Portfolio

A Brief Introduction About Myself

By Chun-Wei Liu

cl3762@columbia.edu

Web Version

Chun-Wei Liu

Columbia University

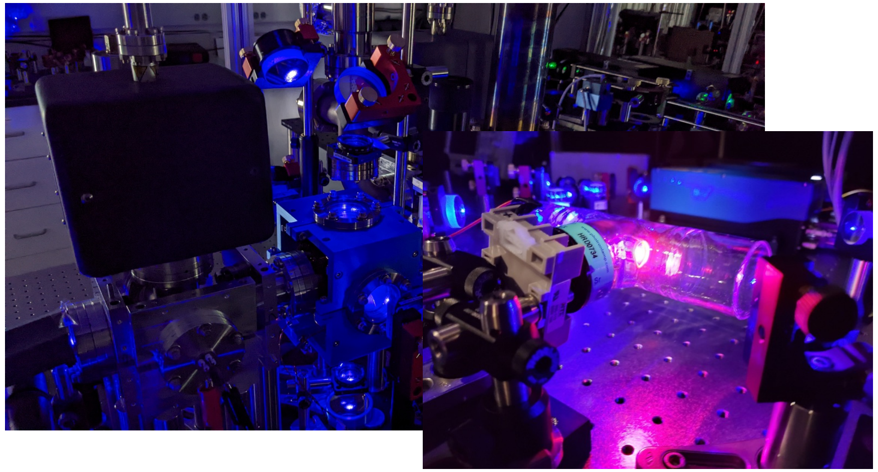
MS in Applied Physics (2022)

- ➢ Research Assistant , Physics Dept. Will Lab, Prof. Sebastian Will
  - *Strontium Atomic Tweezer Array* [DAMOP2022]

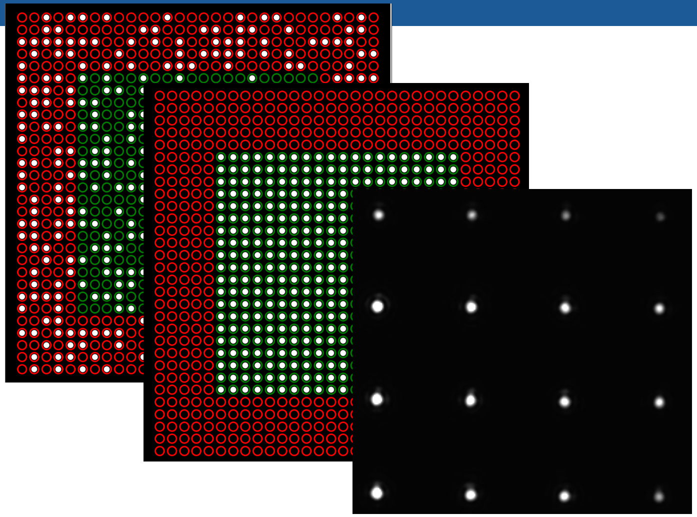
National Cheng Kung University

BS in Civil Engineering (2020) **Most of my time at Physics Dept.*

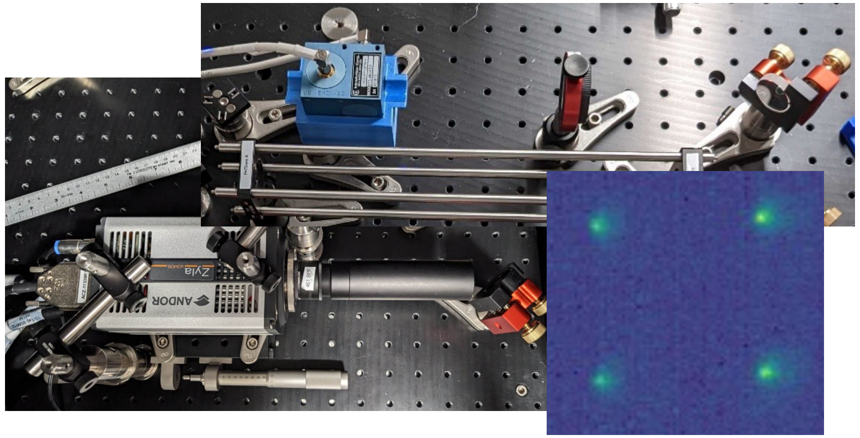
- ➢ Research Assistant , Physics Dept. Matterwave Lab, Prof. Pei-Chen Kuan
  - *Quantum Walks*
- ➢ Research Assistant, Civil Engineering Dept. AI Material Lab, Prof. Yun-Che Wang
  - *Machine Learning in Metamaterial Design.* [APCOM2019][CTAM44][MLDT2021][USNCCM16]
  - *Computational Molecular Dynamics*



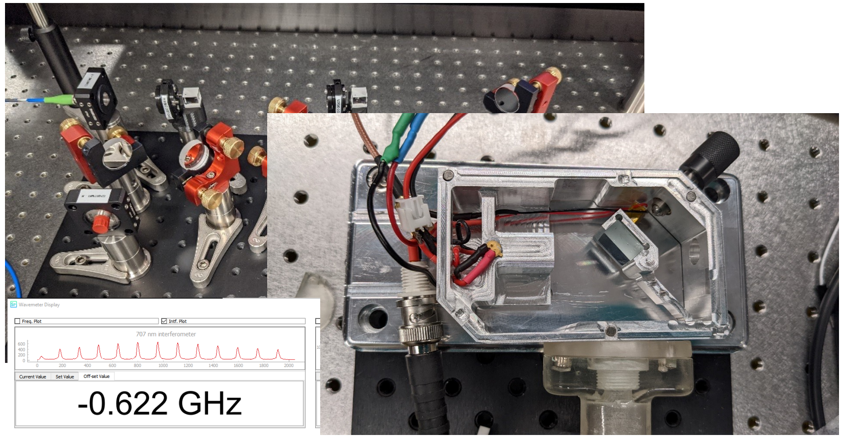
Laser cooling (2D/3D MOT)



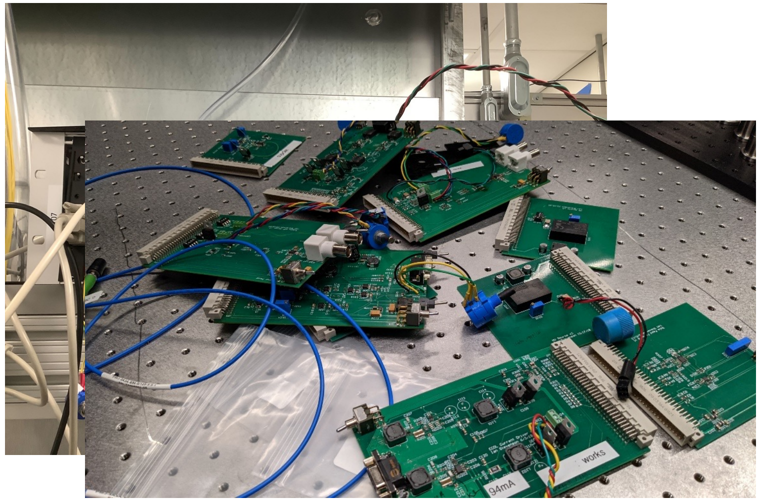
Software Package Development (Quantum Control)



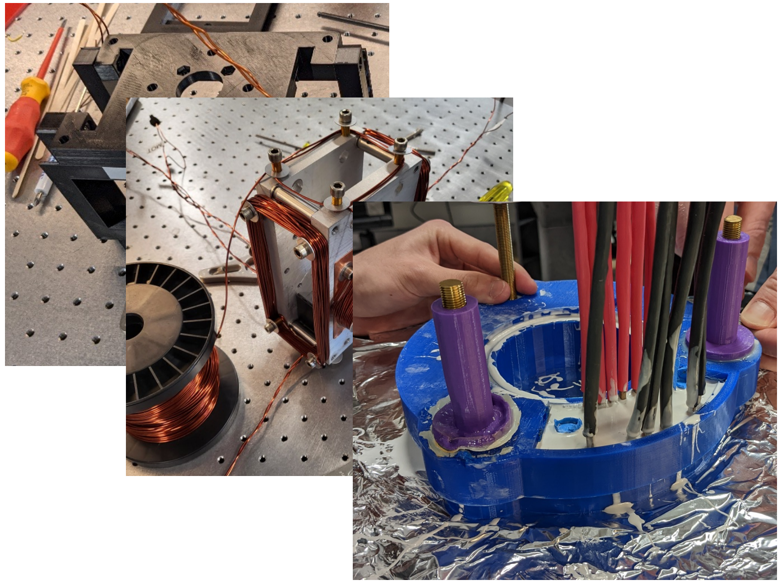
Single Atom Trapping/Imaging



Laser and fiber optics

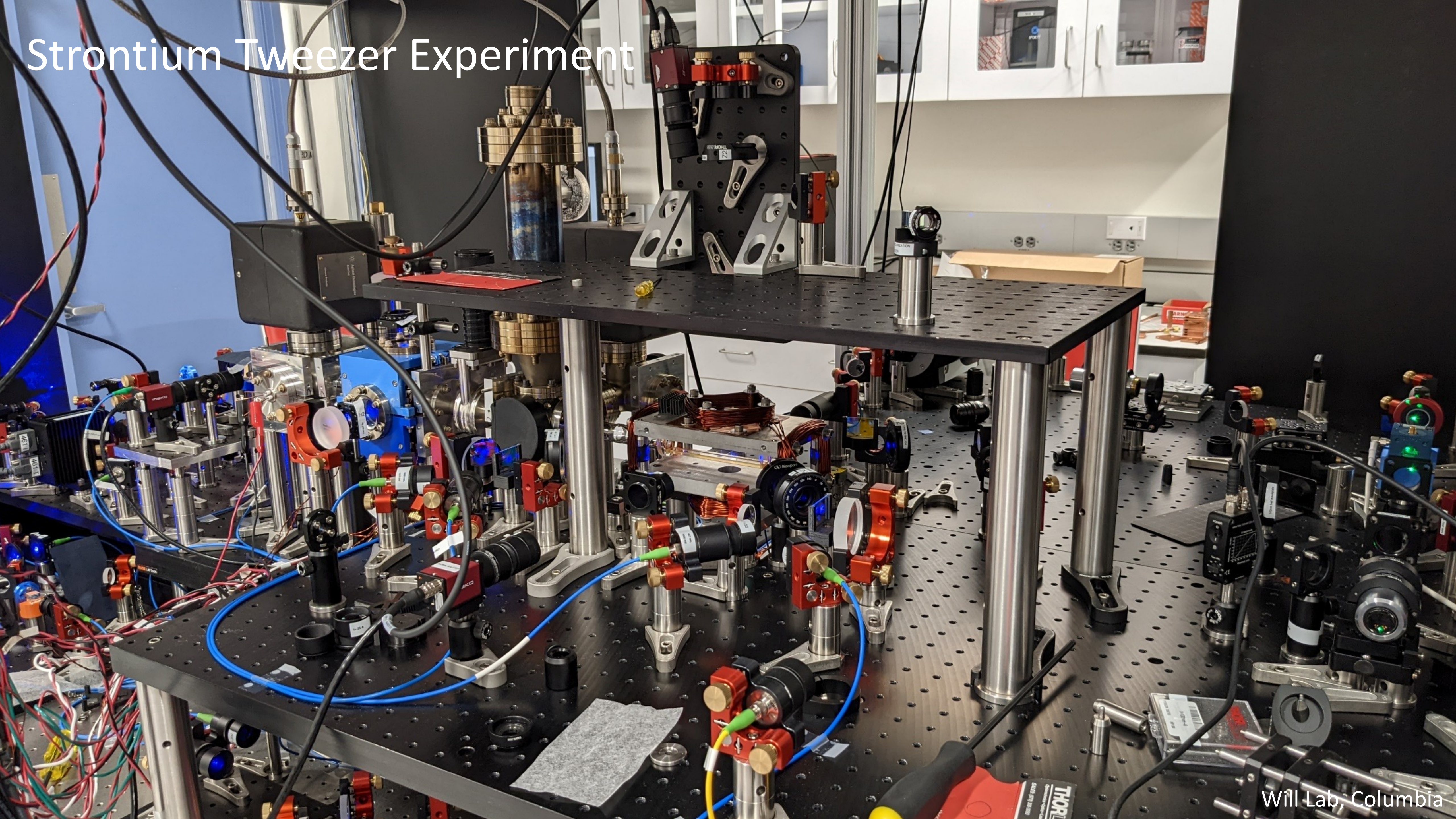


Electronics (AOM drivers/ DIO)



