



PASQAL

**Quantum computing with
programmable array of atoms**

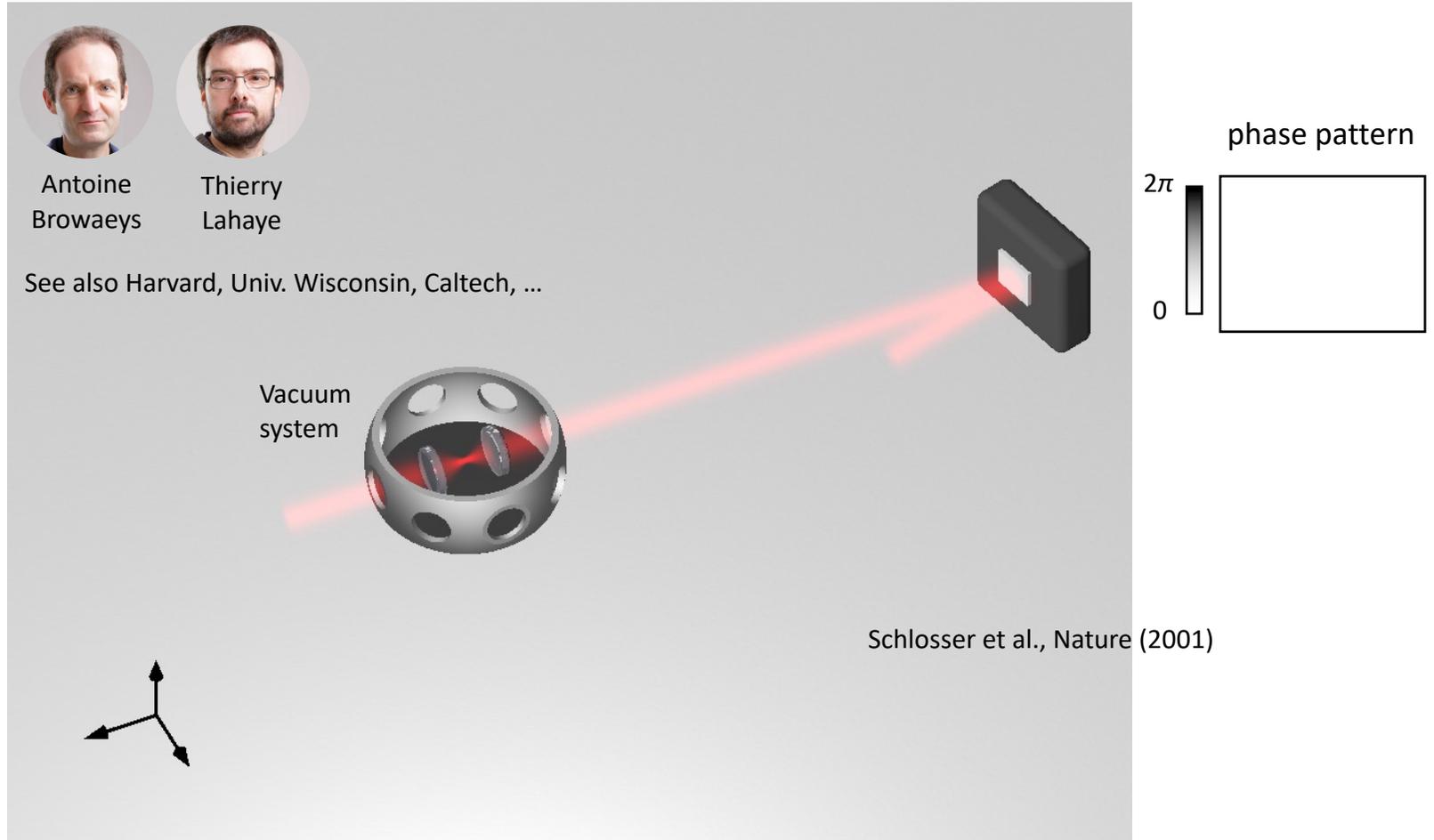
Teratec -- June 2022

FRESNEL


PASQAL

Neutral atom quantum processors

A technology pioneered at IOGS:
Trapped Rb atoms in an array of
optical tweezers¹

