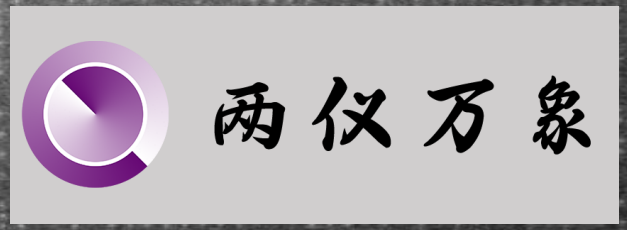
Trapping over 10,000 individual atoms in a tweezer array by a single metasurface

Wenlan Chen

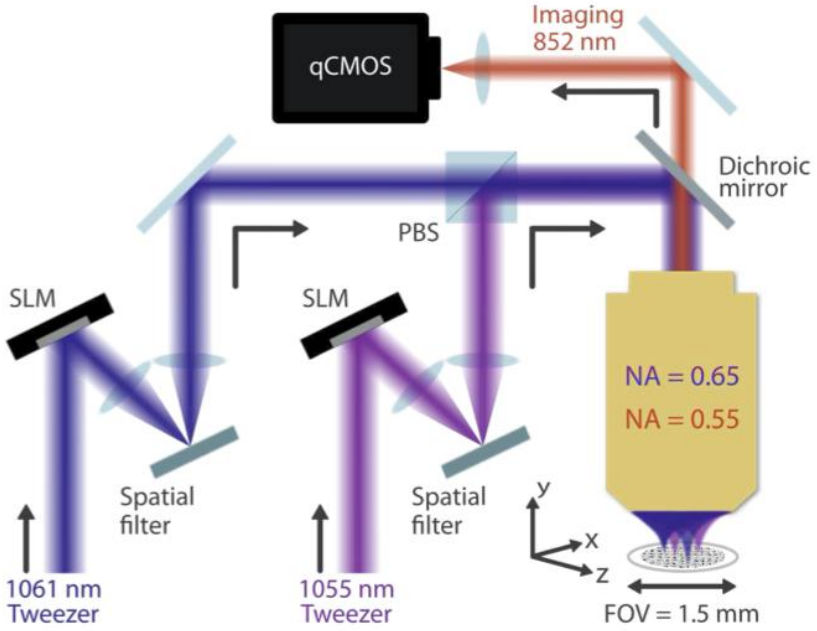
ICAP 2026, Wuhan

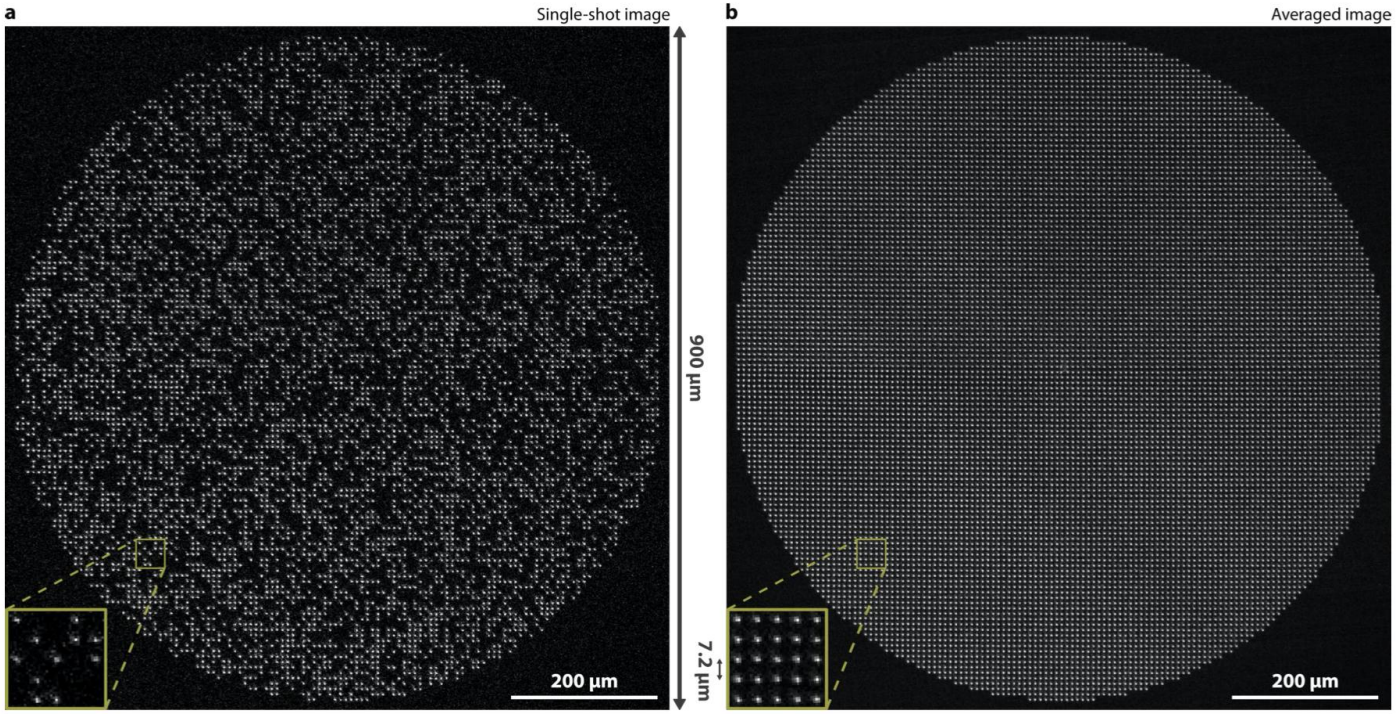


- Classical computers perform computations by regulating electric currents
- Quantum computers perform computation by manipulating the quantum states of microscopic particles
- Quantum computing demands individual, high-precision control of millions or even tens of millions of microscopic particles in their quantum states, pushing the limit of precise manipulation of the quantum world.

