

IQuEra>

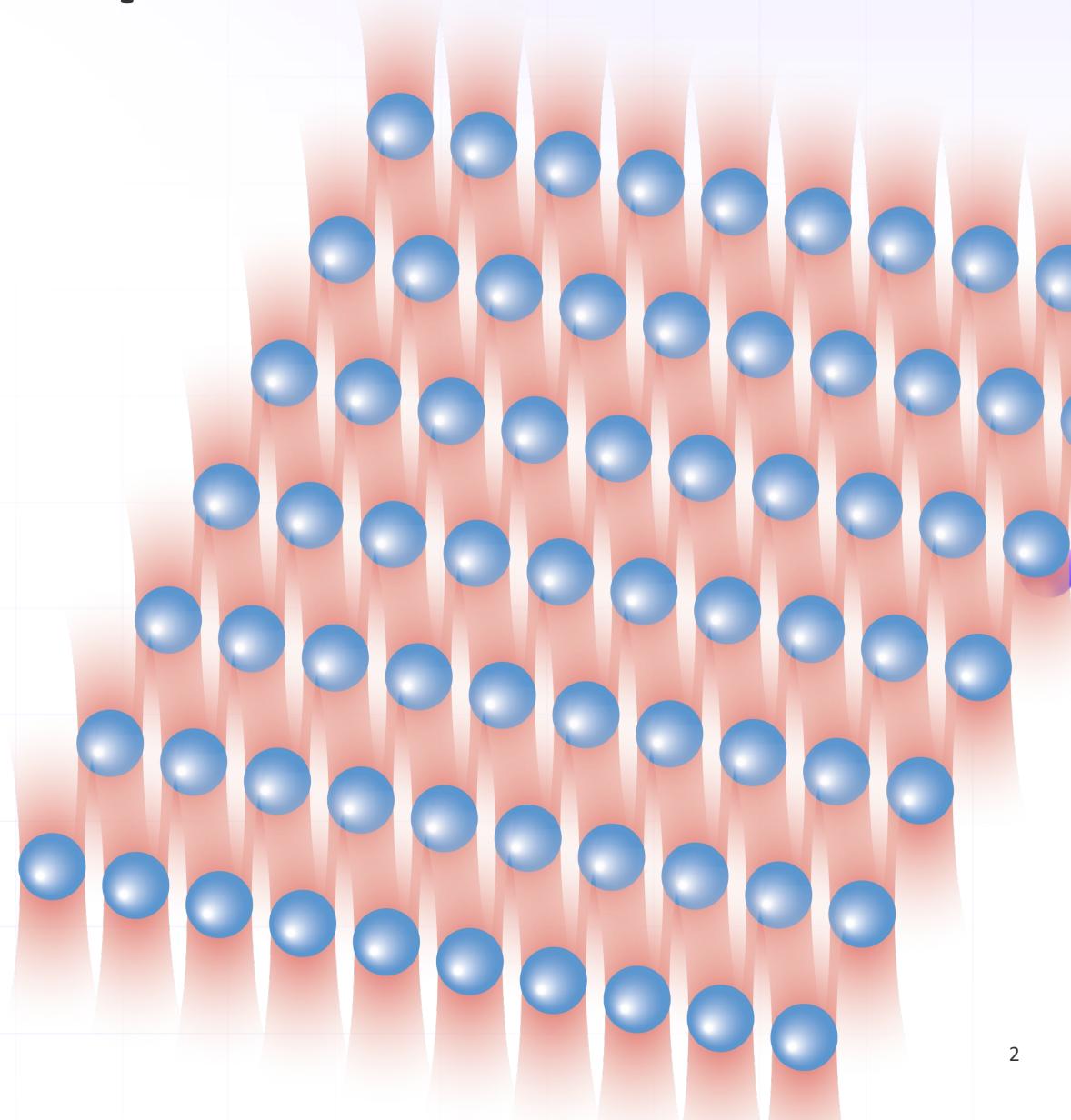
Intro to Neutral-atom Quantum Computing

ETH Quantum Hackathon 2024

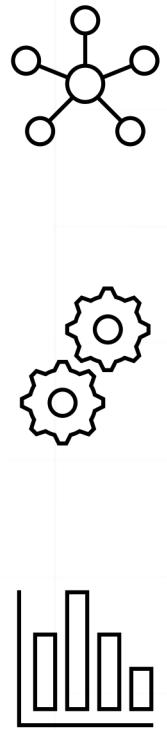
Pedro Lopes, PhD + Phillip Weinberg, PhD

Why neutral-atom quantum processor

- Densely packed qubits (atoms)
- Efficient qubit control
- Flexible problem encoding
- The fastest path to quantum error correction
- New ways to think quantum computing!

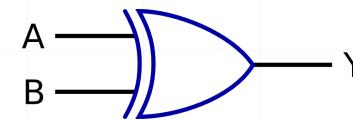
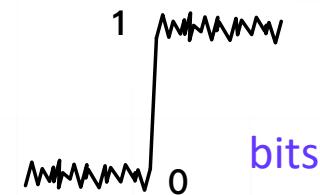


Quantum computing == new rules!



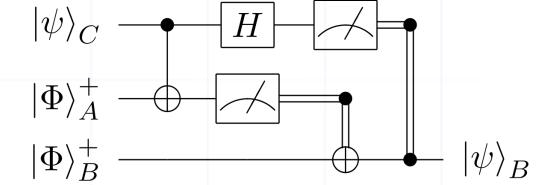
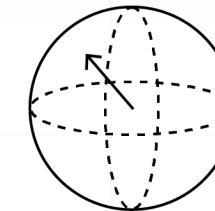
Information input
↓
Information processing
↓
Results & output