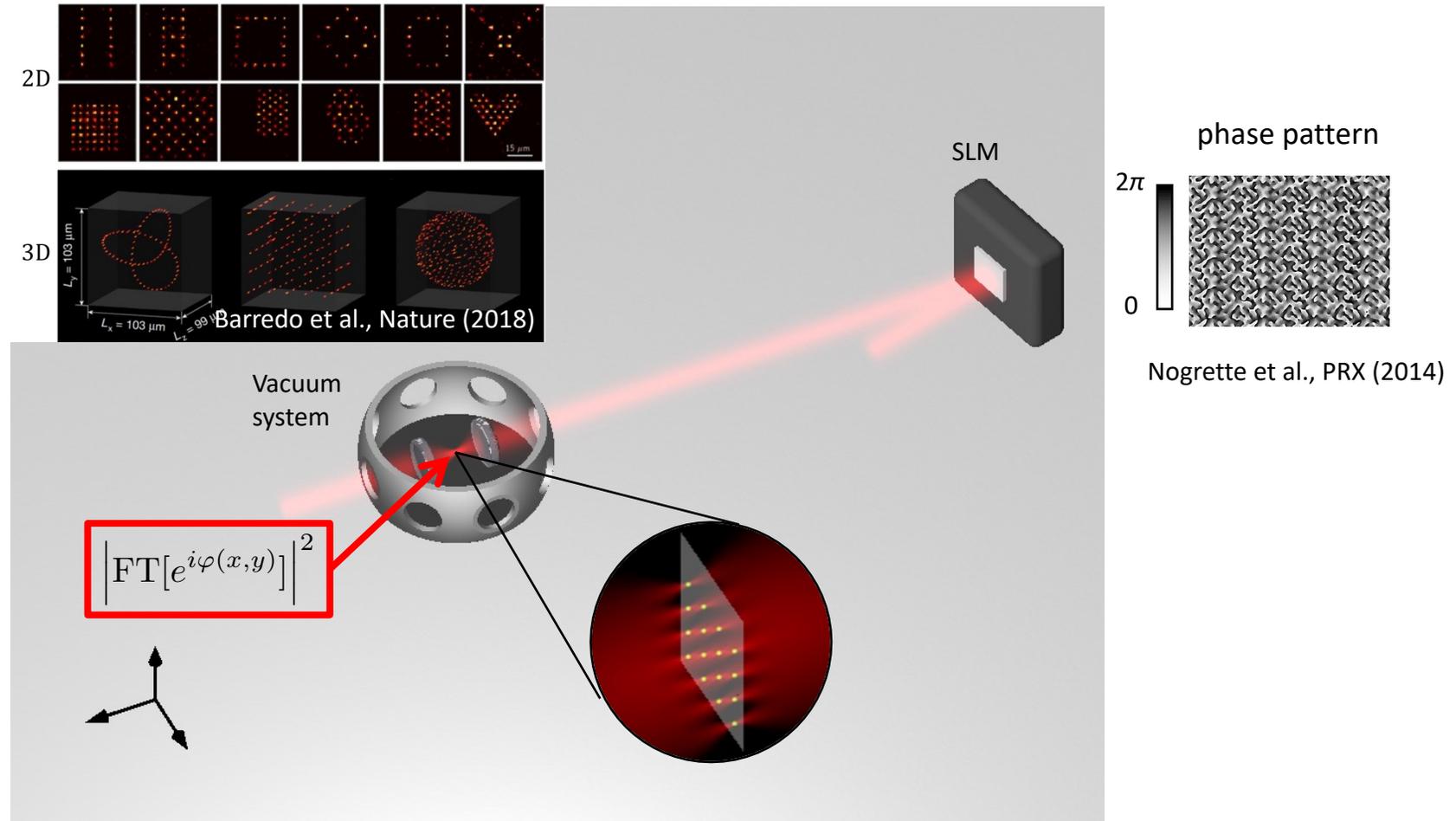


¹Quantum computing with neutral atoms, [Quantum 4, 327 \(2020\)](#)

Neutral atom quantum processors

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Using a SLM, one can reconfigure
the geometry of the qubit register



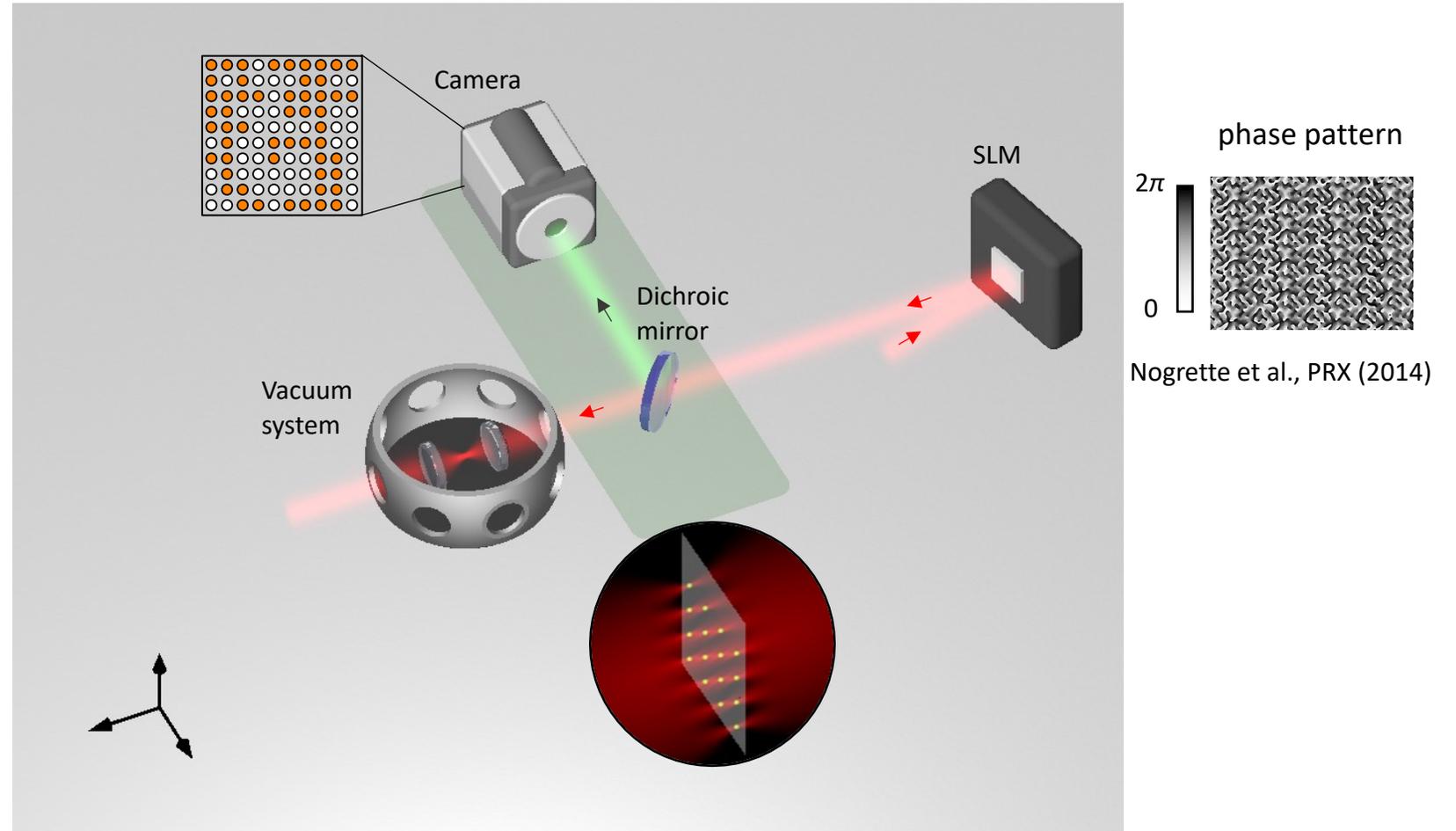
¹Quantum computing with neutral atoms, [Quantum 4, 327 \(2020\)](#)

Neutral atom quantum processors

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Atoms are imaged using a camera
with single-site resolution



