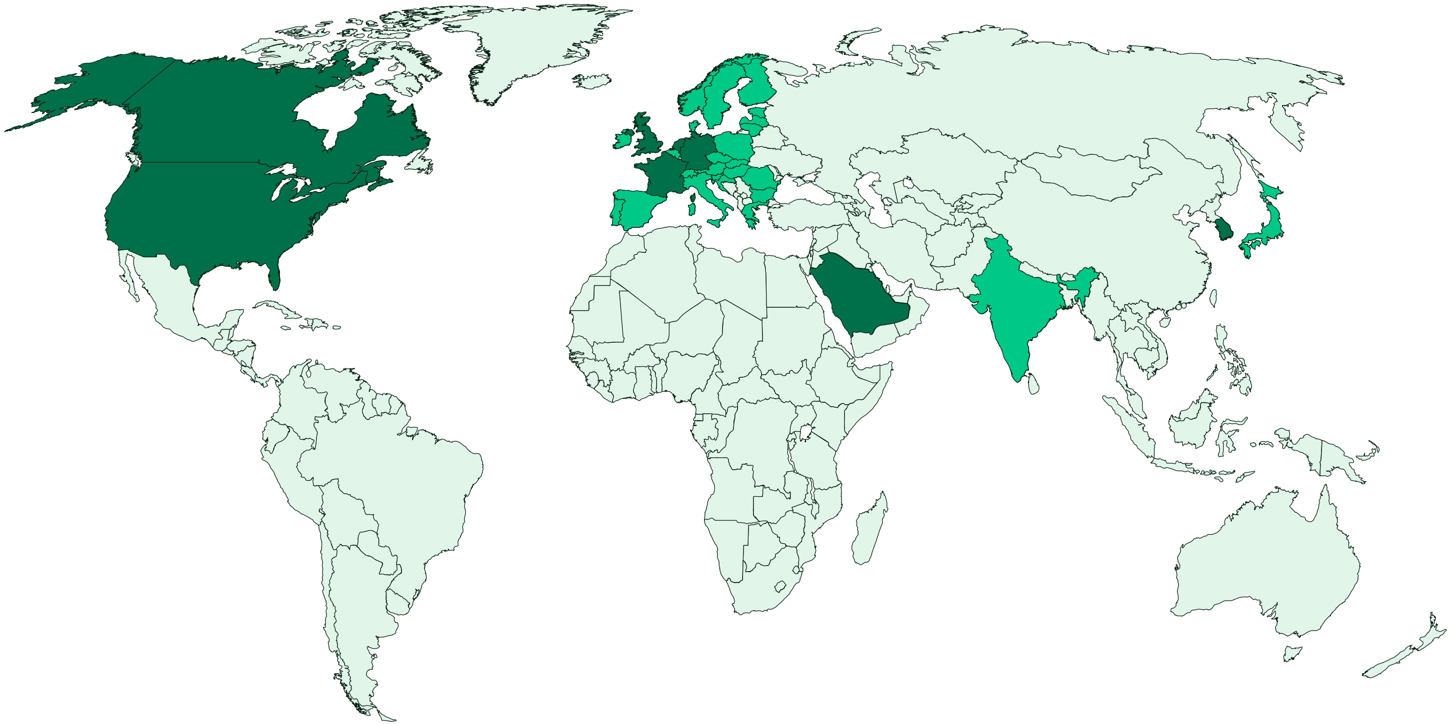
Pasqal Defining the quantum reality

Benchmarking optimisation problems with neutral atoms

Constantin Dalyac, PhD

TQCI 2025 – Palaiseau

Pasqal in the world



Local team

Community (Cloud Hours & Services)

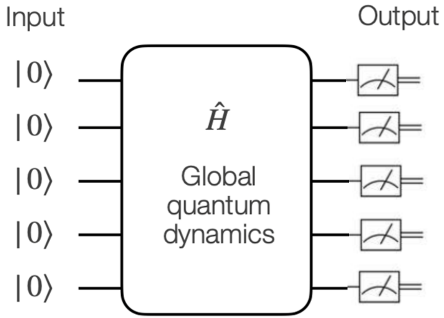
Neutral Atom QPUs

Pasqal

Analog Control

Programming a Hamiltonian sequence

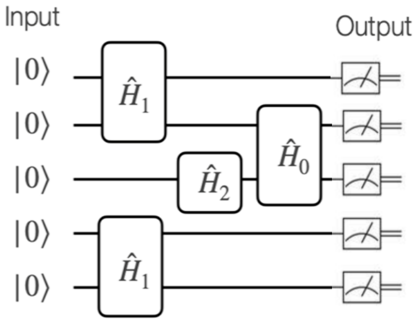
Parameters can be tuned continuously. The Hamiltonian faithfully describes the dynamics of a physical quantum system.