Classical



Deterministic

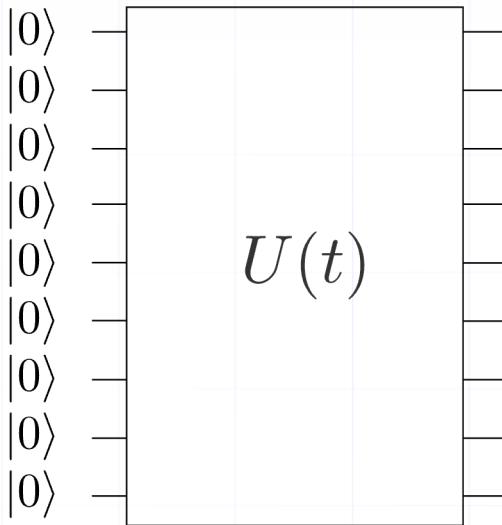
Quantum



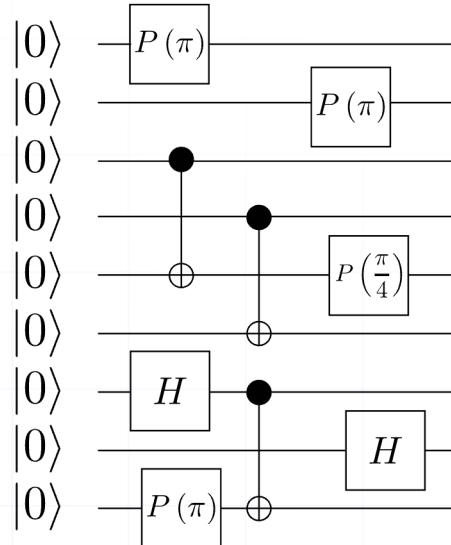
Probabilistic & deterministic

Paradigms of Q. Information processing

Analog operation



Digital operation



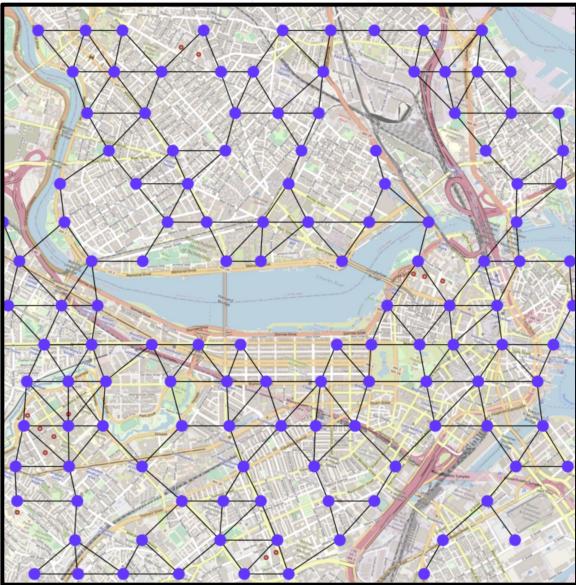
Designed for the early stage of maturity of the quantum computing resources of today...

- ✓ Robustness to errors
- ✓ Efficient control
- ✓ Single-step large entanglement
- ✗ Universal applicability

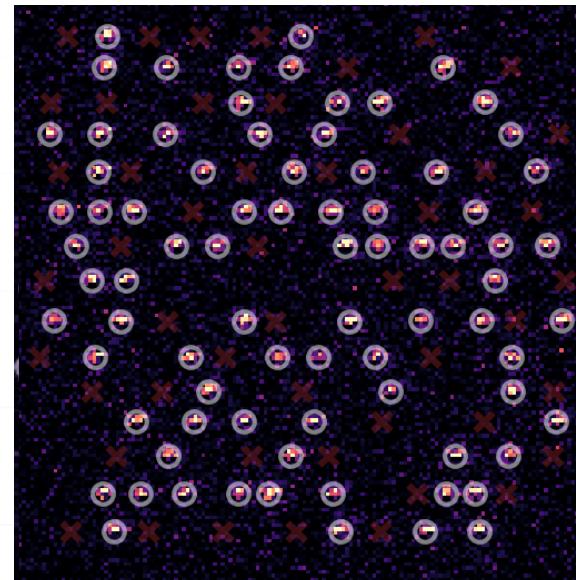
More on analog processors:
[Nature volume 607, p. 667–676 \(2022\)](#)

FPQA = Efficient Problem Encoding

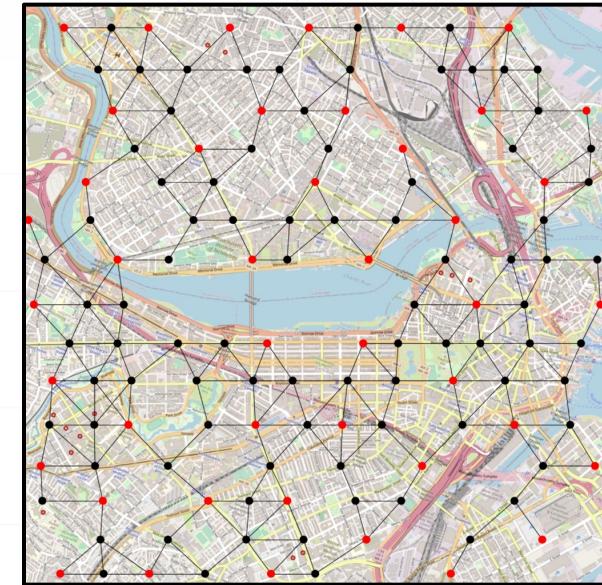
Problem: choosing optimal locations in Boston