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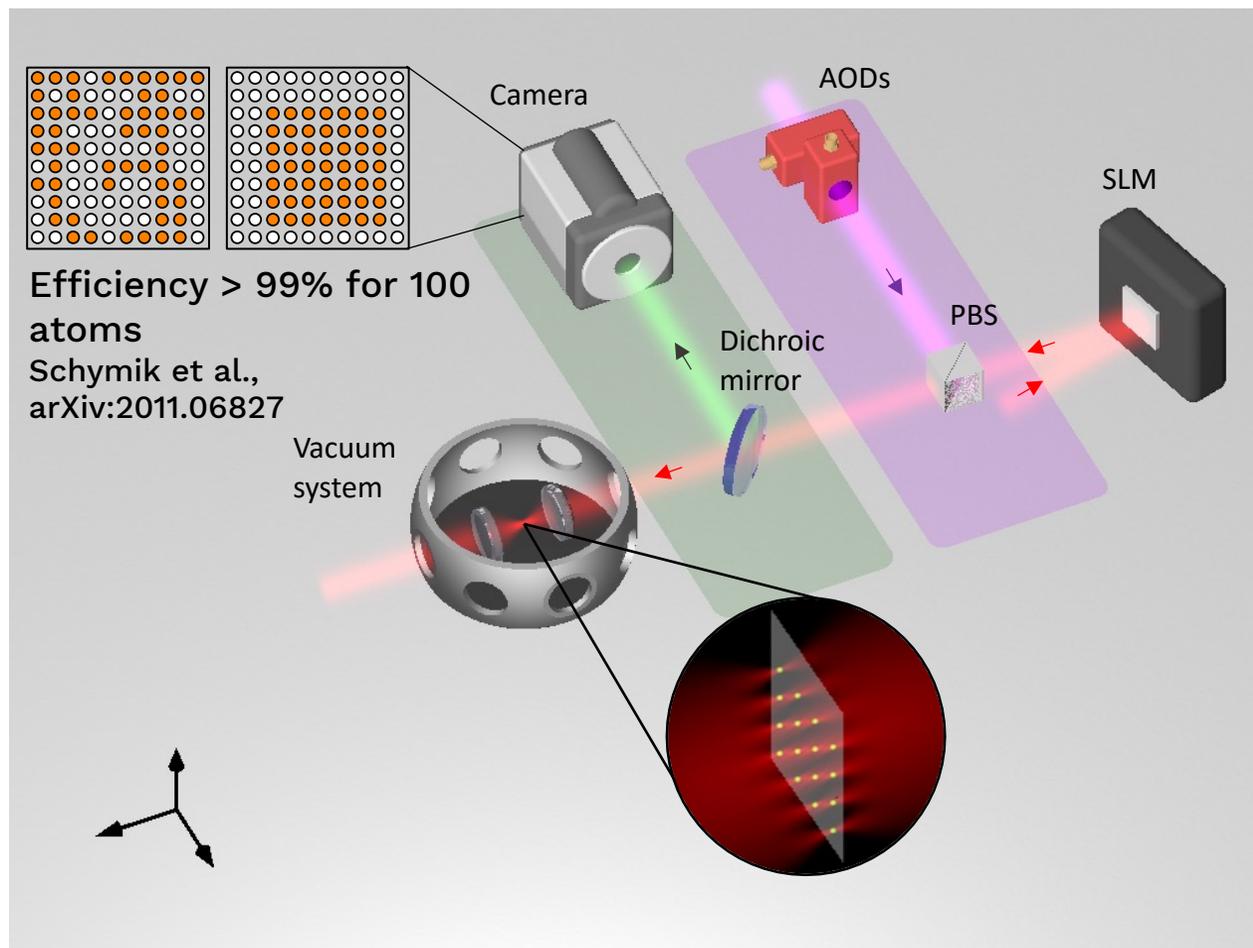
PASQAL's processor is designed to offer scalability for a wide range of algorithms

A technology pioneered at IOGS:
Trapped Rb atoms in an array of
optical tweezers¹

Using a SLM, one can reconfigure
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Atoms are imaged using a camera
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With an additional optical tweezer,
one can re-arrange the geometry of
the registers, atom by atom.

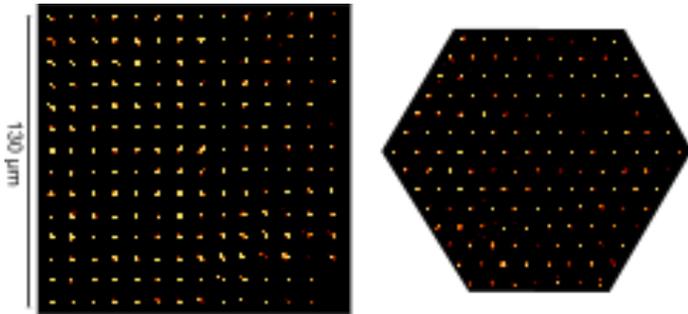


¹Quantum computing with neutral atoms, [Quantum 4, 327 \(2020\)](#)

Neutral Atoms : a unique approach to quantum computing

A unique scalability potential:

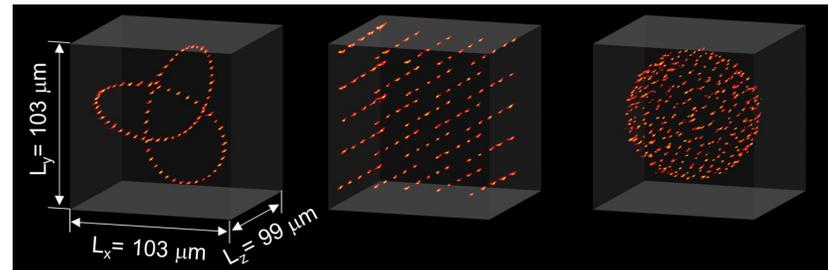
Our QPUs offer quantum registers with 100+ qubits as of today, and we have a clear blueprint for a **1000-qubit processor by 2023**



Experimental realisation of quantum registers with 196 qubits¹. Each dot is the captured fluorescence from an individual atom.

High flexibility level:

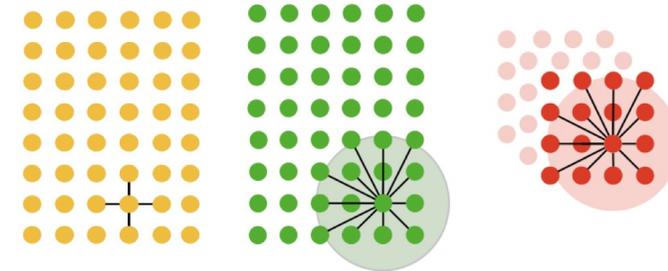
Our QPUs can be configured in different geometries: **1D, 2D & 3D**, paving the way towards a Universal Quantum processor



Experimental realisation of quantum registers in different geometries.

