PADUA QUANTUM COMPUTING AND SIMULATION CENTER

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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

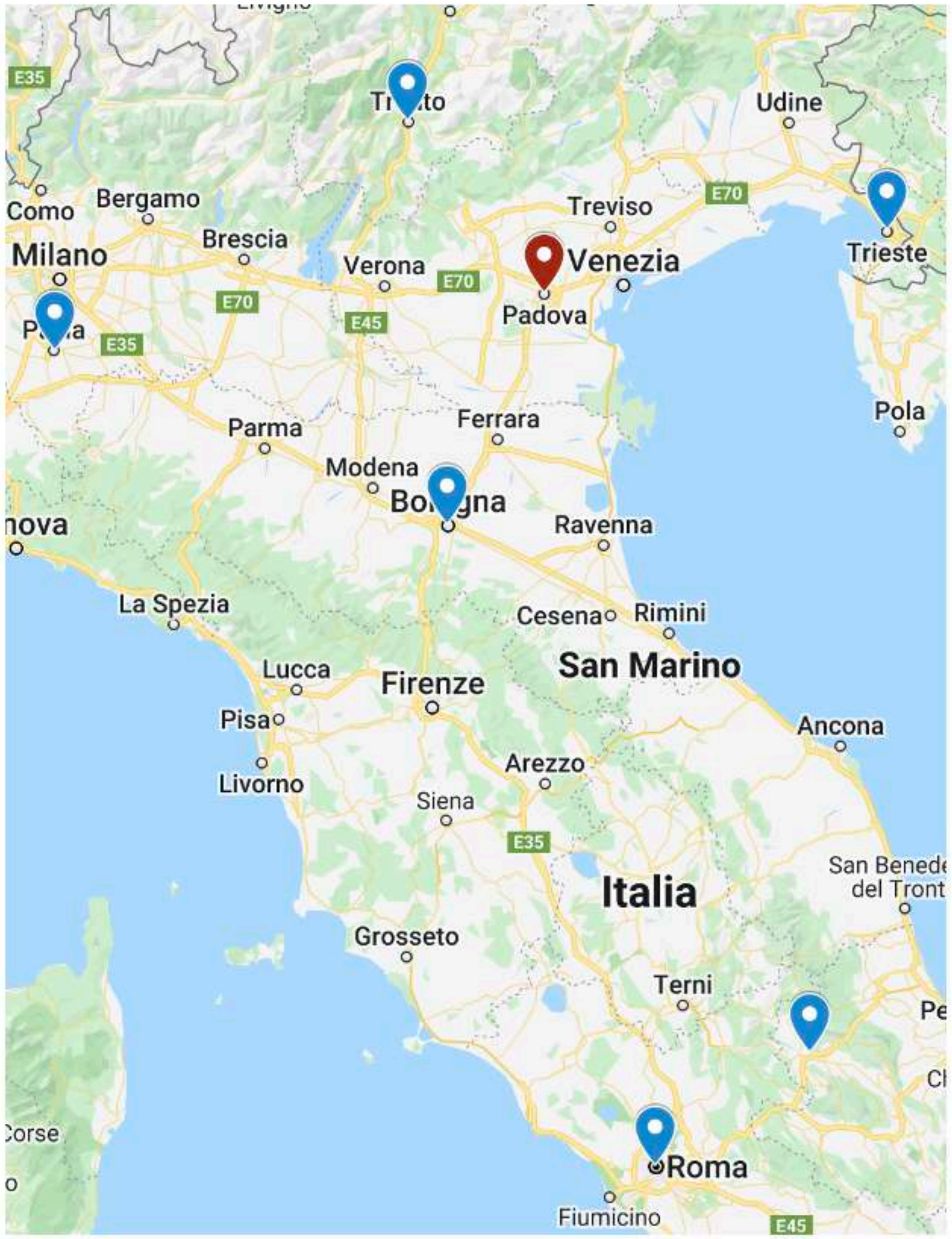
Q@TN

PADUA TECH

CINECA

arakne do I.T. better

neat



ECOSYSTEM

INFN Istituto Nazionale di Fisica Nucleare

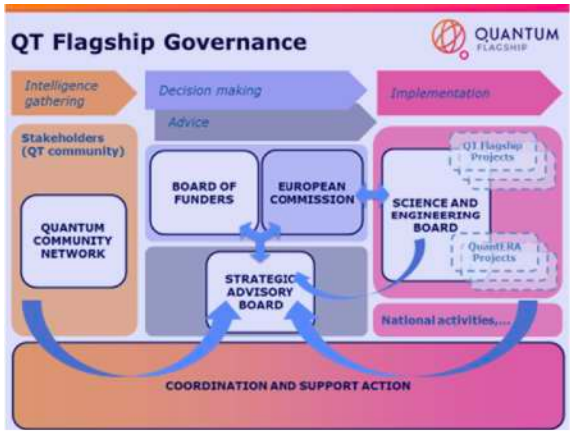
CERN openlab

CINECA

Google Research

qruise

AQT



QUANTUM FLAGSHIP

PASQUANS

QuSCo

QUANTERA

QTFLAG

T-NISQ

QuantHEP

800 ANNI 1222·2022 UNIVERSITÀ DEGLI STUDI DI PADOVA

quantum.dfa.unipd.it

2020 World Class Research Infrastructure

Quantum@Unipd

ICSC Centro Nazionale HPC, Big Data e Quantum Computing

PRIN

MIUR

Bundesministerium für Bildung und Forschung

DFG

JÜLICH Forschungszentrum

Quantum technologies – from basic research to market

A Federal Government Framework Programme

bwGRiD

Pilot Project

2018-2022

FPA - PASQUANS2

2023-2030

Quantum simulator

with 10000 qubits!