Gate-based Control

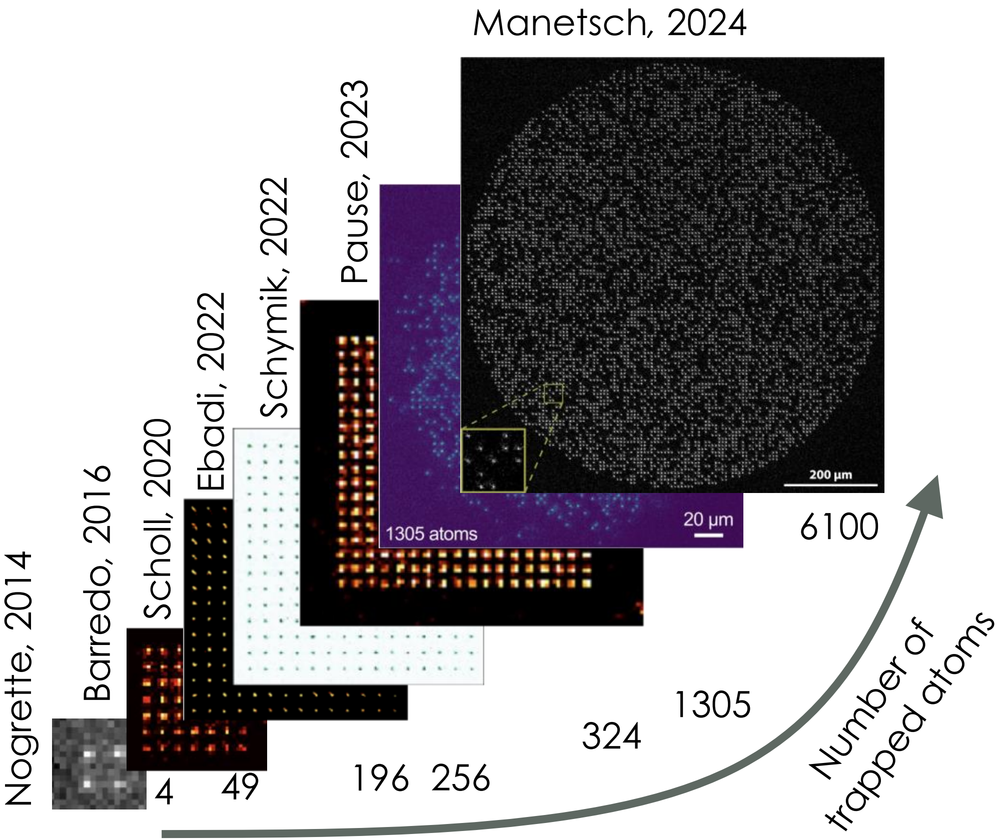
Programming a quantum circuit with digital quantum gates

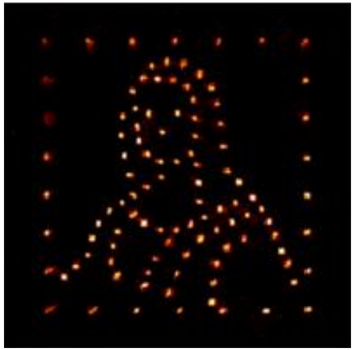
Elementary operations are discrete digital quantum gates, that can act either on individual qubits, or on several qubits at the same time.