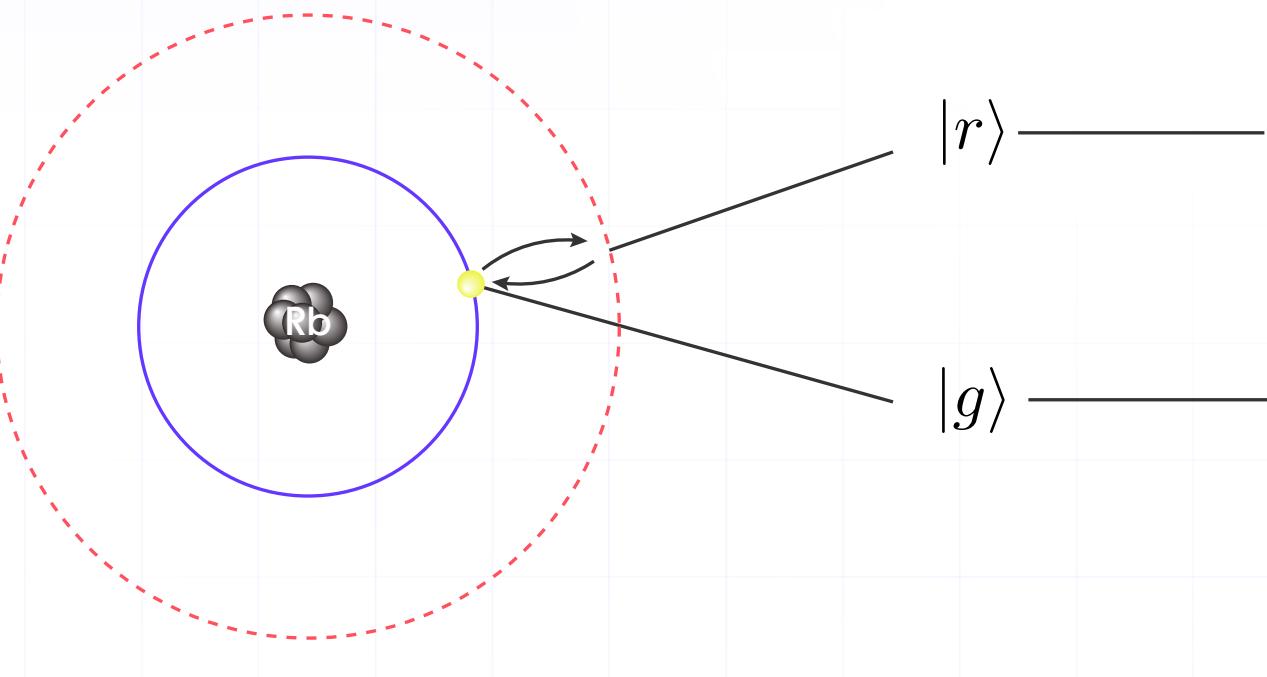
Possible locations as atom coordinates



Solution



Architecture: qubits by puffing-up atoms



Periodic Table of the Elements

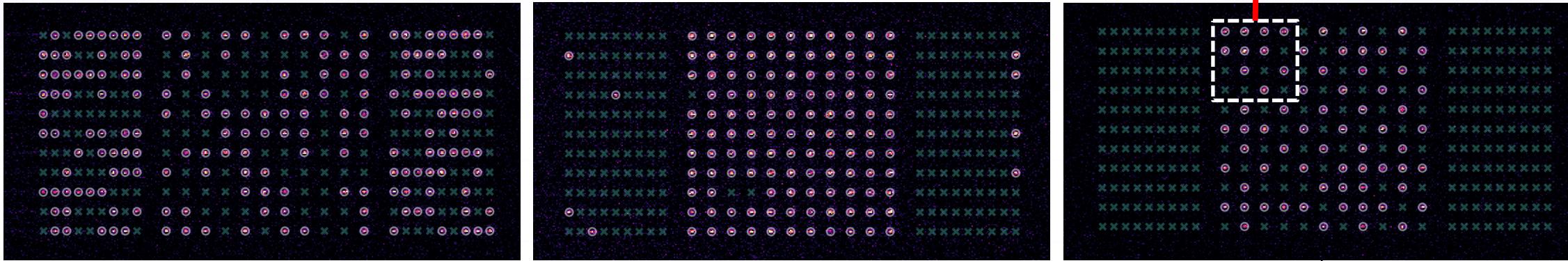
This detailed periodic table provides a comprehensive overview of the elements, including their atomic number, symbol, name, atomic weight, and electrons per shell. It also includes color-coded background patterns for different element categories and additional data such as melting and boiling points, density, and ionization energy.

Key features of the table include:

- Atomic Number:** The element's position in the sequence of elements.
- Name:** The element's name.
- Symbol:** The element's standard symbol.
- Atomic Weight:** The element's mass number.
- Electrons per shell:** The distribution of electrons in the element's shells.
- State of matter [color of name]:** The element's state at room temperature (Gas, Liquid, Solid).
- Subcategory in the metal-metalloid-nonmetal trend (color of background):** Categories include Alkali metals (red), Alkaline earth metals (blue), Transition metals (yellow), Post-transition metals (green), Noble gases (pink), Actinides (purple), Lanthanides (orange), and Reactive nonmetals (grey).
- Unknown chemical properties:** Elements for which no specific information is available.

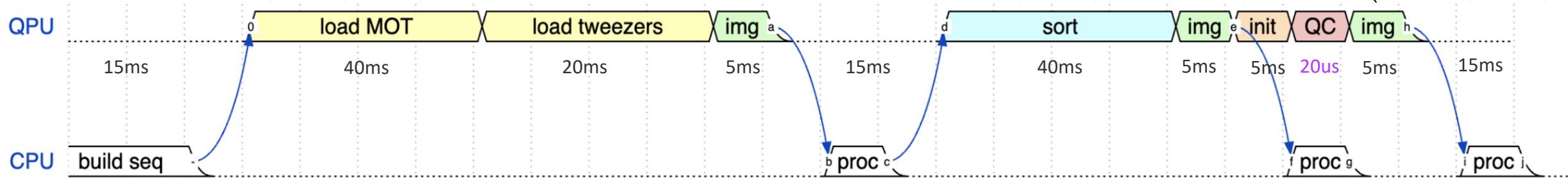
The table is organized into groups and periods, with the first group (IA) on the far left and the last group (VIIA) on the far right. The lanthanide and actinide series are included as separate blocks below the main body of the table.

QPU cycle



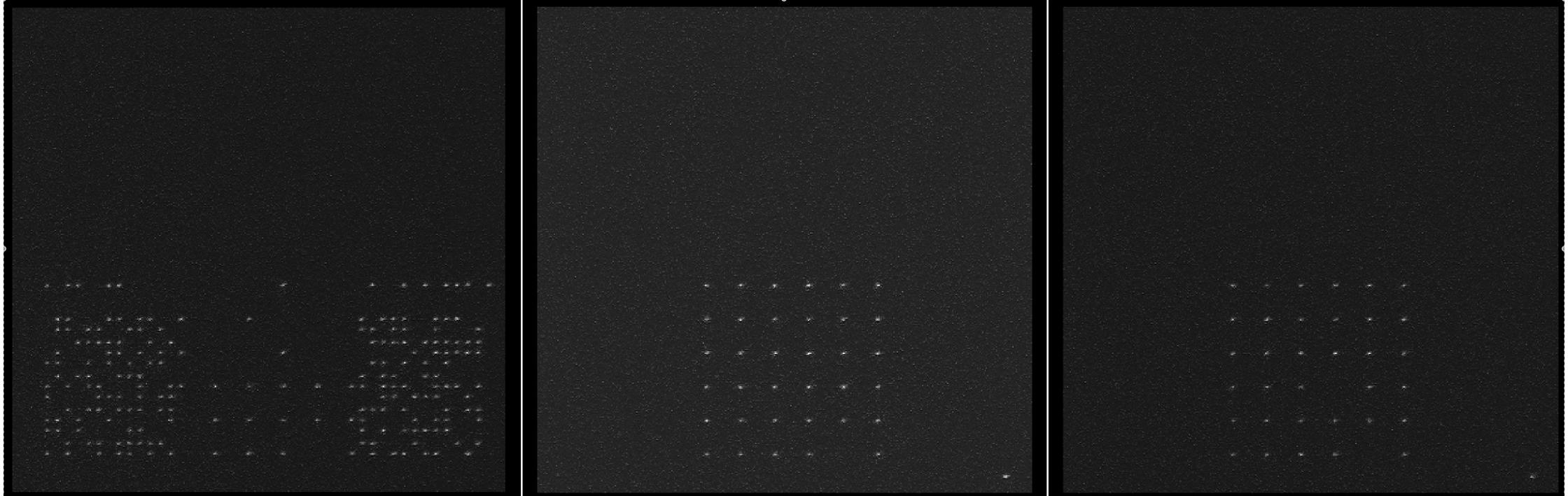
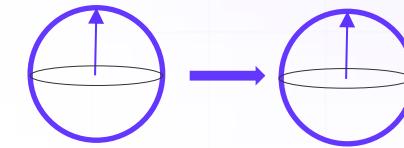
1	1	1	1
1	1	1	0
0	1	0	1
0	0	1	0