The wondering earth,
science fiction movie 2019

02 Trapping large-scale atoms in static tweezer array

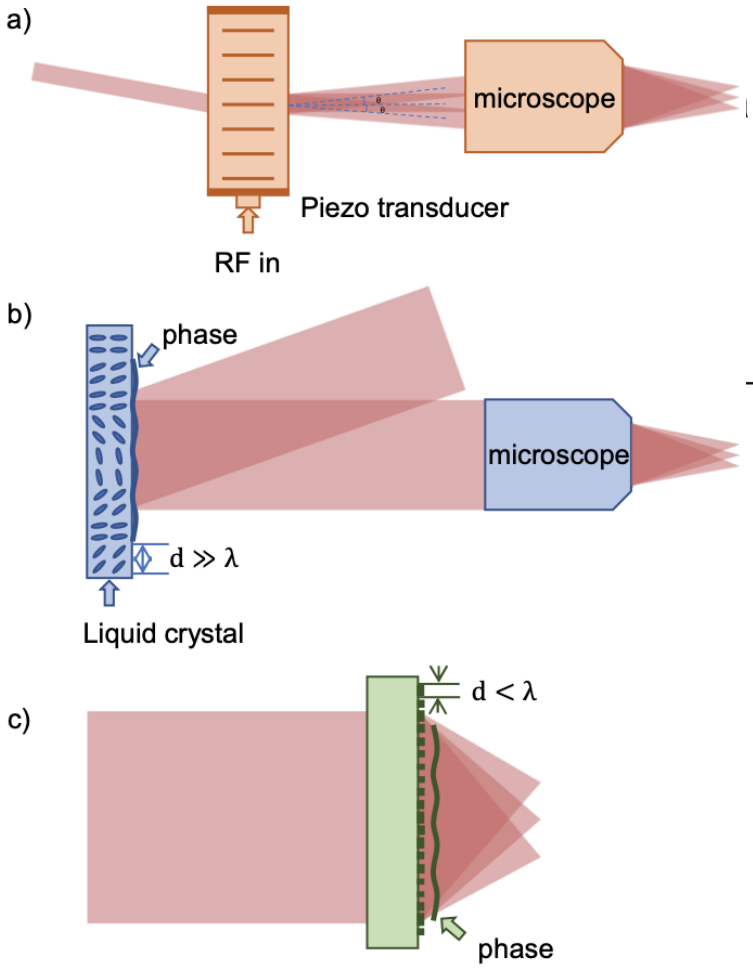


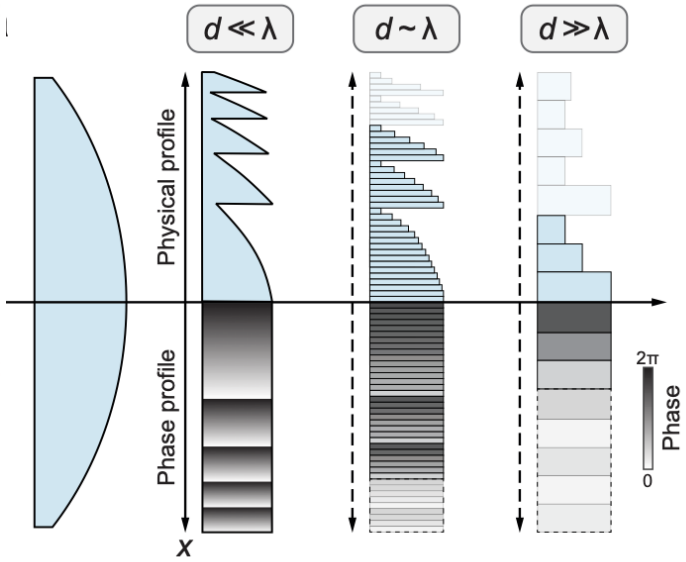


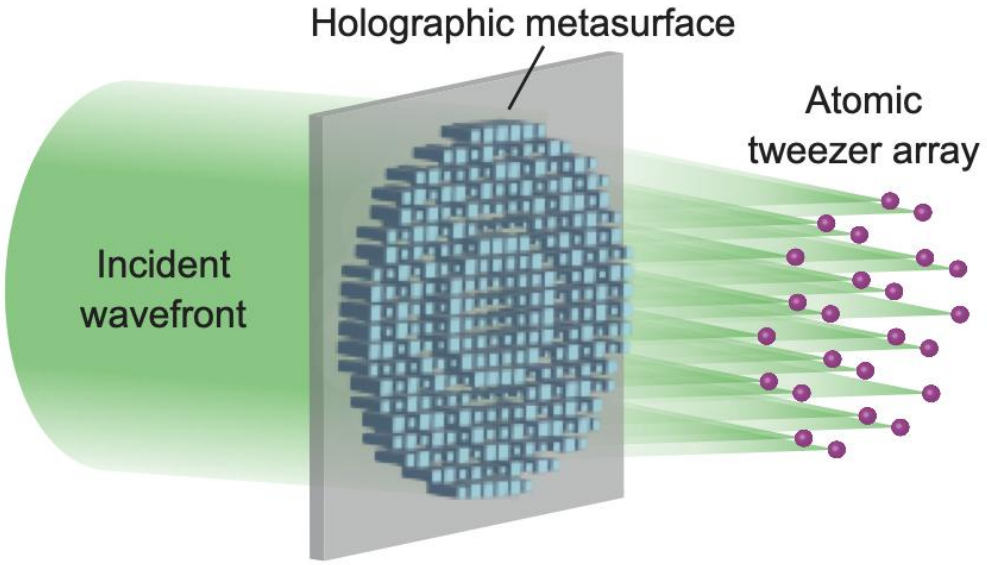
Manuel Endres group, Nature 647, 60 (2025)