QUANTUM COMPUTING AND SIMULATION CENTER

Infrastructure

Quantum Computation & Simulation

Quantum interfaces & Networks

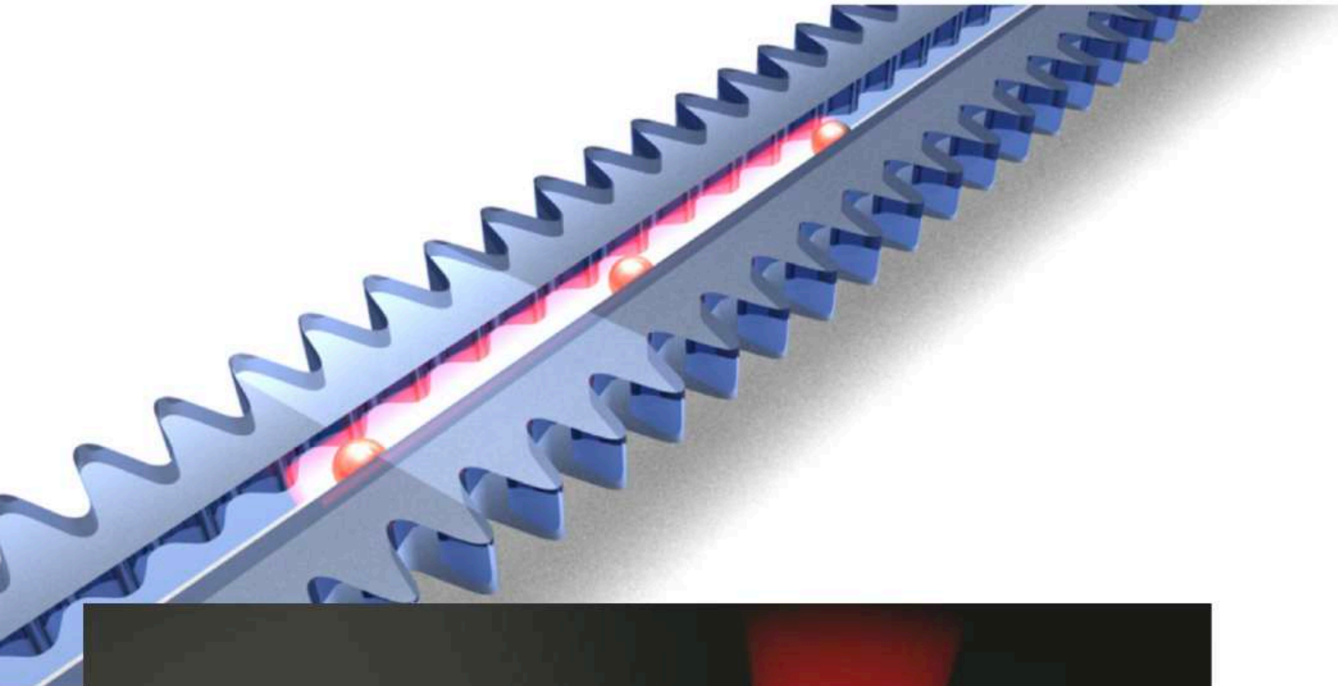
Quantum & Classical software

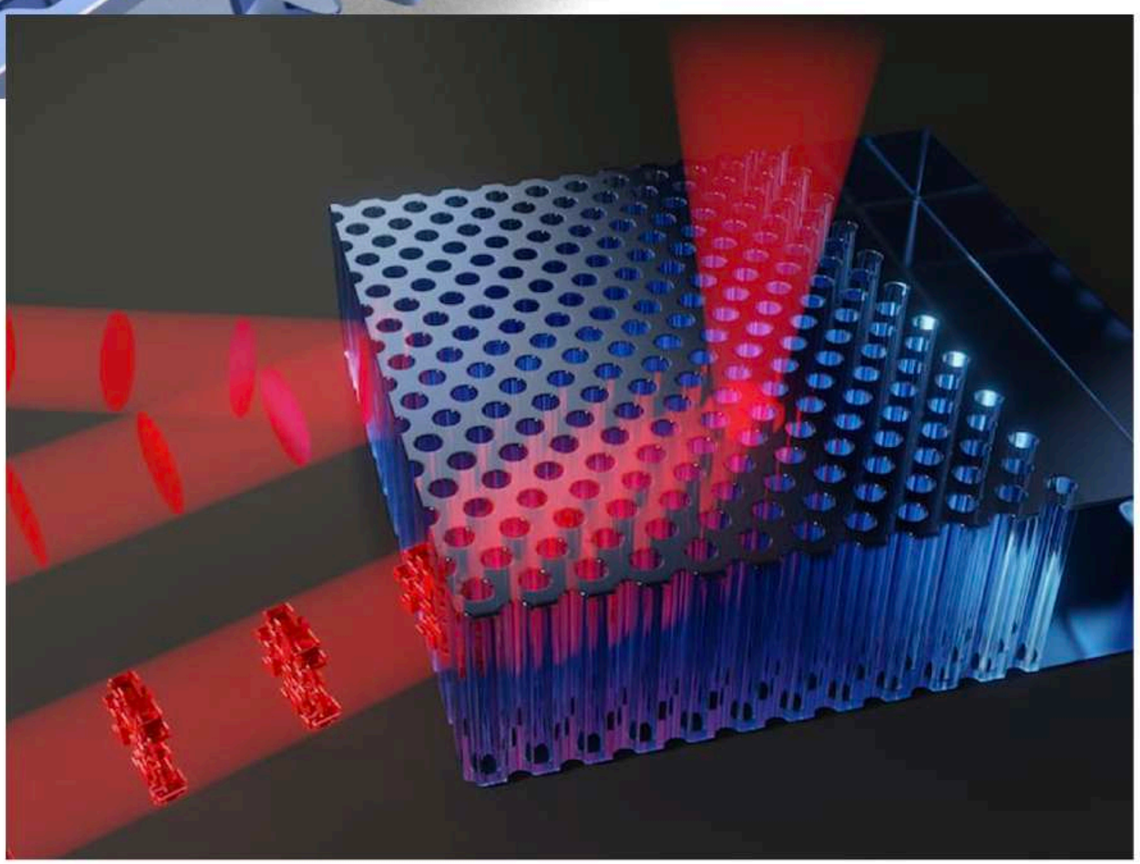
Support

Education, Dissemination, & Technological transfer

Management & coordination

Quantum interfaces
& Networks





Analog quantum simulators with coupled photons and atoms

Exploring new dimensions for novel phases of light-and-matter in:

- Suspended atoms coupled to photonic waveguides
- Atoms trapped within photonic crystals

Image courtesy:
[1] A.P. Burgers *et al.* PNAS **116**, 2
[2] Ravitej Uppu *et al.* PRL **126**, 177402