High connectivity:

One-to-many. We can design the connectivity between qubits by adjusting the distance between atoms and the geometry of the quantum register



¹P. Scholl et al. Quantum simulation of 2D antiferromagnets with hundreds of Rydberg atoms, [Nature 595, 233-238 \(2021\)](#)

Controls of a neutral-atom QPU

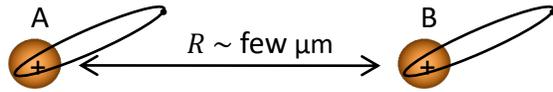
Our efforts towards industrialized QPUs

Application

Controls of a neutral-atom QPU

Processing quantum information

Rydberg interaction as entanglement resource



Jaksch et al., PRA (2000)
Saffman, RMP (2010)
Browaeys & Lahaye, Nat. Phys. (2020)

$$H_{ising} = \frac{\hbar\Omega}{2} \sum_{i=1}^N \sigma_i^x - \hbar\delta \sum_{i=1}^N \sigma_i^z + \sum_{j<i} \frac{C_6}{r_{ij}^6} n_i n_j, \quad n_i = \frac{\sigma_i^z + 1}{2}$$

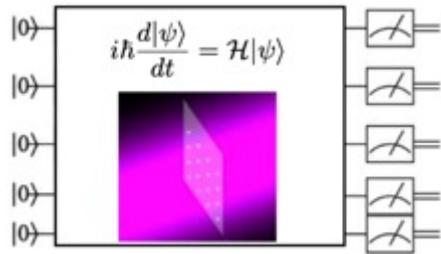
$$H_{XY} = \frac{\hbar\Omega}{2} \sum_{i=1}^N \sigma_i^x - \frac{\hbar\delta}{2} \sum_{i=1}^N \sigma_i^z + 2 \sum_{j<i} \frac{C_3}{r_{ij}^3} (\sigma_i^+ \sigma_j^- + \sigma_i^- \sigma_j^+)$$

Two controls modes supporting versatility

Quantum resources can be used in two different modes:

ANALOG CONTROL

programming a Hamiltonian sequence



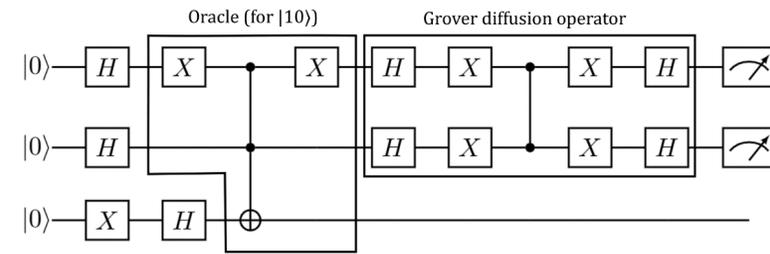
$$H = \sum_j [\hbar\delta(t) \sigma_j^z + \hbar\Omega(t) \sigma_j^x] + \sum_{i,j} U_{i,j} \sigma_i^z \sigma_j^z$$

The Hamiltonian faithfully describes the dynamics of a physical system or the constraints of an operational case. Parameters can be tuned continuously.

This computation mode is not universal but offers better performances, allowing for the implementation of practical use cases as of today.

DIGITAL CONTROL

programming a quantum circuit with digital quantum gates

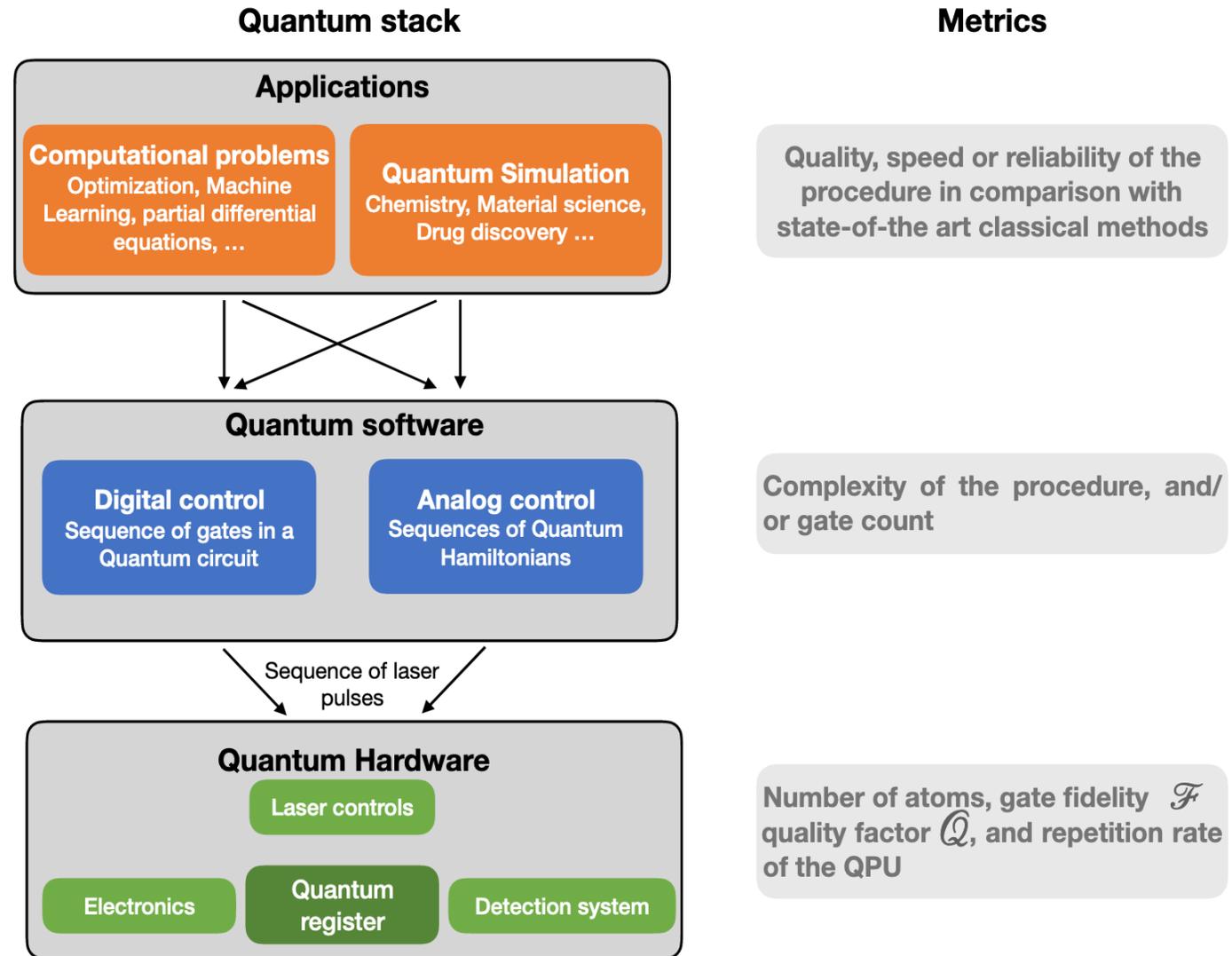


Elementary operations are discrete digital quantum gates, that can act either on individual qubits, or on several qubits at the same time.