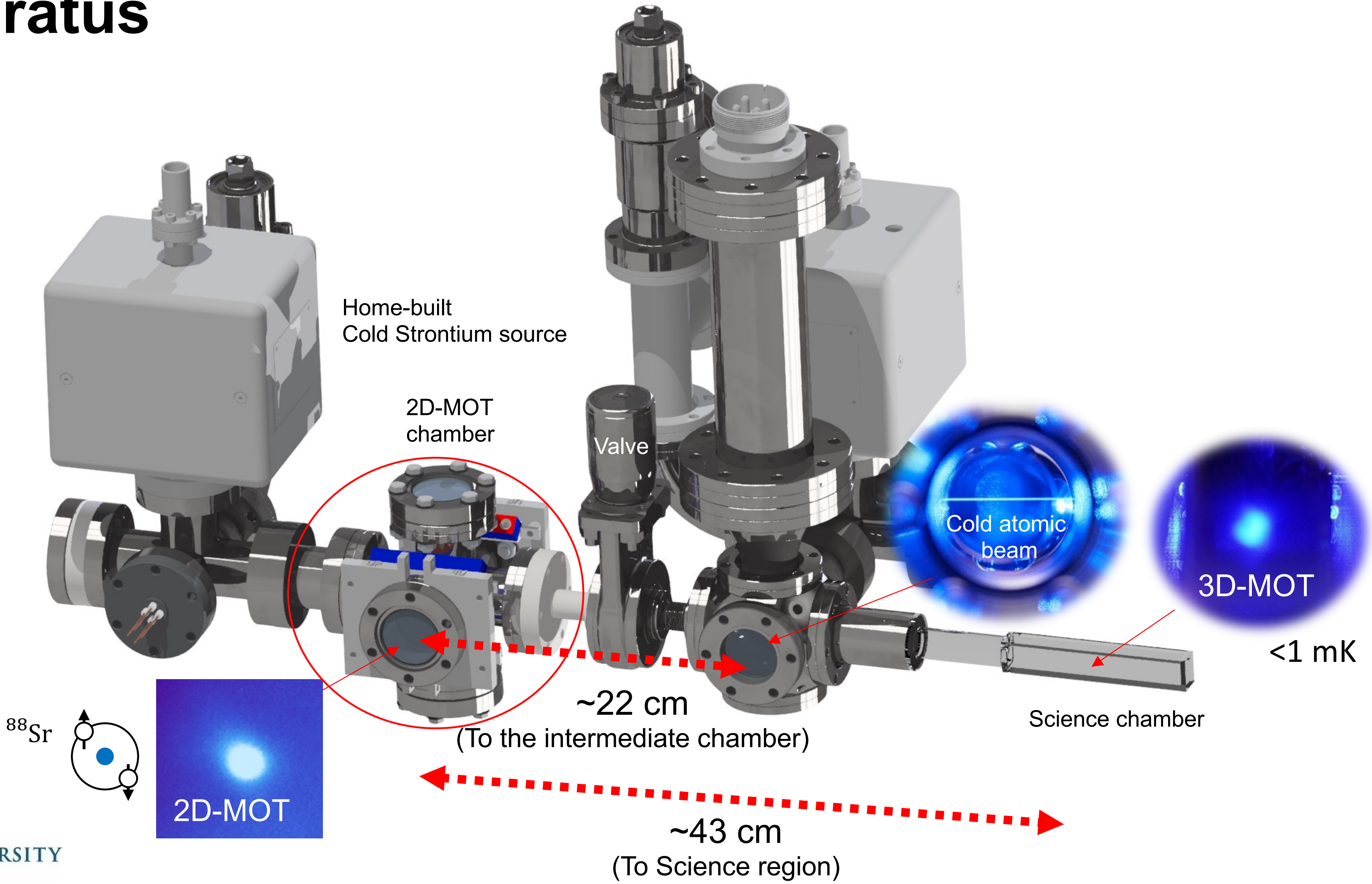
Coil Machining/Winding

Strontium Tweezer Experiment



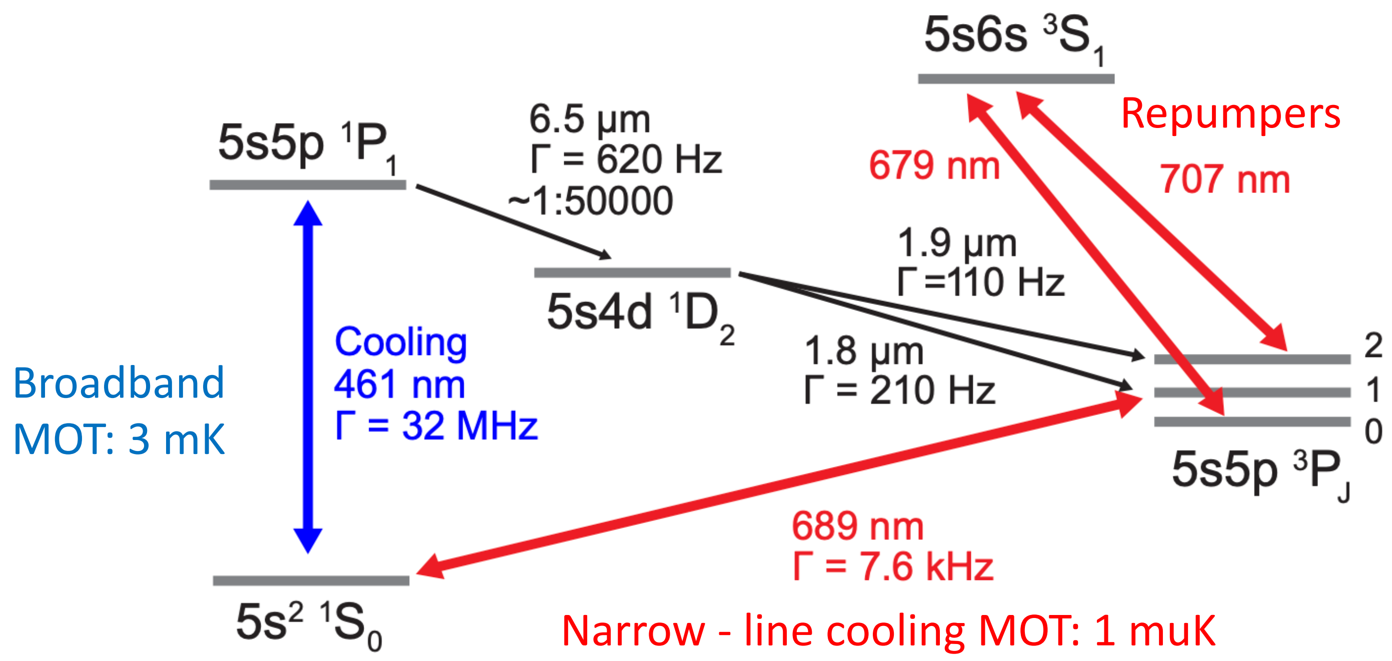
Will Lab, Columbia

Apparatus

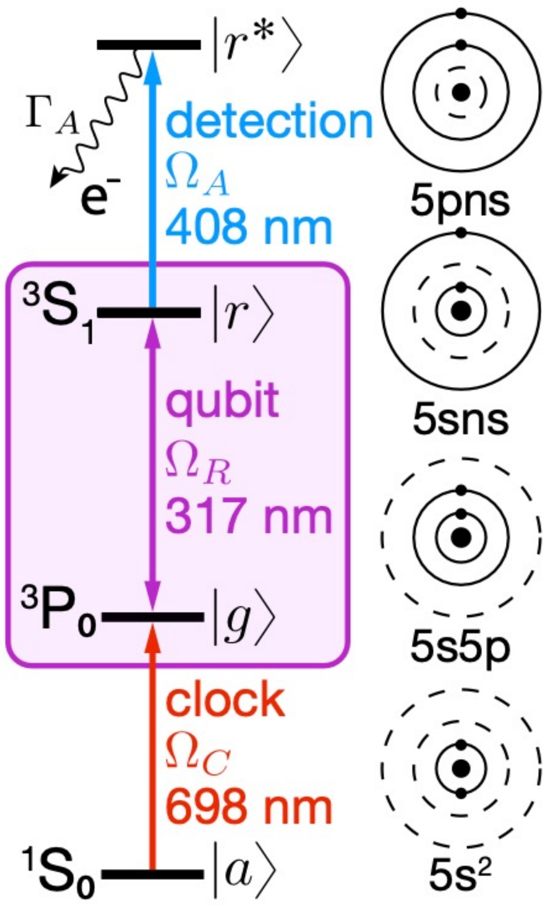

Home-built
Cold Strontium source
2D-MOT
chamber
Valve
Cold atomic
beam
3D-MOT
<1 mK
~22 cm
(To the intermediate chamber)
Science chamber
^{88}Sr
2D-MOT
~43 cm
(To Science region)

Strontium-88 (Bosonic)

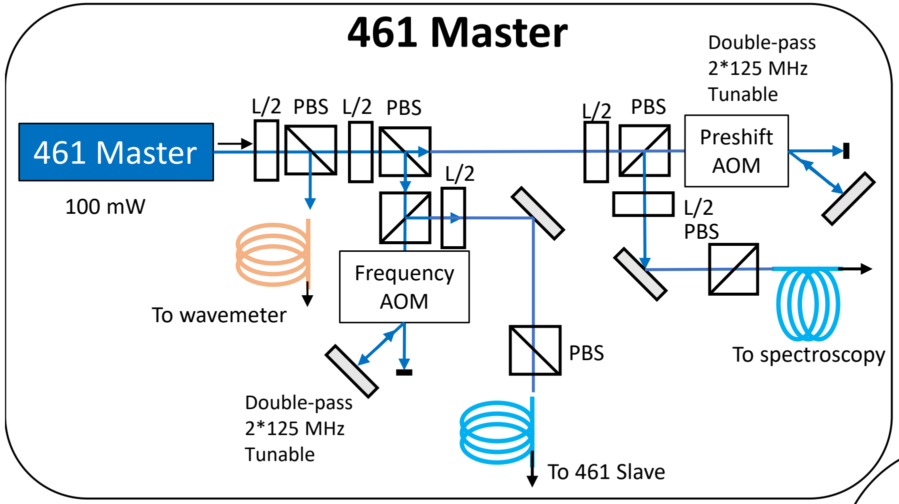
- **MOT Cooling Scheme**

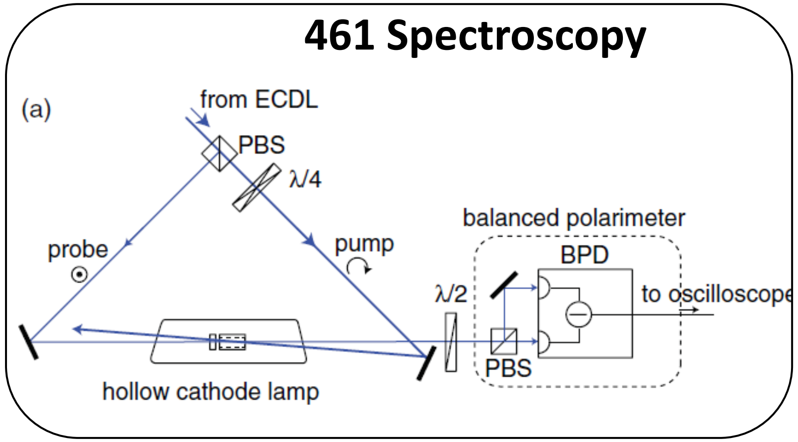


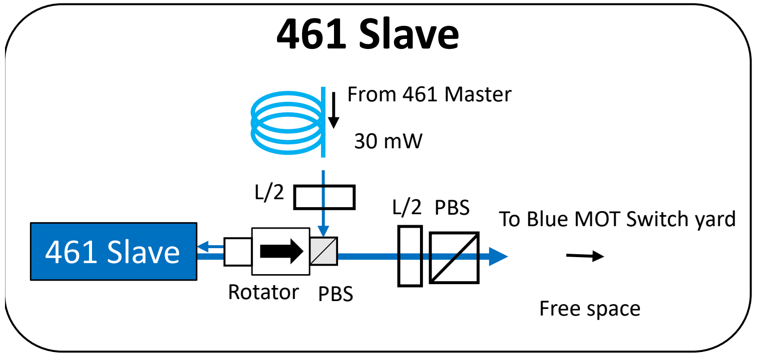
- **Rydberg Scheme**

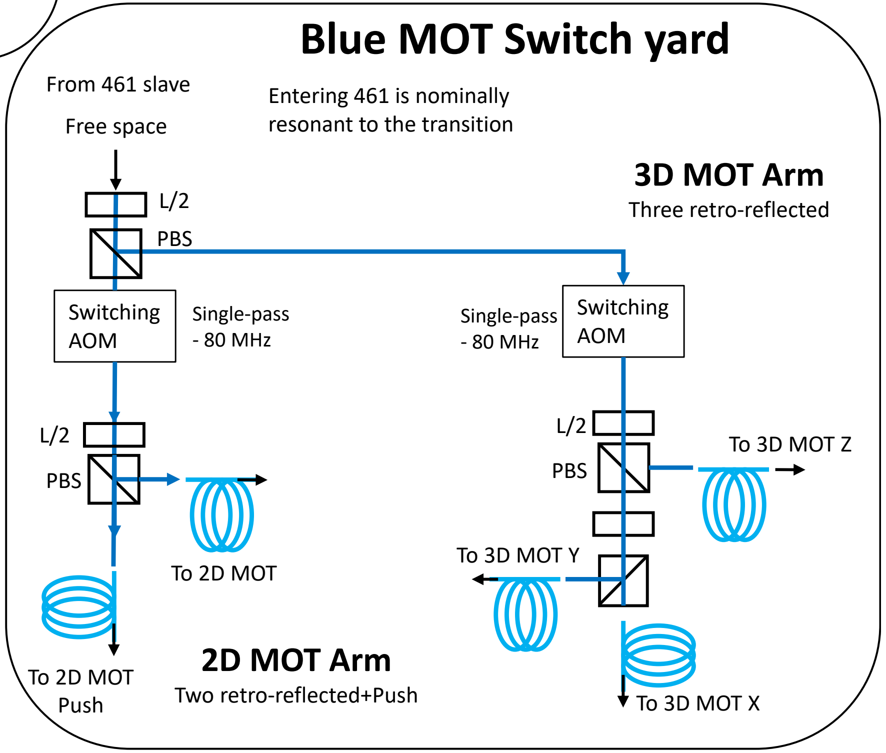


Laser Source: 461nm (Broad Cooling)

