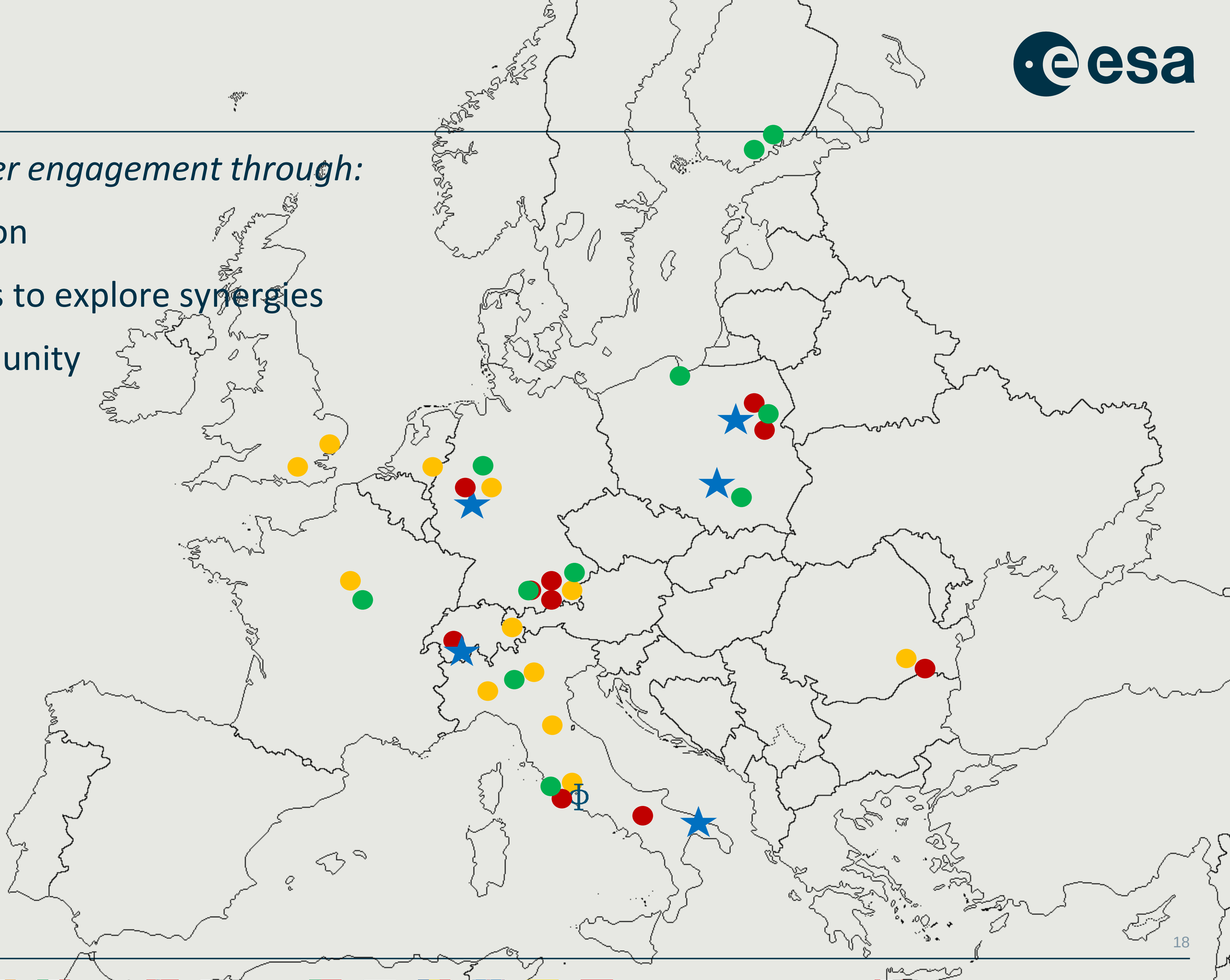
JÜLICH Forschungszentrum

JAGIELLONIAN UNIVERSITY IN KRAKÓW

QC4EO Network

Community building and stakeholder engagement through:

- Workshop and event organisation
- Consult QC and EO communities to explore synergies
- Support emerging QCxEO community



- ● QC4EO Study
- ★ Co-funded research
- ● Partners / visitors
- ● Community / events

ESA Φ-lab's Initiative on Quantum Computing for Earth Observation (QC4EO)