This computation mode is universal. The reached performances with neutral atoms systems are comparable with performances of other platforms.

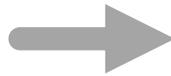
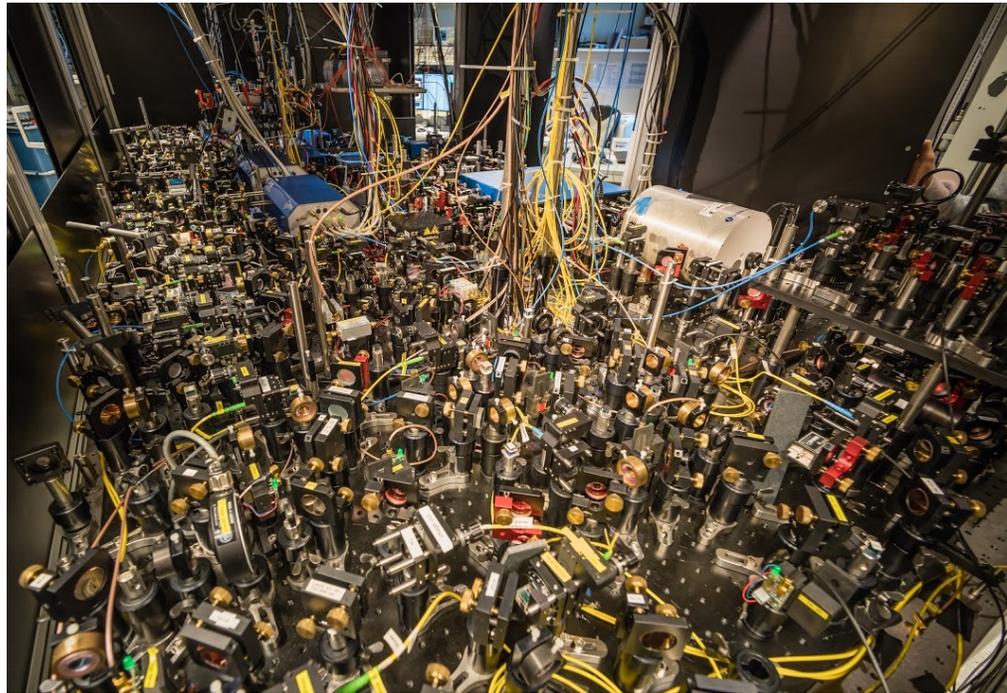
A numerical study realized by: M. Troyer (Microsoft), A. J. Daley (Strathclyde), I. Bloch (MPQ) and P. Zoller (Innsbruck), comparing the **requirements to simulate the same quantum dynamics** of a 10x10 2D Hubbard model system using an **analogue vs digital** modes: with typical error level of 1% of the analogue mode → 10⁶ gate operations are required with F > 0.999999

