ICSC Centro Nazionale HPC, Big Data e Quantum Computing

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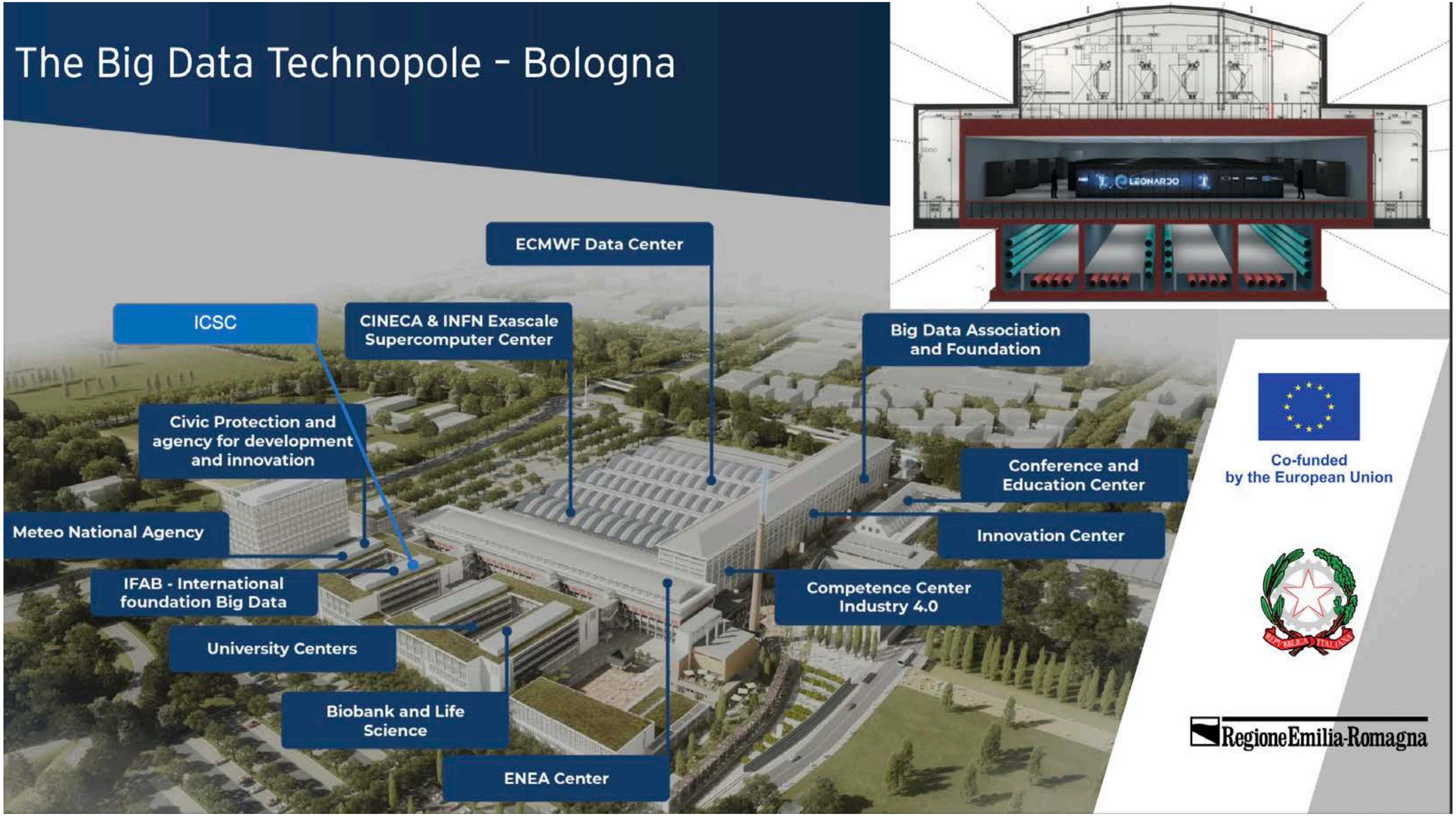
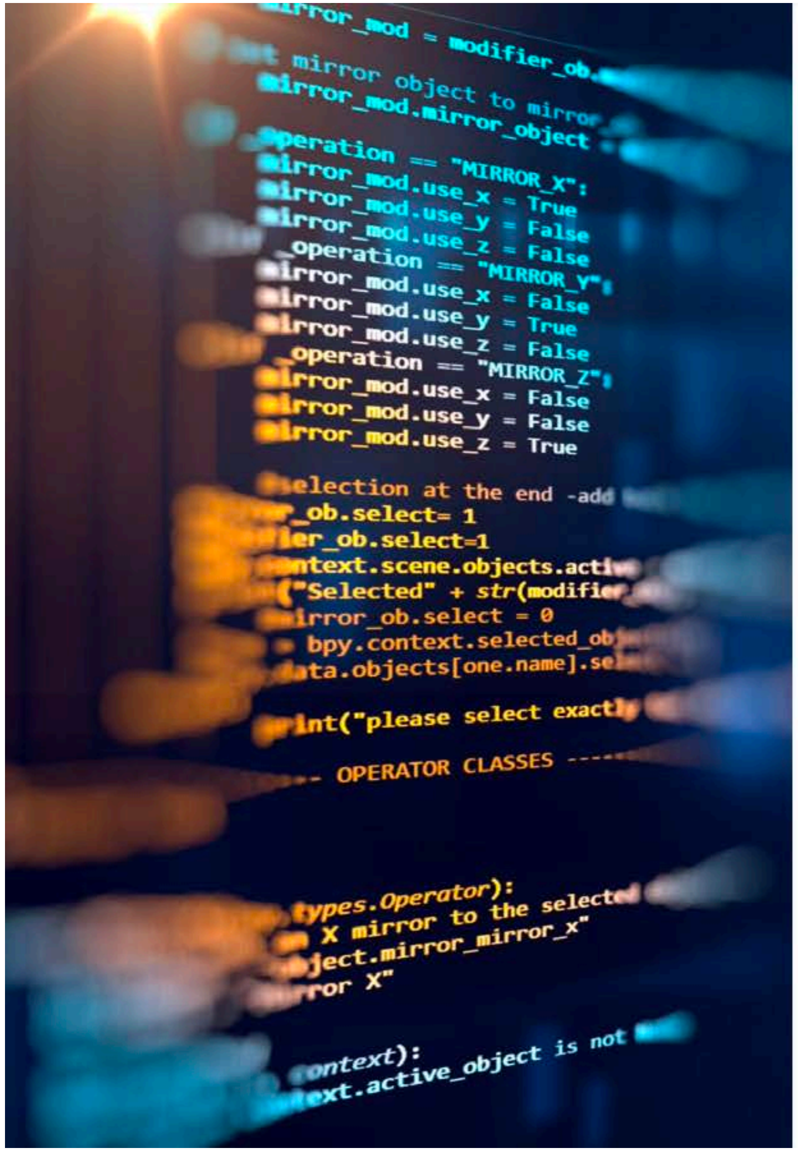
Dipartimento di Fisica e Astronomia Galileo Galilei · INFN Istituto Nazionale di Fisica Nucleare · Università degli Studi di Padova

https://www.supercomputing-icsc.it


The Big Data Technopole - Bologna
ECMWF Data Center
ICSC
CINECA & INFN Exascale Supercomputer Center
Big Data Association and Foundation
Civic Protection and agency for development and innovation
Conference and Education Center
Meteo National Agency
Innovation Center
IFAB - International foundation Big Data
Competence Center Industry 4.0
University Centers
Biobank and Life Science
ENEA Center
LEONARDO
Co-funded by the European Union
Regione Emilia-Romagna



5 pillars of the action plan

1. Build a **world-class** supercomputing cloud infrastructure to store, manage and process all the produced data
2. Set up **centers of excellence** with teams of high-level experts to develop domain applications
3. Set up strong **links** between **Academia, Industry and Public Administration**
4. **Train** the next generation of data scientists and managers to become **experts** in the digital transition
5. Implement structural **measures for innovation** and **for dissemination**

5 key elements

World-class Infrastructure	Living Labs	Centers of Excellence	Integrated Ecosystem	Leadership
1 Enabling the research and innovation potential	2 Co-design future HPC and microprocessor architectures and big data technologies	3 Creating value from data and maximizing socio-economic impact	4 Empowering and training people, attracting and retaining international talent, inspiring young entrepreneurs	5 Strengthen Italian competitiveness and lead Europe to become a world player in the data driven society

Secure, Sustainable and Resilient

ICSC Founding Members: a public private partnership

25
Universities

12
Research Institutions

15
Strategic private partners

Public Research Institutions Founding Members: a pervasive initiative throughout Italy

National Institutions

INFN · CINECA · ENEA · Consiglio Nazionale delle Ricerche · INGV · Consortium GARR · INAF

Hub Only

UNIMORE · UNIVERSITÀ DI PARMA · OGS

Private Founding Members: strategic players for digital transformation

eni · LEONARDO · Terna Driving Energy · sogei

autostrade per l'italia · ENGINEERING THE DIGITAL TRANSFORMATION COMPANY

FINCANTIERI · HUMANITAS RESEARCH HOSPITAL · UPMC LIFE CHANGING MEDICINE

FERROVIE DELLO STATO ITALIANE · UnipolSai ASSICURAZIONI

ThalesAlenia Space a Thales / Leonardo company · INTESA SANPAOLO

Highly-qualified group of large leading companies covering most of the strategic industrial sectors involved by digital transformation at the national level

fondazione innovazione urbana

Strategic partner to implement and develop the digital twin pilot case of an urban complex system

iFAB INTERNATIONAL FOUNDATION BIG DATA & ARTIFICIAL INTELLIGENCE FOR HUMAN DEVELOPMENT

Industry-driven not-for-profit international organization aimed at: (1) aggregating companies, including SMEs, to engage with ICSC through a structured partnership, (2) funding research and innovation projects, (3) promoting the Big Data Technopole