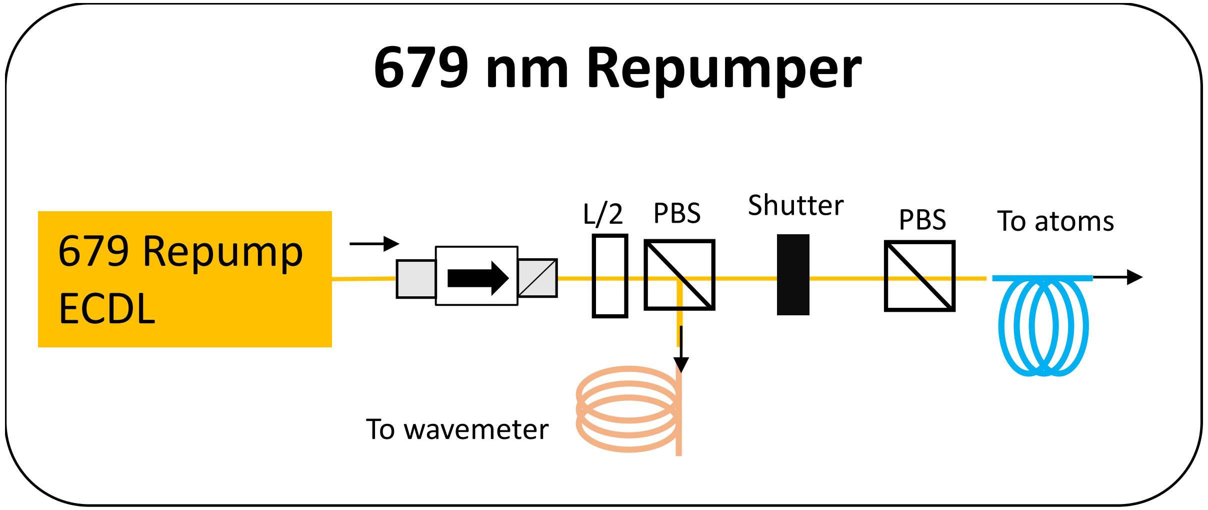


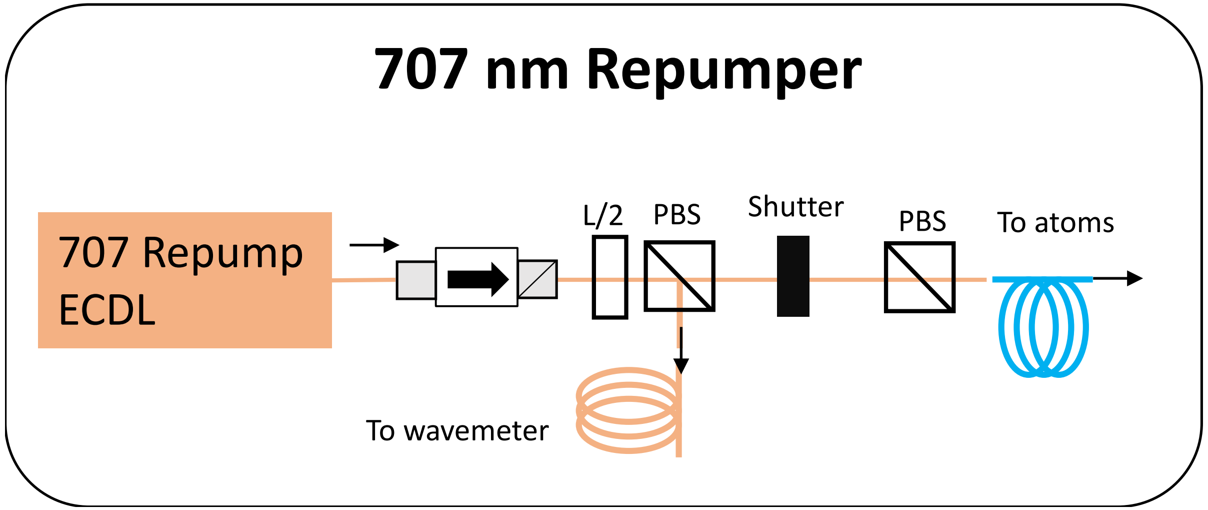




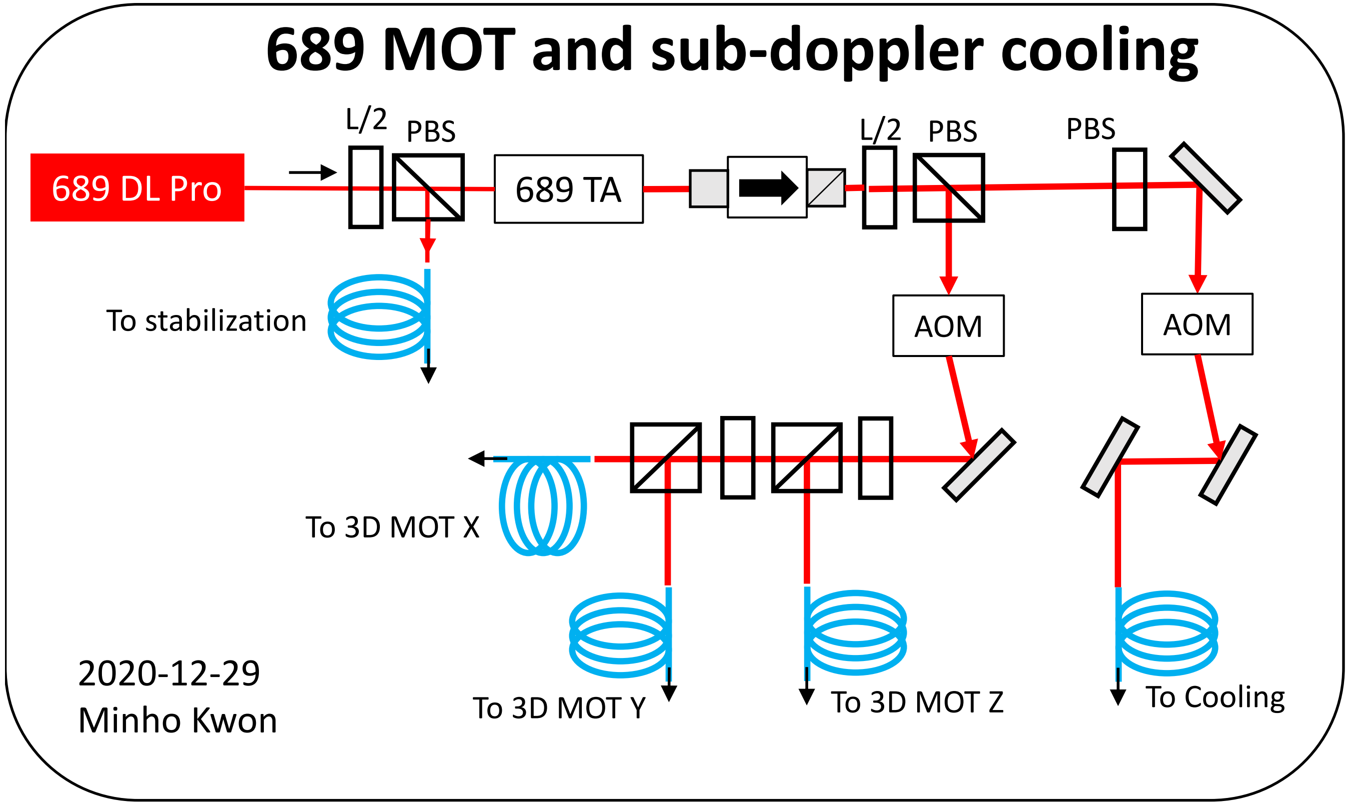


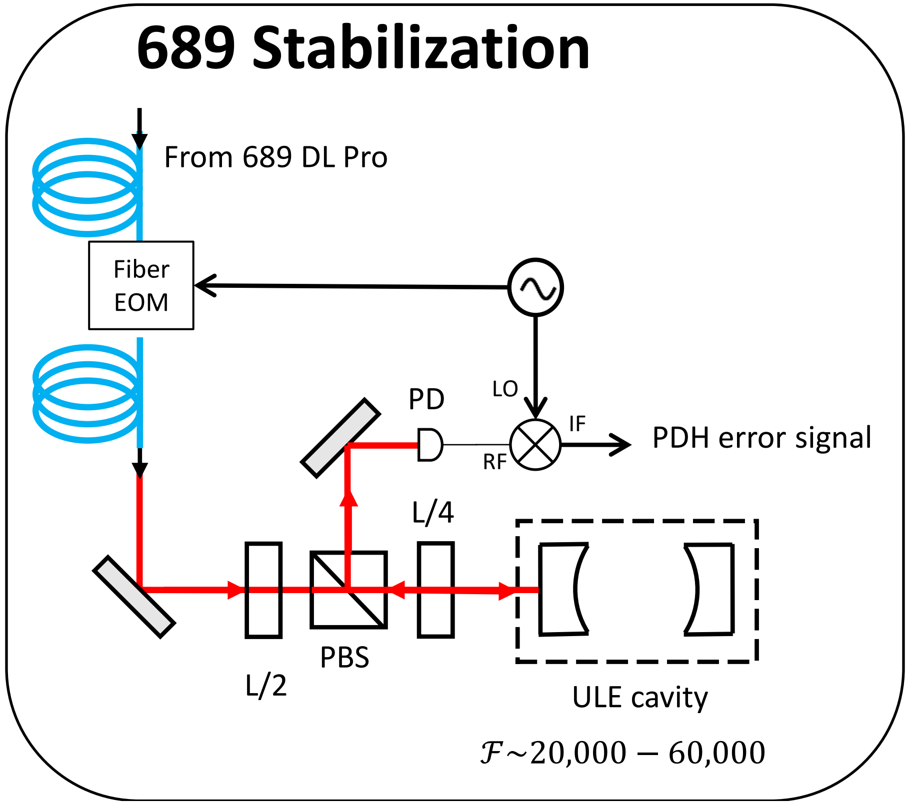
Laser Source: Repumpers



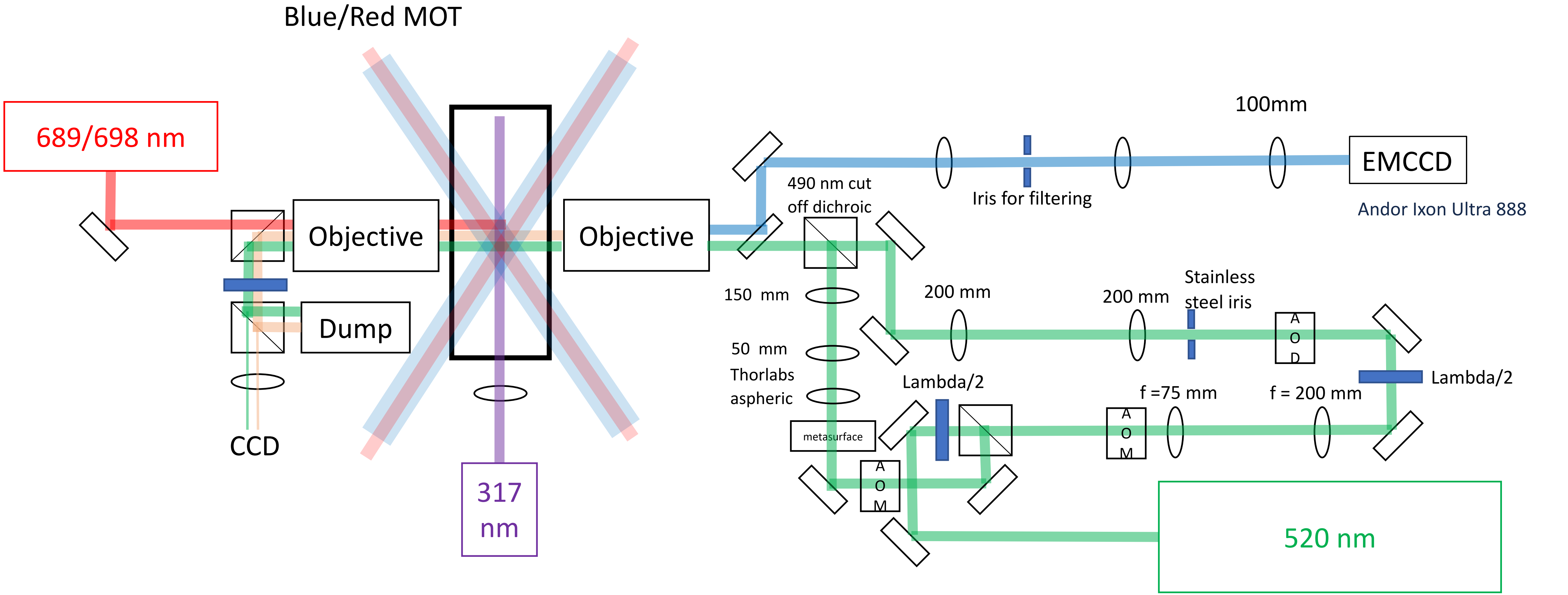


Laser Source: 689 nm (Narrow-line Cooling)





Optical Layout



The measured response time of AOD = 2.6 us
Input beam diameter of AOD = 3.3 mm
Output beam diameter of the laser ~1.2 mm
Input beam diameter to metasurface ~ 1.2 mm

1040

The layout drawing credit: Minho

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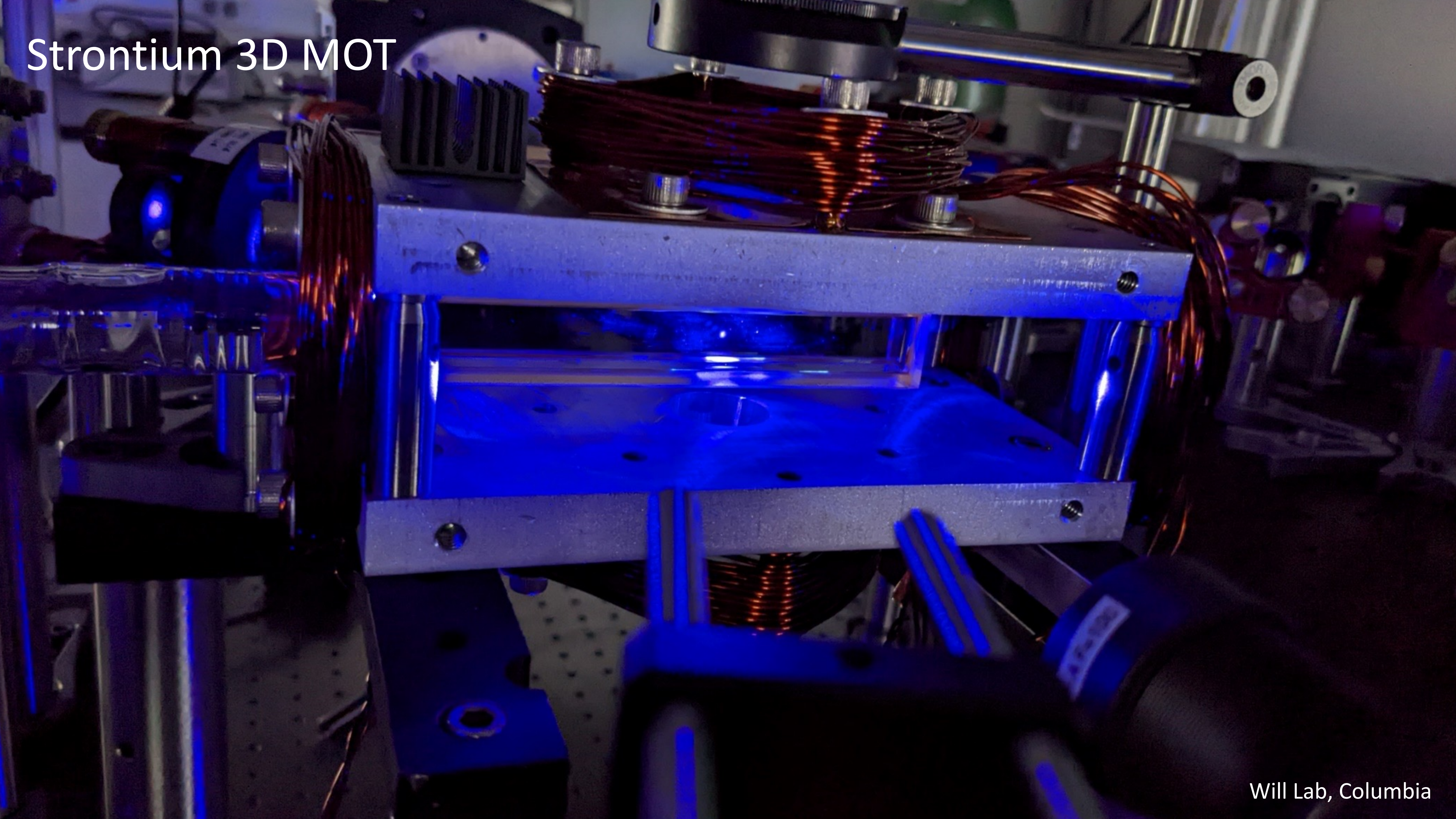
Strontium 3D MOT



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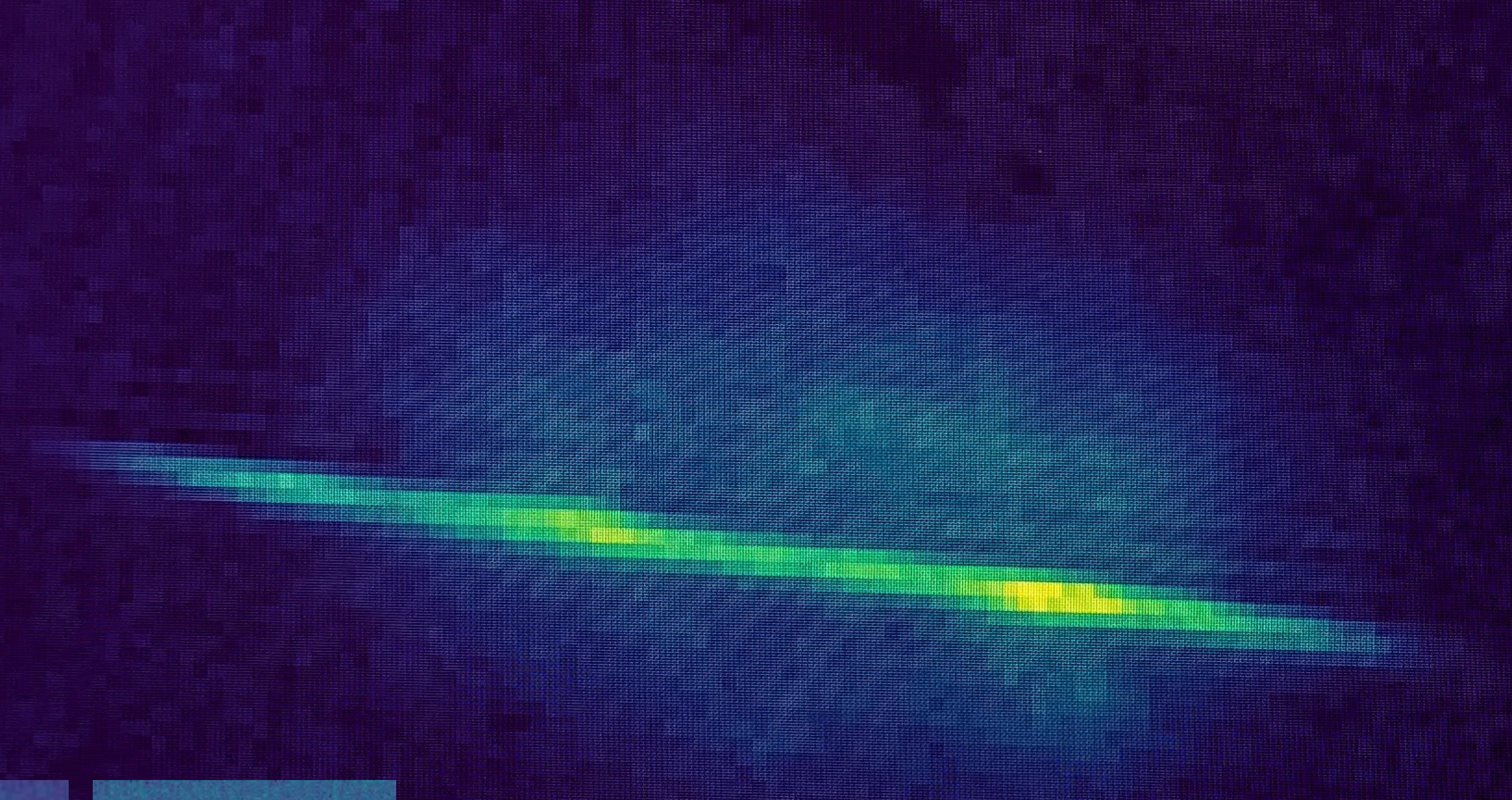
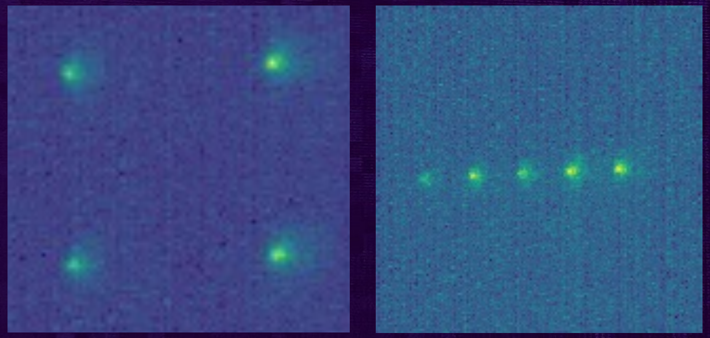
Strontium in Optical Dipole Trap