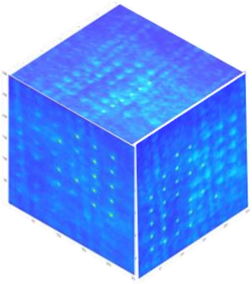
	Pros	Cons
Analog Control	Naturally implemented in our platform: shine a Rydberg laser on atoms not too far away & *voilà* Intrinsic high-fidelity Fast: ~1μs!	Restrained: cannot do whatever calculation we want Potentially harder to scale
Gate-based Control	This is how a classical computer works Clear path to perform quantum error correction	Far Far Away More active control of what happens: **requires exquisite control**

Scalability and arbitrary configuration

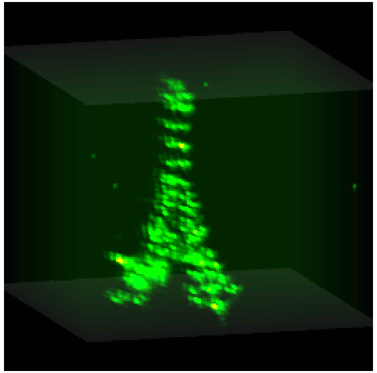




Schymik *et al*, 2020, PRA



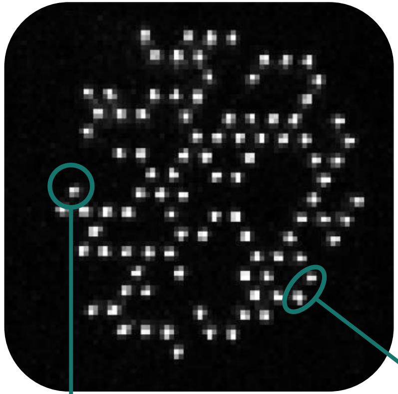
Dalyac *et al*, 2023, PRA

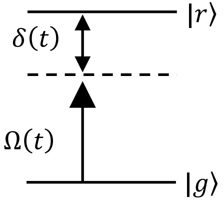


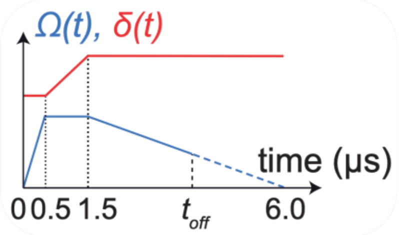
Barredo *et al*, 2018, Nature

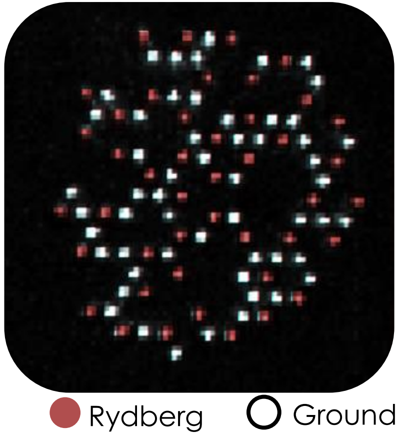
Rydberg blockade for UD-MIS

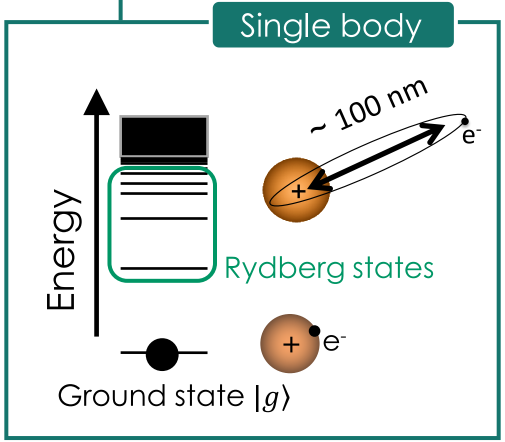
Pasqal

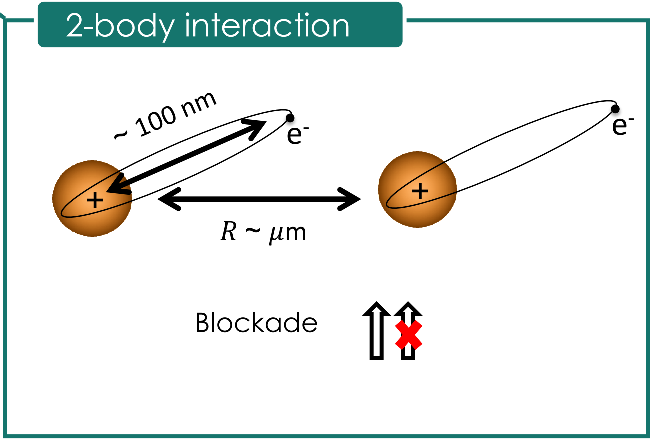












Optimisation with neutral atoms

- Dalyac & Leclerc, *European Physical Journal A*, 2024
- Ebadi, *Nature*, 2021
- Nguyen, *PRX Quantum*, 2023