Jianwei Pan group, Phys. Rev. Lett. 135, 060602 (2025)
Mikhail Lukin group, Nature 646, 1075 (2025)
Pasqal, Phys. Rev. Applied 22, 024073 (2024)

Diffractive optical elemement

metasurface Spatial light modulator







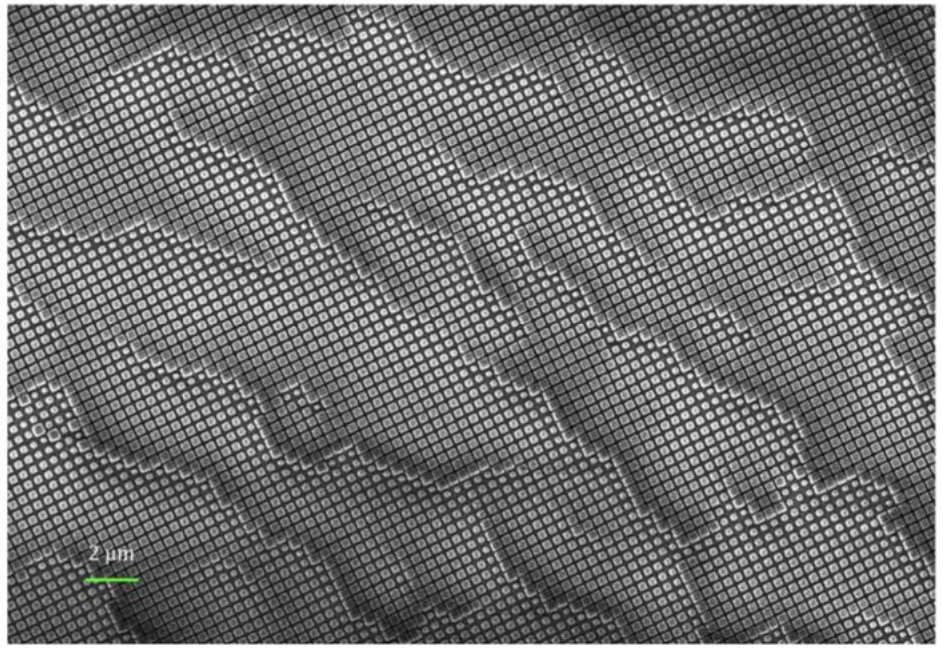
Mark Saffman group, Nanophotonics 10, 2703 (2021)