Tweezer Array

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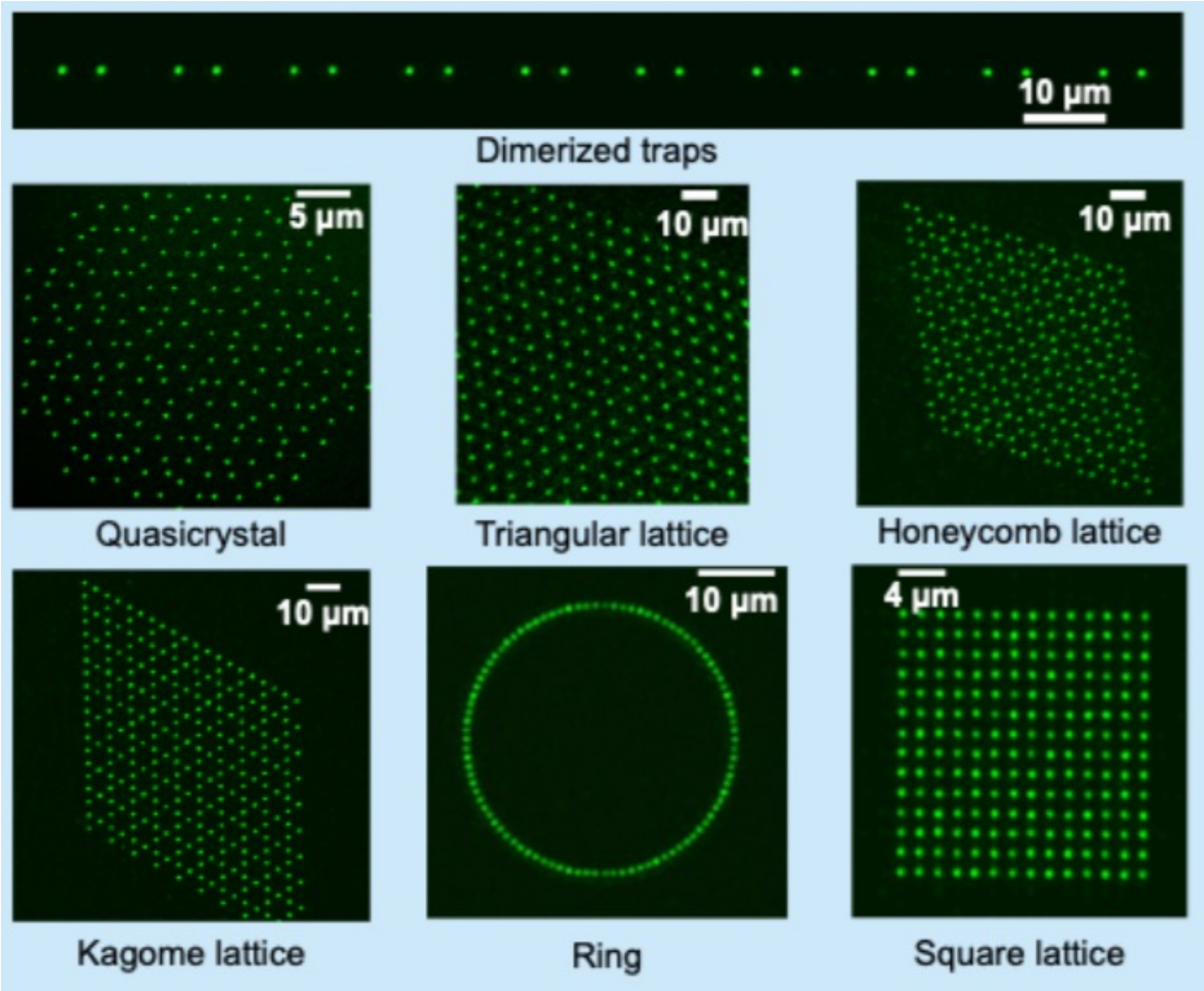
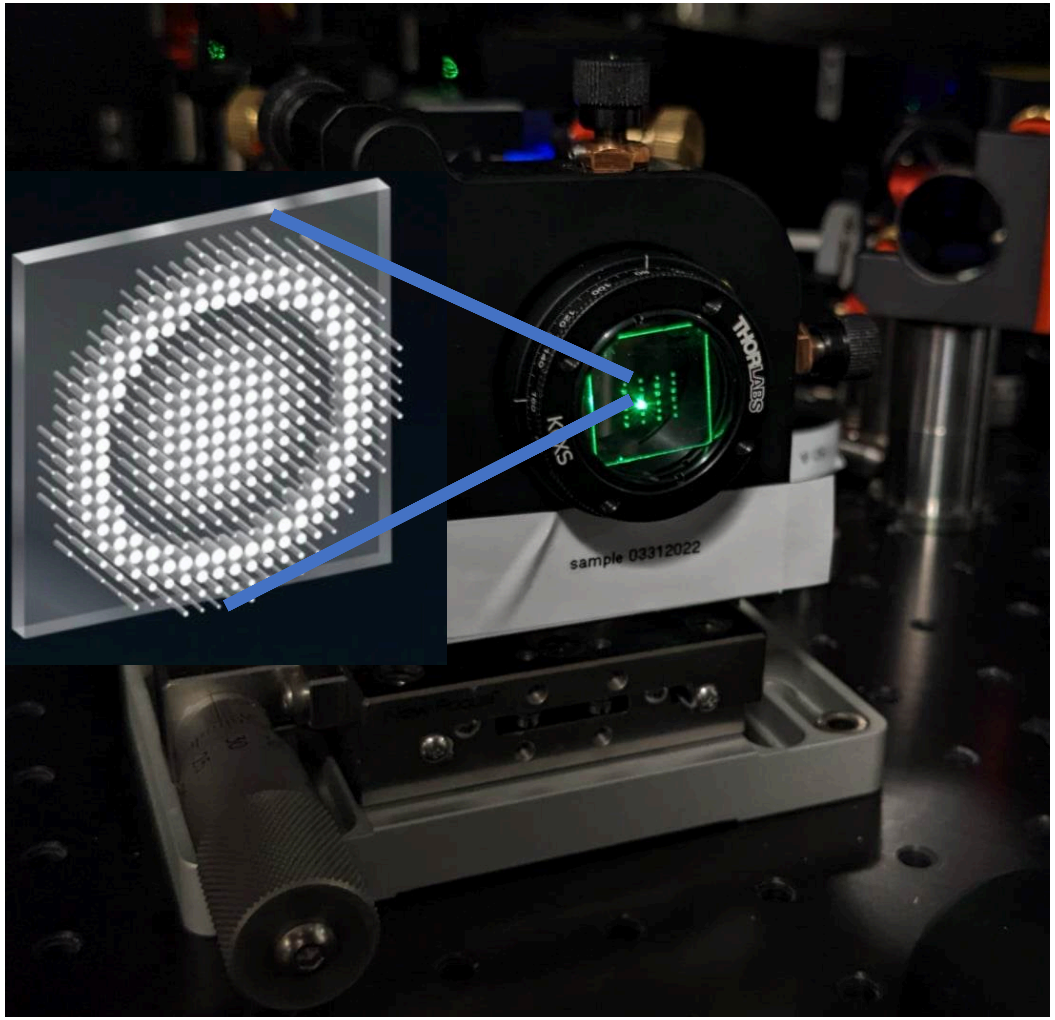
Metasurface Tweezer Array





Contents

1 **Atom Rearranging**

Graph Theory, Algorithm Design

2 **Laser Multiplexing System**

Front-end, Back-end

3 **Computational Mechanics**

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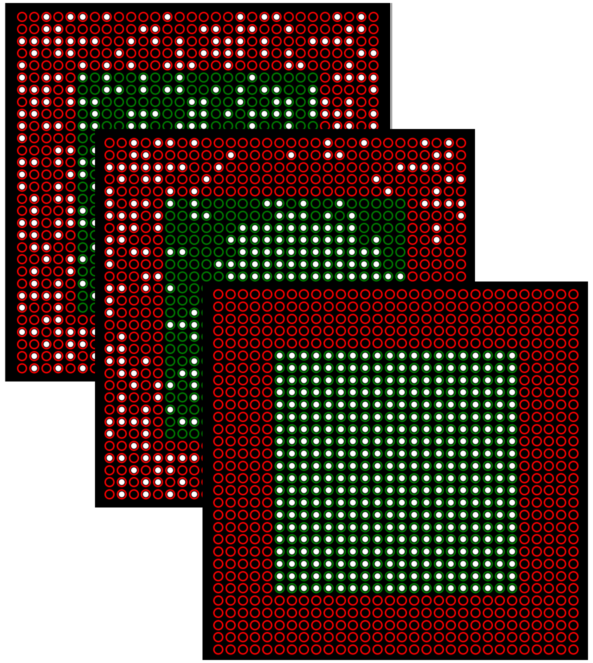
4 **Quantum Walk**