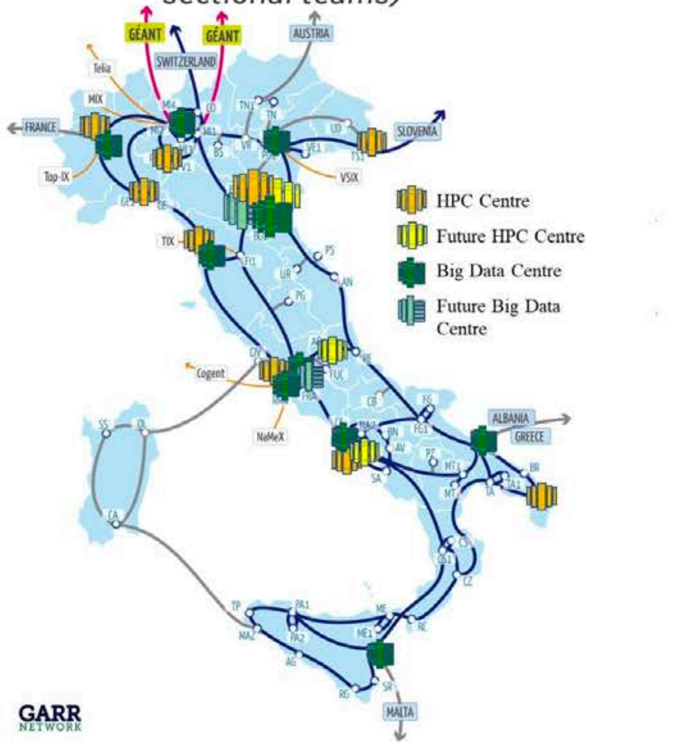
The ICSC will include ten **thematic Spokes** and one *Infrastructure* spoke

EDUCATION & TRAINING, ENTREPRENEURSHIP, KNOWLEDGE TRANSFER, POLICY, OUTREACH

1. FUTURE HPC & BIG DATA
2. FUNDAMENTAL RESEARCH & SPACE ECONOMY
3. ASTROPHYSICS & COSMOS OBSERVATIONS
4. EARTH & CLIMATE
5. ENVIRONMENT & NATURAL DISASTERS
6. MULTISCALE MODELING & ENGINEERING APPLICATIONS
7. MATERIALS & MOLECULAR SCIENCES
8. IN-SILICO MEDICINE & OMICS DATA
9. DIGITAL SOCIETY & SMART CITIES
10. QUANTUM COMPUTING

0 SUPERCOMPUTING CLOUD INFRASTRUCTURE

equipped with high-level teams of experts integrating the Spokes working groups (mixed cross-sectional teams)



ICSC: Main figures over the next 3 years

1575
Personnel shared by partners

250+
New researchers

300+
New PhDs

40 ME
Open calls

Sustainable & Well balanced (territory, gender, age, size)

40 ME
Innovation grants

SPOKE 10
QUANTUM COMPUTING

Istituzione leader

POLITECNICO MILANO 1863

Istituzione co-leader

UNIVERSITÀ DEGLI STUDI DI PADOVA

ENTI Partecipanti

CINECA
Consiglio Nazionale delle Ricerche
INAF Istituto Nazionale di Astrofisica
INFN Istituto Nazionale di Fisica Nucleare
IIT Istituto Italiano di Tecnologia
Sapienza Università di Roma
Università degli Studi di Bari Aldo Moro
Alma Mater Studiorum Università di Bologna
Università di Catania
Università degli Studi di Milano Bicocca
Università degli Studi di Napoli Federico II
Università di Pisa
Università di Pavia

Privati Partecipanti

enel
iFAB International Foundation Big Data and Artificial Intelligence for Human Development
Intesa Sanpaolo
sogei
Thales Alenia Space — a Thales / Leonardo company

Why quantum computing?

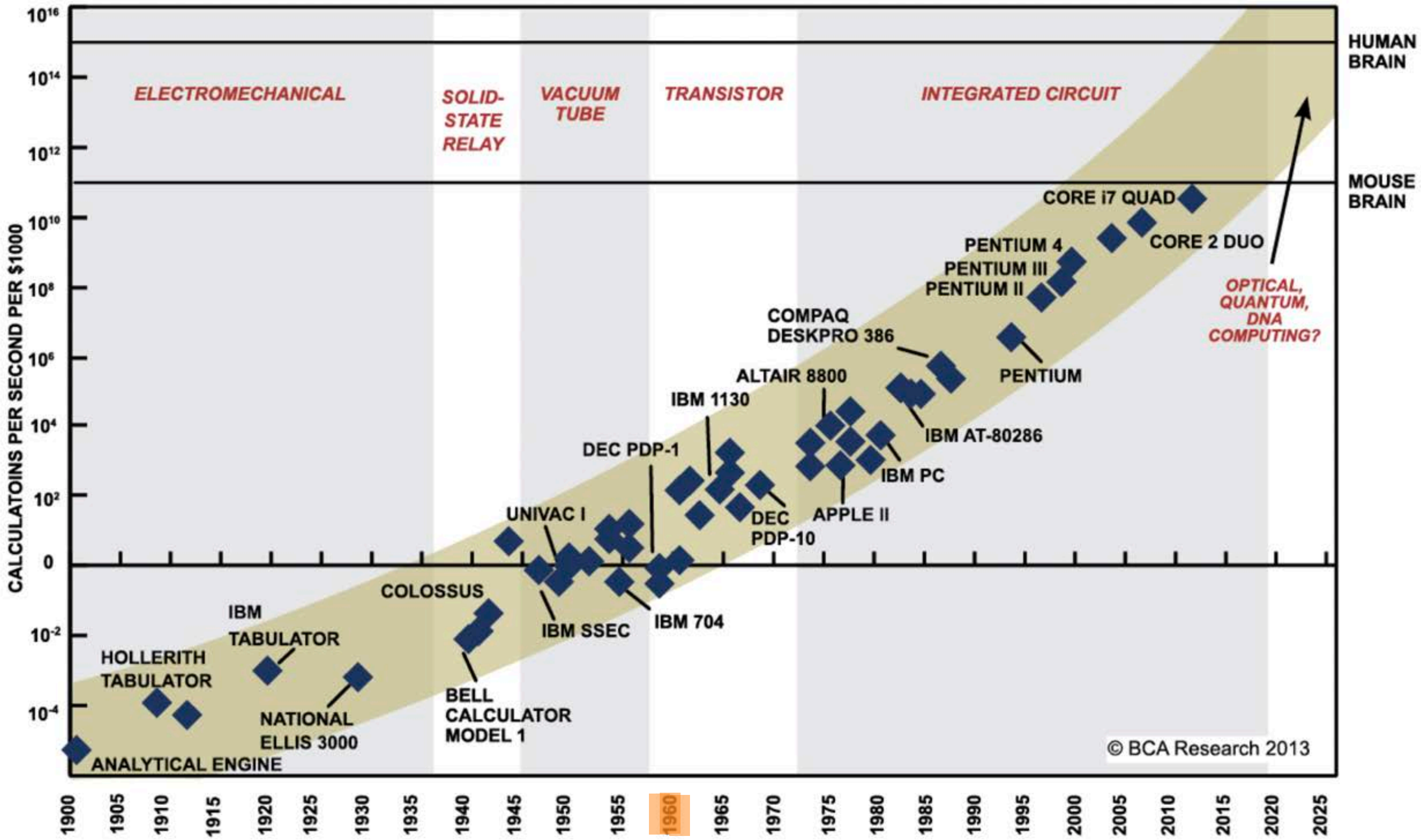
1965 Moore law

- Computer power double for a constant cost every two years (since 1960)

PLATEAU

- Expensive and difficult nanofabrication techniques (<10nm!!)

- Quantum effects are no longer negligible



SOURCE: RAY KURZWEIL, "THE SINGULARITY IS NEAR: WHEN HUMANS TRANSCEND BIOLOGY", P.67, *THE VIKING PRESS*, 2006. DATAPOINTS BETWEEN 2000 AND 2012 REPRESENT BCA ESTIMATES.

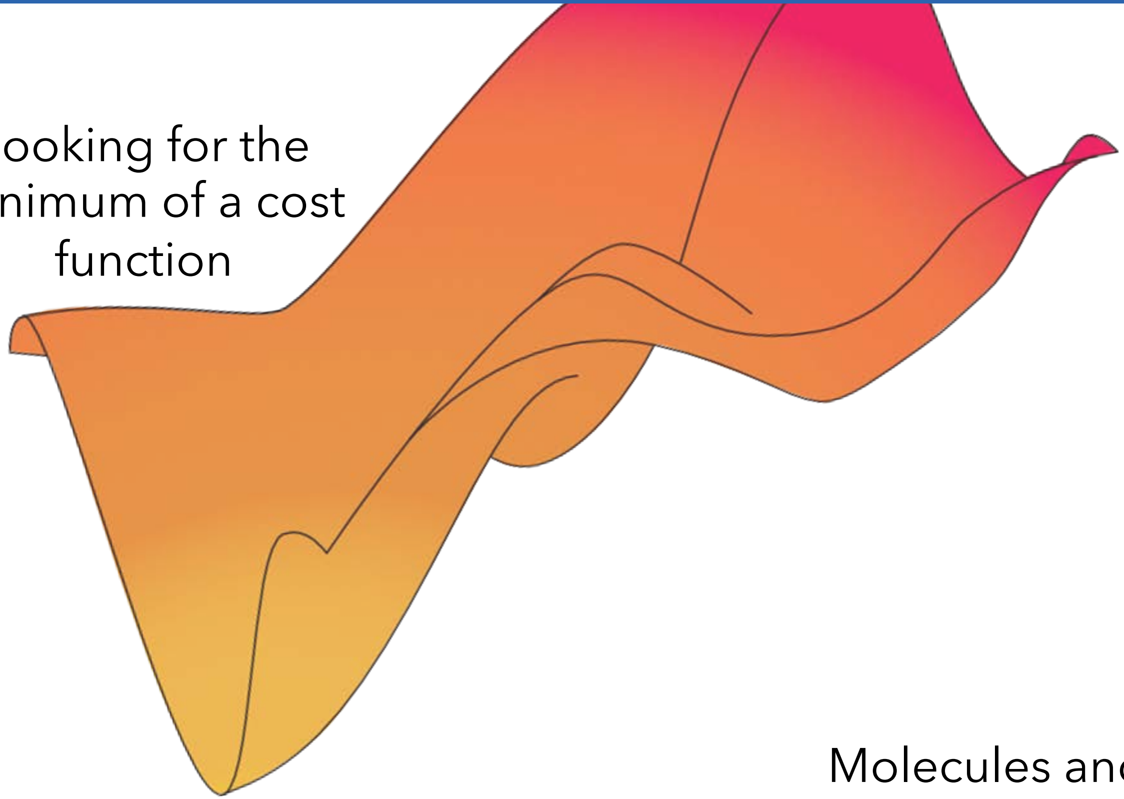
Earth Observation

Traffic

Combinatorial optimization problems

(QAOA, quantum annealing, …)