Quantum Stack of neutral atom Quantum Processors

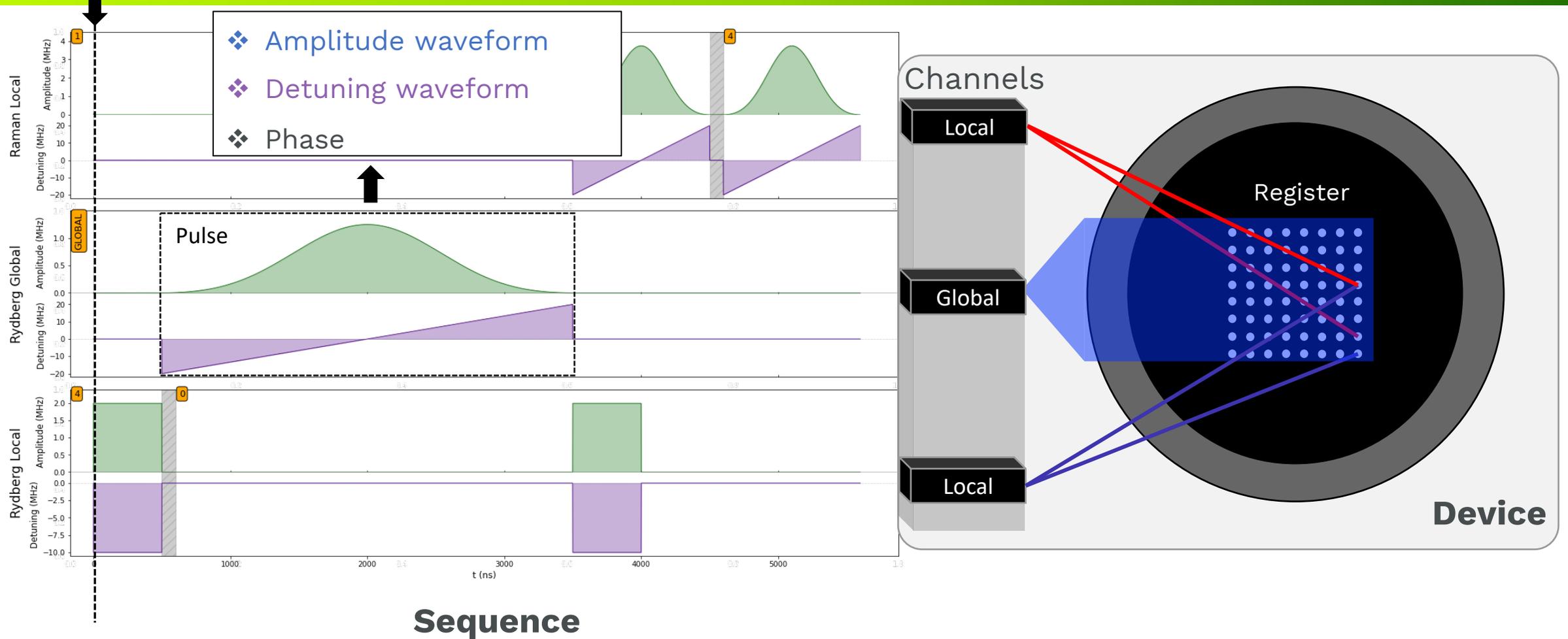


Taking the technology out of the lab

Pasqal : from an academic experiment to an industrial machine



Anatomy of a Pulser Sequence



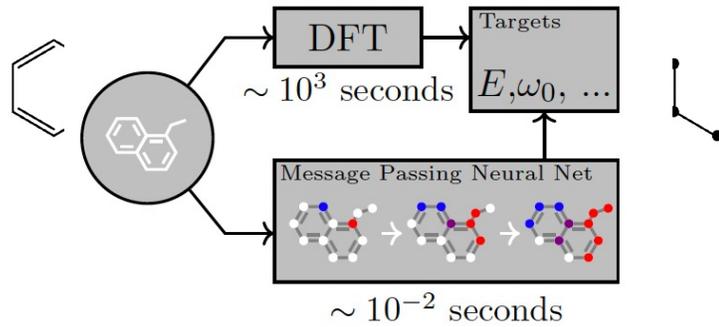
GitHub Repository: <https://github.com/pasqal-io/Pulser>

Documentation: <https://pulser.readthedocs.io/>

Paper: *Silvério et al.*, Quantum 6, 629 (2022), <https://arxiv.org/abs/2104.15044>

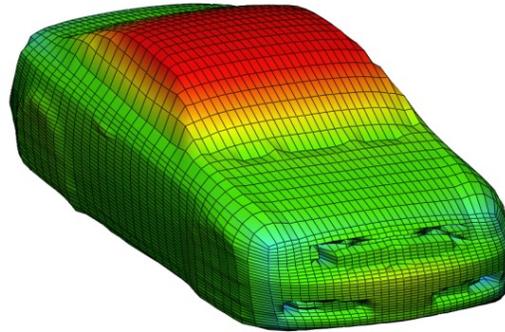
A few applications

Quantum Machine Learning Phys Rev. A 2021 and experimental results upcoming



MOLECULES

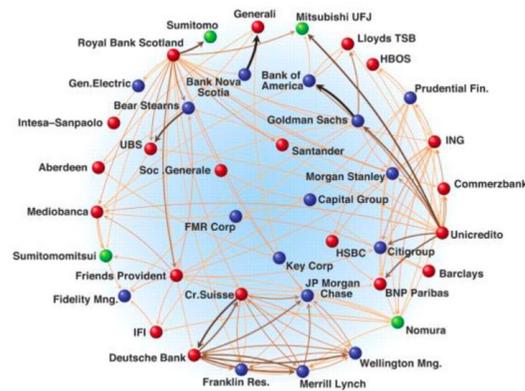
Gilmer et al. *Neural Message Passing for Quantum Chemistry*



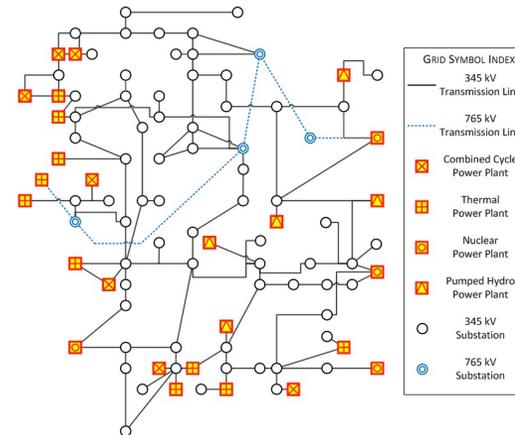
3D shapes



Social networks



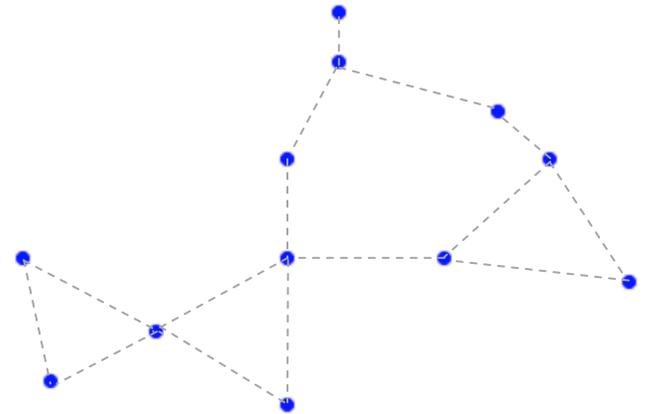
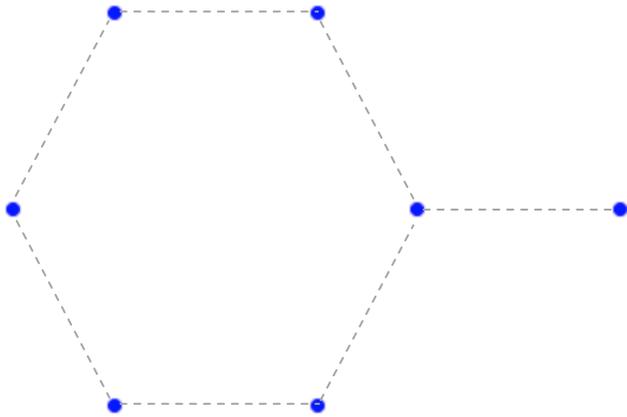
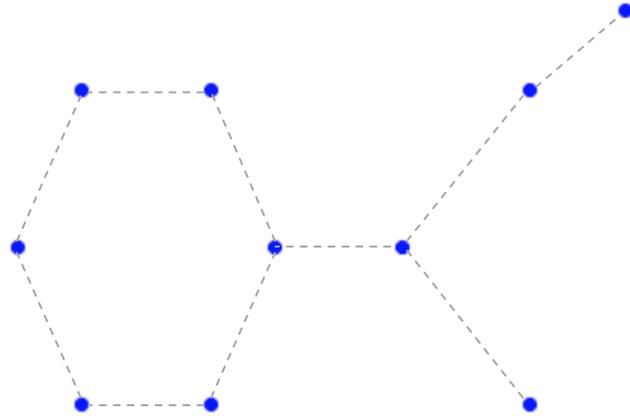
Economic networks