Sebastian Will group, Nature 649, 859 (2026)

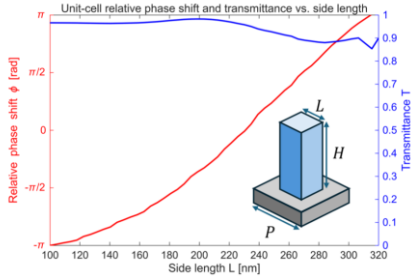
Y. Wang et al, Chin. Phys. Lett. 43, 010606 (2026)

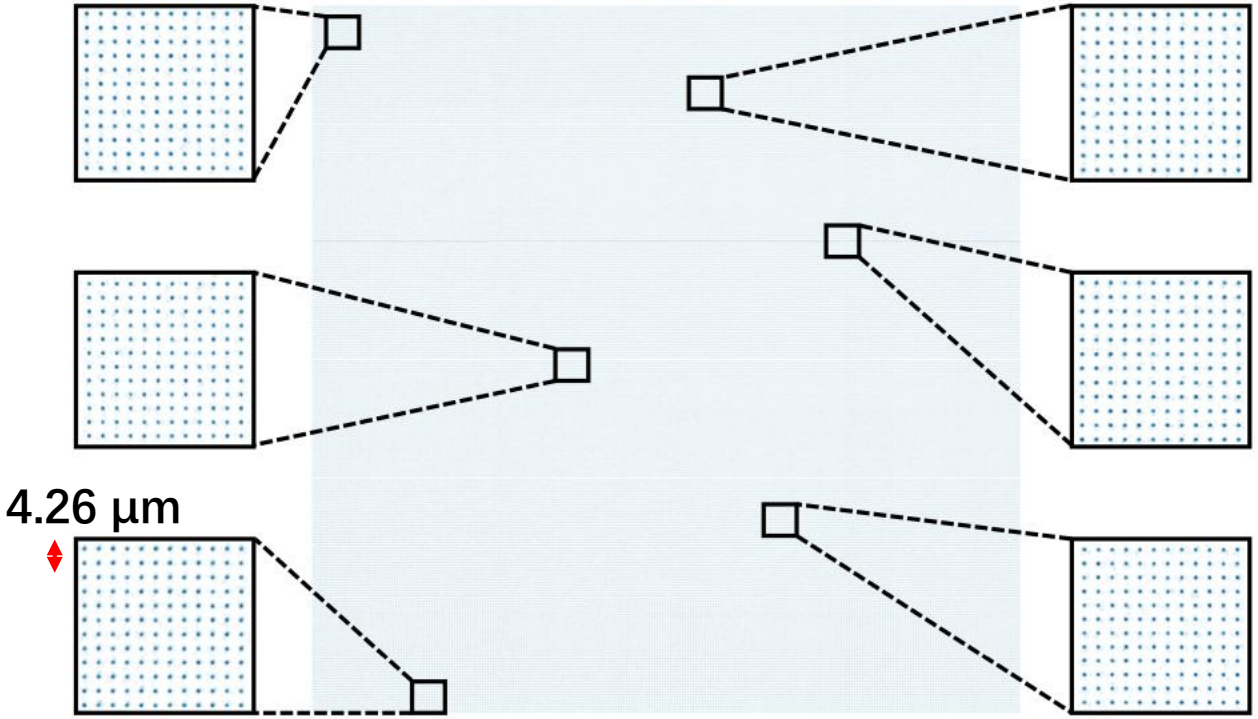
Optical tweezer array of **280*280 tweezers** by 5mm metasurface

- Tweezer waist **1 um**， intensity nonuniformity **9%**
- transmission **92%**， diffraction efficiency **67.5%**