State
detection
> 95%



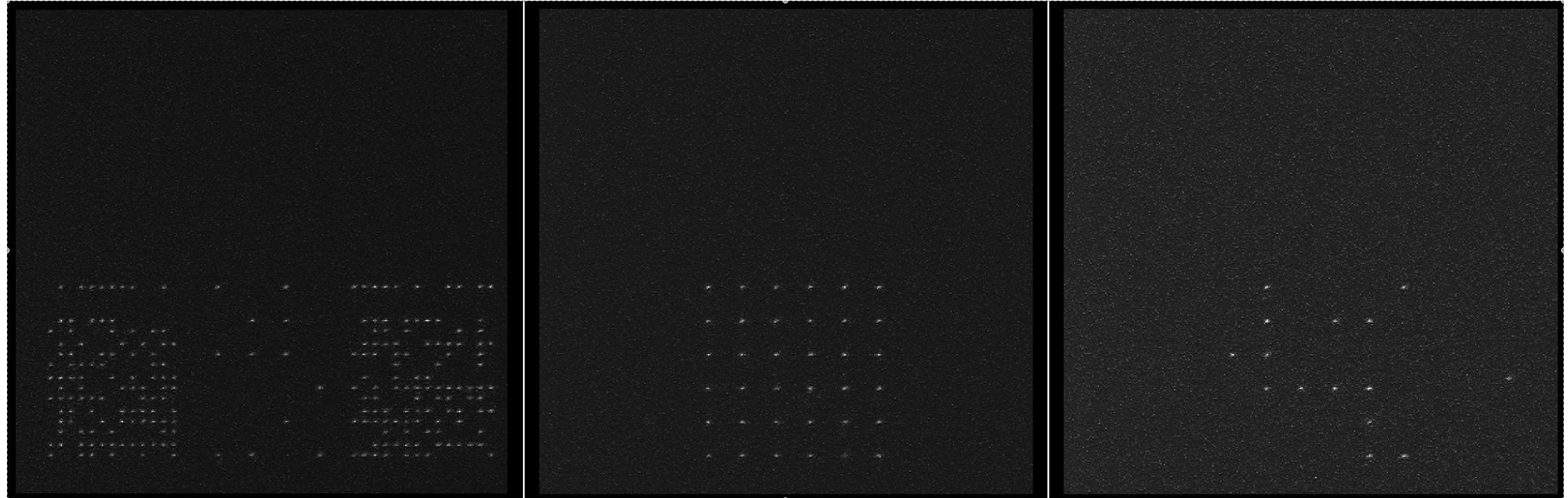
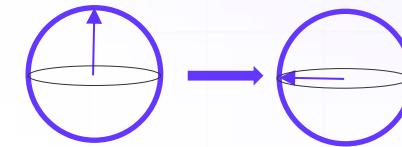
What qubit control really looks like:

2π pulse

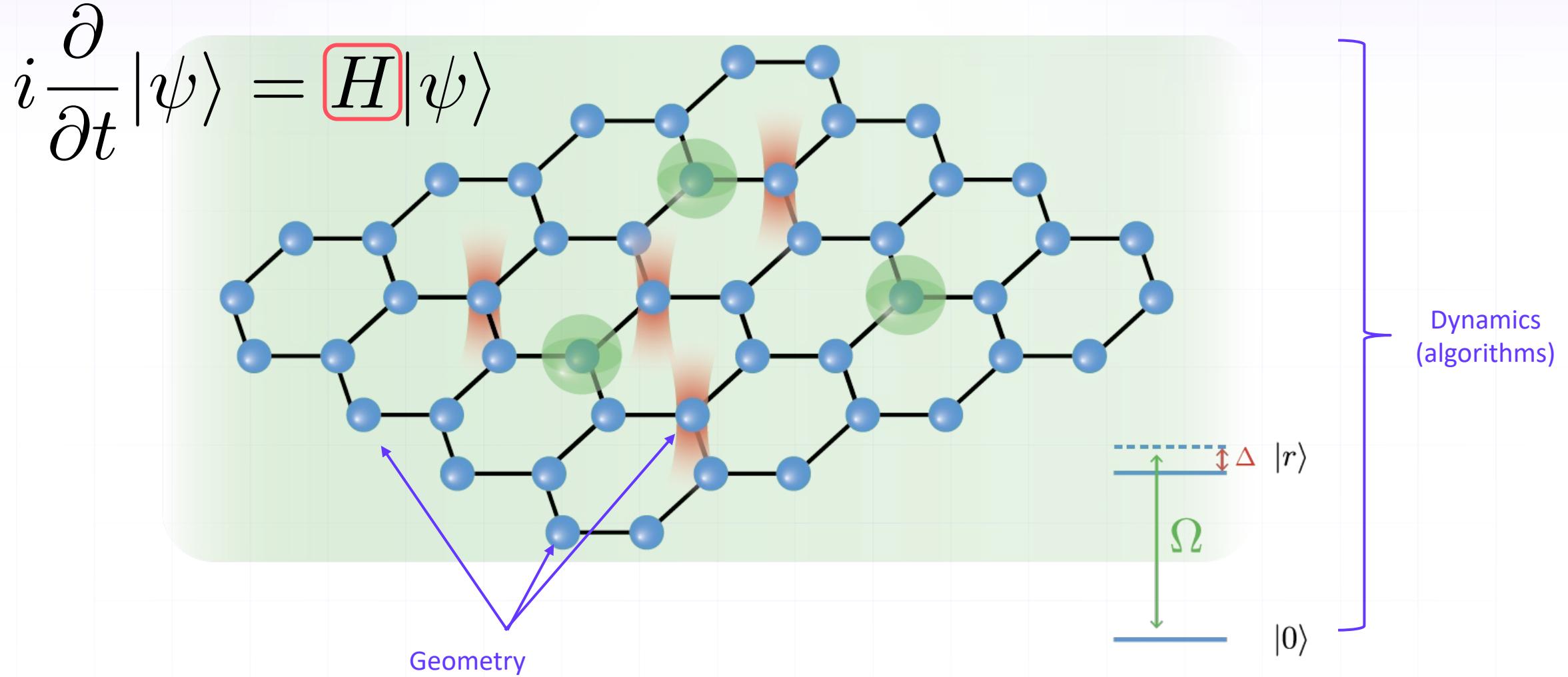


What qubit control really looks like:

$\pi/2$ pulse

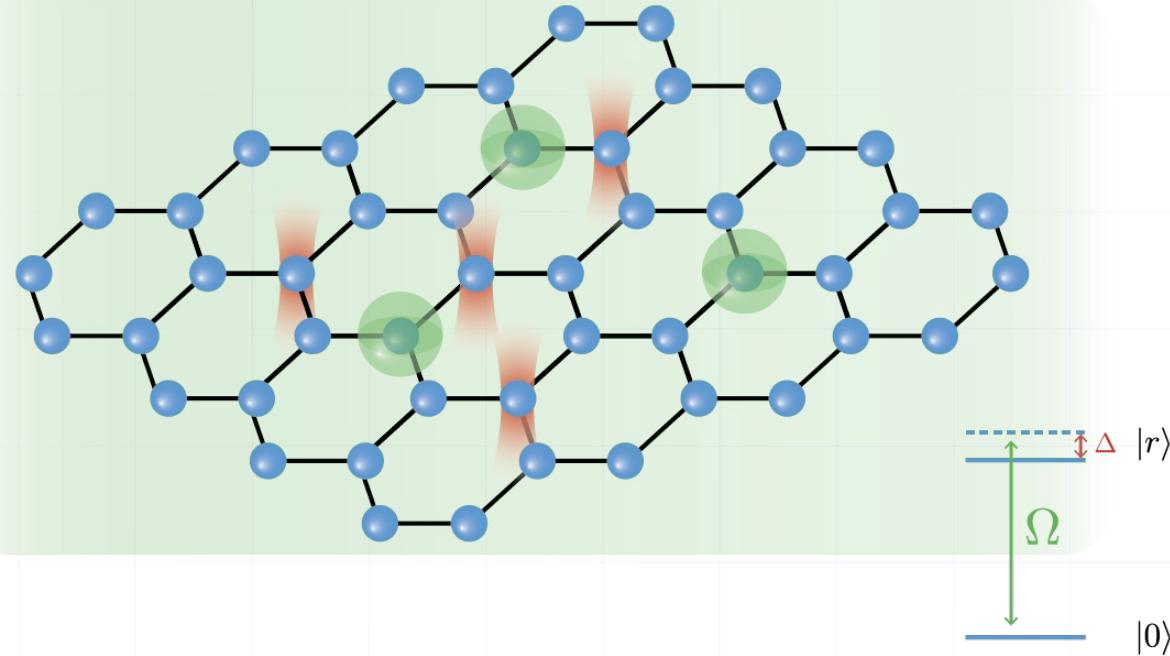


A neutral-atom quantum processor



Analog quantum dynamics control

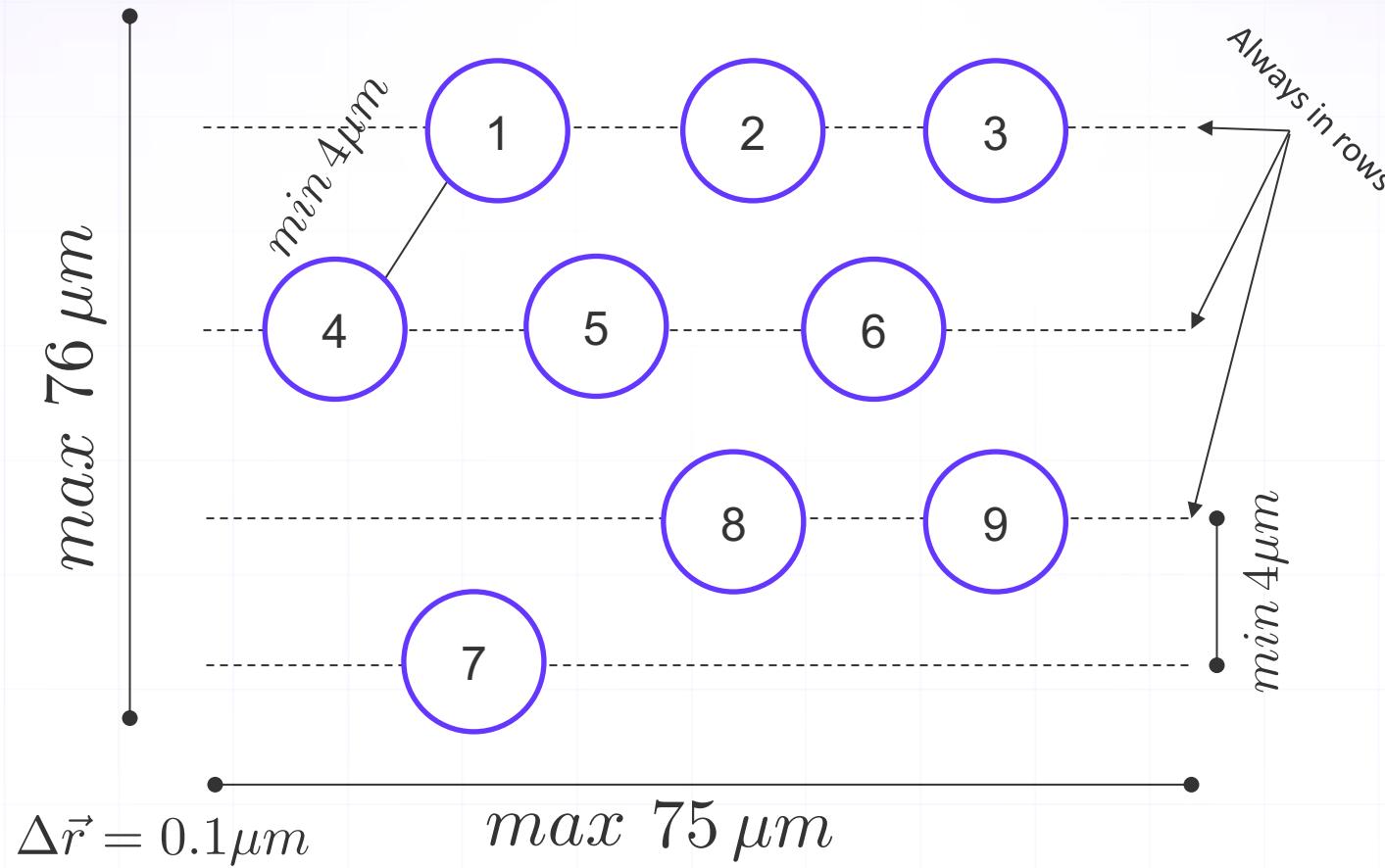
$$H = \sum_i \frac{\Omega(t)}{2} (e^{i\phi(t)} |g_i\rangle\langle r_i| + e^{-i\phi(t)} |r_i\rangle\langle g_i|) - \sum_i \Delta(t) n_i + \sum_{i < j} V_{ij} n_i n_j$$