Pasqal Defining the quantum reality

03

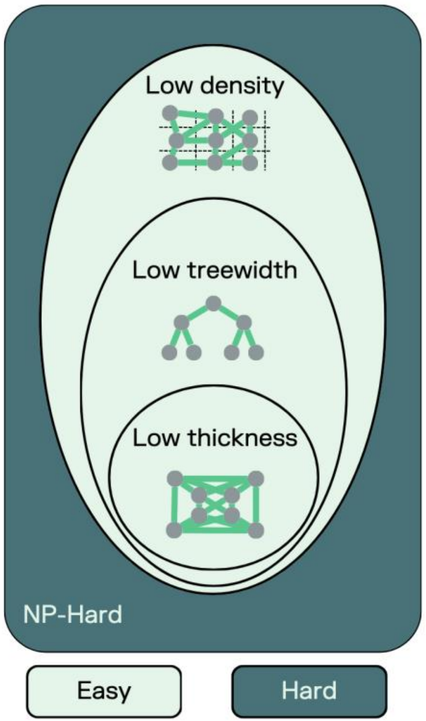
Is UD-MIS (*really*) a hard problem?

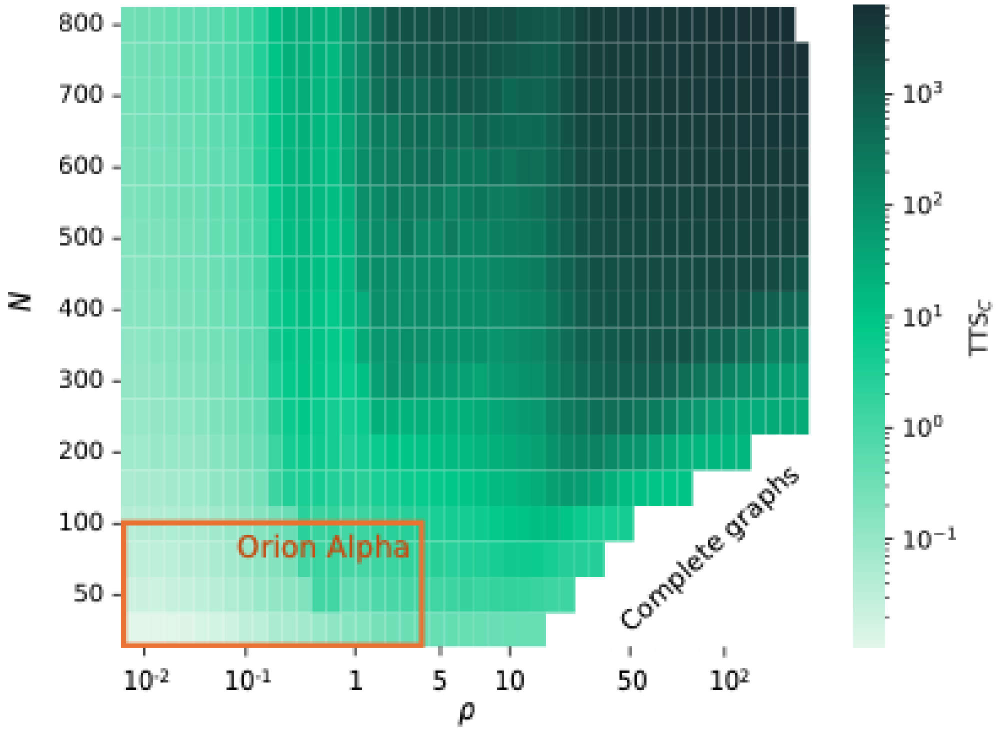
Identifying hard native instances for the maximum independent set problem on neutral atoms quantum processors
arXiv:2502.04291

MIS and classical state-of-the-art algorithms

A classical solver's time-to-solution (TTS) when solving to optimality the Maximum Independent Set on Kings Lattice graphs of size 289, compared to the best performance of a neutral-atom QPU.