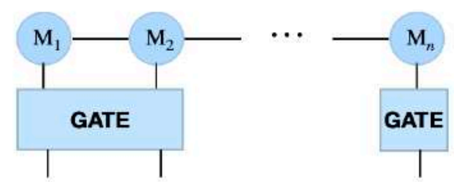
Emulators for quantum computers

Quantum & Classical software

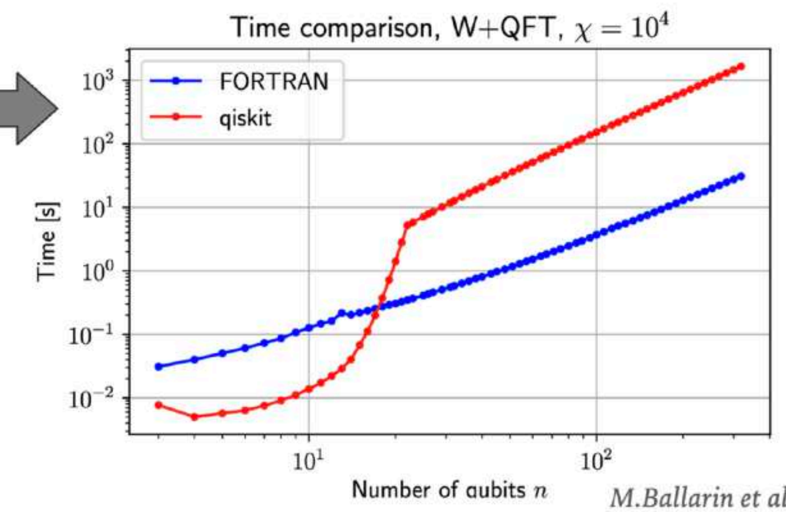
Quantum circuits

Quantum computing Platforms Superconducting, Trapped ions, or neutral atoms

Quantum circuits emulator

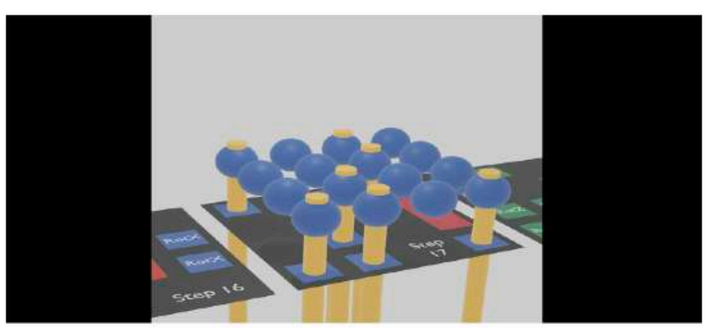


- Quantum circuit as a tensor network
- Measurement of local observables
- Efficient sampling of the final state



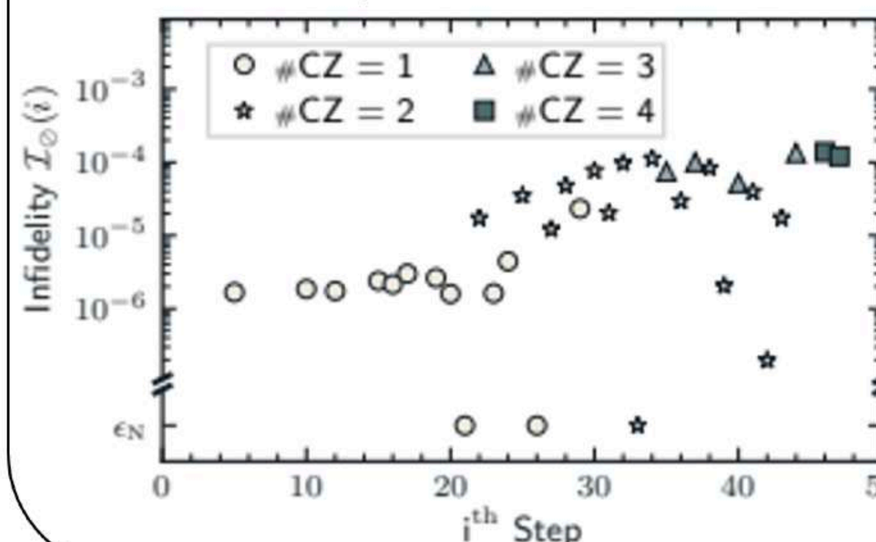
M.Ballarin et al.

Digital twin approach



1) Up to 8x8 atoms
2) Schedule native gates
3) Gates as pulses
4) Study crosstalk
5) Run simulation