Quantum Information Theory

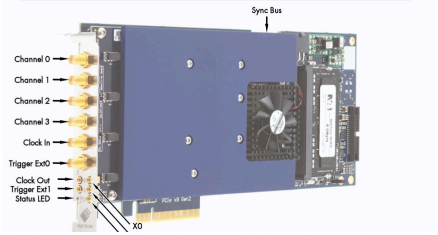
Atom Rearranging

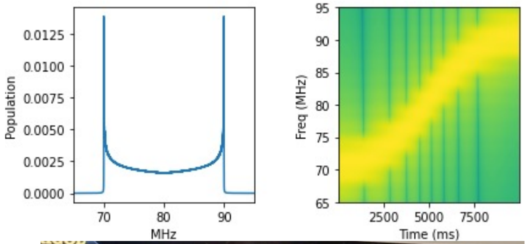
Non-Collision Path

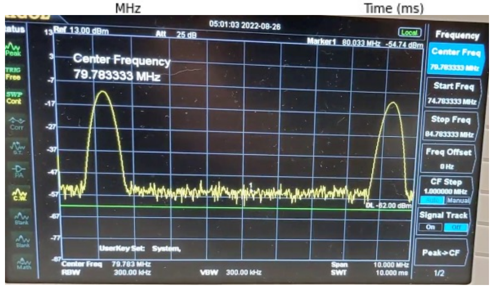


Algorithm: Graph Theory

AWG/VCO

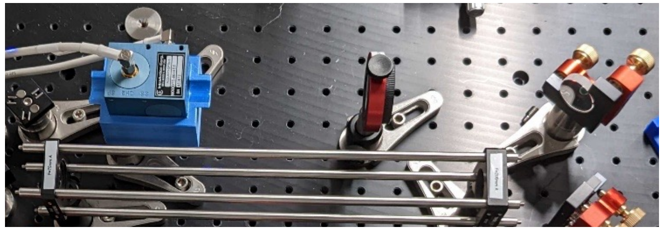


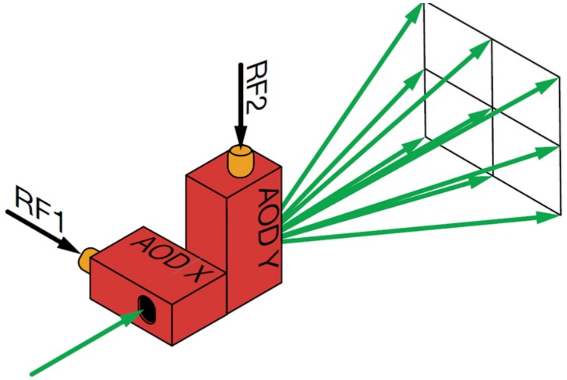




RF Signal Generation

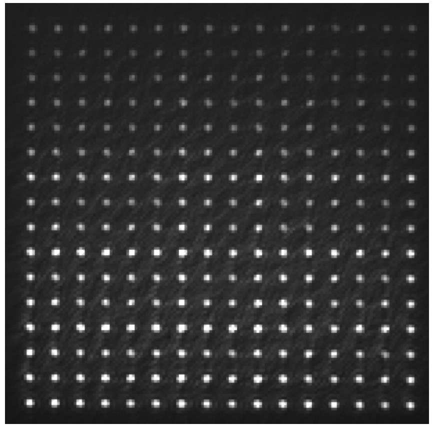
AOD





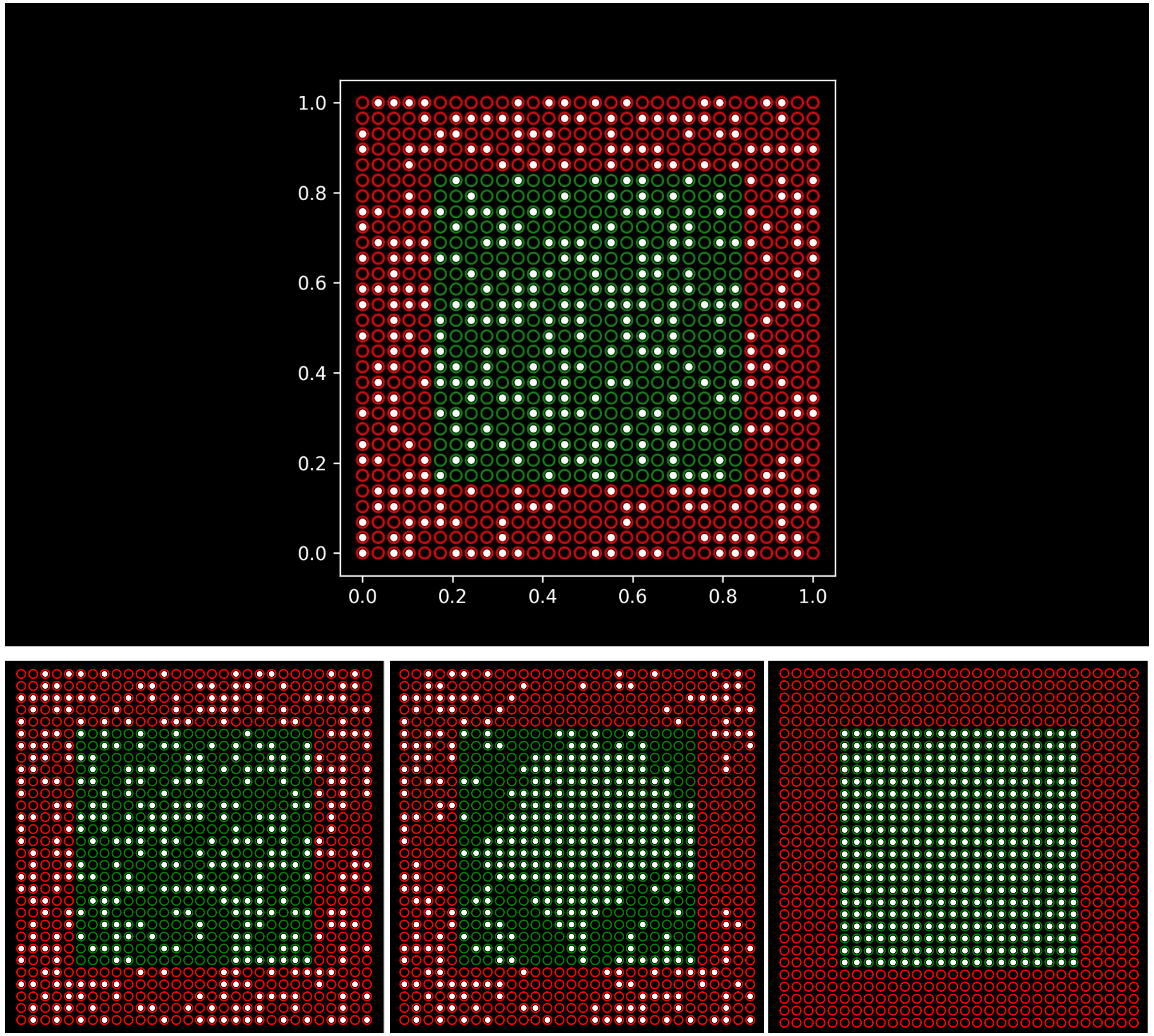
AOD Tweezer Moving

Compact Traps



Atomic Array

Atom Rearranging – As a linear sum assignment problem



- Goal: Finding the min number of moves to form compact array
- Bipartite Matching: Minimum cost for each atom to travel to target
  Jonker-Volgenant or Hungarian algorithm
- Pathfinding: Shortest path on graph
  Dijkstra's algorithm
- Non-collision: Reordering

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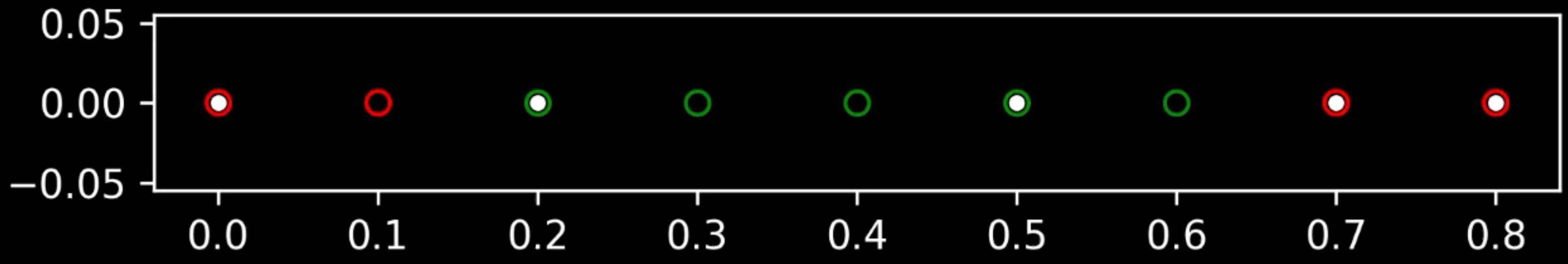
Kai-Niklas Schymik, et al. " Enhanced atom-by-atom assembly of arbitrary tweezer arrays." Phys. Rev. A **102**, 063107 (2021).

Atom Rearranging:
Moving Tweezer

Will Lab, Columbia

Atom Rearranging: Parallel Moving Tweezers



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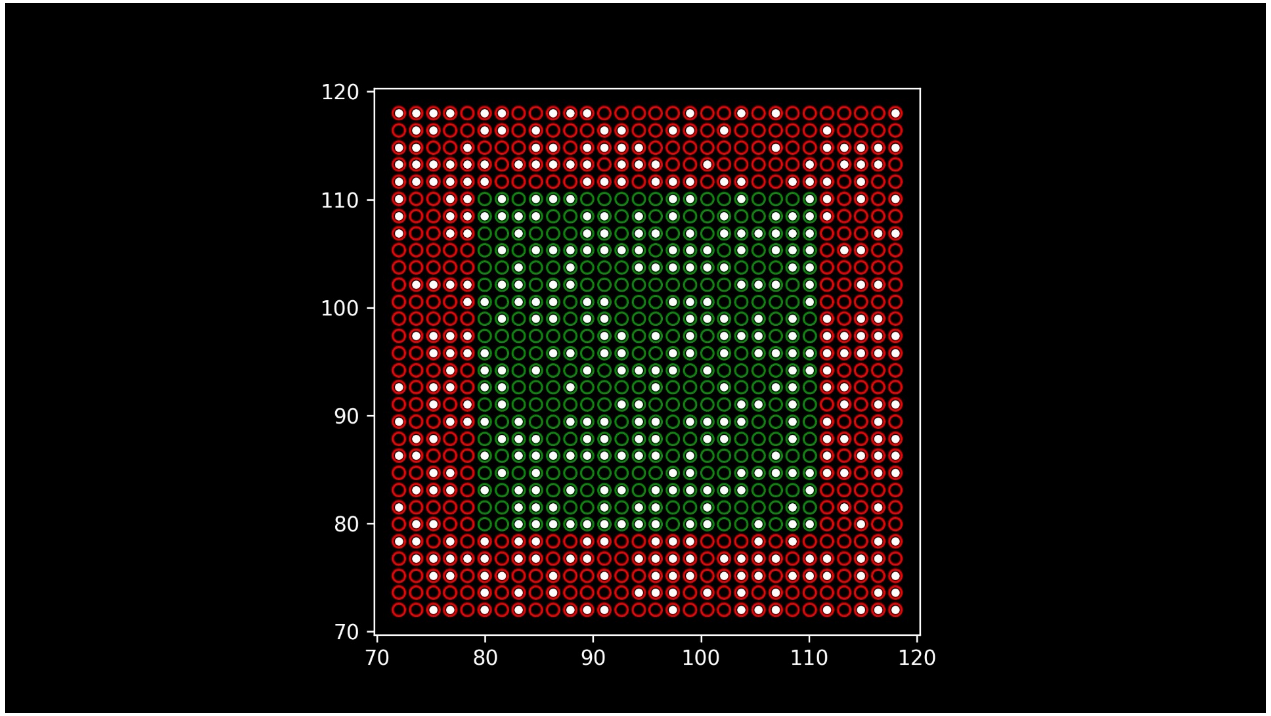
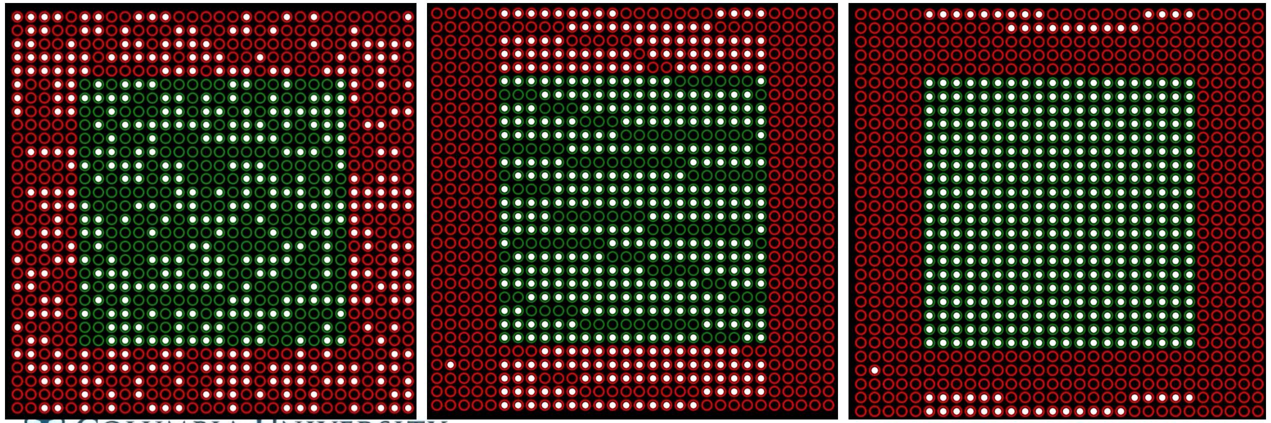
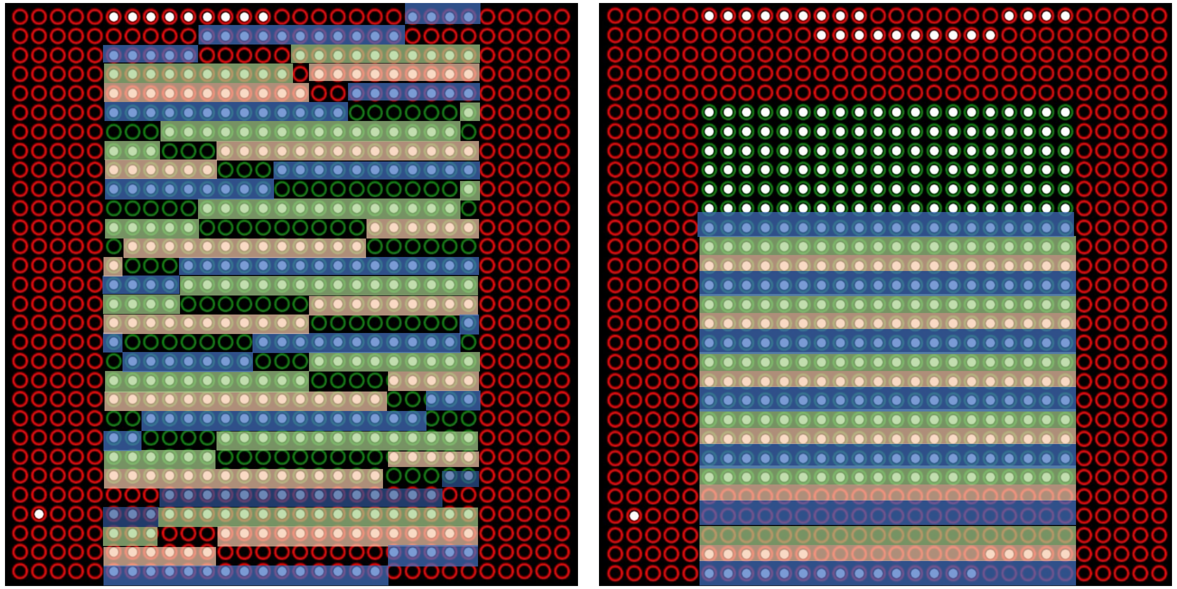
Atom Rearranging – As a Tetris Game





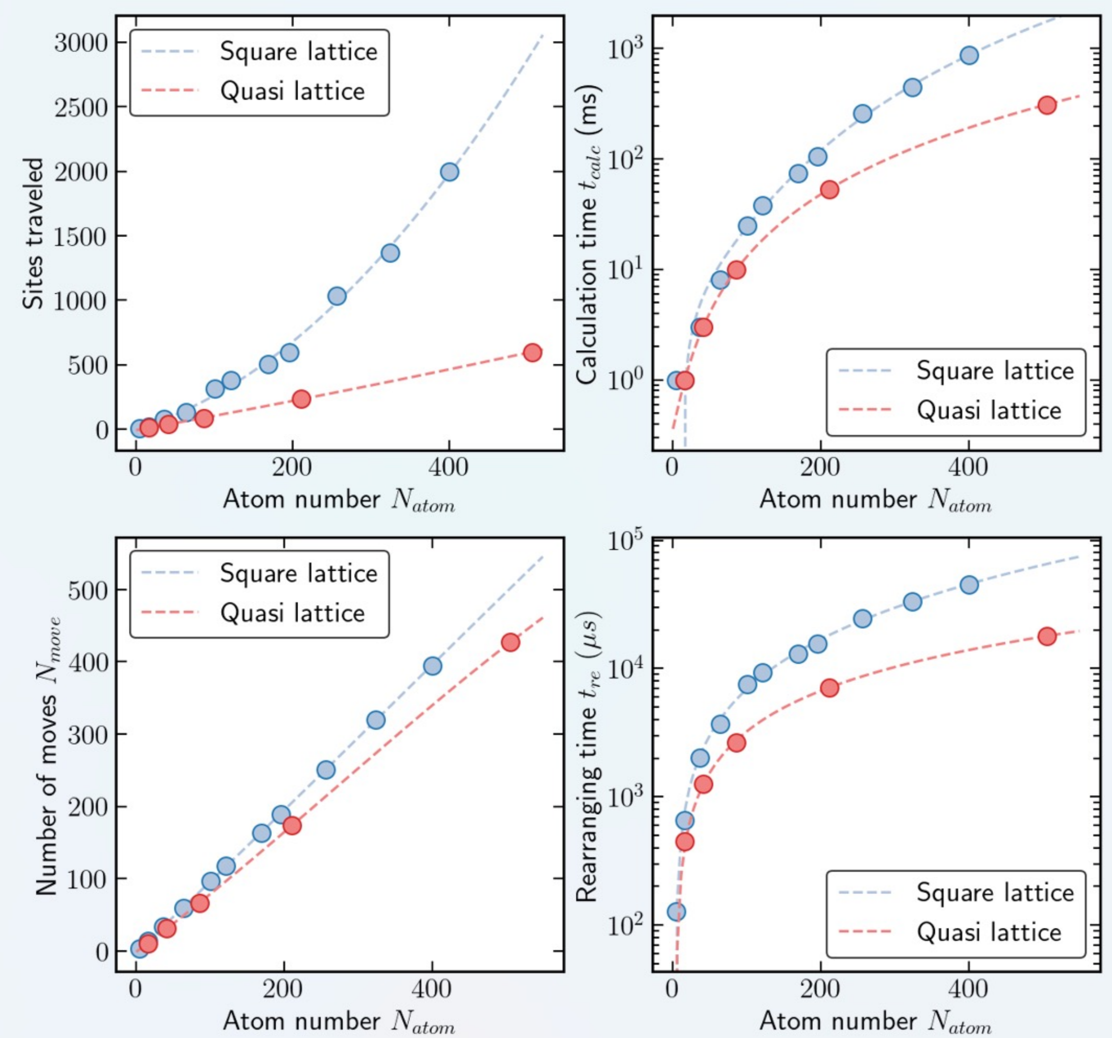
Parallel Rearranging:

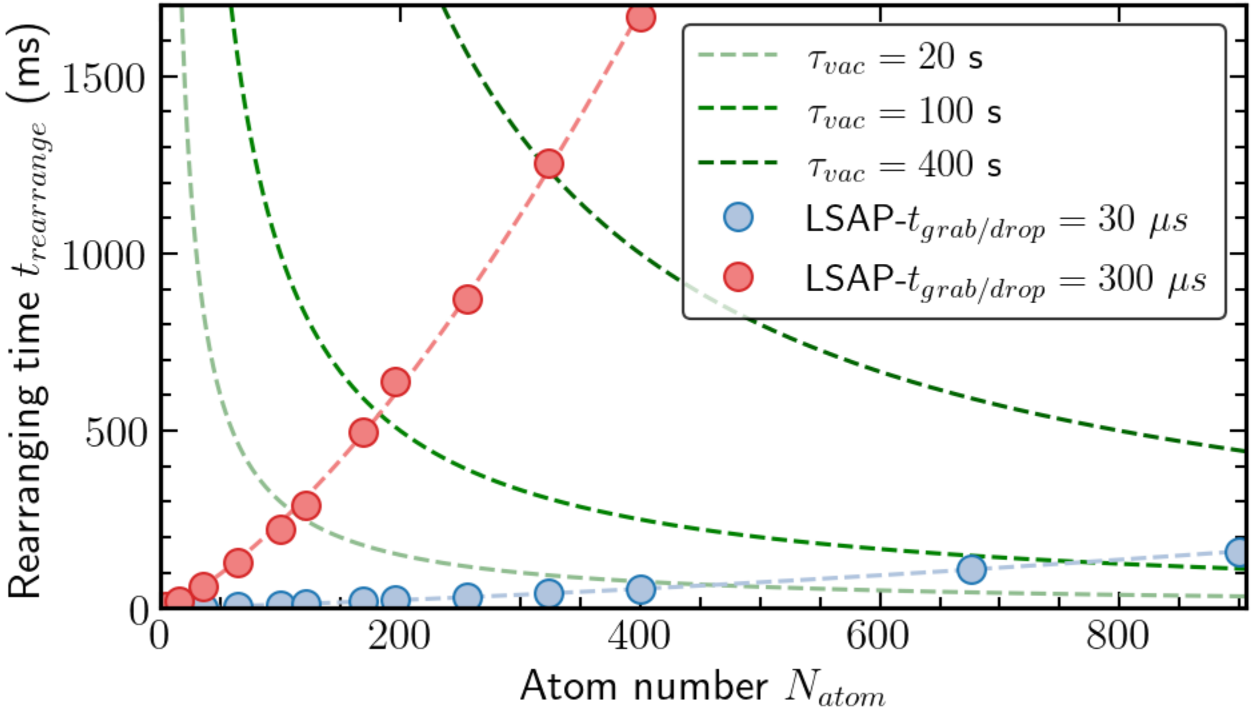
- Sorting Row by row to ensure we can fill each target row
- Compress column by column



Shuai Wang, et al. "Overlapping Bose-Einstein condensates of Na 23 and Cs 133." arXiv:2210.10364 (2022).

Atom Rearranging: Algorithm Performance





Atom Rearranging: Gallery

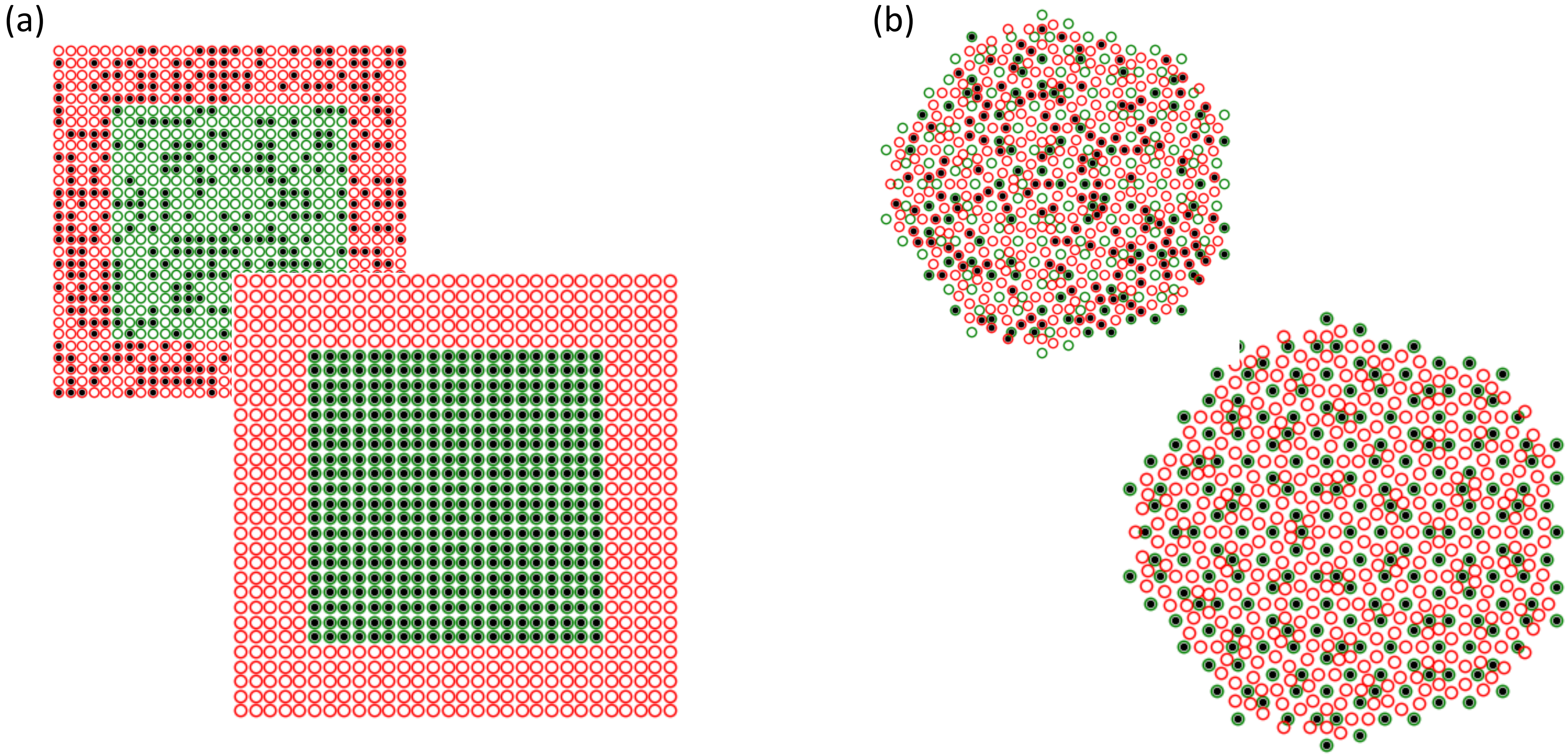
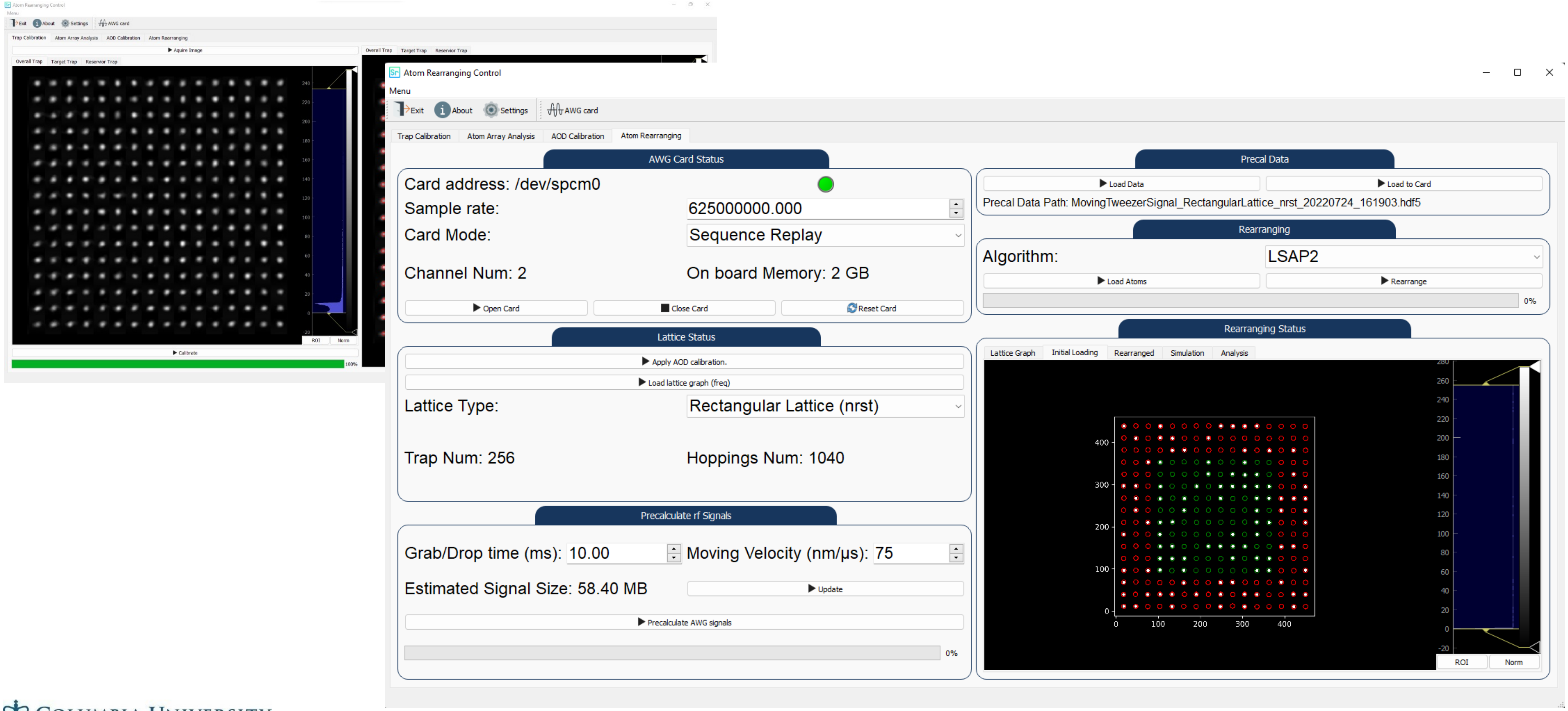


Fig.1 (a) 20x20 Square lattice (b) Quasi-lattice with 216 target trap sites

Atom Rearranging: User Interface



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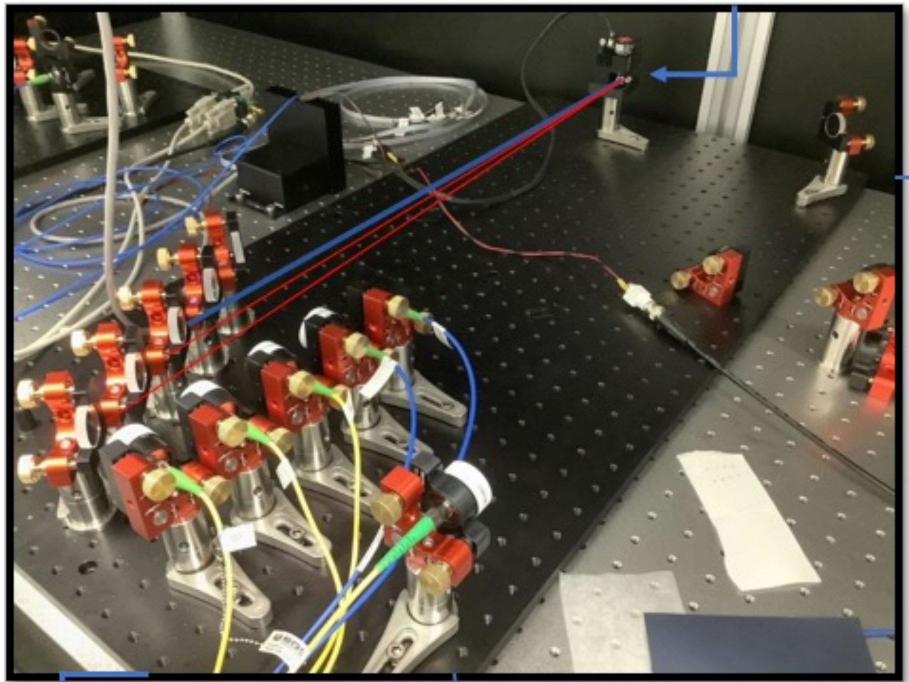
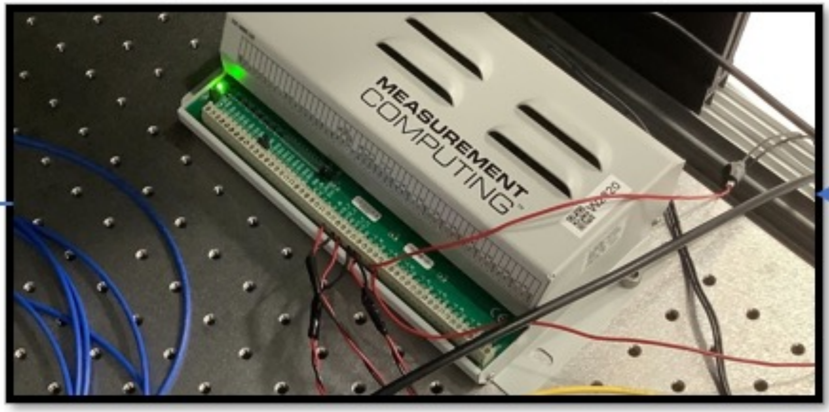
The Galvo System - Hardware

Galvo



DAQ for Galvo



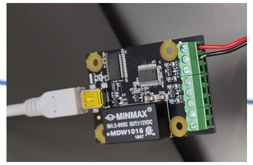
Beam source

Wavemeter

Main Computer

Software Suite:

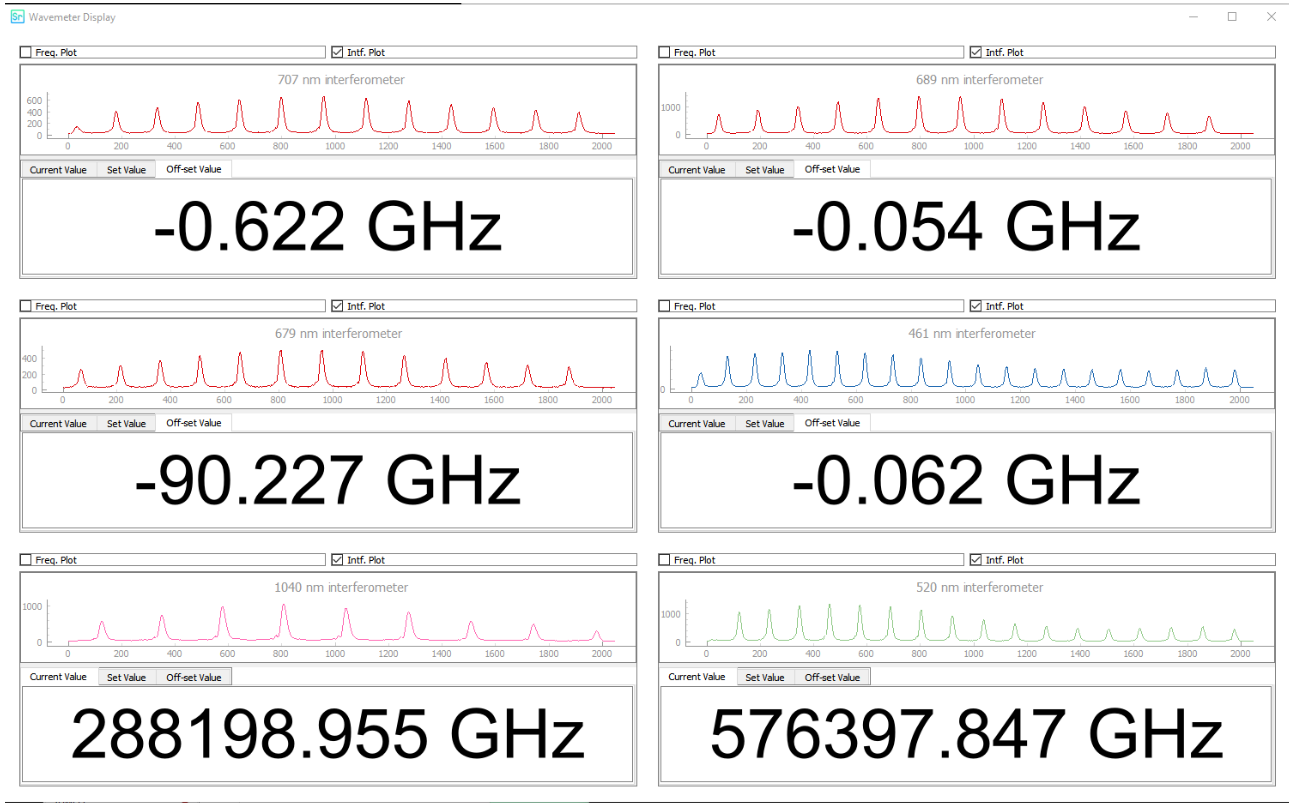
- Wavemeter Display
- Galvo Control Panel
- PID Control Panel



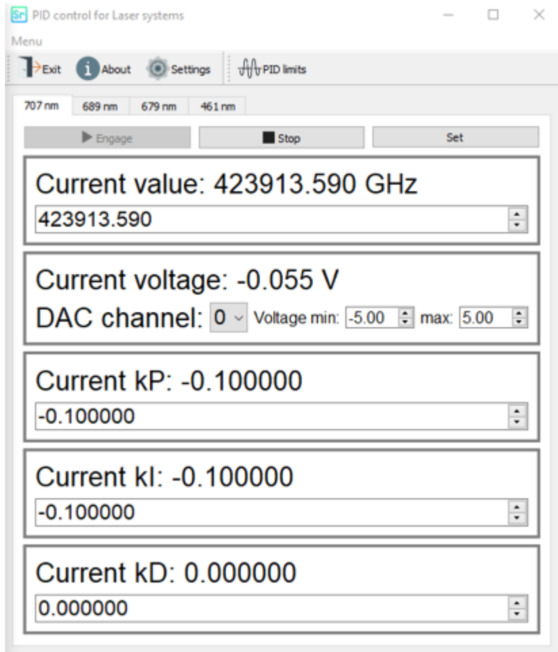
DAQ for PID

Laser Multiplexing System- Software

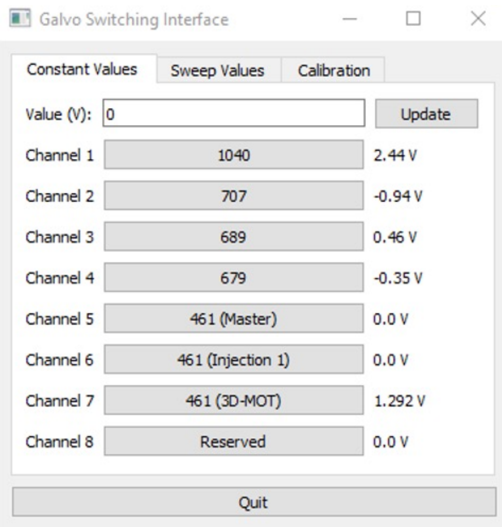
Wavemeter Display



PID Control Panel



Galvo Control Panel



Laser Multiplexing System- Gallery

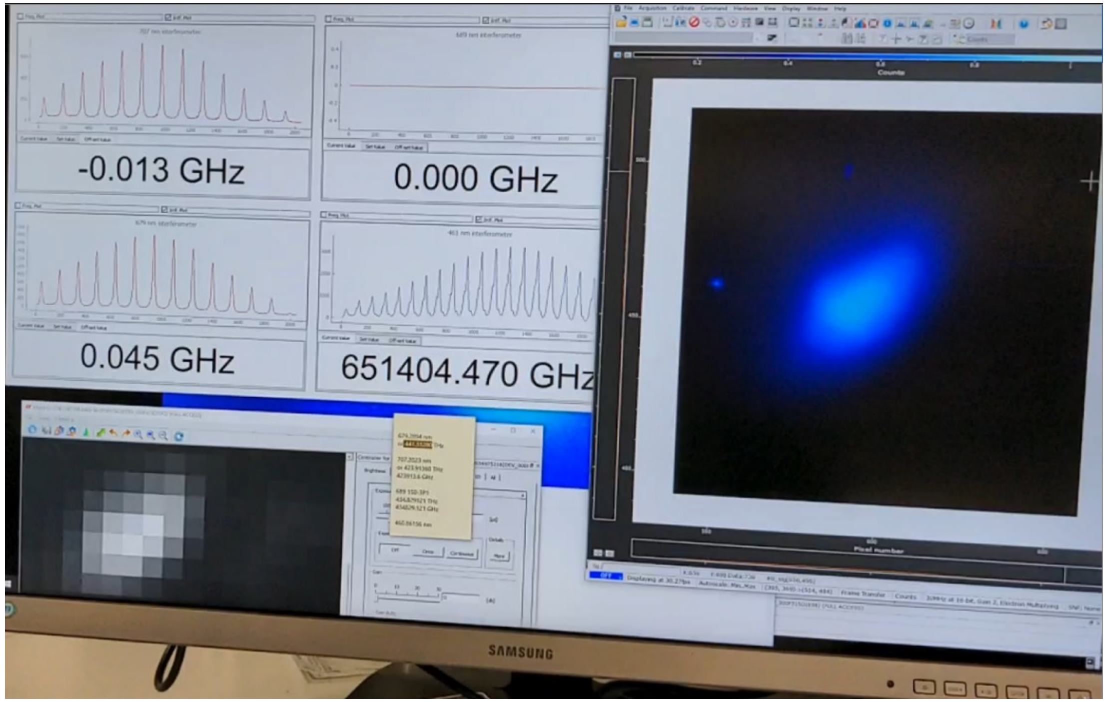


Fig.1 Blue MOT and required lasers

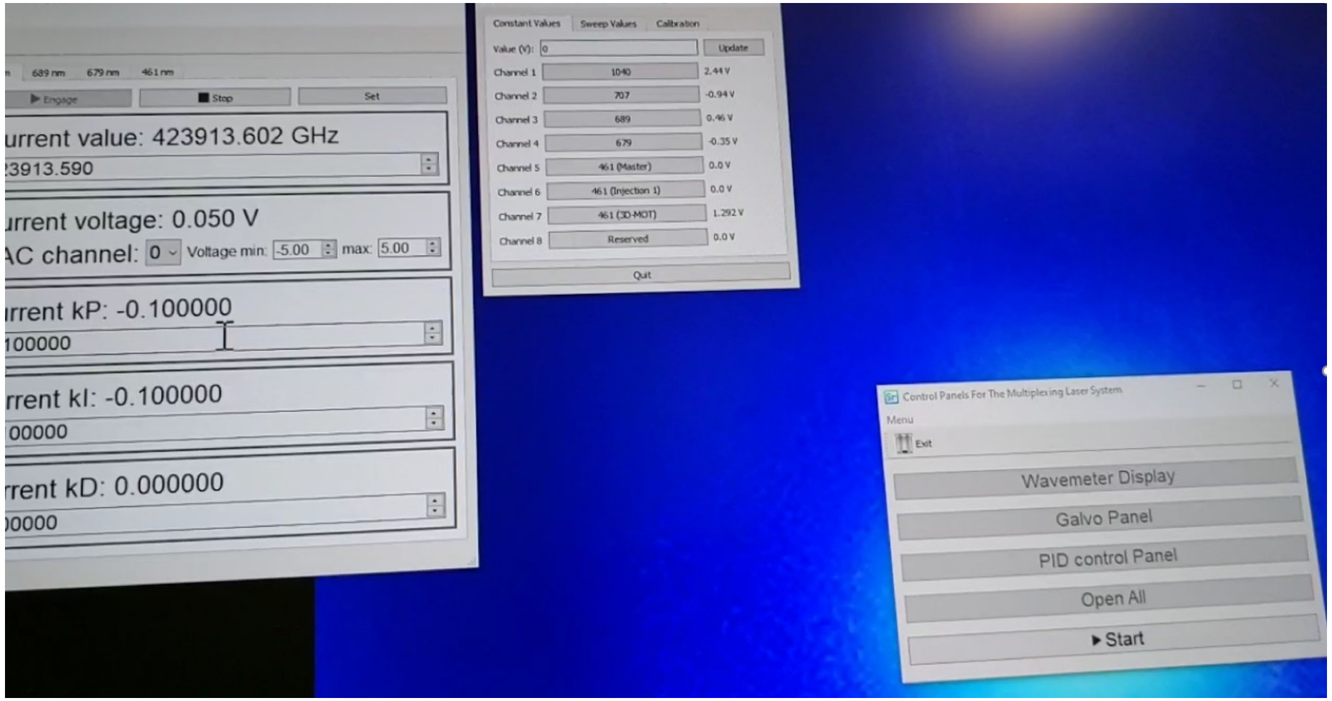


Fig.2 Software Suite

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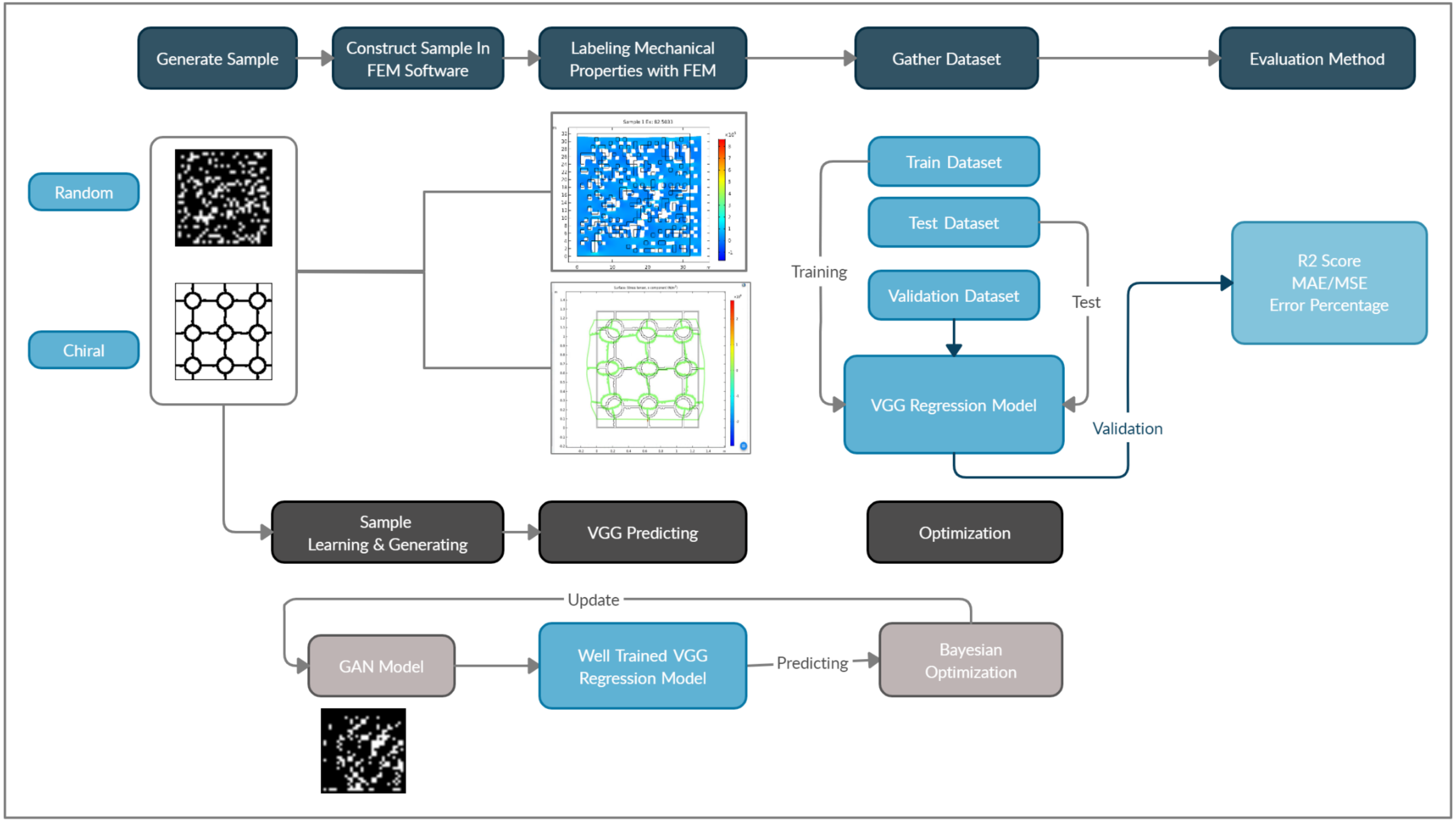
Computational Mechanics: Workflow



Implemented Methods

- Image classification: VGG16/19 (Simonyan etal. 2015)

- Material image generation: Generative Adversarial Neural Networks (GANs)
  - GAN (IJ Goodfellow 2014)
  - CGAN (M Mirza etal. 2014)
  - WGAN series (M Arjovsky etal. 2017)
  - StyleGAN (Tero Karras etal. 2019)

- Finite element method (COMSOL Multiphysics)
  - COMSOL Multiphysics via MATLAB

- Molecular Engineering
  - LAMMPS
  - High Performance Computing: GCP, AWS

Gallery

Table 5: The predicting accuracy of VGG19/Xception on sample dataset.