General perspectives:

- *Increase the **mutual awareness** of the needs and capabilities of the **Quantum Computing** and **Earth Observation** communities*
- *Create new **synergies**, building on shared experience in **AI**, optimisation, and **high-performance computing***
- *Prepare the ground for the opportunities that will be presented when the quantum community will be able to produce hardware and software for applied problems*

ESA Φ-lab's Initiative on Quantum Computing for Earth Observation (QC4EO)

Practical perspectives:

- *Look for* ***practical applications and use-cases****, enabled by increased quantum volume*
- *Understand the* ***advantages*** *(faster, better, etc.?) brought by QC with* ***exploratory activities***
- ***Design hybrid computing*** *frameworks including traditional CPU, GPU, HPC and new paradigms such as quantum and neuromorphic computing for optimal problem solving*

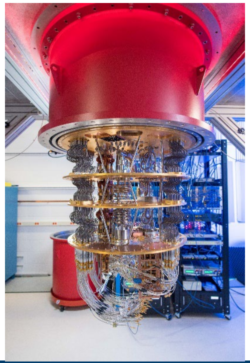
Make Space for Europe

SAVE THE DATE!

6th ESA Quantum Technology Conference | 19 – 21 September 2023 | Matera, Italy

- *Follow us: https://www.esa.int/ / https://philab.esa.int/*
- *Join ESA Φ-lab: https://jobs.esa.int/*

- *Contact: bertrand.le.saux@esa.int*



Quantum Computing: Benchmarking

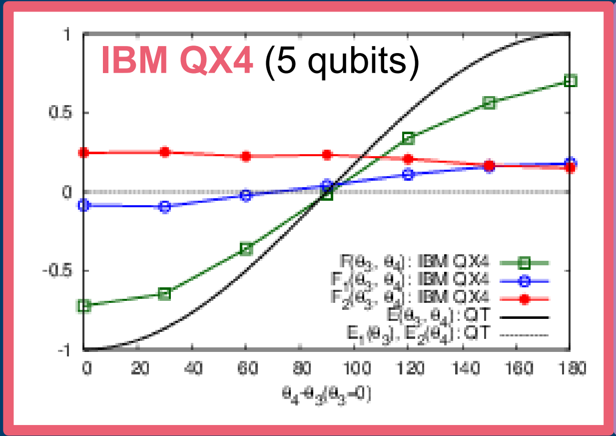
Quantum Computer Hardware and Quantum Algorithms

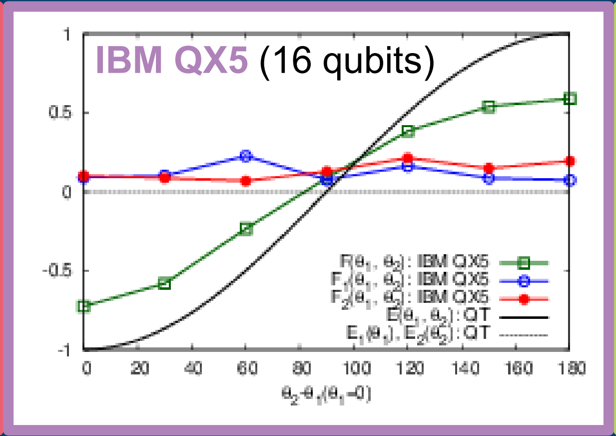
Teratec Quantum Computing Initiative Seminar | May 11, 2023 | KRISTEL MICHIELSEN

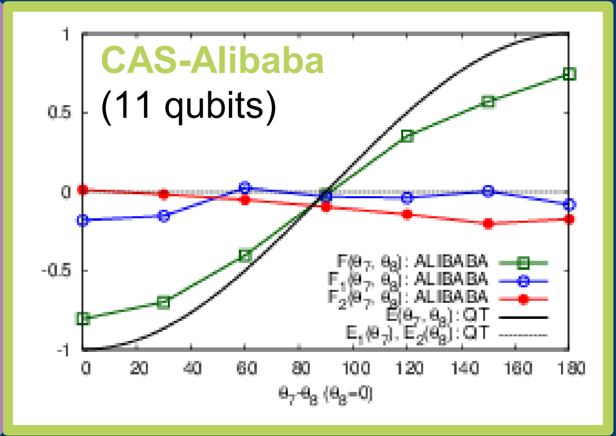
Benchmarking Quantum Computer Hardware by Simple Algorithms