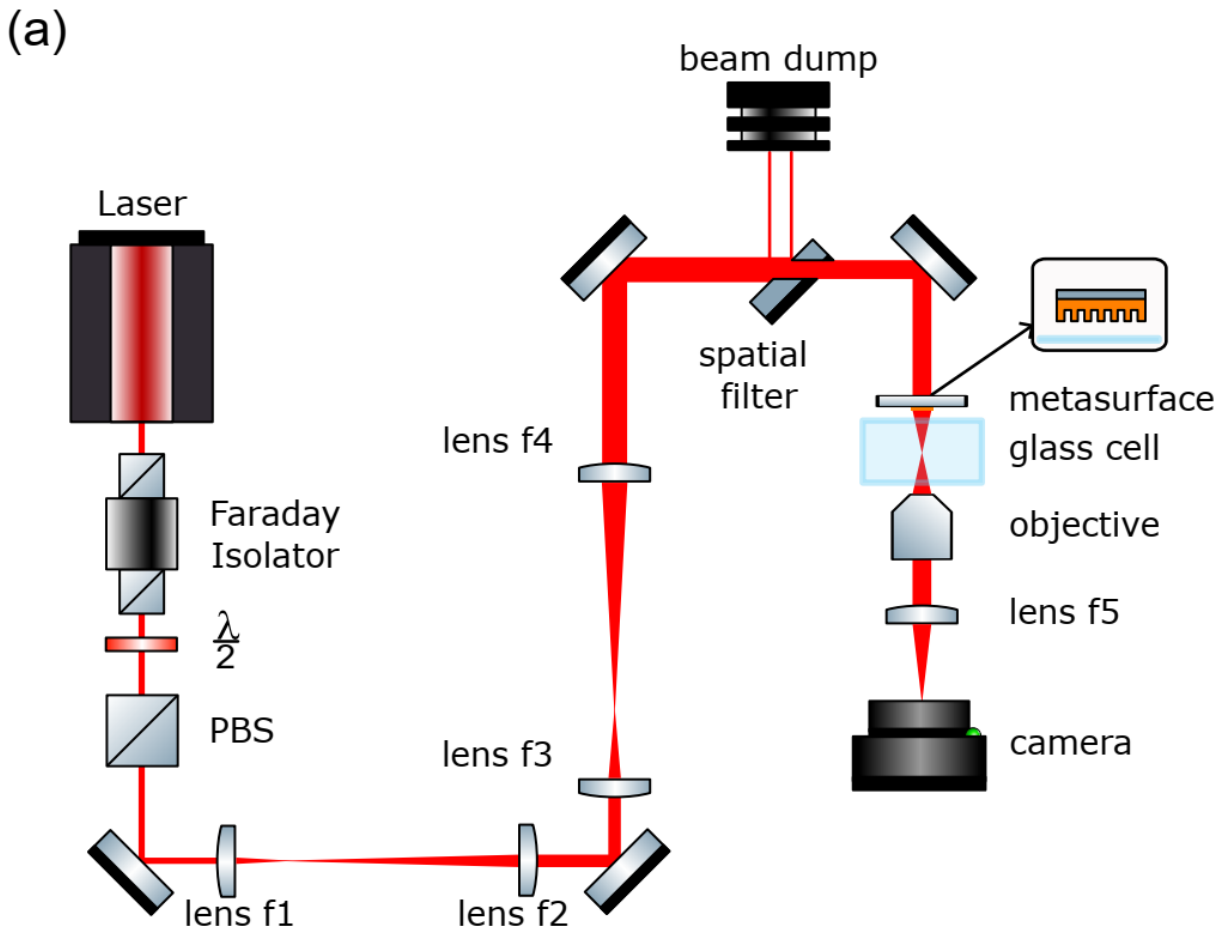


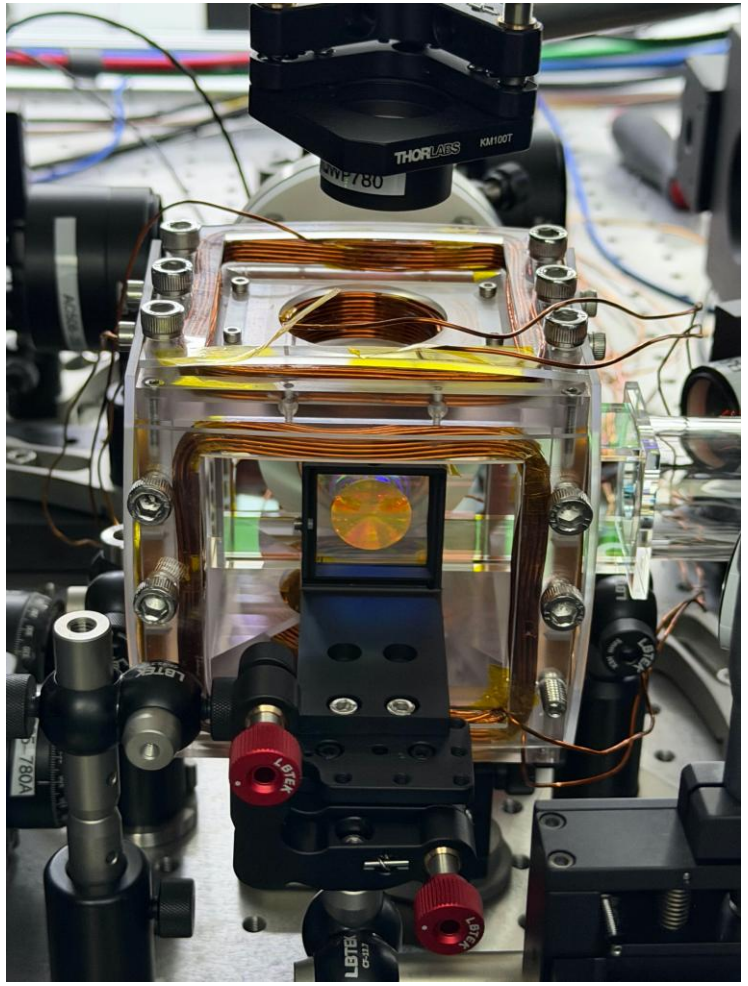
silicon nitride pillar on fused-silica substrate





