Quantum Algorithms on a Programmable Atomic Tweezer Array

Aaron Holman*, Weijun Yuan, Max Aalto, Quan Gan, Minho Kwon, Sebastian Will

Department of Physics, Columbia University, NY, 10027; *a.holman@columbia.edu

TweeSr

Introduction

Quantum Computing
• Specialized computers (ie GPU)
• Superposition and entanglement
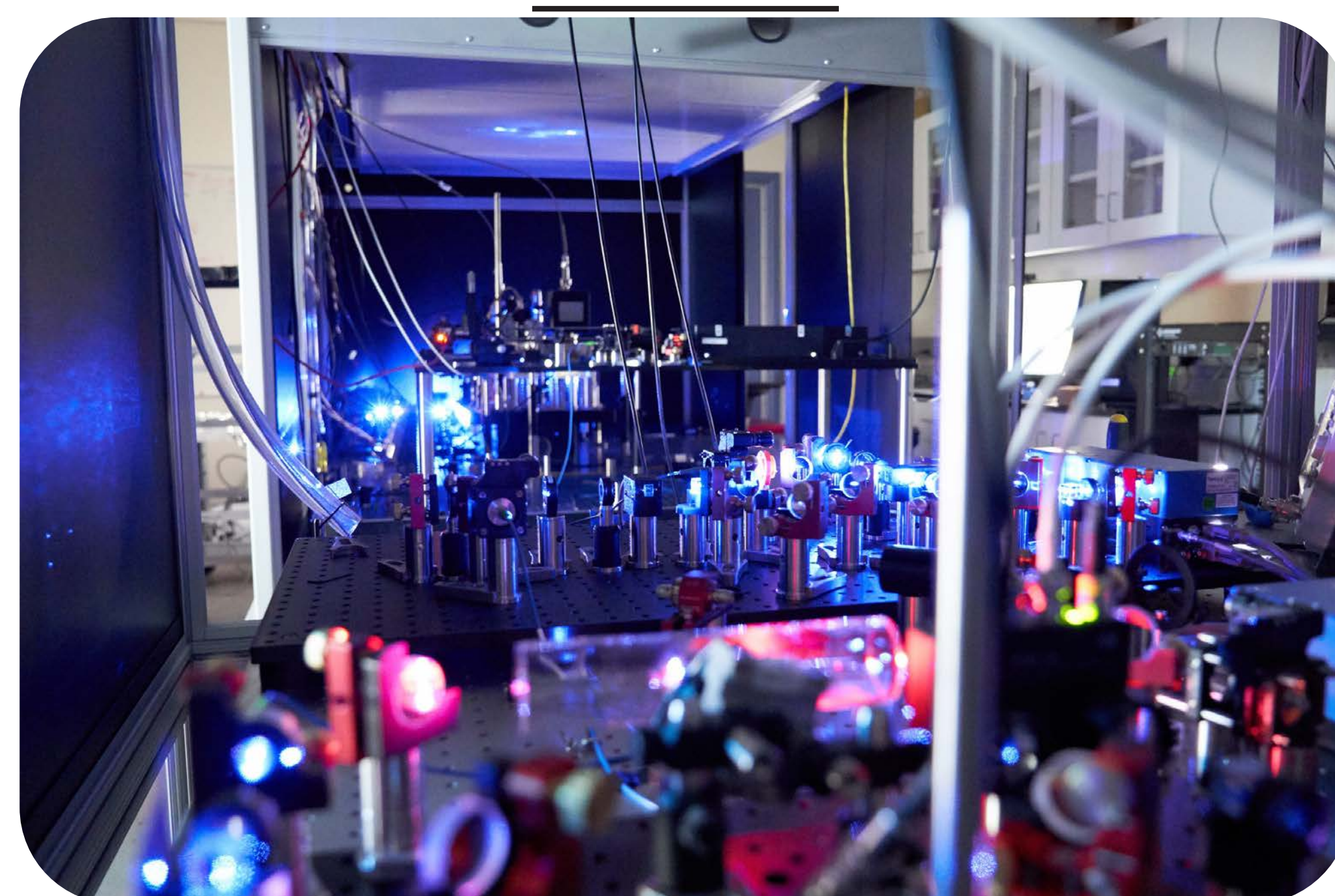• Leading paradigm to solve classically computationally intensive problems