$$n_i = 1 * |r_i\rangle\langle r_i| + 0 * |g_i\rangle\langle g_i|$$

$$V_{ij} \sim d_{ij}^{-6}$$

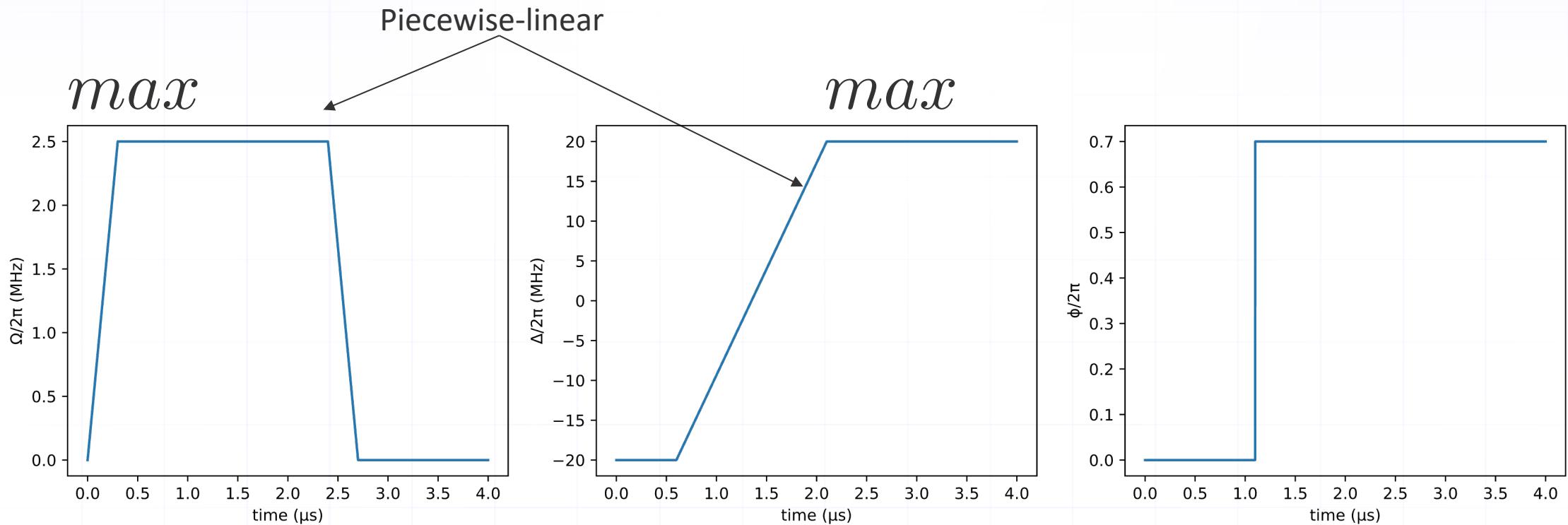
Hardware constraints: Geometry



More details @
<https://queracomputing.github.io/Bloqade.jl/dev/capabilities/>

Hardware constraints: dynamics

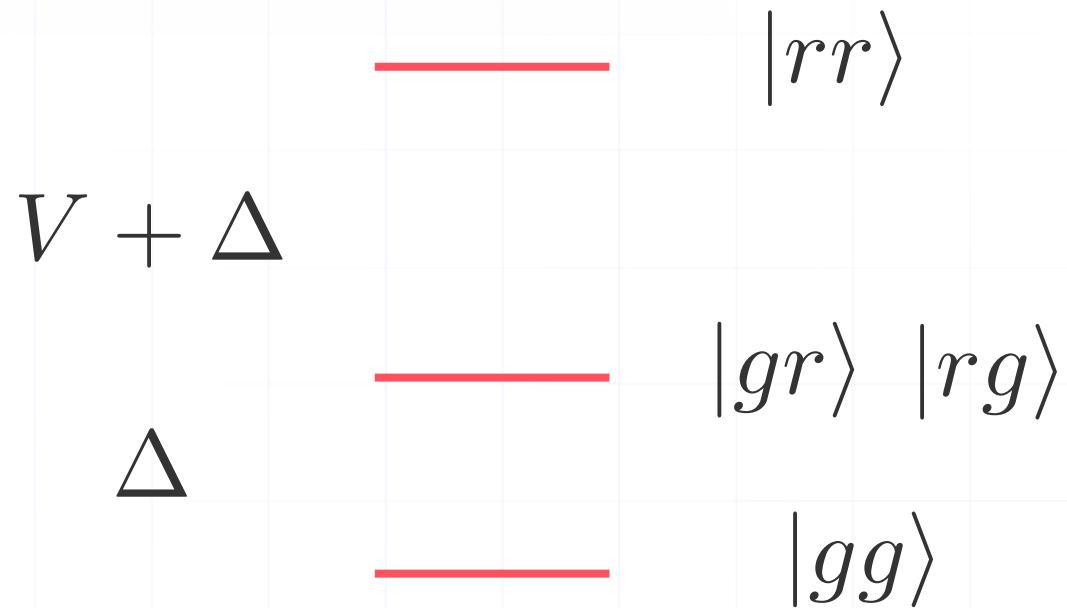
Activity: Encoding waveforms on Bloqade