Property	Description	Random		Chiral	
		Accuracy	R^2	Accuracy	R^2
Ex	Young's modulus in x direction	98.82	0.997	99.04	0.987
Ey	Young's modulus in y direction	99.24	0.999	99.10	0.989
v_{xy}	Poisson'a ratio in x direction	98.63	0.671	93.67	0.999
v_{yx}	Poisson'a ratio in y direction	98.13	0.675	85.94	0.999
B	Bulk modulus	98.63	0.997	98.50	0.997
G_s	Simple shear modulus	99.24	0.999	98.64	0.991
G_p	Pure shear modulus	98.96	0.998	84.02	0.773

Fig.1 VGG Network Performance

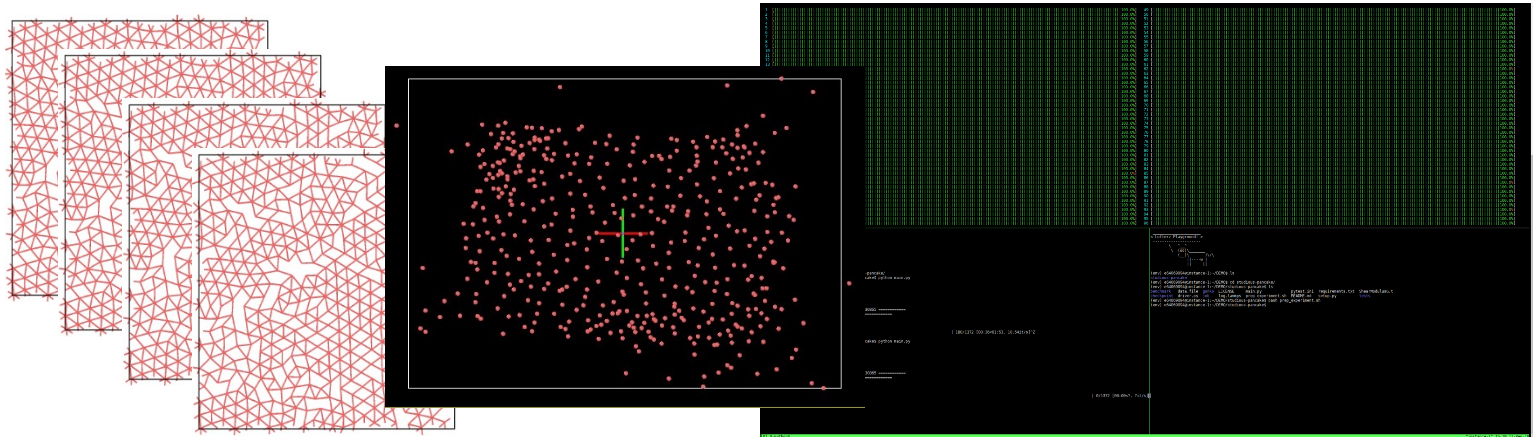


Fig.2 Computational Molecular Dynamics

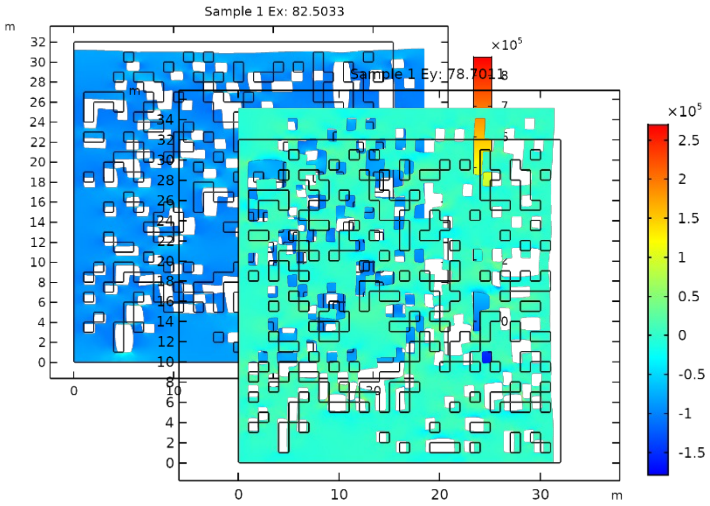


Fig.3 Finite Element Method

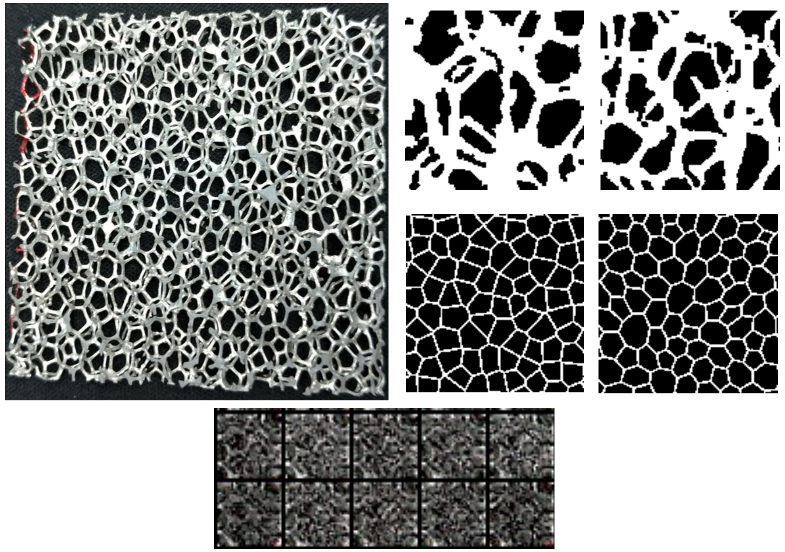


Fig.4 Material Modeling via GAN

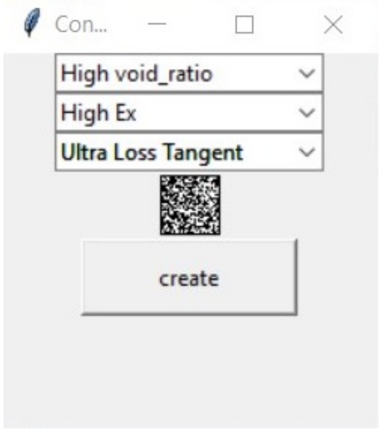


Fig5. Deploy Application

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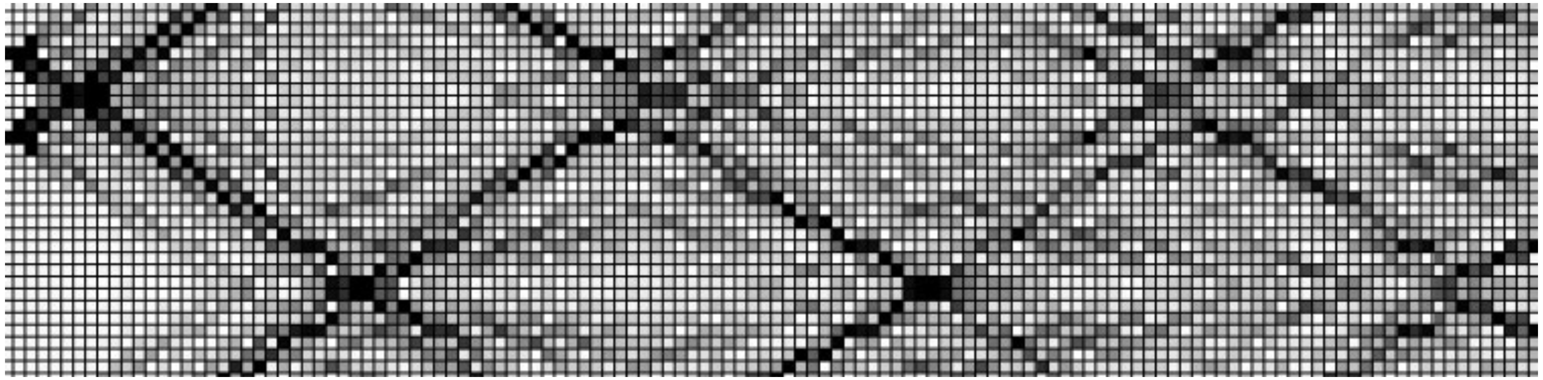
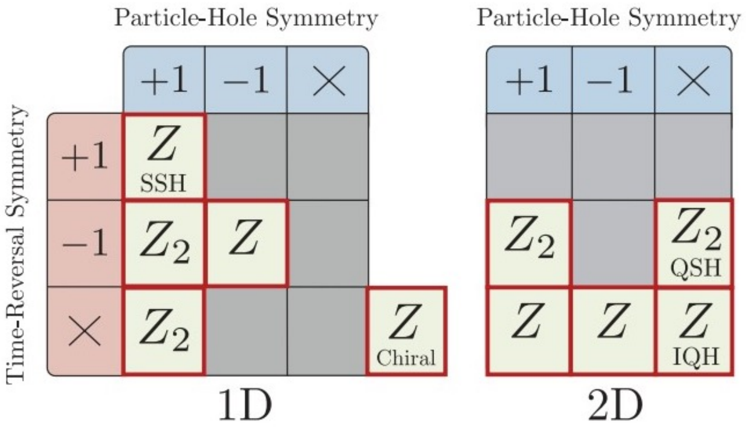
Quantum Walk: Possible Formulations of Quantum Simulators



“Quantum Cellular Automata/Quantum Lattice Gases”, Mayer, J. Stat. Phys., 1996

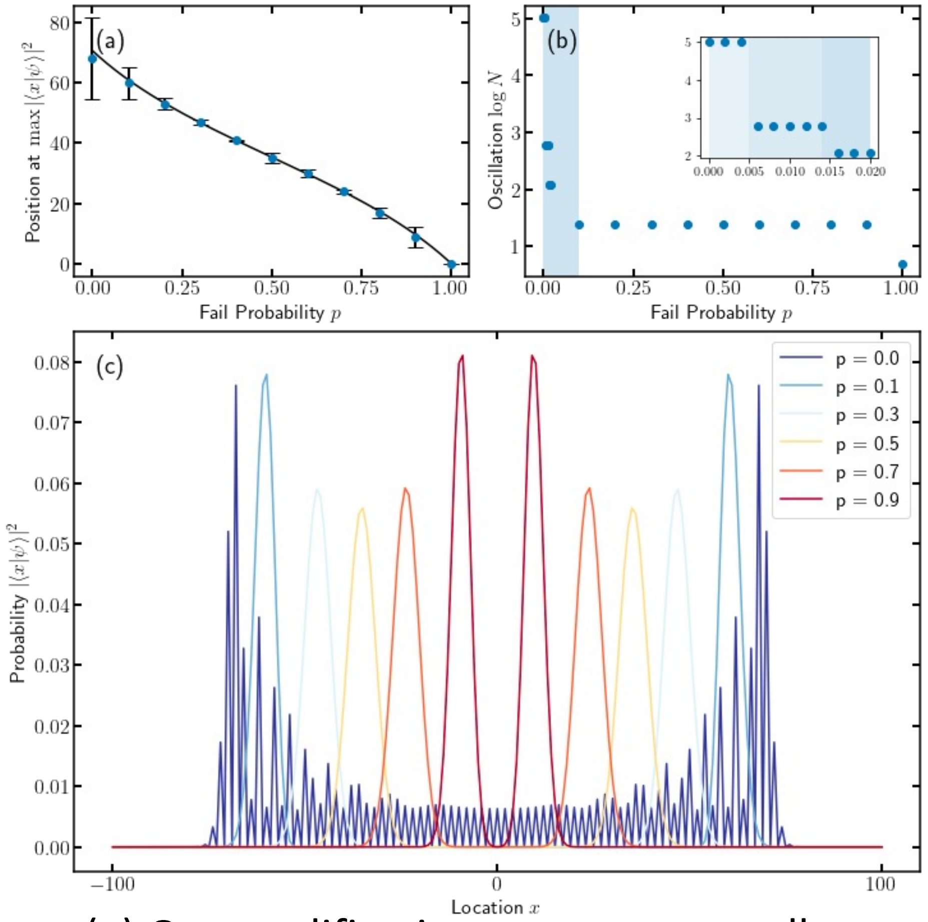


$\mathcal{T}^2$ (TRS)	$\mathcal{P}^2$ (PHS)	Γ^2 (CS)	1D DTQW protocol
1	1	1	$TR_y(\theta)$ or $T_\downarrow R_y(\theta_2) T_\uparrow R_y(\theta_1)$
—	—	1	$U^\alpha_{ss} =$ $TR_\alpha(\theta)$ or $T_\downarrow R_\alpha(\theta_2) T_\uparrow R_\alpha(\theta_1)$
-1	-1	1	$\begin{pmatrix} U^\alpha_{ss} & 0 \\ 0 & (U^\alpha_{ss})^T \end{pmatrix}$
—	1	—	$U_{ss'} = T_\downarrow R_y(\theta_2) T_\uparrow R_y(\theta_1) T$
-1	1	1	$\begin{pmatrix} U_{ss'} & 0 \\ 0 & (U_{ss'})^T \end{pmatrix}$

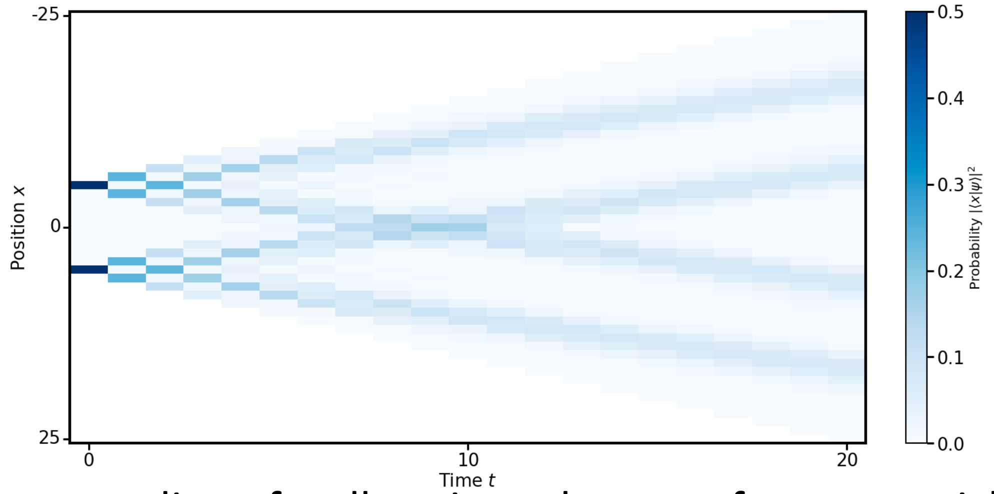
$\mathcal{T}^2$ (TRS)	$\mathcal{P}^2$ (PHS)	Γ^2 (CS)	2D DTQW protocol
—	—	—	$U^\beta_{2D} = T_3 R_y(\theta_1) T_2 R_\beta(\theta_2) T_1 R_y(\theta_1)$
-1	—	—	$\begin{pmatrix} U^\beta_{2D} & 0 \\ 0 & 1 \end{pmatrix} e^{-i\tau_y\sigma_y\varphi/2} \begin{pmatrix} 1 & 0 \\ 0 & (U^\beta_{2D})^T \end{pmatrix}$
—	-1	—	$\begin{pmatrix} U^\beta_{2D} & 0 \\ 0 & (U^\beta_{2D})^* \end{pmatrix}$
—	1	—	$U_{2D} = T_3 R_y(\theta_1) T_2 R_y(\theta_2) T_1 R_y(\theta_1)$
-1	1	1	$\begin{pmatrix} U_{2D} & 0 \\ 0 & (U_{2D})^T \end{pmatrix}$

“Exploring topological phases with quantum walks”, Kitagawa *etal.*, PRA, 2010

Quantum Walk: Our Model (under preparation)



(a) Our modification to quantum walk can demonstrate soliton behavior.



(b) The spreading of walkers in real space of a two particle quantum walk in our model. A favorable candidate in spatial search.

$$H(\theta,k) \propto \begin{pmatrix} \omega(\theta,k) - i\ln\eta(\theta,k)^{1/2} & 0 \\ 0 & -\omega(\theta,k) - i\ln\eta(\theta,k)^{1/2} \end{pmatrix}$$

$$\widetilde{\Psi}_R(k,t) = \sqrt{\frac{\eta(\theta,k)^t}{2\pi}}\left(i\cos\omega t + v(\theta,k)\sin(\omega t) + ie^{i\delta(\theta,k)}\sqrt{1-\left(v(\theta,k)\right)^2}\sin(\omega t)\right)$$

$$\widetilde{\Psi}_L(k,t) = \sqrt{\frac{\eta(\theta,k)^t}{2\pi}}\left(\cos\omega t + iv(\theta,k)\sin(\omega t) - e^{-i\delta(\theta,k)}\sqrt{1-\left(v(\theta,k)\right)^2}\sin(\omega t)\right)$$

(c) We are arguing that it can also be a strong candidate of quantum simulator in exploring topological effects.

Tetrahedral MOT – Rb87

Single-laser, one beam, tetrahedral magneto-optical trap

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