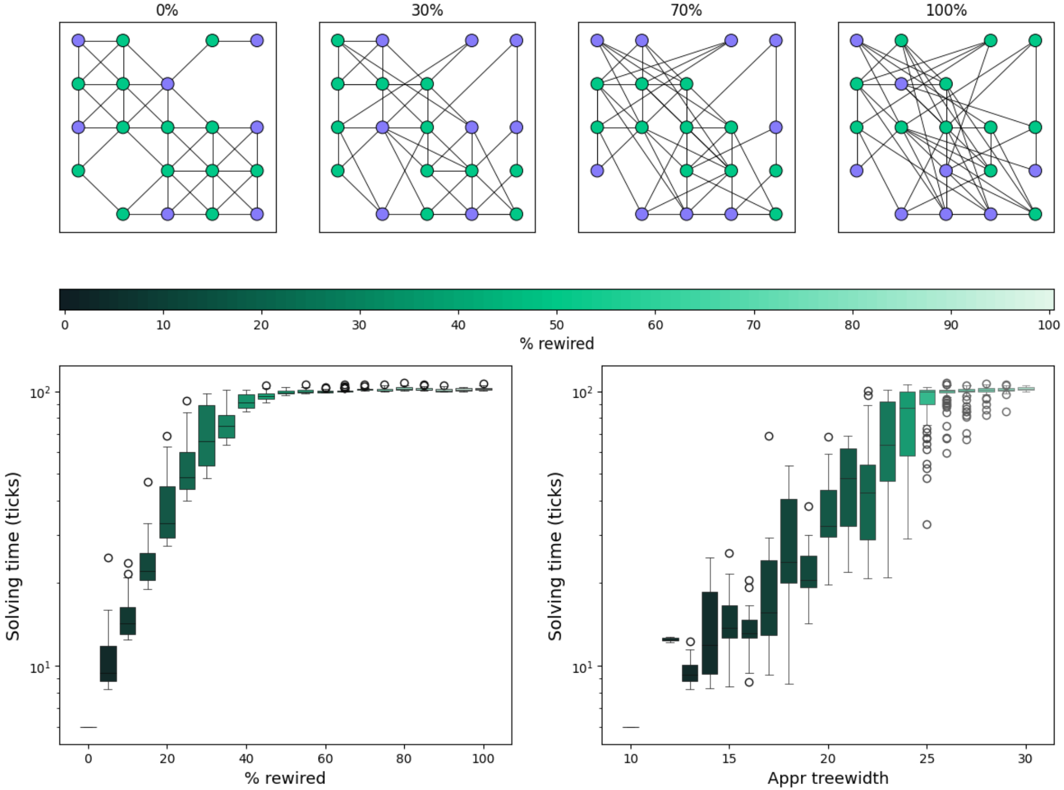
Finding hard native UD-MIS instances

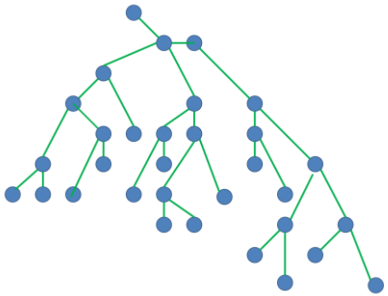




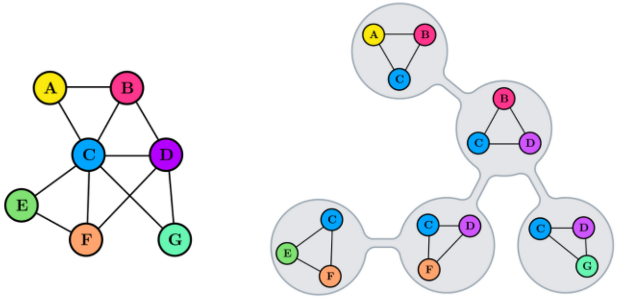
The impact of treewidth

Pasqal





A tree



A tree decomposition

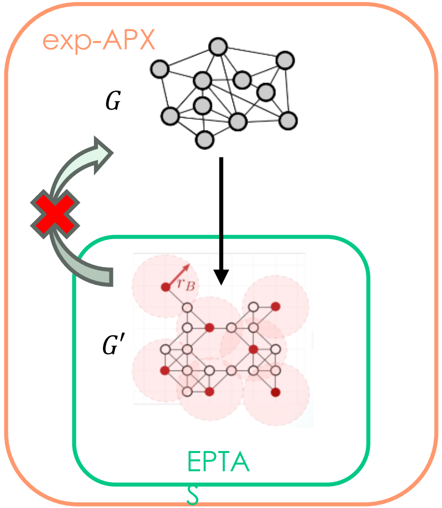
Quantum optimisation with arbitrary connectivity

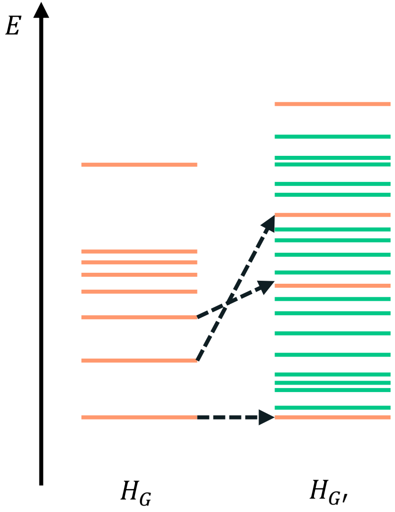
Approximations cannot be preserved

Recent methods [Nguyen23] have been proposed to encode any graph problem G with arbitrary connectivity into a unit-disk graph G'.
What happens when you get an approximate solution r ?

exp-APX: $r \simeq e^{-n}$

EPTAS: $\forall\, \varepsilon > 0, r = 1 - \varepsilon,$ poly$(1/\varepsilon)$