Comparison and resolve errors per step: GHZ state



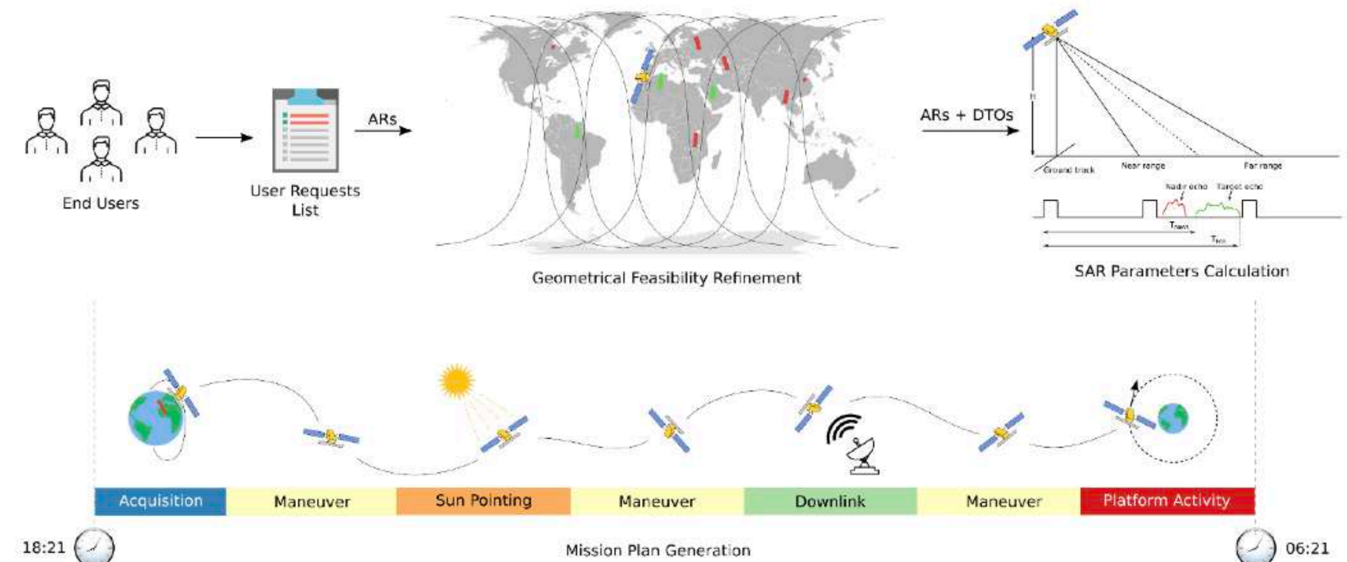
D. Jaschke, A. Pagano, S. Weber, and SM arxiv:2210.03763

Quantum computing for industry

Education, Dissemination, & Technological transfer

Contacts with new Industry partners

Mission planning for earth observation



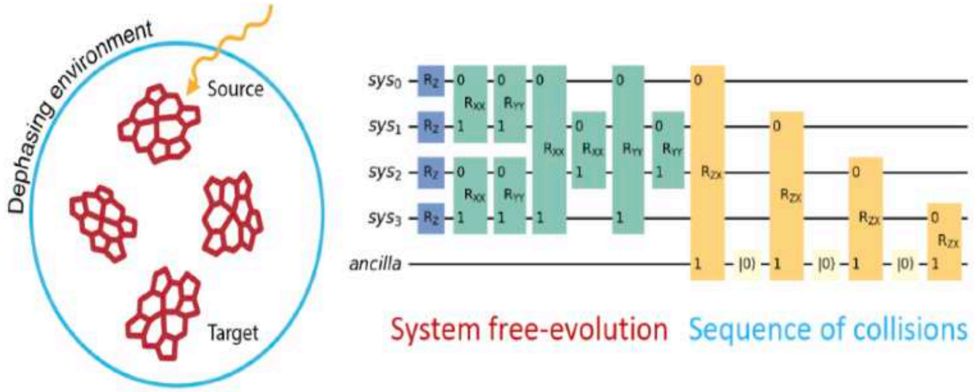
Hard optimization problems

combinatorial optimization (Knapsack problem)

from single satellite to constellations

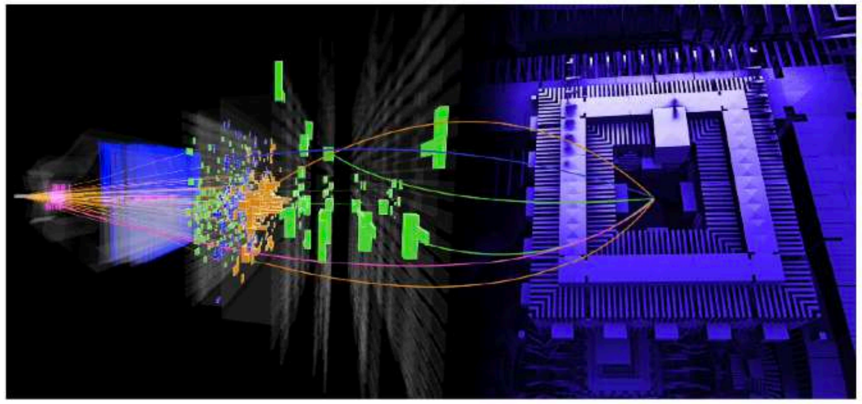
- Identification of use cases in the field of mission planning
- Estimate (hybrid) QPU-specs for realistic problems