K. Michielsen, et al, Advances in Parallel Computing 34 (IOS Press, Amsterdam, 2019), pp. 101 - 119

K. Michielsen, et al, Comp. Phys. Comm. 220, 44-55 (2017)



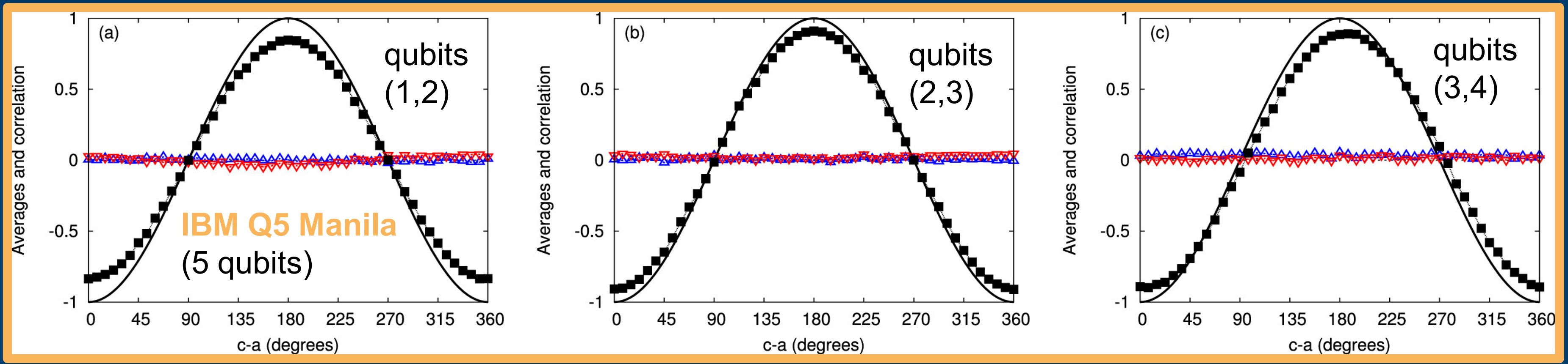




2018

SINGLET STATE

H. De Raedt, et al, Annals of Physics 453, 169314 (2023)



2022

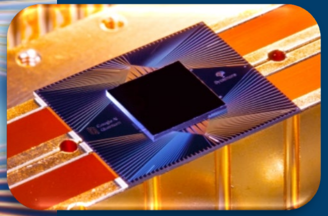
Benchmarking Quantum Computer Hardware with Emulators

- Emulator JUQCS - Jülich Universal Quantum Computer Simulator

  K. De Raedt, et al., Comp. Phys. Comm.176, 121 - 136 (2007)
  H. De Raedt, et al., Comp. Phys. Comm. 237, 47 - 61 (2019)
  D. Willsch, et al., Comp. Phys. Comm. 278, 108411 (2022)

  - Benchmarking Google’s quantum processor Sycamore

F. Arute, et al, Nature 574, 505-510 (2019)



- Emulators of real time dynamics for benchmarking quantum processors
  - IBM (transmon qubits)

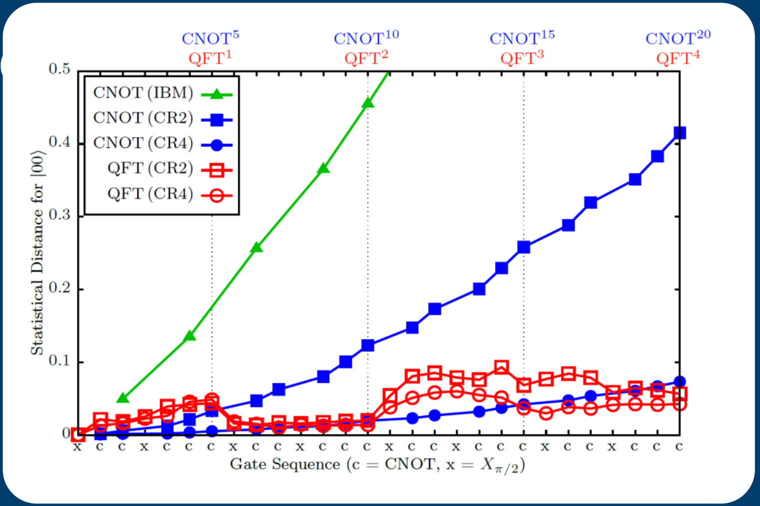
    D. Willsch, et al., Phys. Rev. A 96, 062302 (2017)