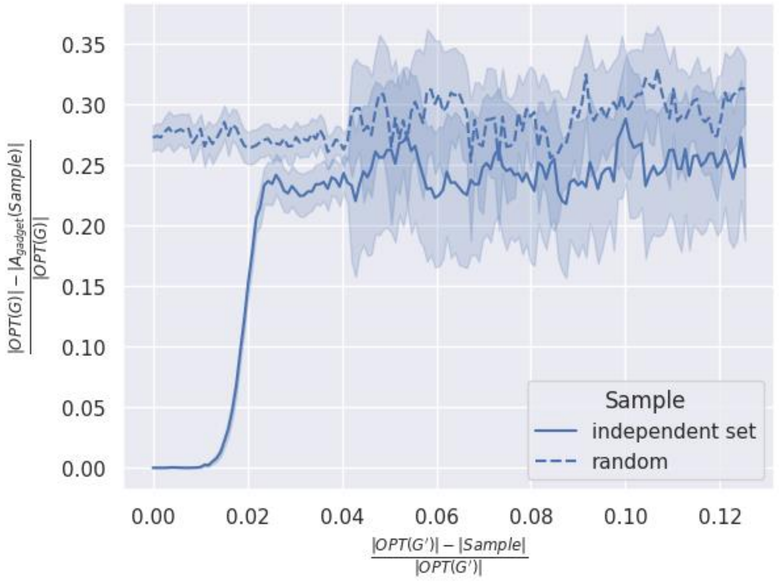




Testing gadgets in practice

How do approximate solutions on the augmented graphs G' impact the quality of the generated solution on the original graphs G?

G : Erdos-Renyi graph, n=28, p=0.4 G' : weighted UD graph, n=3000.



Summary and conclusion

Pasqal

- Locality/ structure can be harnessed by classical methods to find optimal solutions in short times.
- Treewidth is a good proxy of hardness.
- Gadgets do not preserve approximations and hinder tackling general graphs.
- Scaling up to a **thousand** atoms with a **1 kHz** repetition rate is a necessary step toward demonstrating a computational advantage with quantum methods.

Christmas photo

Pasqal

Pasqal