BIT
QUBIT

38   87.62
Sr
Strontium
[Kr] 5s²
Alkaline Earth Metal

Our Platform
• Optically trapped strontium
• Applications in Quantum Computing, Simulation, and Optics
• Cross disciplinary - atomic physics, novel metasurfaces, and quantum optics
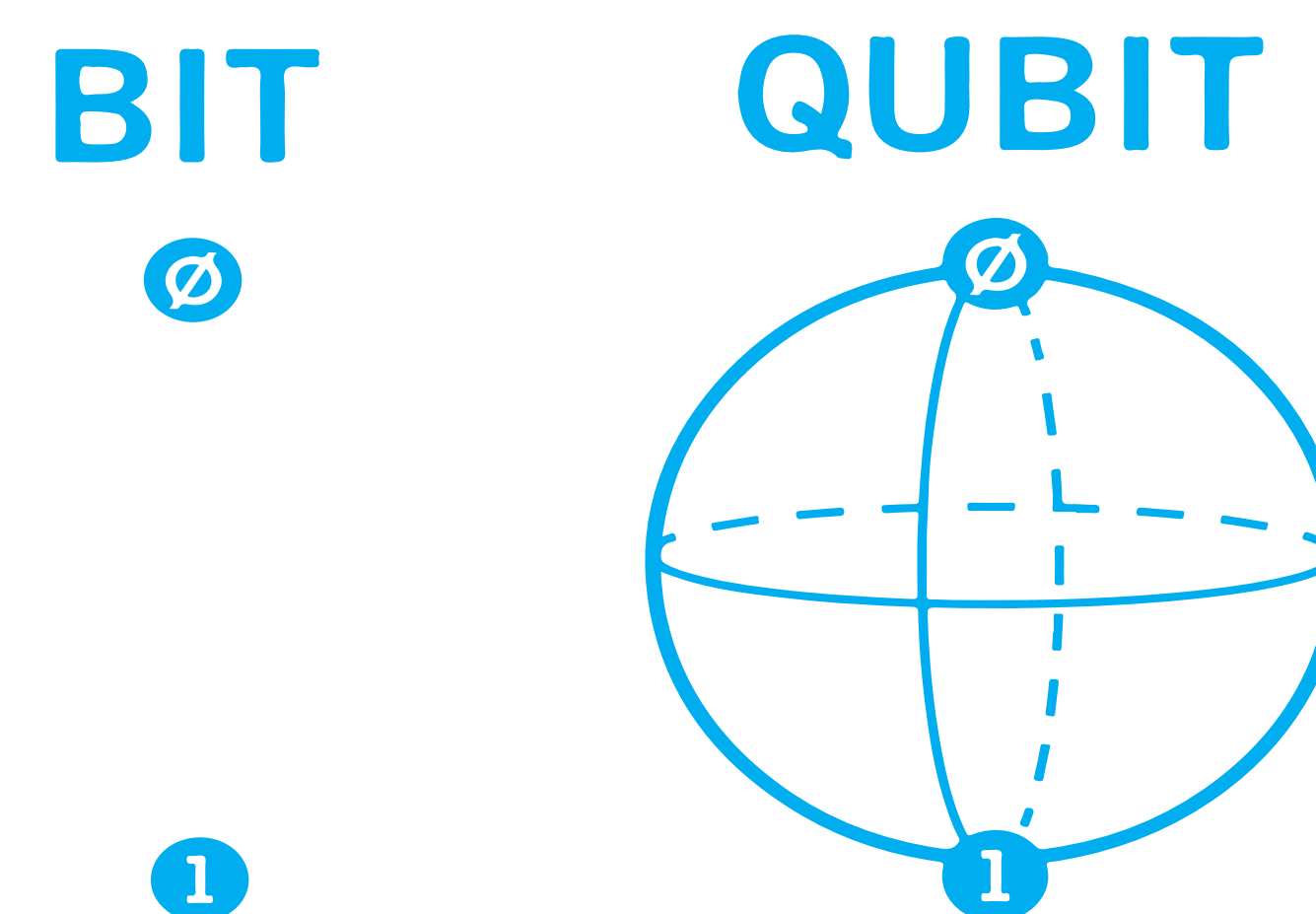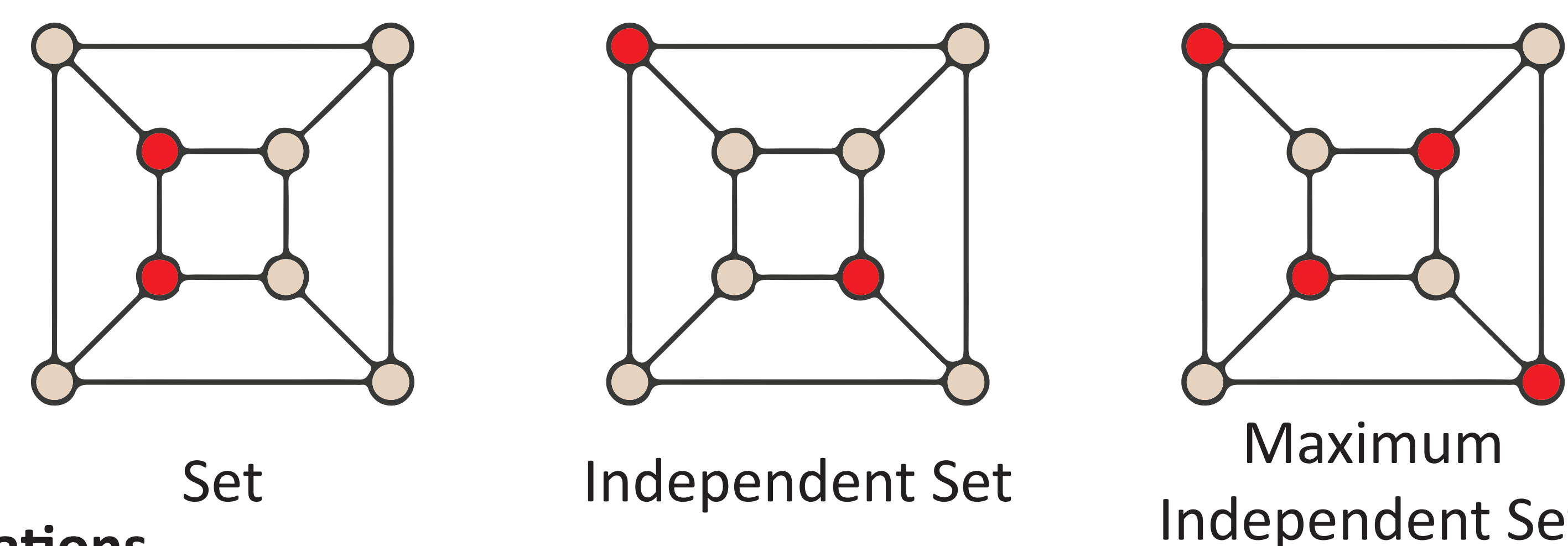
Why Neutral Atoms?
• All atoms are identical
• Multiple options for qubit basis
• Long lived (seconds)
• Arbitrary geometry
• Tunable interaction range
• Large array size

Our Lab!