  - D-Wave (flux qubits)

    M. Willsch, et al, Phys. Rev. A 101, 012327 (2020)

  - OpenSuperQ (transmon qubits)

    H. Lagemann, et al., Phys. Rev. A106, 022615 (2022)
    H. Lagemann, et al, arXiv:2211.11011



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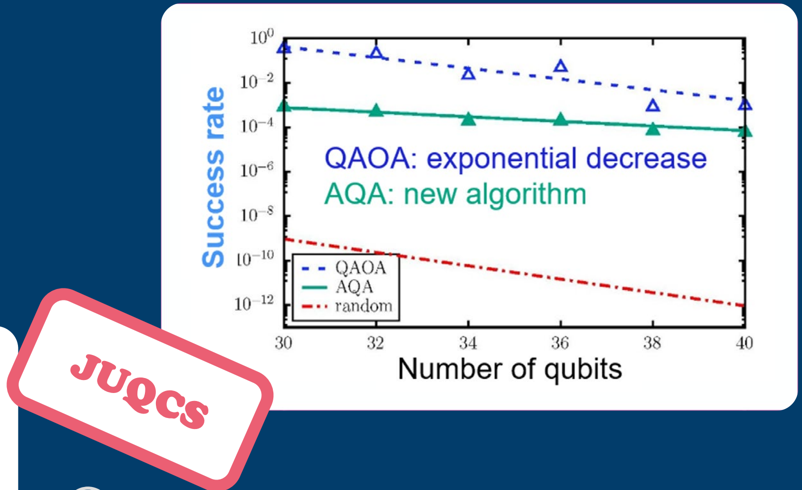
Benchmarking Quantum Algorithms

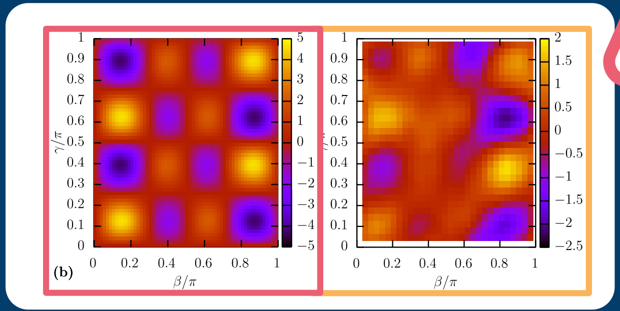
- Quantum Approximate Optimization Algorithm (QAOA) and Approximate Quantum Annealing (AQA)
  - Simplified Tail Assignment Problems, optimization problems to plan flights between airports so that routes do not overlap

D. Willsch, et al, Comput. Phys. Commun. 278, 108411 (2022)

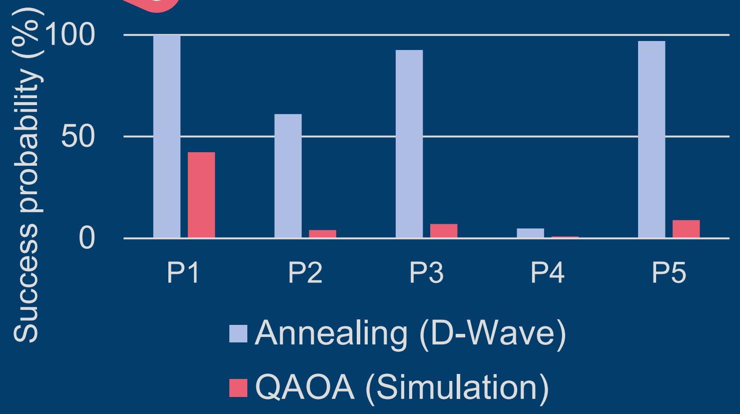


- QAOA and quantum annealing
  - 2-SAT problems

M. Willsch, et al, Quantum Inf. Process. 19, 197 (2020)



IBM-Q16 Melbourne



- Variational Quantum Eigensolver (VQE)
  - Ground state energy calculation of the Heisenberg model

M.S. Jattana, et al, Front. Phys. 10, 907160 (2022)

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