Y. Wang et al, Chin. Phys. Lett. 43, 010606 (2026)

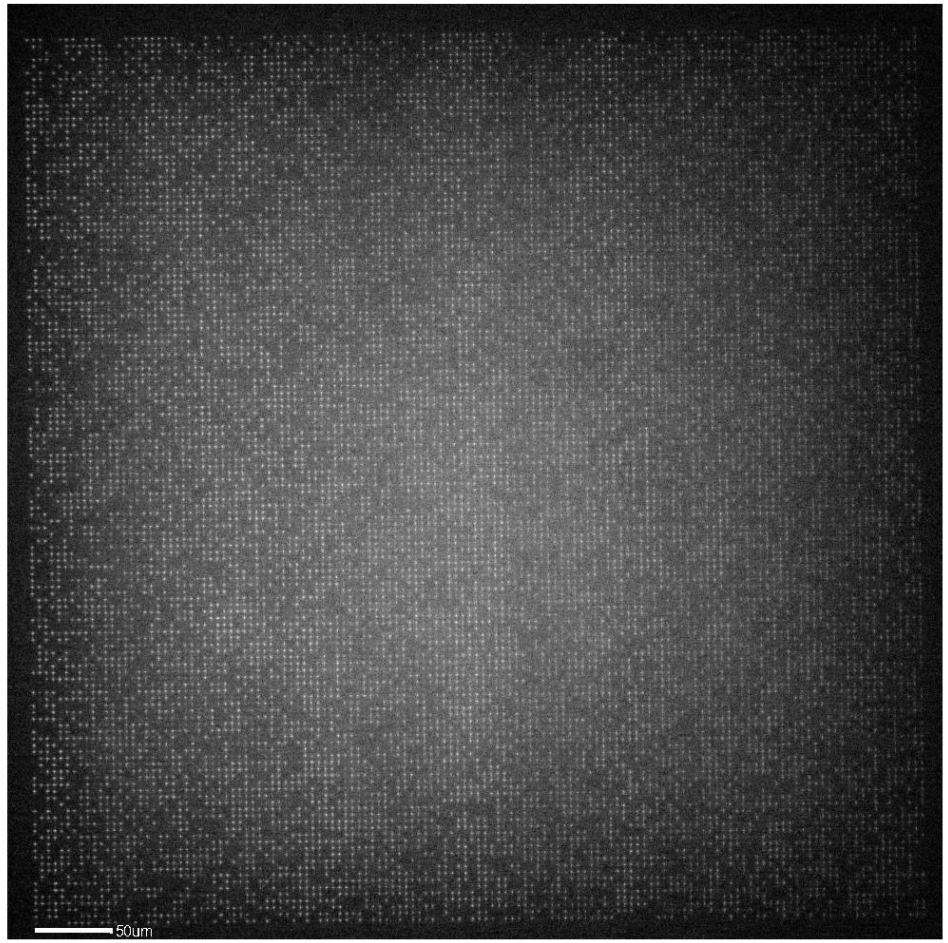




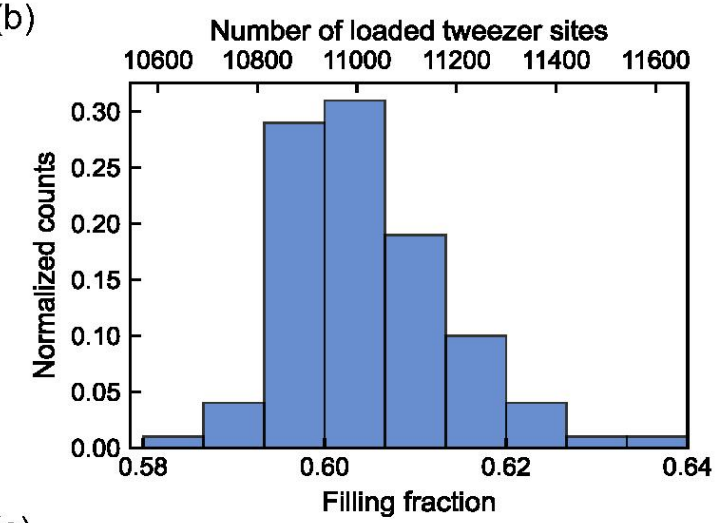
Metasurface outside the vacuum chamber

06 Trapping 11,000 atoms using 18,225 tweezer array

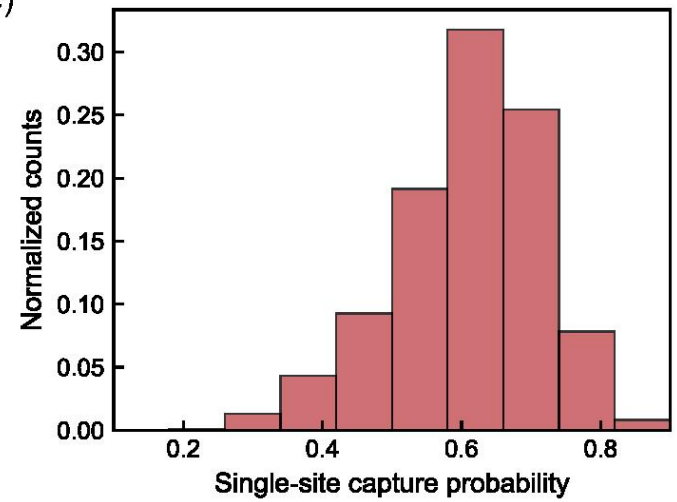
(a)



(b)



(c)