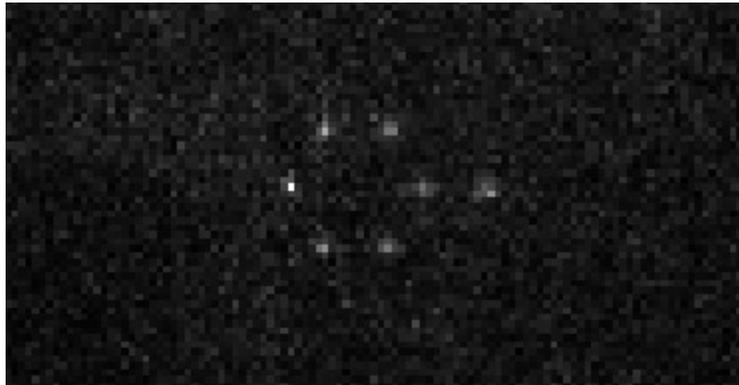
Power networks

Image credits to be found at: Jure Leskovec, Stanford CS224W, <http://web.stanford.edu/class/cs224w/slides/01-intro.pdf>

Examples of graphs

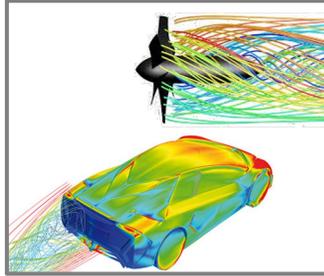


Atom registers

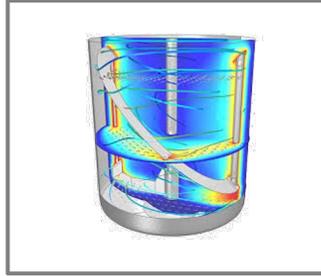


Multiphysics simulations

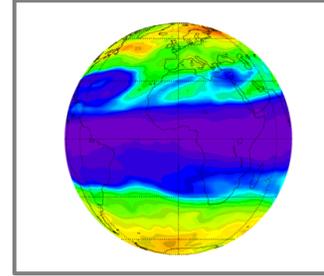
Mechanical Engineering



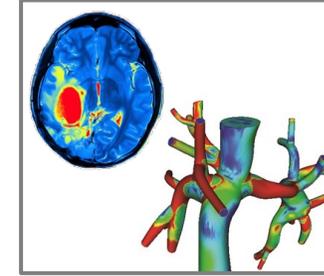
Chemical engineering



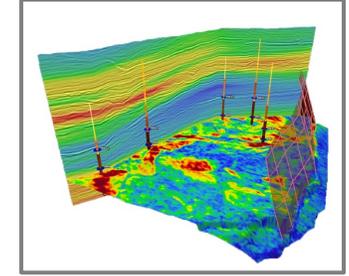
Metrology & Climate



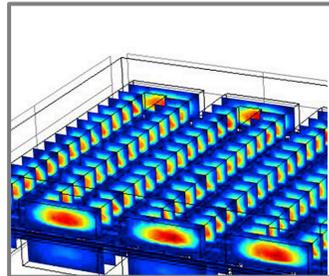
Biomedical



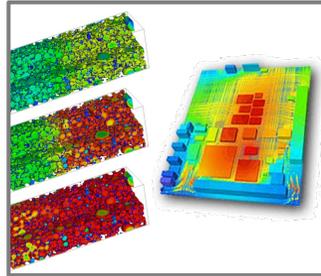
Oil & Gas



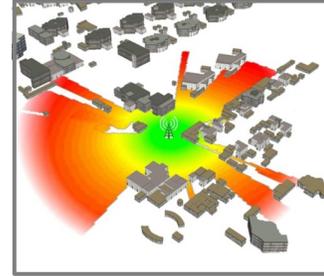
Fuel cell design



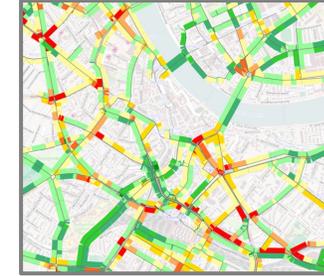
Batteries & Electronics



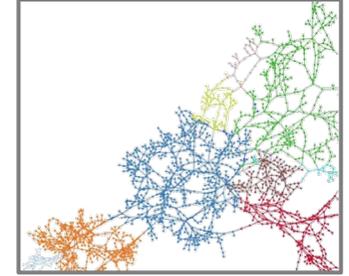
Wireless networks



Traffic & Logistics

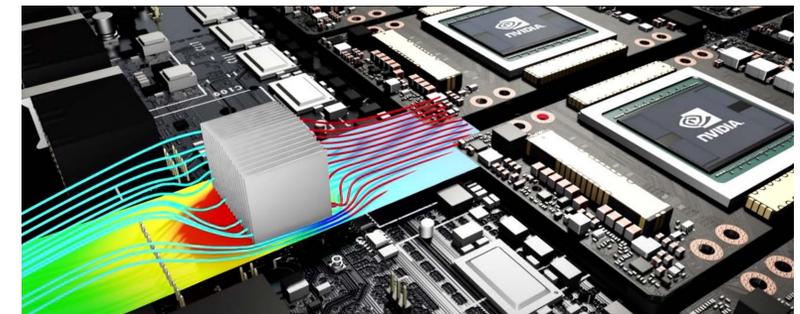
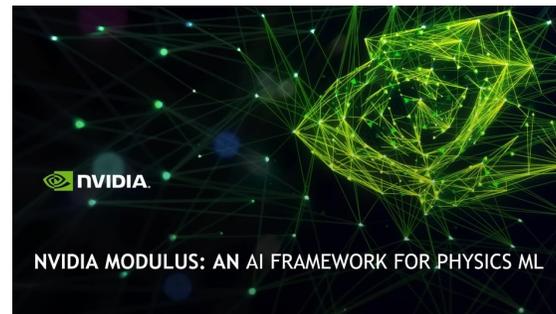
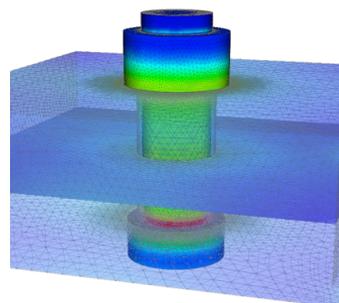