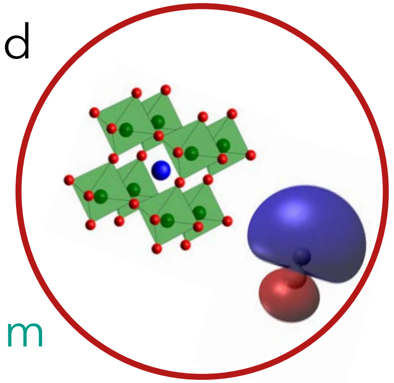
looking for the minimum of a cost function



Portfolio optimization

Machine Learning

Molecules and Materials

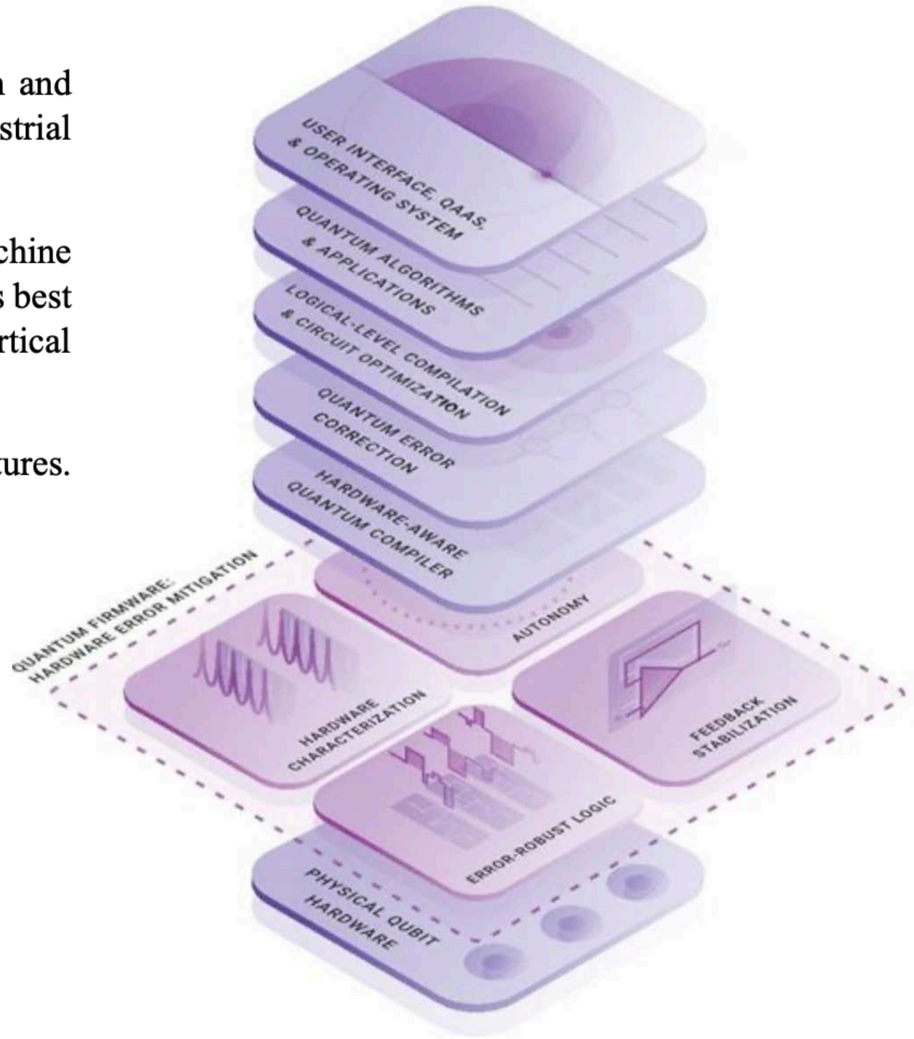


(VQE, quantum deflation, …)

Layer 1. Applications. High-level quantum applications for the solution of special-purpose research and industrial use cases (chemistry, biology, high energy and condensed matter physics, data-science. industrial optimization, etc.).

Layer 2. Algorithms. General purpose algorithms (e.g., linear algebra, variational eigensolvers, machine learning, hard optimization, etc.). The research challenge is to identify general-purpose library algorithms best suited to be accelerated on near-term quantum computers and that can be used as building blocks for vertical applications.

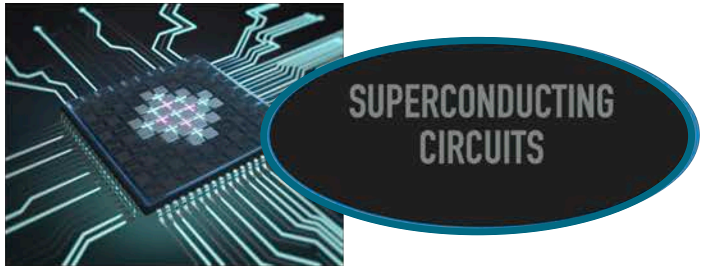
Layer 3. Emulation. Software for the emulation on classical computers of particular quantum architectures. Benchmarking and verification of quantum computations.

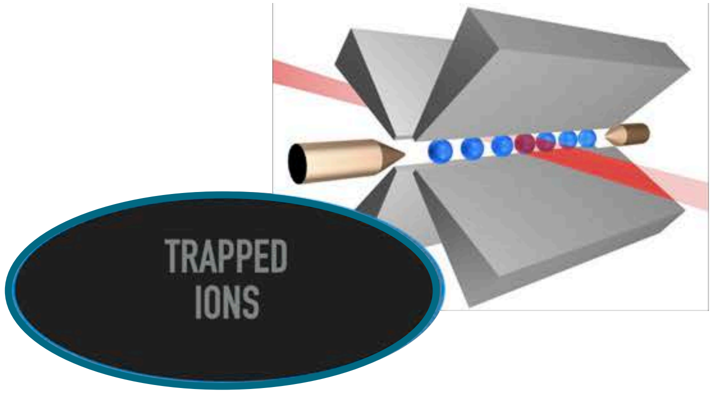


Layer 4. Compilation. Tools for compilation and optimization of algorithms. Toolchains for hw/sw codesign of special-purpose quantum accelerators.

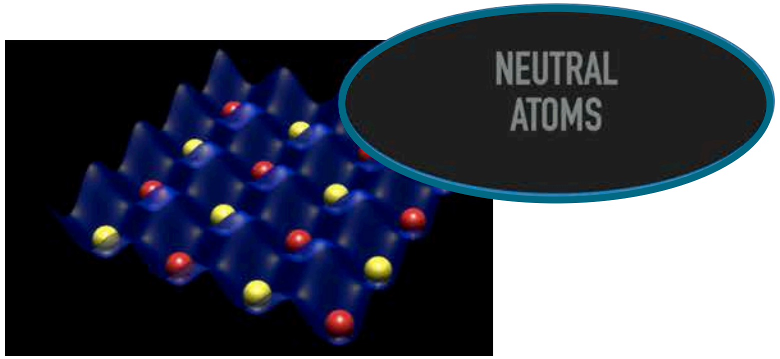
Layer 5. Firmware. Low-level software for the physical operation of specific quantum computers: control of physical operations, optimization of the operations, measurement protocols, scheduling of the operations, automatic calibration, etc.

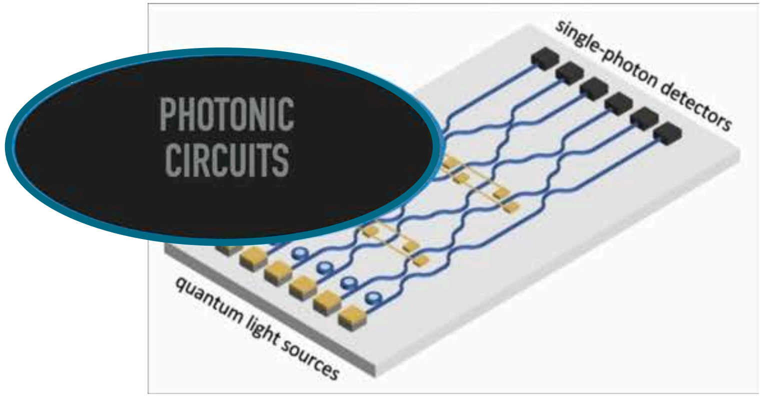
Layer 6. Hardware. Quantum computer hardware components. Here, the research challenge is to play a role in the international production chain.