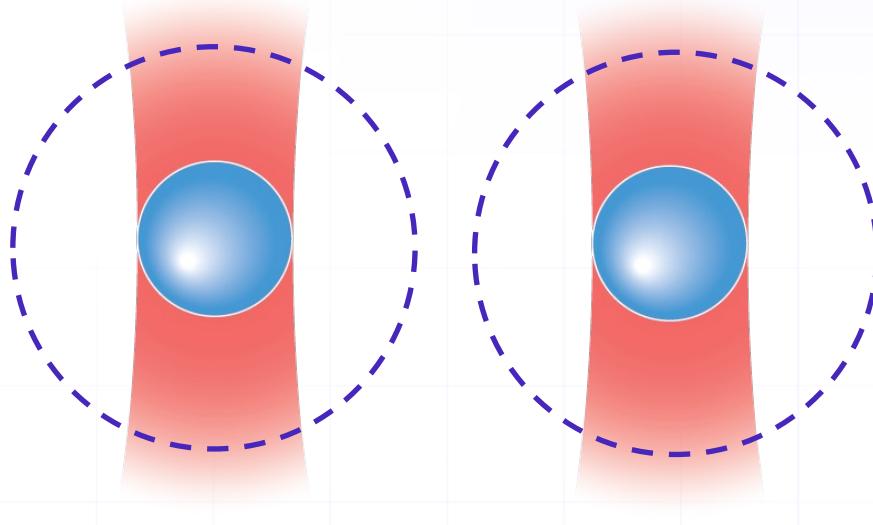
$$t_{max} = 4 \mu s$$

Piecewise-constant

Rydberg blockade: phenomenology



$$V \sim d^{-6}$$



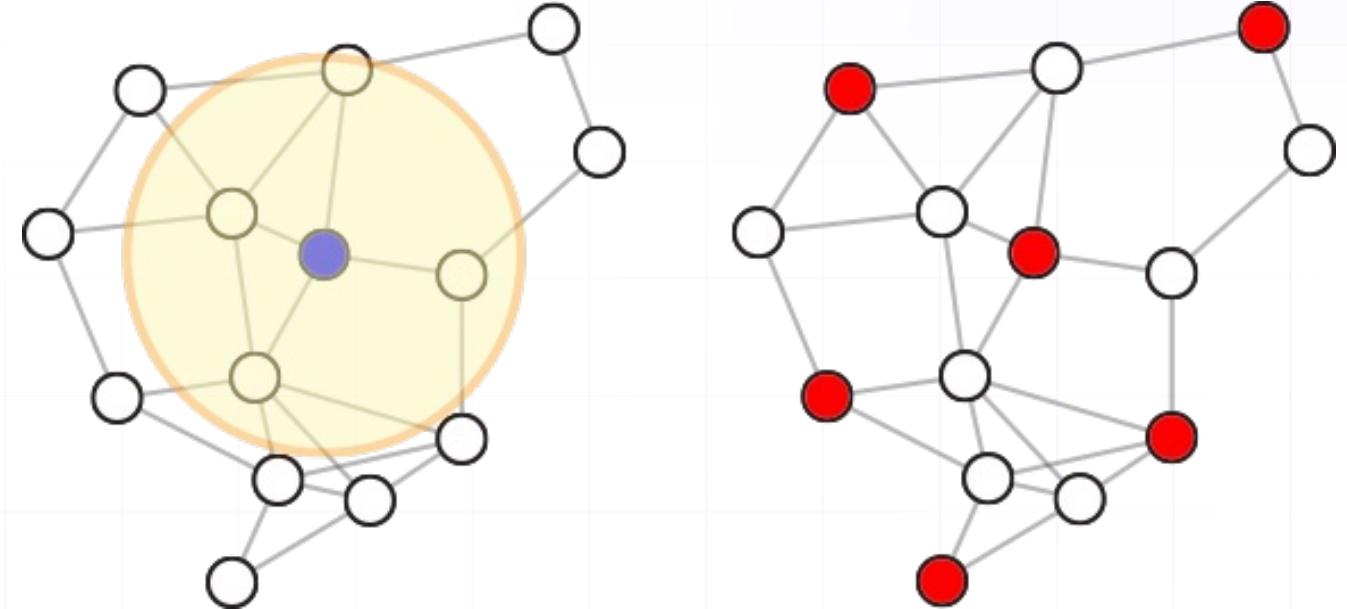
d

$$R_b = (C_6 / \sqrt{\Omega^2 + \Delta^2})^{1/6}$$

Rydberg blockade: utility

Maximum
Independent
Set

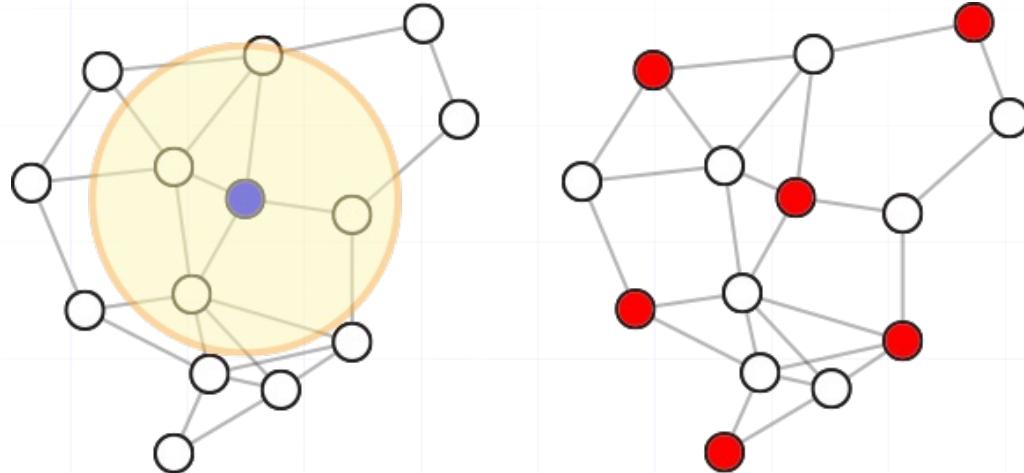
(NP-Complete)