B. Fresch



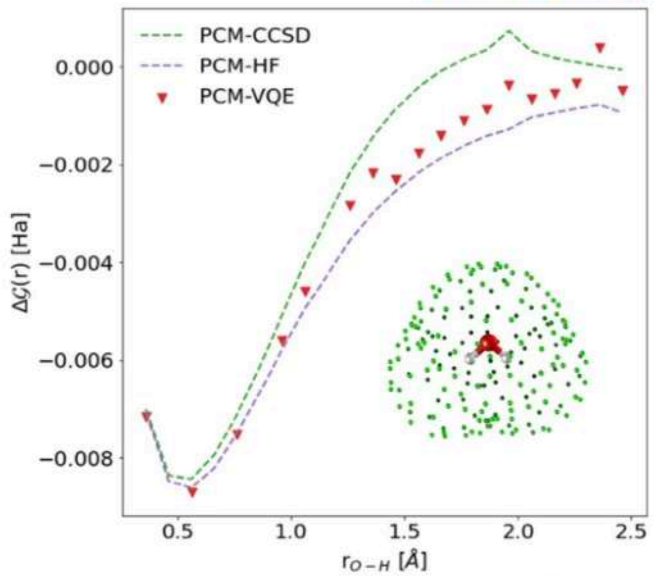
Quantum algorithms for simulating energy and charge transfer dynamics in molecular networks. Non-unitary dynamics of the open system via effective representations of the environment in the quantum circuit.

D. Lucchesi



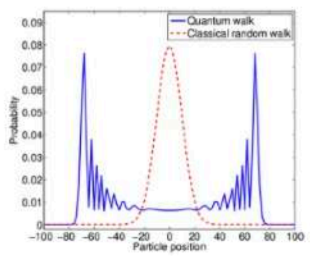
Insight on the structure of the jets produced in proton-proton collisions at LHC. We are working within LHCb collaboration to investigate the b quark originated jets.

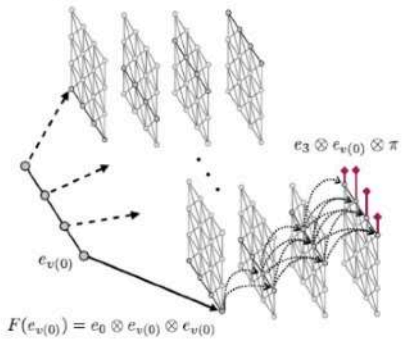
S. Corni



Quantum algorithms for electronic states of molecules in gas phase and in solution, their structures, and their optical properties

F. Ticozzi





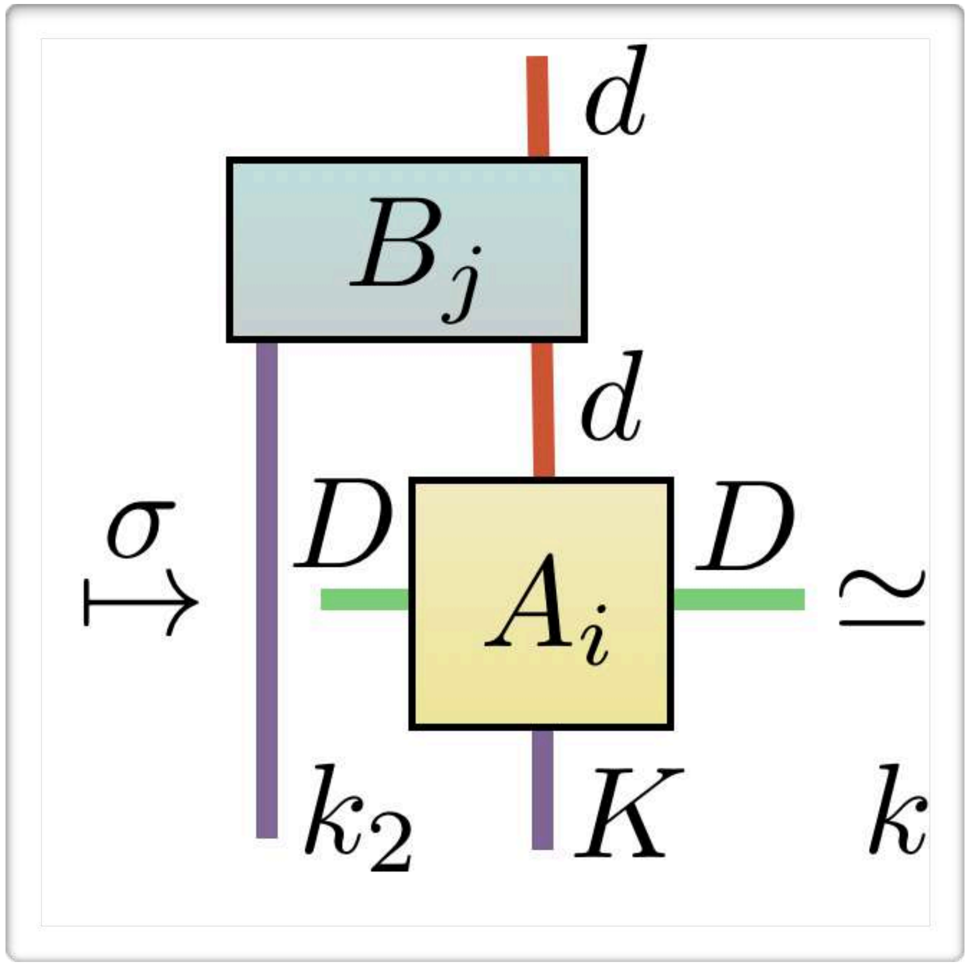
Dynamical systems for quantum computing, minimal representation and efficient simulations