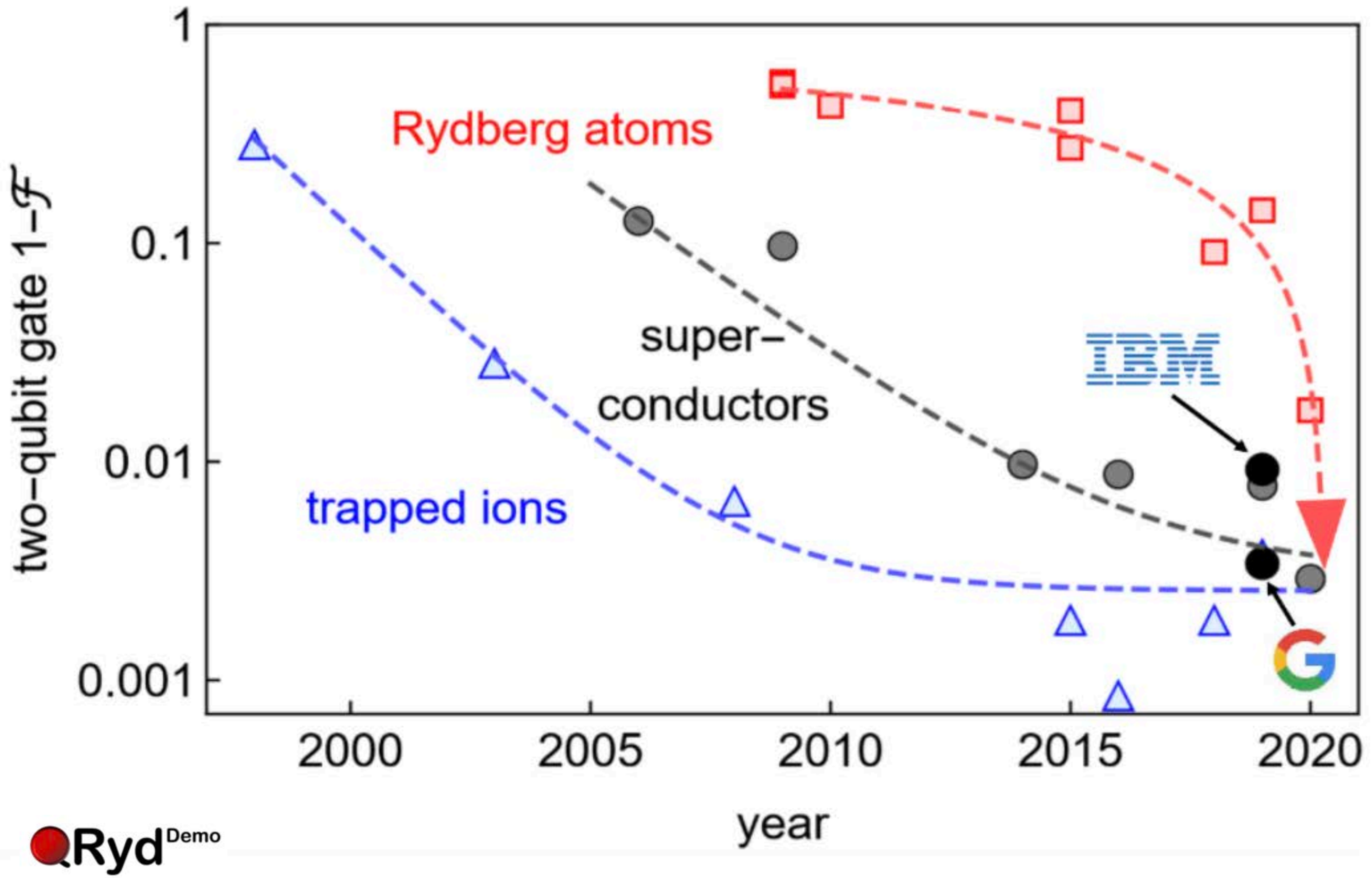




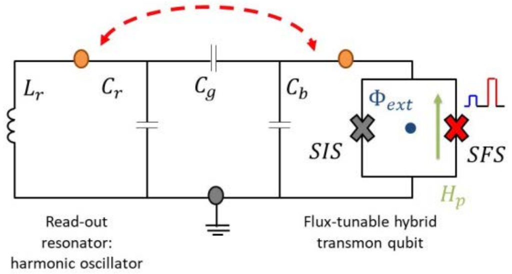
Physical systems

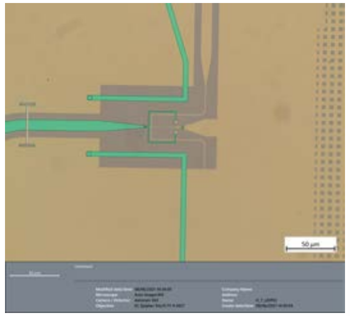





two-qubit gate 1−$\mathcal{F}$
1
0.1
0.01
0.001
Rydberg atoms
super–
conductors
trapped ions
IBM
2000
2005
2010
2015
2020
year
QRyd Demo

Realization of a scalable superconducting quantum computer





- Università di Napoli Federico II

- The main target is the realization of a scalable superconducting quantum computer employing a quantum processor with a number of qubit larger than 5. This final target requires both assembling different commercial components and developing state-of-the art advanced superconducting devices in an unique machine operating at 10 mK. We are developing our protype buidling on well-established technologies based on Al Josephson junctions and on control and read-out solutions based on consolidated microwave protocols. At the same time we are searching novel hardware, custom cells and circuits to be integrated into current architectures. The final system is aimed at being one node of the national quantum computation facilities system, with the special feature of being scalable, open-source and open to hardware implementations with time. With the awareness that nowadays quantum algorithms can better function on specific architectures, we aim at offering to the national community a versatile machine which can evolve in time. We are working on an architecture with more than 20 qubits.

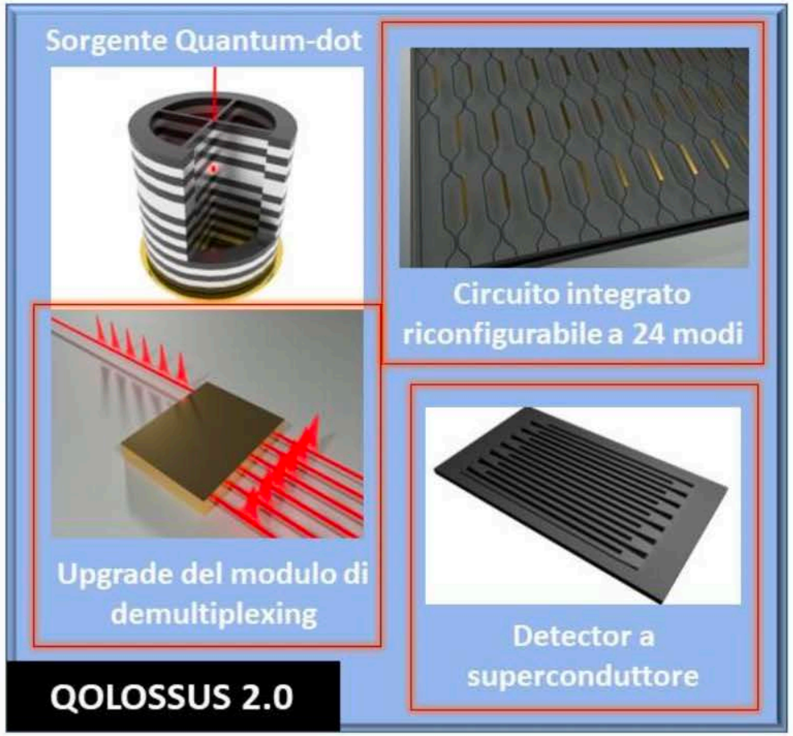
Sapienza Università di Roma

Titolo della Ricerca: Macchina avanzata di Boson Sampling e algoritmi di quantum machine learning

Team di Lavoro
Referente Scientifico: Fabio Sciarrino (Dipartimento di Fisica)
Personale di Massa Critica: Fabio Sciarrino, Nicolò Spagnolo, Rinaldo Trotta, Claudio Conti, Francesco Basso Basset, Stefano Giagu, Andrea Messina (Dipartimento di Fisica), Massimo Panella (Dipartimento di Ingegneria dell'Informazione, Elettronica e Telecomunicazioni)

Obiettivi e risultati previsti

- Realizzazione e certificazione di una macchina avanzata di Boson Sampling con $n=5$ fotoni e $m=24$ modi
- Algoritmi quantistici e Machine Learning su near-term quantum devices
- Quantum Deep learning per vantaggio quantistico su NISQ devices



Attività in collaborazione con:

Consiglio Nazionale delle Ricerche
Università degli Studi di Milano Bicocca
Università degli Studi di Napoli Federico II
Università di Pavia

INFN Spoke 10 – WP3 (Firmware and Hardware platforms)

Tasks and objectives:

1. Design of superconducting qubits.
2. Test at cryogenic temperatures single components for quantum circuits.
3. Setup of a cryogenic testbed for qubit control and readout.
4. Qubit characterization in a radiopure cryogenic environment.
5. Generation of control and readout pulses on a RFSoC board
6. Test of quantum circuits with two or more coupled qubits.