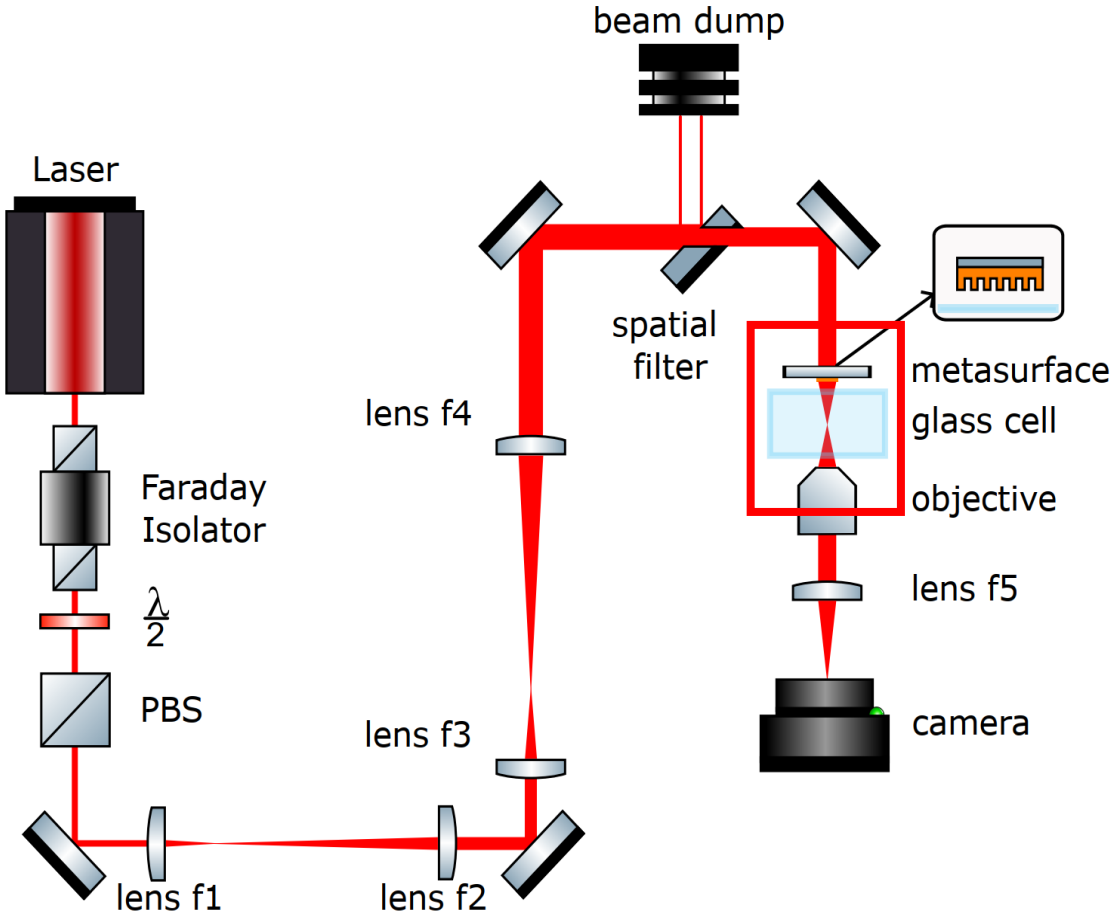


33W laser

135 * 135 array
(18225 tweezers)
Waist 1.1 um

Over 10,000 trapped single atoms

Y. Wang et al., arXiv: 2606.02715



Y. Wang et al., arXiv: 2606.02715