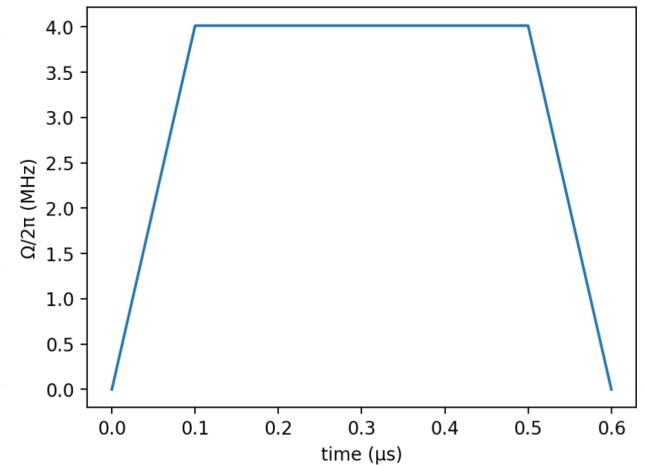
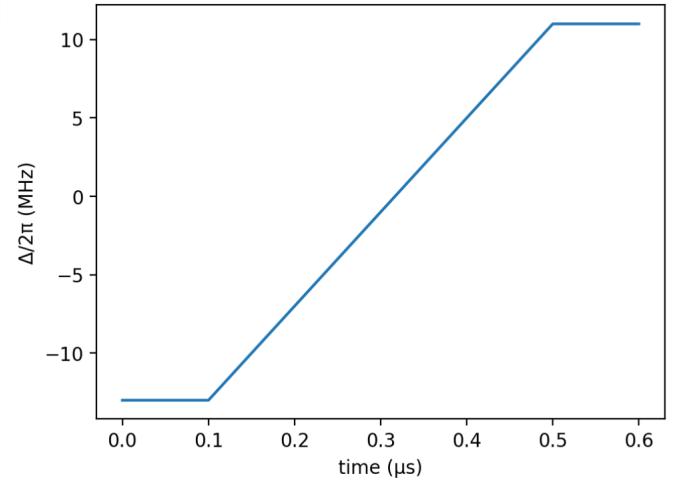
Adapted from Ebadi et. al Science,
376, 6598 (2022)

An algorithm for MIS

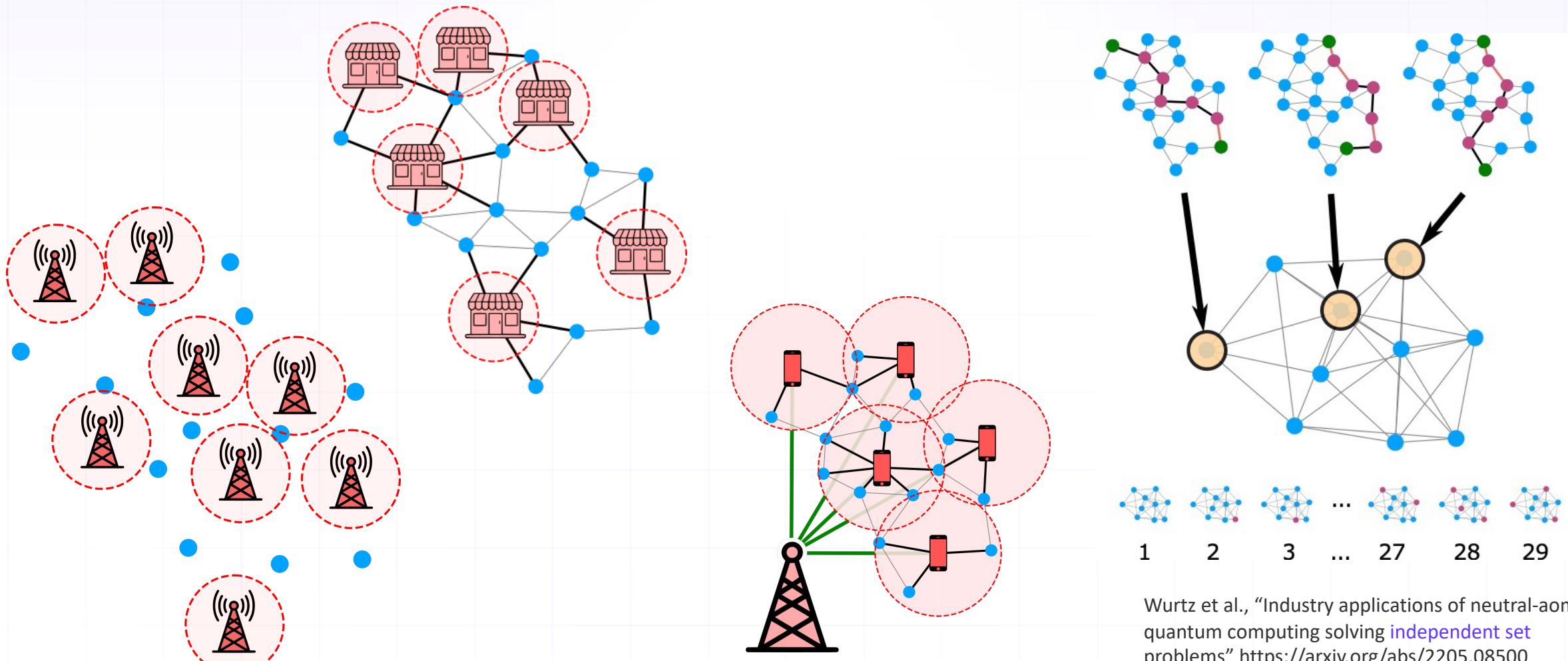
$$H = \Omega(t) \sum_i (|g_i\rangle\langle r_i| + H.c.) - \Delta(t) \sum_i n_i + \sum_{i < j} V_{ij} n_i n_j$$



$$R_b = (C_6 / \Delta)^{1/6}$$



MIS applications are ubiquitous



Wurtz et al., "Industry applications of neutral-atom quantum computing solving [independent set](#) problems" <https://arxiv.org/abs/2205.08500>

Programming neutral atoms in 5 steps

1. Define atom positions => Rydberg radius
2. Define time traces of Hamiltonian parameters
3. Initialize Hamiltonian
4. Evolve!
5. Measure!