5 INFN laboratories instrumented with dilution refrigerators and RF electronics

Research Units:

- ❑ LNF
- ❑ LNL
- ❑ LNGS
- ❑ INFN Roma
- ❑ INFN Pisa

Close collaboration with Uni MiB and CNR IFN

Quantum Computing and Simulation Center

Investment of 6 M€

National strategic partnerships

Trapped ion quantum computer

INFN Istituto Nazionale di Fisica Nucleare

UNIVERSITÀ DI PAVIA

UNIVERSITÀ DEGLI STUDI DELL'AQUILA

TQT

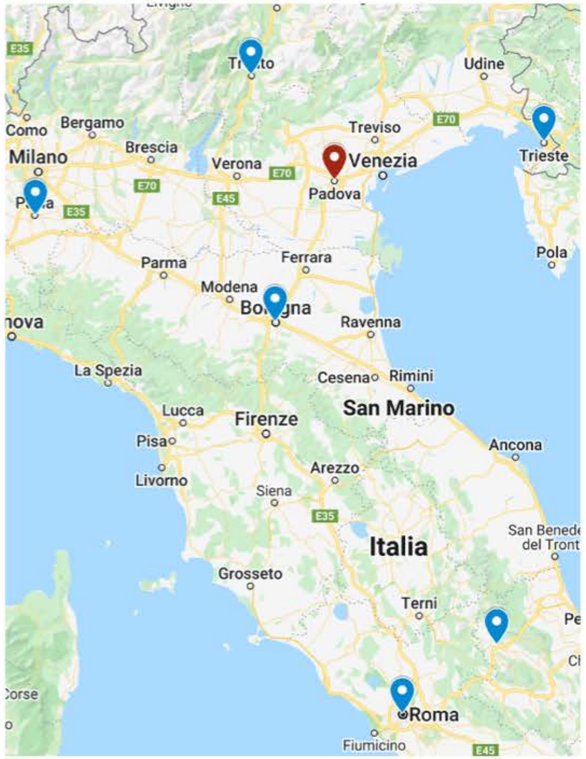
Q@TN

PADUA TECH

CINECA

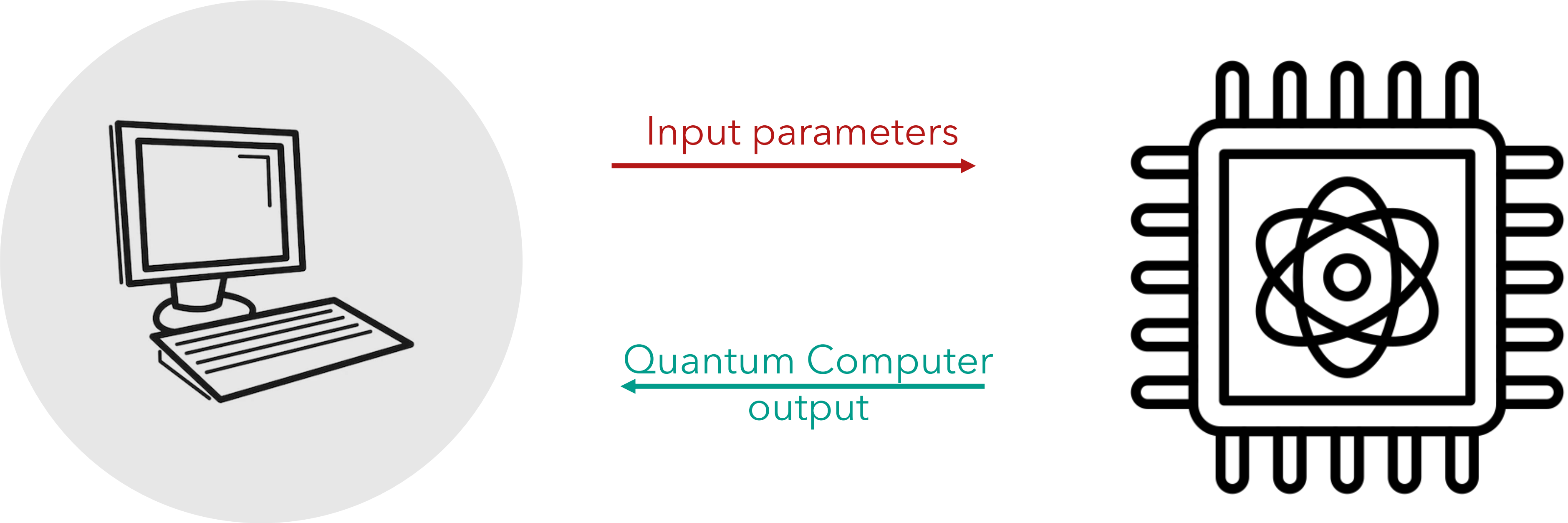
arakne do I.T. better

neat



qcsc.dfa.unipd.it

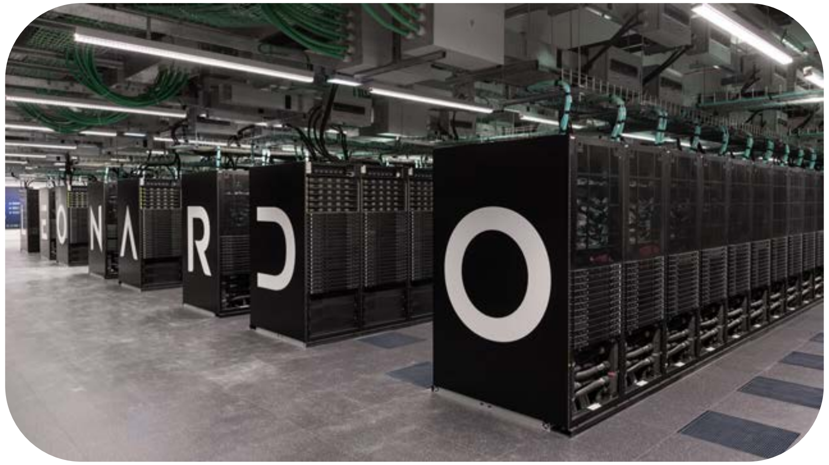
Hybrid quantum-classical algorithms



Memory available instead of QC
Doesn't solve efficiently certain tasks

Solve hard problems with quantum algorithms

Hybrid quantum-classical algorithms



Leonardo @ CINECA
Supercomputer
3500 CPU, 14000 GPU

Input parameters →

← Quantum Computer output

Pasqal (neutral atoms)
300 qubits

Quantum computing for industry

Contacts with new Industry partners

ThalesAlenia Space
a Thales / Leonardo company

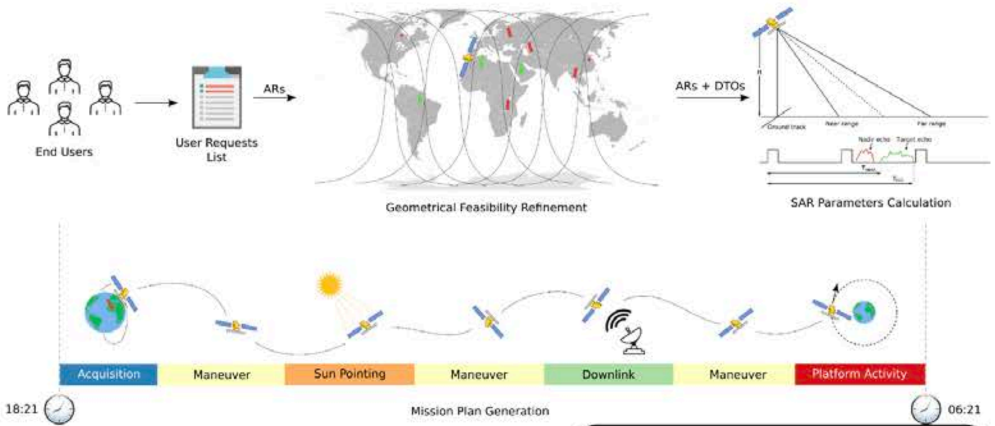
spindox
DIGITAL SOUL

LEONARDO

ASI
Agenzia Spaziale Italiana

Hard optimization problems

Mission planning for earth observation



combinatorial optimization (Knapsack problem)

from single satellite to constellations

- Identification of use cases in the field of mission planning
- Estimate (hybrid) QPU-specs for realistic problems

Finanziato dall'Unione europea NextGenerationEU
Ministero dell'Università e della Ricerca
Italiadomani PIANO NAZIONALE DI RIPRESA E RESILIENZA
ICSC Centro Nazionale di Ricerca in HPC, Big Data and Quantum Computing

QUANTUM COMPUTING AND SIMULATION CENTER

Computer quantistico: le opportunità per le aziende italiane

13 Aprile 2023

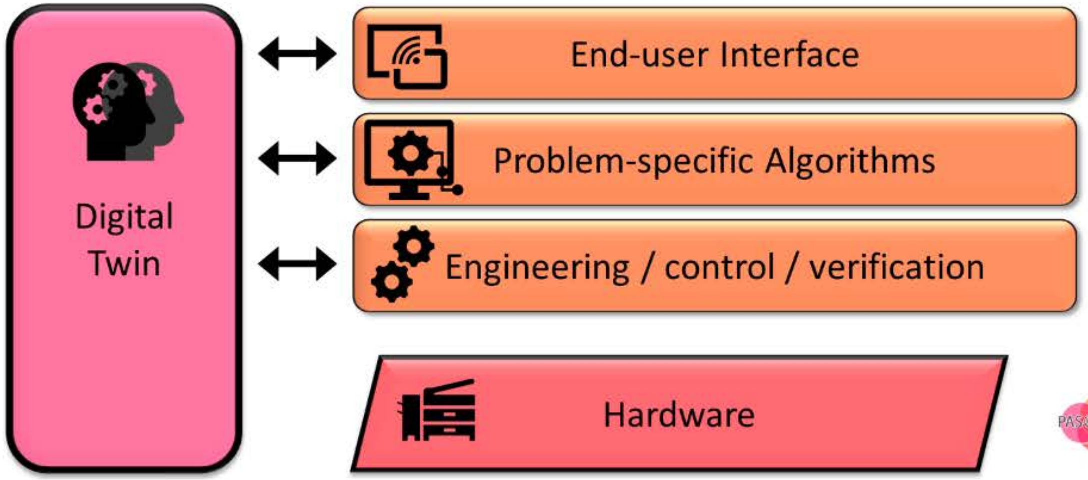
Centro Universitario, Via Zabarella 82 - Padova

Programma

9:30 Benvenuto ai partecipanti
10:00 Saluti istituzionali

Interventi

10:15 Quantum Computing and Simulation Center dell'Università di Padova
10:30 Osservatorio Quantum Computing del Politecnico di Milano
10:45 Amazon Web Services
11:00 Eni
11:15 Enel
11:30 Intesa San Paolo
11:45 Leonardo
12:00 Thales Alenia Space Italia
12:15 Spindox

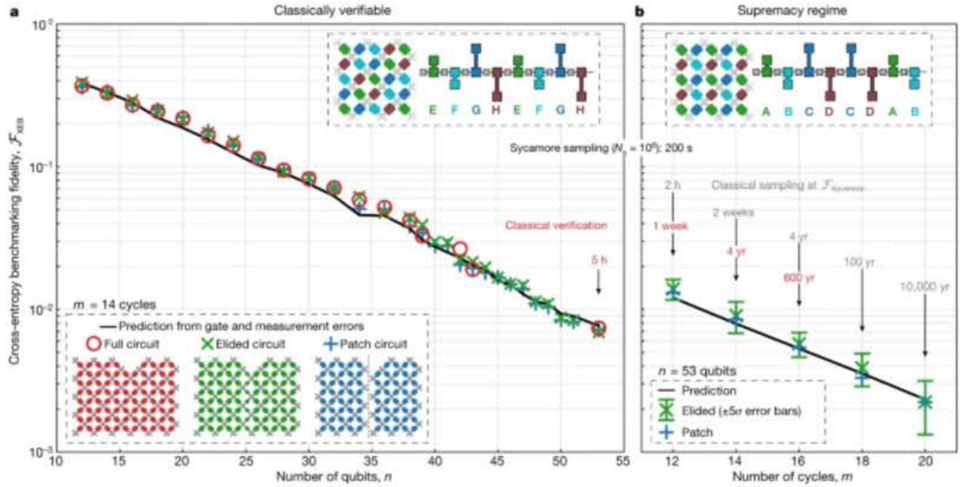


Improved/applied/new algorithms?