Powergrids

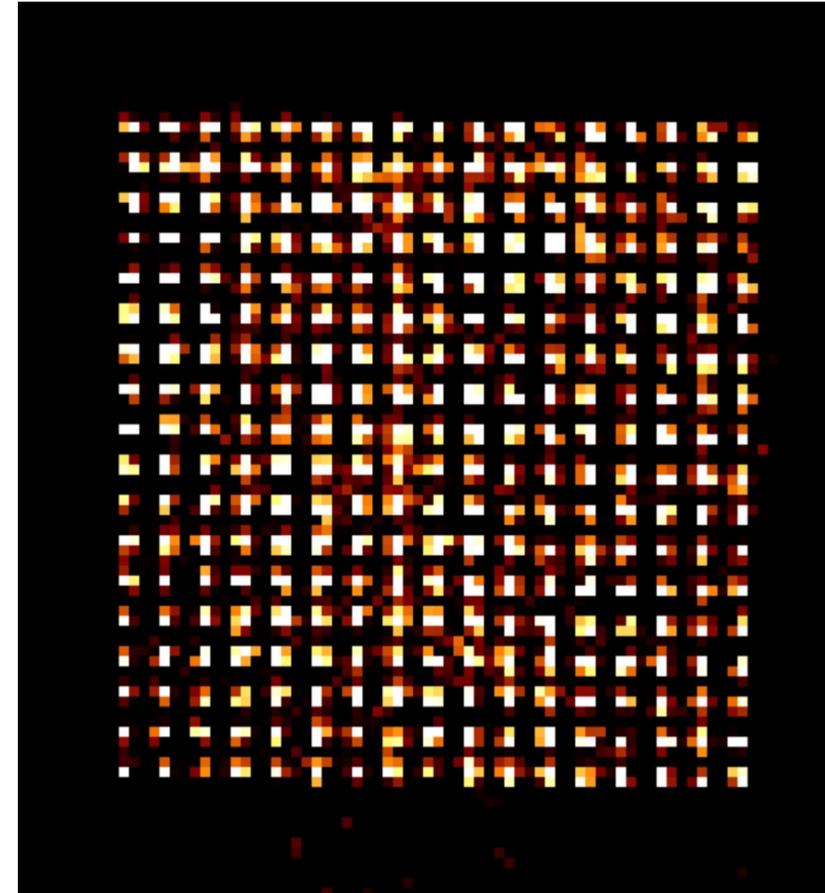
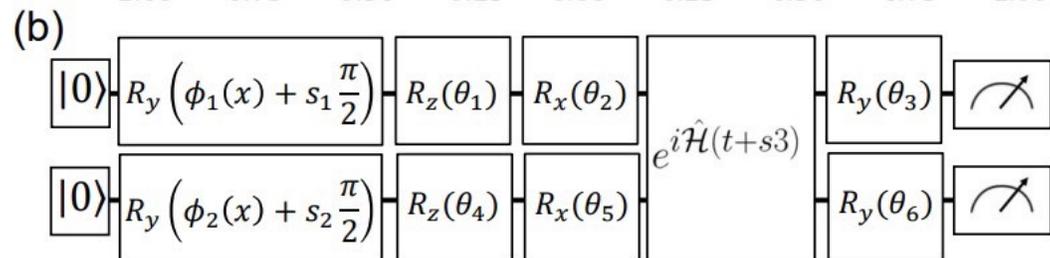
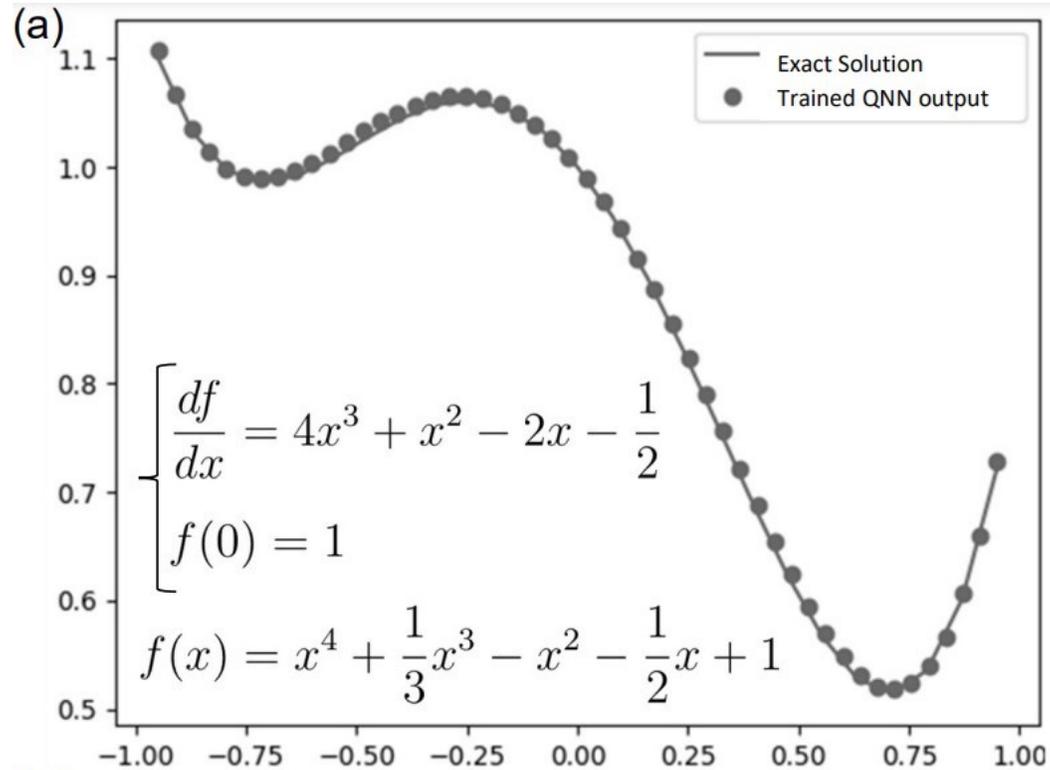


**Computational Challenge:
Solving Differential Equations**

**Traditional Methods: FEM
Latest State-of-the-Art: PINN**



Digital-analog quantum algorithms for solving differential equations



Thank you for your attention



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