Kuhn group (2018) J. Mod. Opt 65, 2133-2141

Maximum Independent Set

MIS
• Definition: Maximum number of vertices with no two adjacent
• NP-Hard Problem

Set

Independent Set

Maximum Independent Set

Applications
• Many problems involving resource allocation can be mapped on to the maximum independent set problem
• Financial Services, Electric Car Charging Stations, and Vaccine Distribution
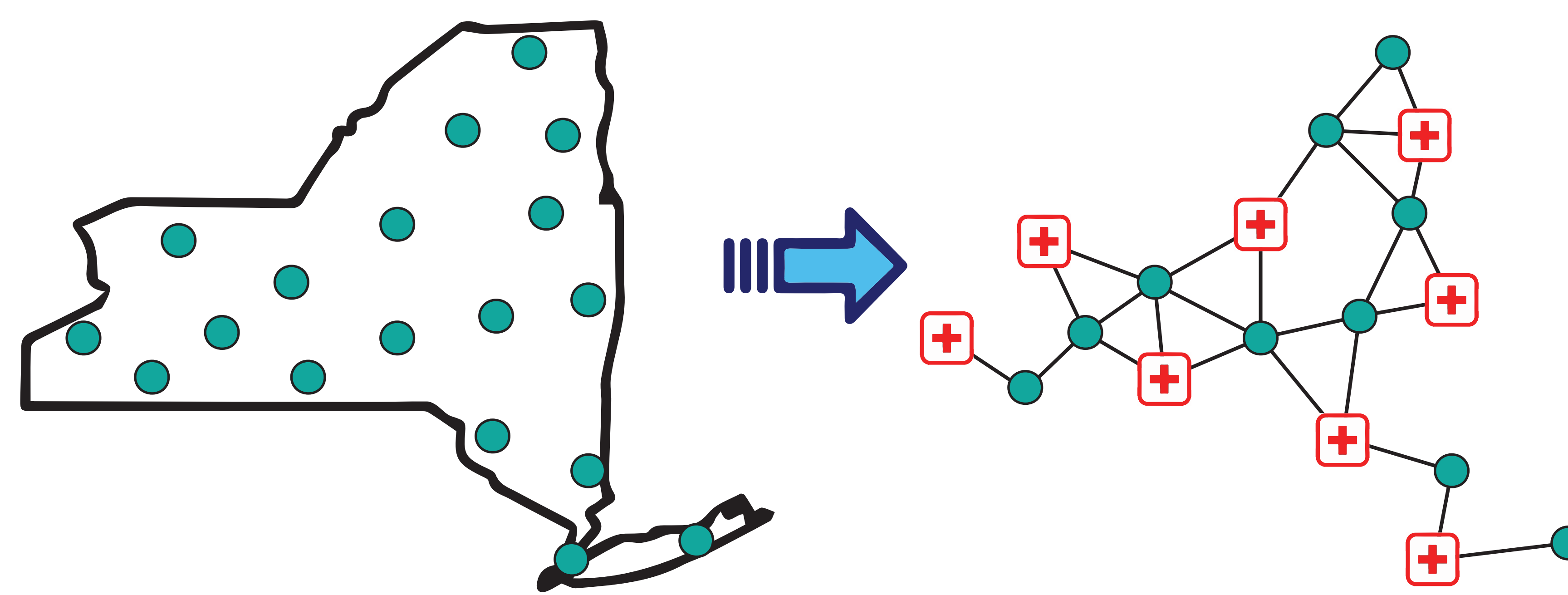
Determining the most accessible locations of vaccine centers for nearby cities
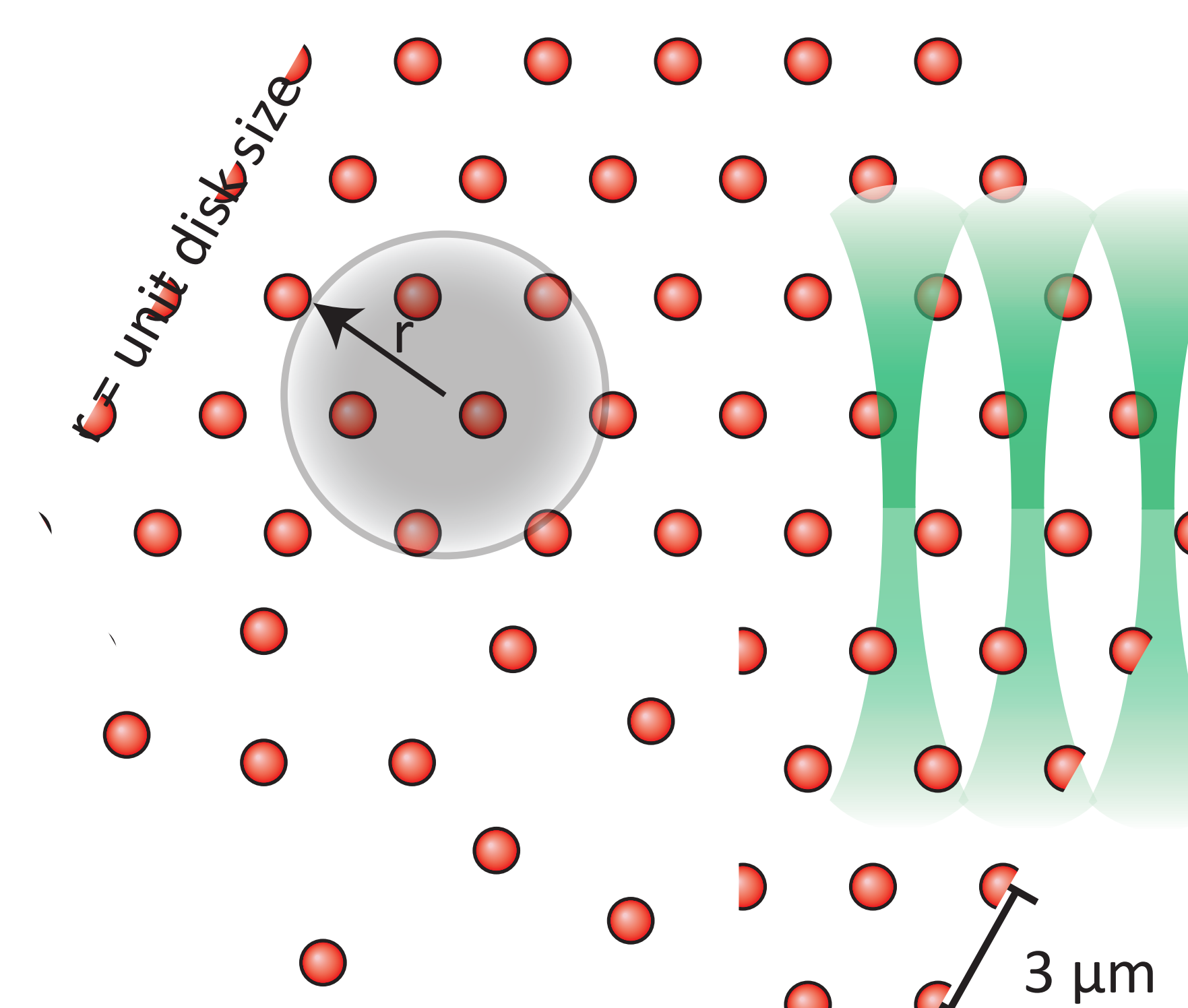
Quantum Adiabatic Algorithm