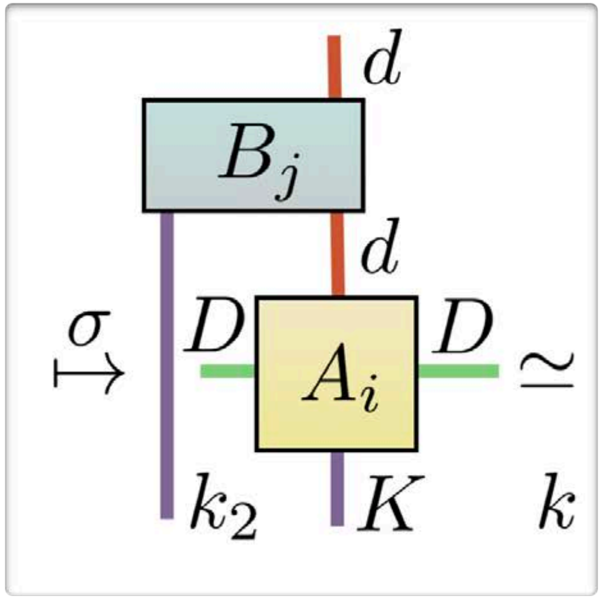
Can quantum computing be useful in your field/market?

Green quantum computing?
Useful quantum advantage?

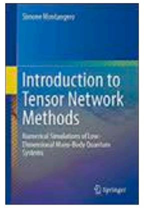
Fig. 4: Demonstrating quantum supremacy.



TENSOR NETWORK ALGORITHMS

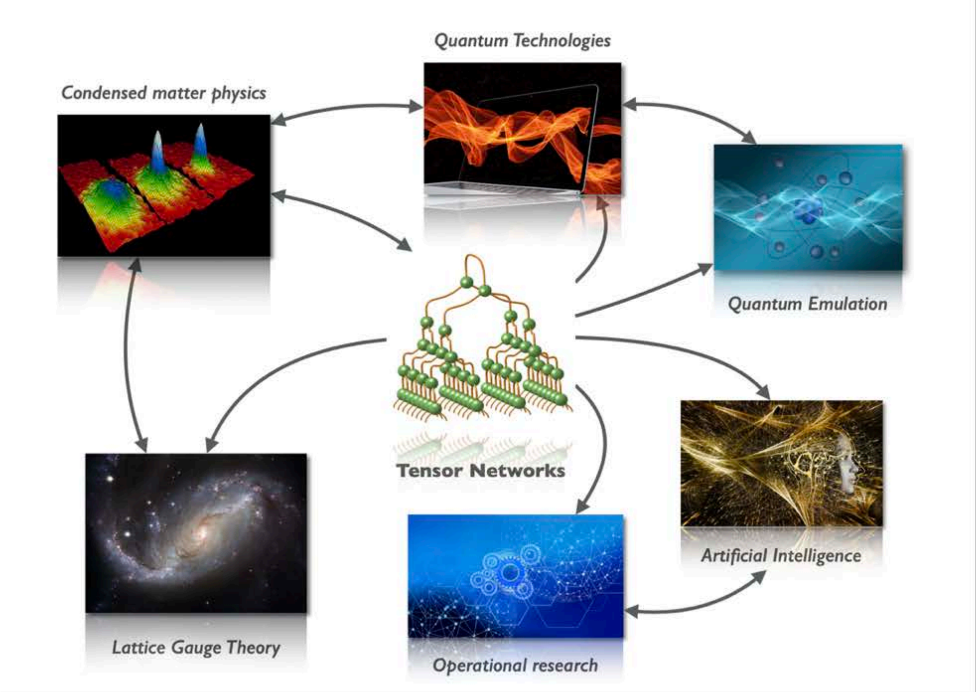


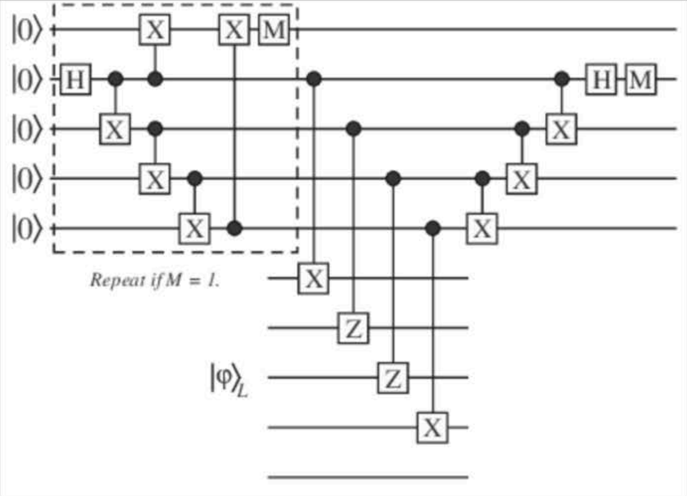
- *State of the art in 1D (poly effort)*
- *No sign problem*
- *Extended to open quantum systems*
- *Machine learning*
- *Data compression (BIG DATA)*
- *Extended to lattice gauge theories*
- ***Simulations of low-entangled systems of hundreds qubits!***

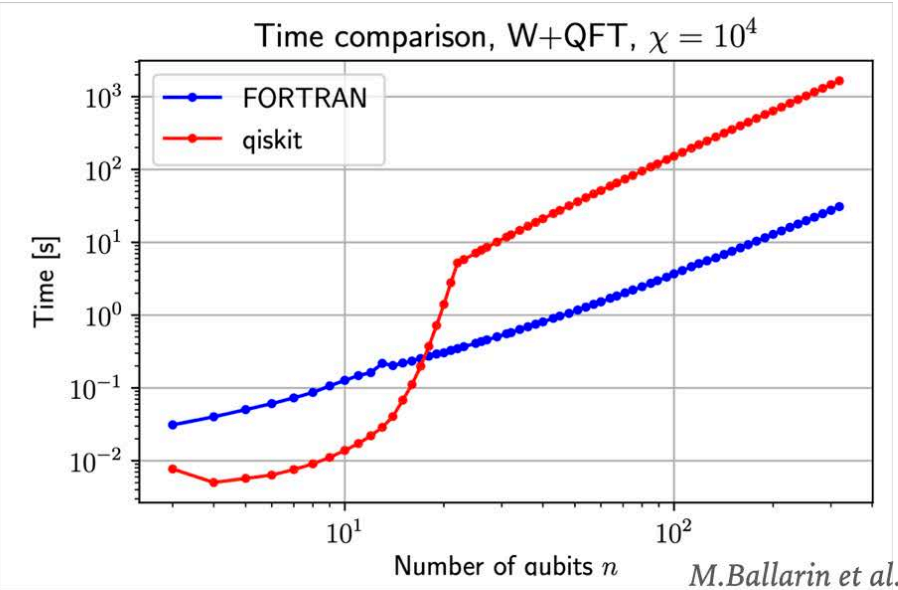


"Introduction to tensor network methods", S.Montangero, Springer (2019)