See also L. Guidoni and D. Gerace's talks…

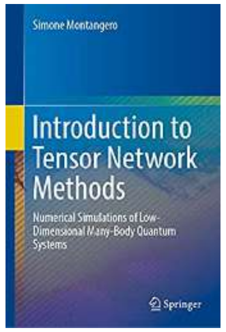
“

When do we really need a quantum simulation/computation?

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)*

LATTICE GAUGE THEORIES

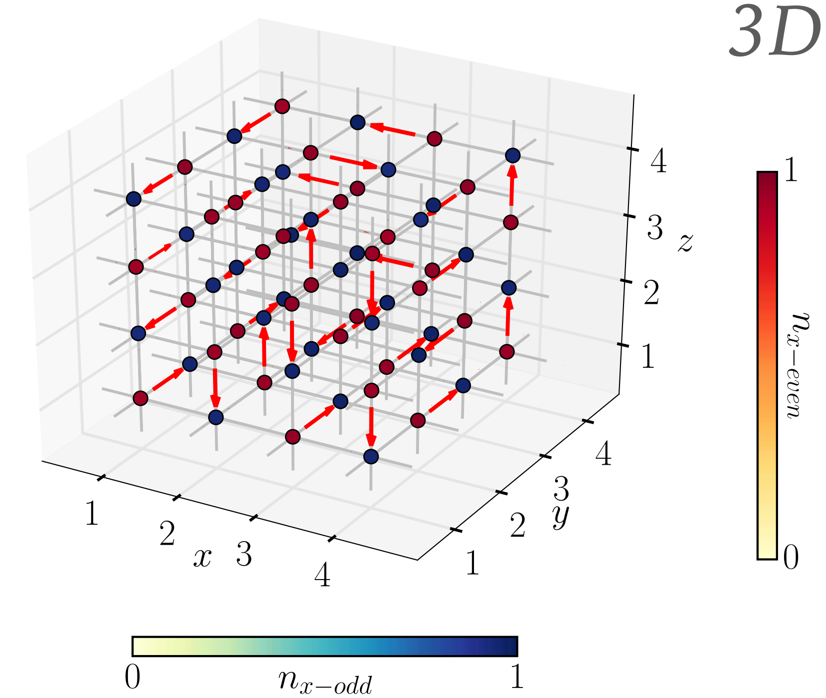
Hilbert space of

∼64x64x64 qubits!