QAA
• Slowly evolve Hamiltonian of a system to end up in the lowest energy state
• Similar to optimizing the classical cost function

Classical vs Quantum Cost Function

$$C_N = -\sum_{i=1}^{N} z_i + U \sum_{\langle i,j \rangle} z_i z_j$$

$$H_P = -\sum_{v \in V} \Delta n_v + \sum_{(v,w) \in E} U n_v n_w$$

Favors being "on"   Penalizes neighboring "on"

Unit Disk Representation
• Graph where nodes are connected if they fall within some unit distance away
• Arbitrary geometry allows for arbitrary graph mapping
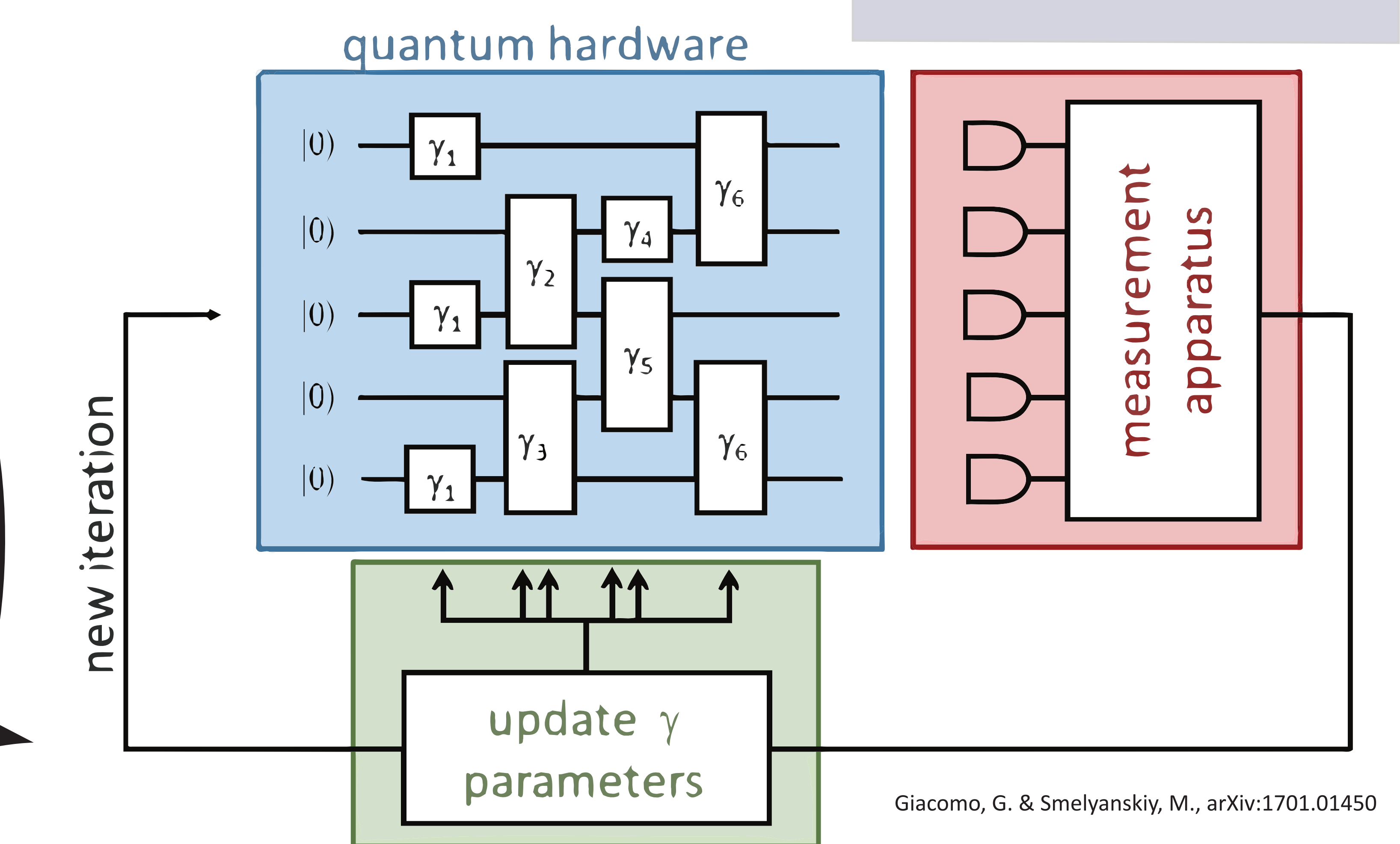• Tunable interaction distance creates edges between nodes