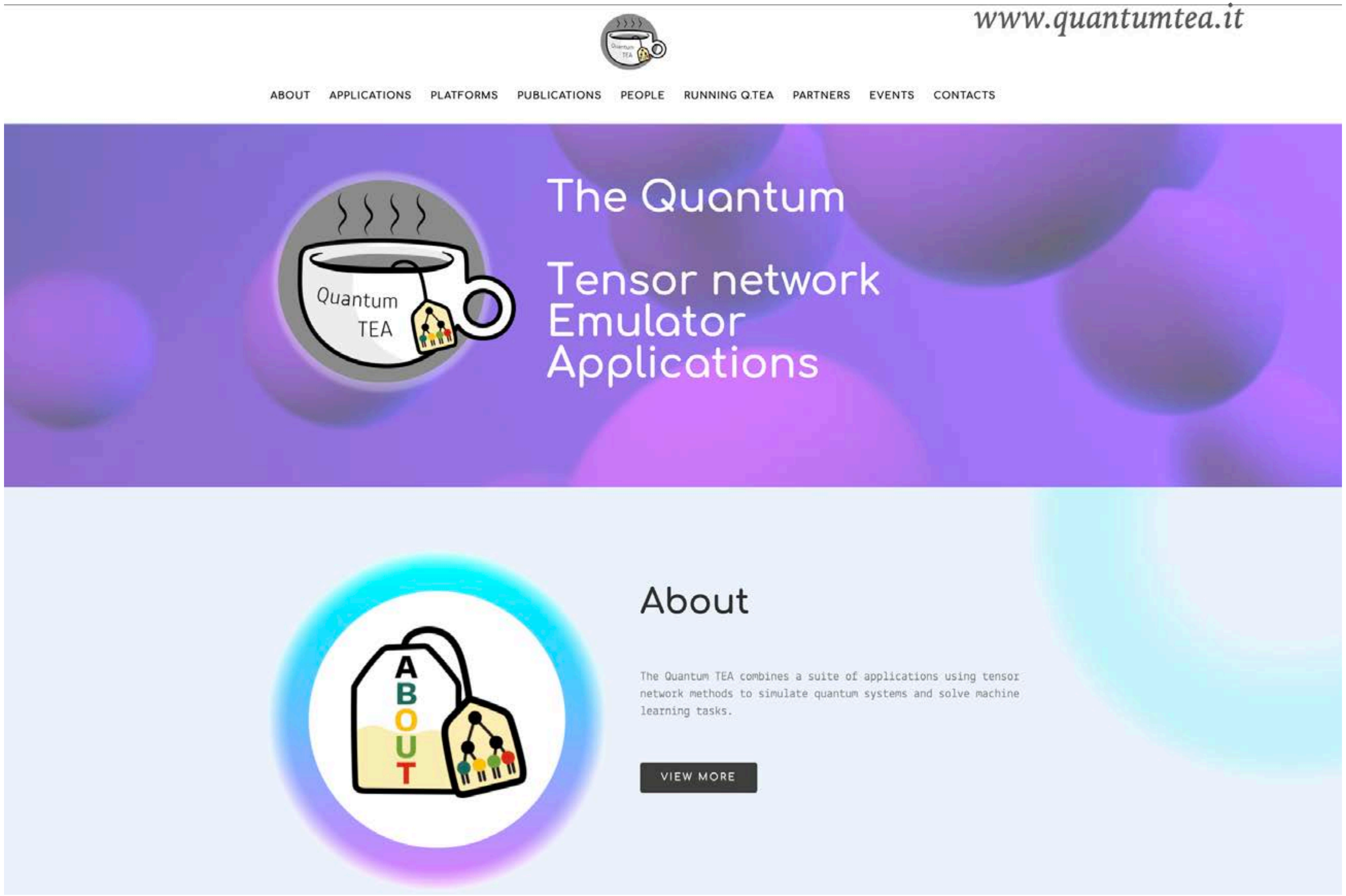
U. Schollwock, RMP (2005) *A. Cichocki, ECM (2013)* *I. Glasser, et al. PRX (2018)*







M.Ballarin et al.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Quantum TEA
The Quantum
Tensor network Emulator Applications
About
ABOUT
The Quantum TEA combines a suite of applications using tensor network methods to simulate quantum systems and solve machine learning tasks.
VIEW MORE

INFN Spoke 10 – WP1 Software

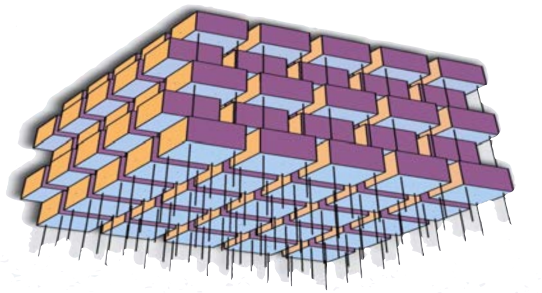
INFN Istituto Nazionale di Fisica Nucleare

- Studio dell'entropia di circuiti quantistici (Lorenzo Sestini – PD)
  - Obiettivo: migliorare training e struttura dei circuiti usati nel quantum ML
- Simulazione quantistica (Lorenzo Sestini – PD)
  - Obiettivo: valutare Quantum Born Machines e Quantum GANs per simulare distribuzioni di variabili fisiche e risposte di rivelatori
- Tracciamento di particelle cariche con algoritmi quantistici (C. Bozzi – FE)
  - Obiettivo: valutare Graph Neural Network Quantistiche per il tracciamento di particelle cariche in ambienti densamente popolati degli esperimenti HEP futuri
  - In collaborazione con dottorando UNIFE, si sta aggiungendo un tecnologo a tempo determinato INFN (presa di servizio 15/05)

Partecipazione UNIPV:

Dip. Fisica (A. Bisio, M. Borghi, M. Galli, D. Gerace, L. Maccone, C. Macchiavello)

Dip. Ingegneria Industriale e dell'Informazione (D. Bajoni)



Obiettivi e risultati previsti:

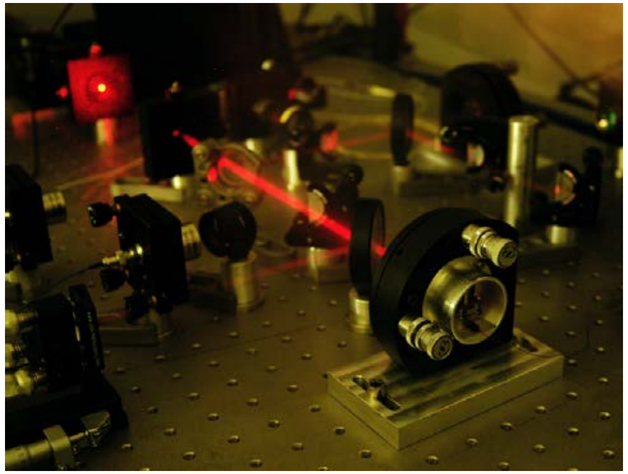
Noise deconvolution methods for qubits and qudits

Direct reconstruction of the Pauli Transfer Matrix of a channel

Estimation of multiple phases & generalization of QPEA algorithm

Quantum cellular automata as a simulation tool for relativistic quantum fields

QQ artificial intelligent recognition of quantum properties, to speed-up quantum chemistry simulations.



Reliable emission of a state of 6 to 10 identical photons delivered in independent channels with high spectral and temporal purity.

Realization of a two-mode integrated squeezer for Gaussian boson sampling.

University of Pisa

Development and Application of Quantum Algorithms, Control and Readout of Superconducting Qubits

TEAM (recruitment of RTDA and PhD still ongoing)

Dept. Computer Science: A. Bernasconi, F. Bonchi, G.M. Del Corso, F. Gadducci

Dept. Information Engineering: M. Macucci, M. Cococcioni, S. Di Pascoli, P. Marconcini, A. Michel, G. Pennelli

Dept. Mathematics: P. Boito, D. Trevisan

Dept. Pharmacy: E. Da Pozzo

Dept. Physics: V. Alba, C. Bonati, M.L. Chiofalo, M. D'Elia, V. Stanzione

EXPERTISE: ***nanoscale electronics; lattice simulations of fundamental interactions and condensed matter systems; programming languages, optimization and machine learning algorithms; biostructure analysis; engineering and simulation of qubit realizations.***

MAIN GOALS AND EXPECTED RESULTS

- **Development and benchmark for near-term quantum computers of different classes of quantum algorithms:** *real time evolution, quantum variational eigensolvers, quantum machine learning, quantum thermal sampling, quantum Markov chains, implementation of error mitigation techniques;*
- **Application of quantum algorithms to a variety of problems and topics:** *gauge theories and Fundamental Interactions, condensed matter systems, Quantitative Biology, protein dynamics prediction, quantum models for neuronal networks, Quantitative Finance, quantum walks in discrete time, optimal quantum transport;*
- **Control and readout of superconducting qubits:** *Design of hardware and firmware components for the control and readout of superconducting qubits, exploiting an FPGA-based board; implementation of a pulse generator system for control and readout of a two-qubit system.*

Quantum computing algorithms for classical and quantum systems

Team: *S. Succi (PI,IIT), S. Artyukhin (IIT), A. Cavalli (IIT), C. Sanavio (PD,IIT), A. Solfanelli (IIT, affiliate), T. Weaving (IIT affiliate)*

Goal: *Development and validation of new quantum algorithms for biochemistry, quantum material science and fluid dynamics applications.*

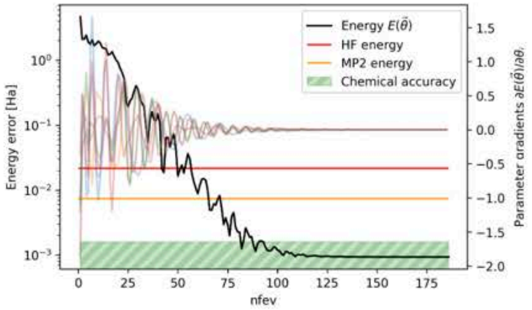
Expected Results:

Theoretical scalability estimates, test and validation on classical and quantum hardware (IBM);

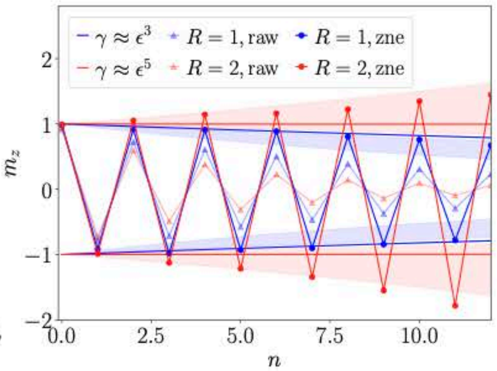
Development of novel noise mitigation strategies; assessment of the persistence of entanglement out of equilibrium,

Novel techniques to handling nonlinearity and dissipation on quantum computers,

Preliminary applications to industrial cases (molecular design, fluid dynamics)