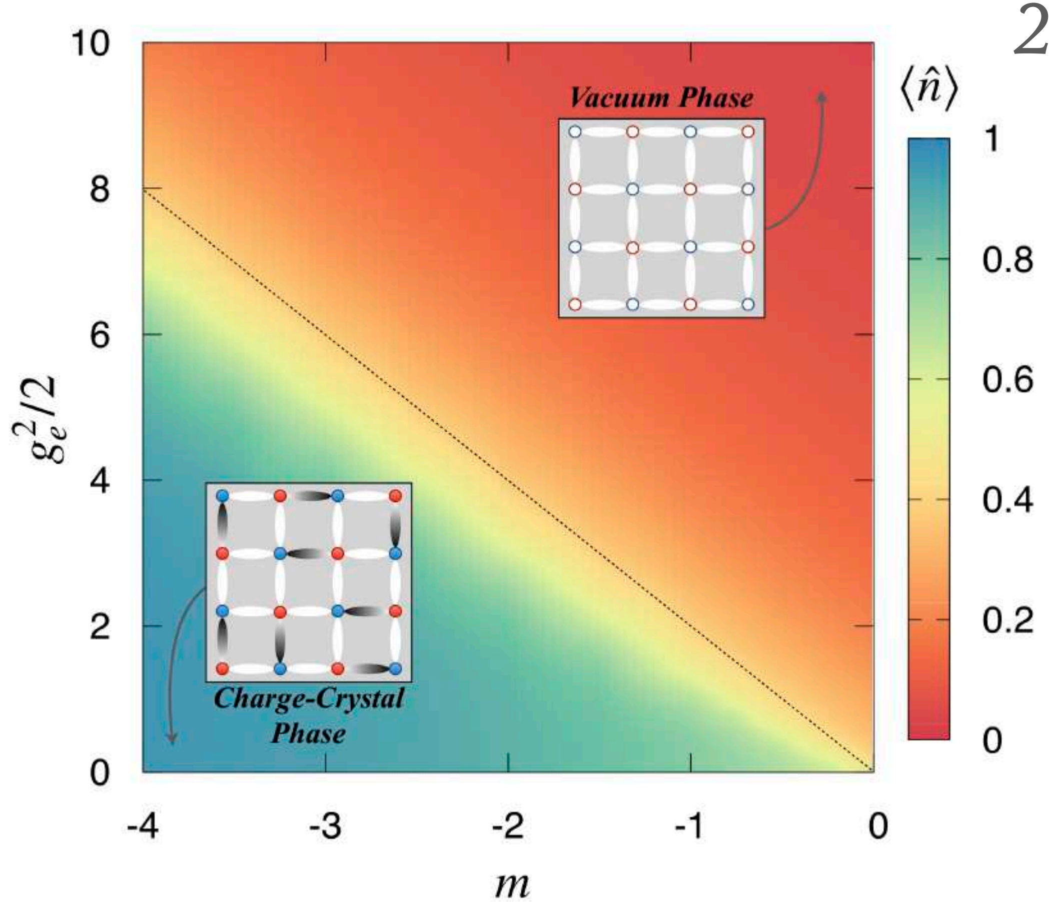
200Kb QRAM

$$\hat{H} = -t \sum_{x,\mu} \left(\hat{\psi}_x^\dagger \, \hat{U}_{x,\mu} \, \hat{\psi}_{x+\mu} + h.c. \right)$$
$$+ m \sum_x (-1)^x \hat{\psi}_x^\dagger \hat{\psi}_x + \frac{g_e^2}{2} \sum_{x,\mu} \hat{E}_{x,\mu}^2$$
$$- \frac{g_m^2}{2} \sum_x \left(\hat{U}_{x,\mu_x} \hat{U}_{x+\mu_x,\mu_y} \hat{U}_{x+\mu_y,\mu_x}^\dagger \hat{U}_{x,\mu_y}^\dagger + h.c. \right)$$

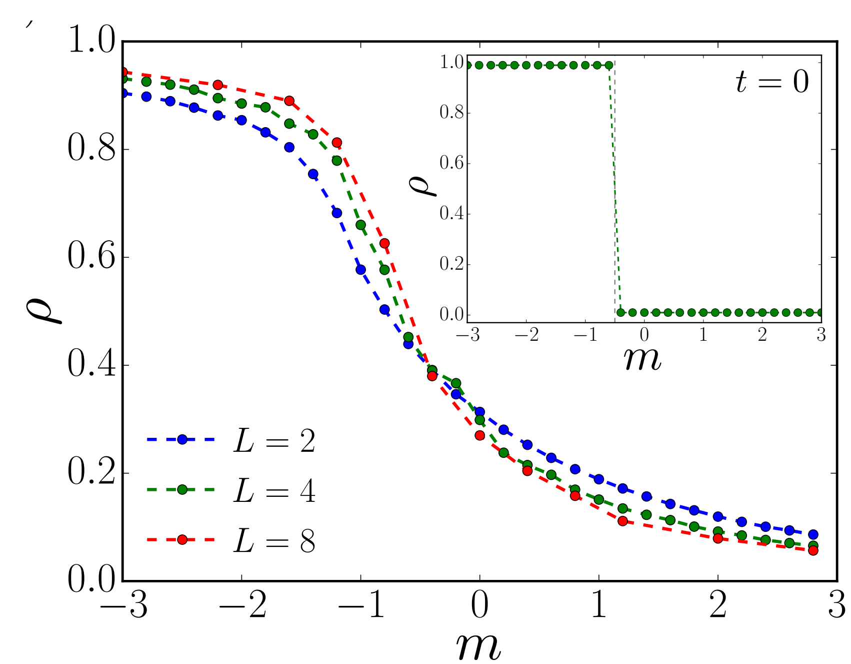
3D



2D



PRX (2020)



Nature Comm. (2021)

RELEASED!

Quantum Matcha Tea

An efficient matrix product state simulator for quantum circuits

FUTURE STEPS AND CONCLUSIONS

- Atom/ion quantum computers are among the leaders of the QT transformation
- Tensor network algorithms can be used to benchmark, verify, support and guide quantum simulations, computations and communication
- Hybrid solutions will give the first results in
  - Complex optimisation problems
  - Machine learning
  - Quantum sensing
  - Optimized protocols

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Website ready soon!

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