r
unit disk size

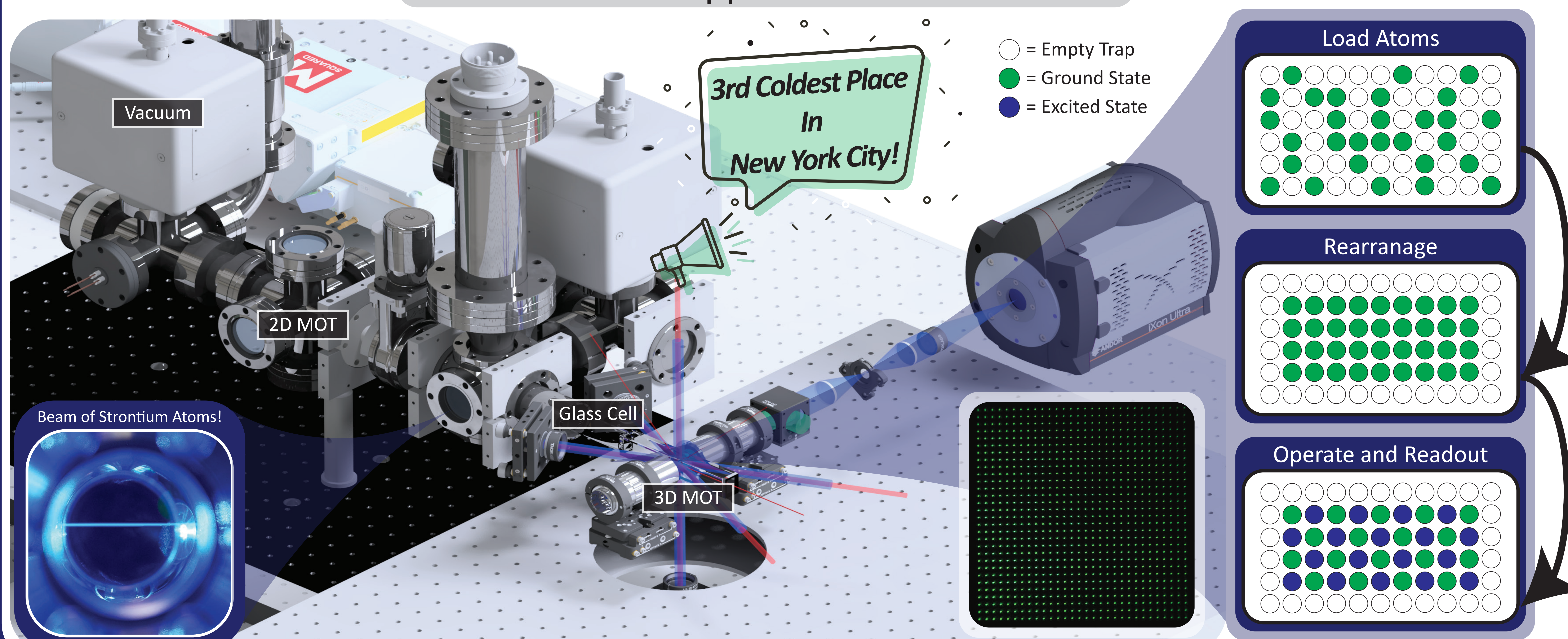3 μm

Quantum Approximate Optimization Algorithm

QAOA
• Quantum/Classical hybrid
• Prepare quantum state and optimize variational parameters
• For MIS, objective function is size of Independent Set

Tunable Parameters
• Laser Intensity
• Laser Detuning
• Laser Phase
(All time dependent)

quantum hardware

measurement apparatus

new iteration

update γ parameters

Giacomo, G. & Smelyanskiy, M., arXiv:1701.01450

Apparatus

Vacuum

2D MOT

Glass Cell

3D MOT

Beam of Strontium Atoms!

3rd Coldest Place In New York City!

○ = Empty Trap
● = Ground State
● = Excited State

Load Atoms

Rearranage

Operate and Readout

Acknowledgements