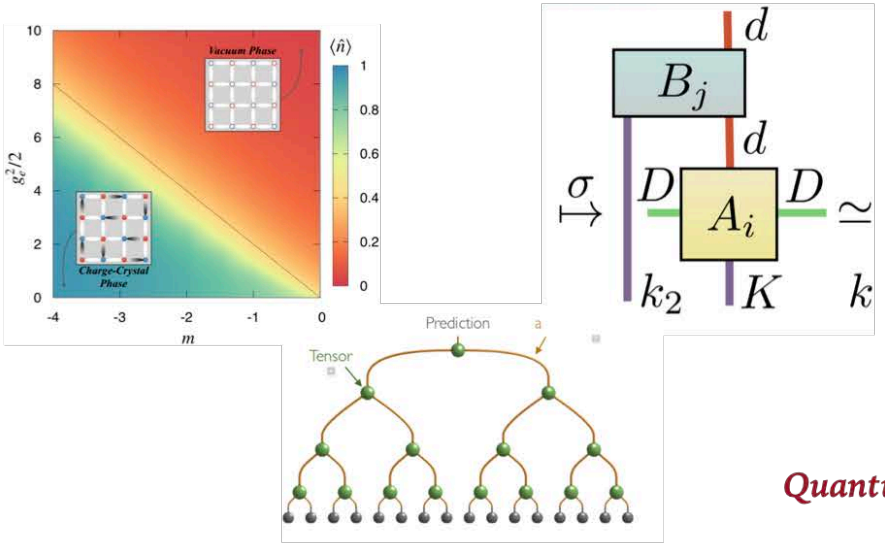


Noiseless 3-quibit CS-VQE simulation of the HCl molecule, T. Weaving et al, submitted to PRX Quantum)

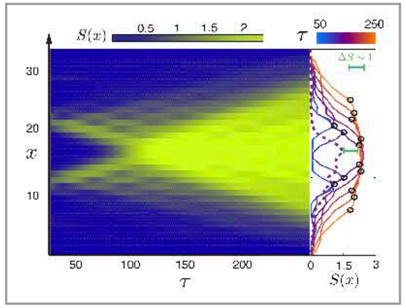


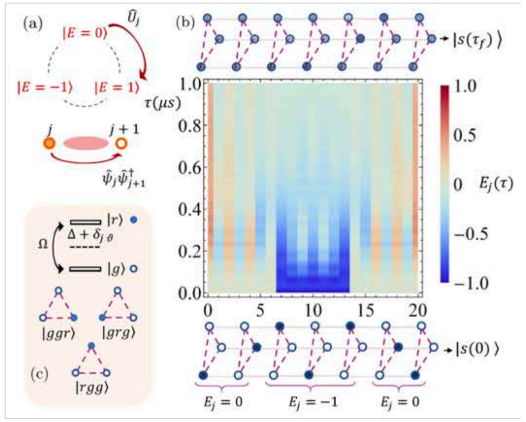
Persistence of entanglement in a` Floquet crystal with mid-range interactions and zero noise extrapolation.
A. Solfanelli et al, to be submitted

Classical simulations and methods



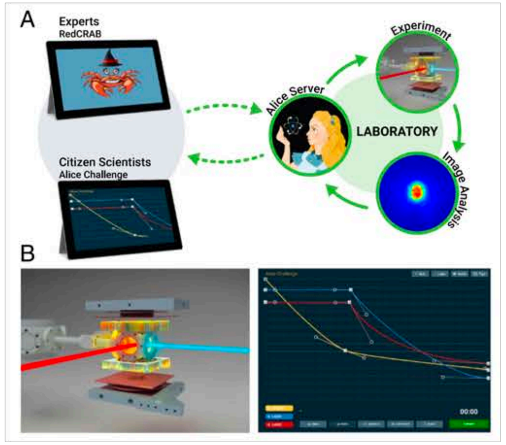
Theoretical development and analysis





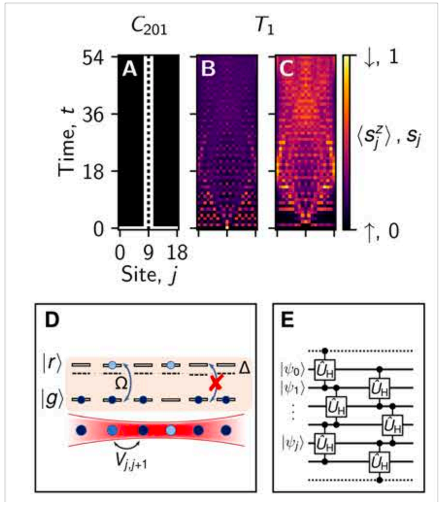
Quantum computer emulation

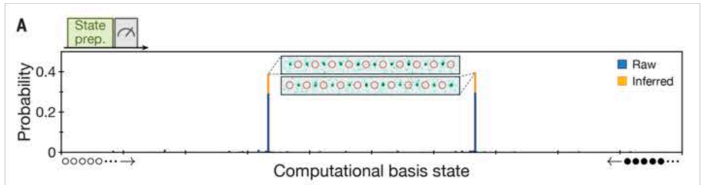
Experiment benchmarking, support and optimisation



PNAS

Remote optimization of an ultracold atoms experiment by experts and citizen scientists

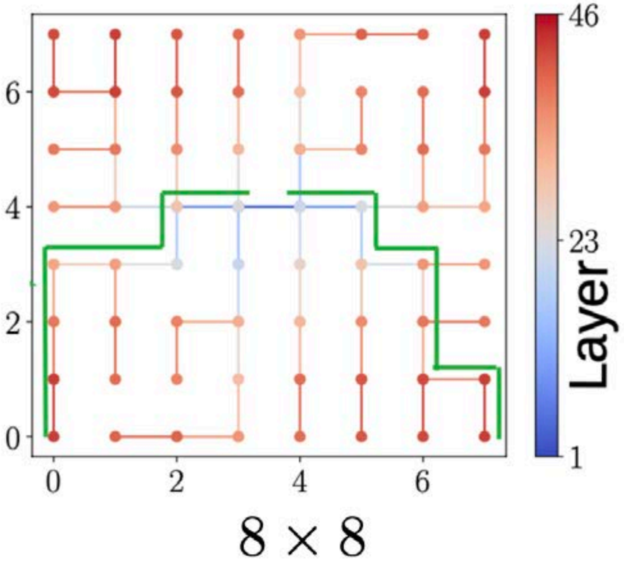


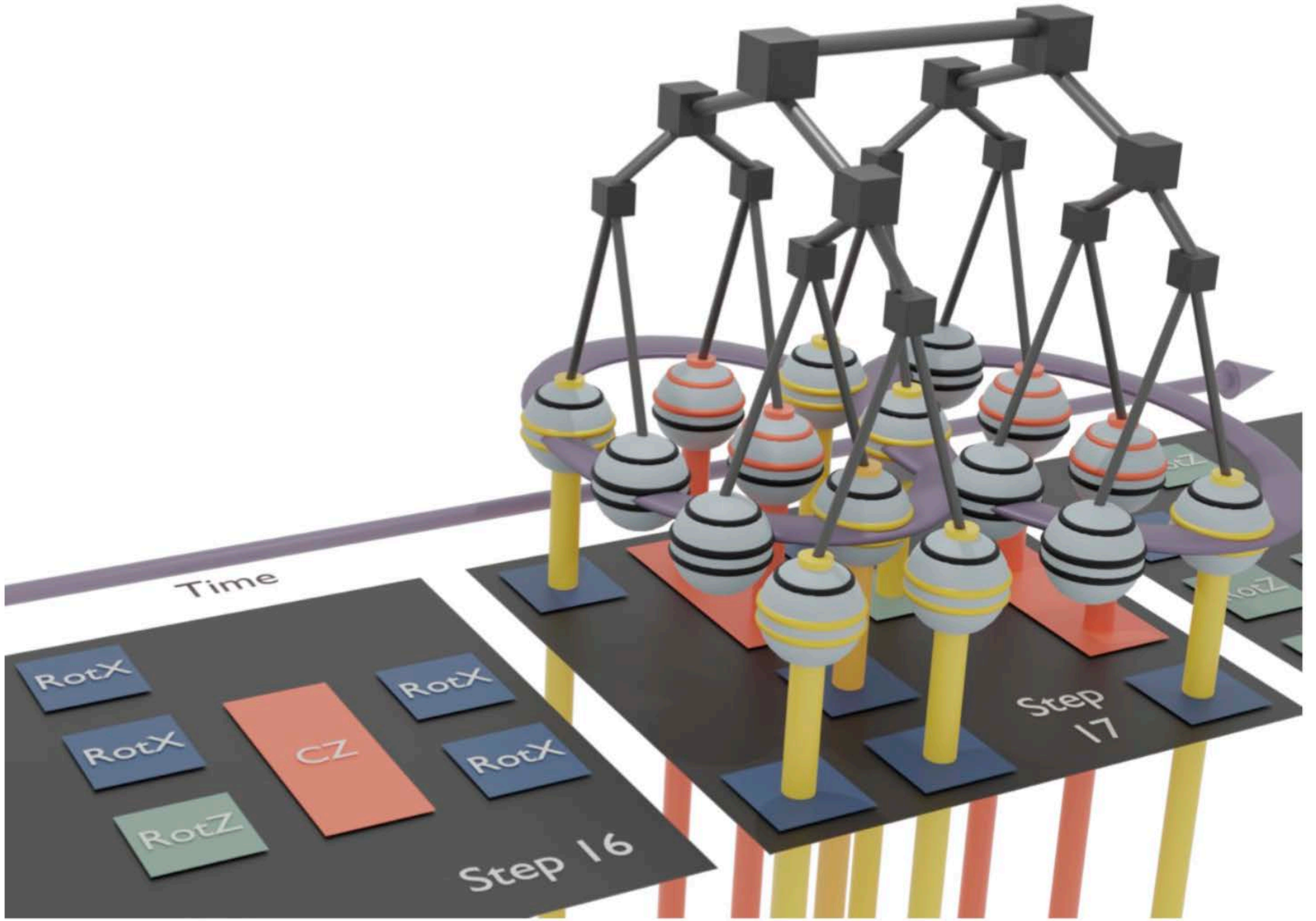


Science

Generation and manipulation of Schrödinger cat states in Rydberg atom arrays

Digital twin of a
Rydberg atom quantum computer





T. Felser, S. Notarnicola, S. Montangero PRL (2021)
D. Jaschke et al arxiv:2210.03763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Thank you!