Power budget

33 W incident beam

⇩

Diffraction efficiency: 67.5%

Truncated Gaussian transmission: 80% (86.5%)

System propagation : 80% (90%)

Effective Airy disk: 87%

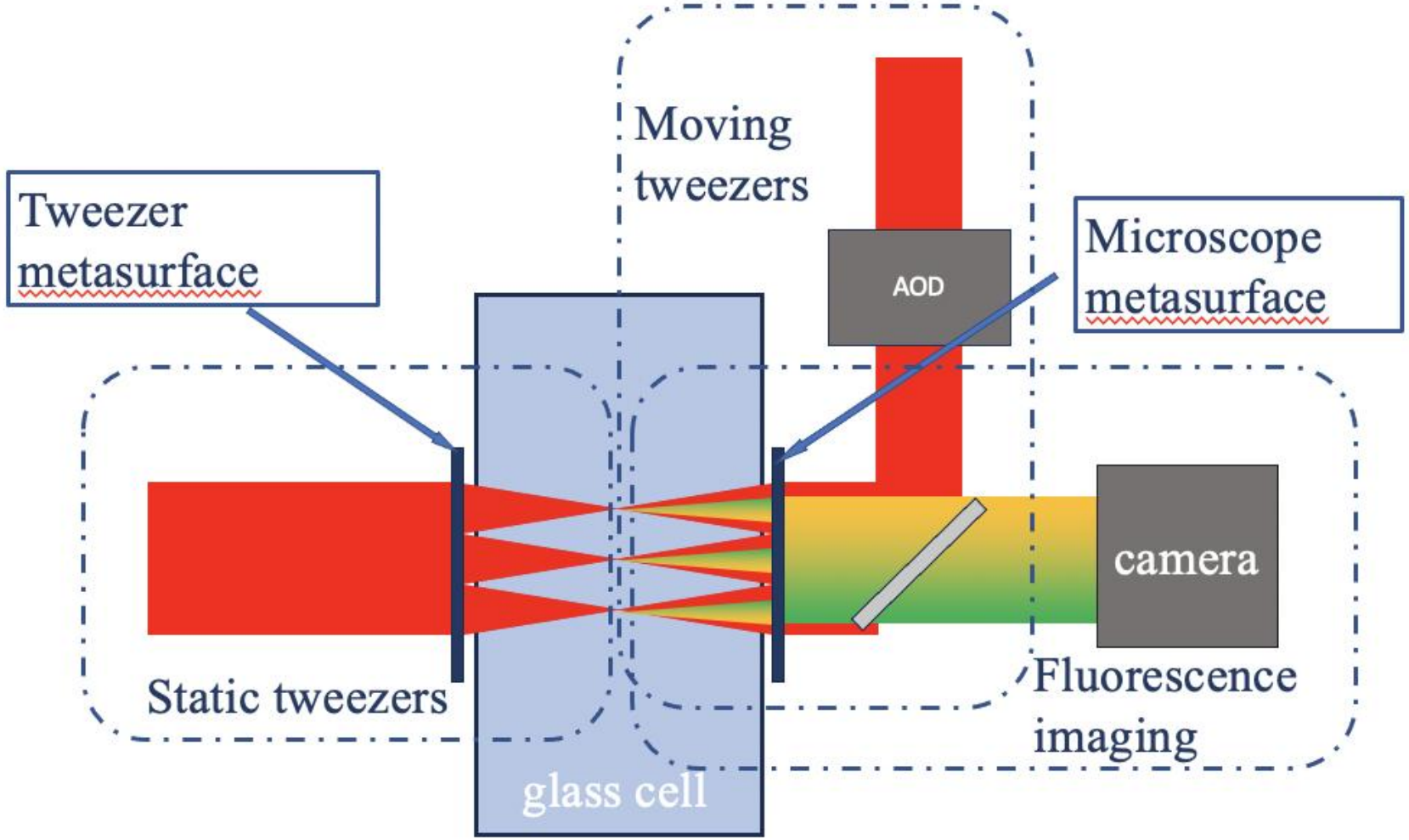
⇩

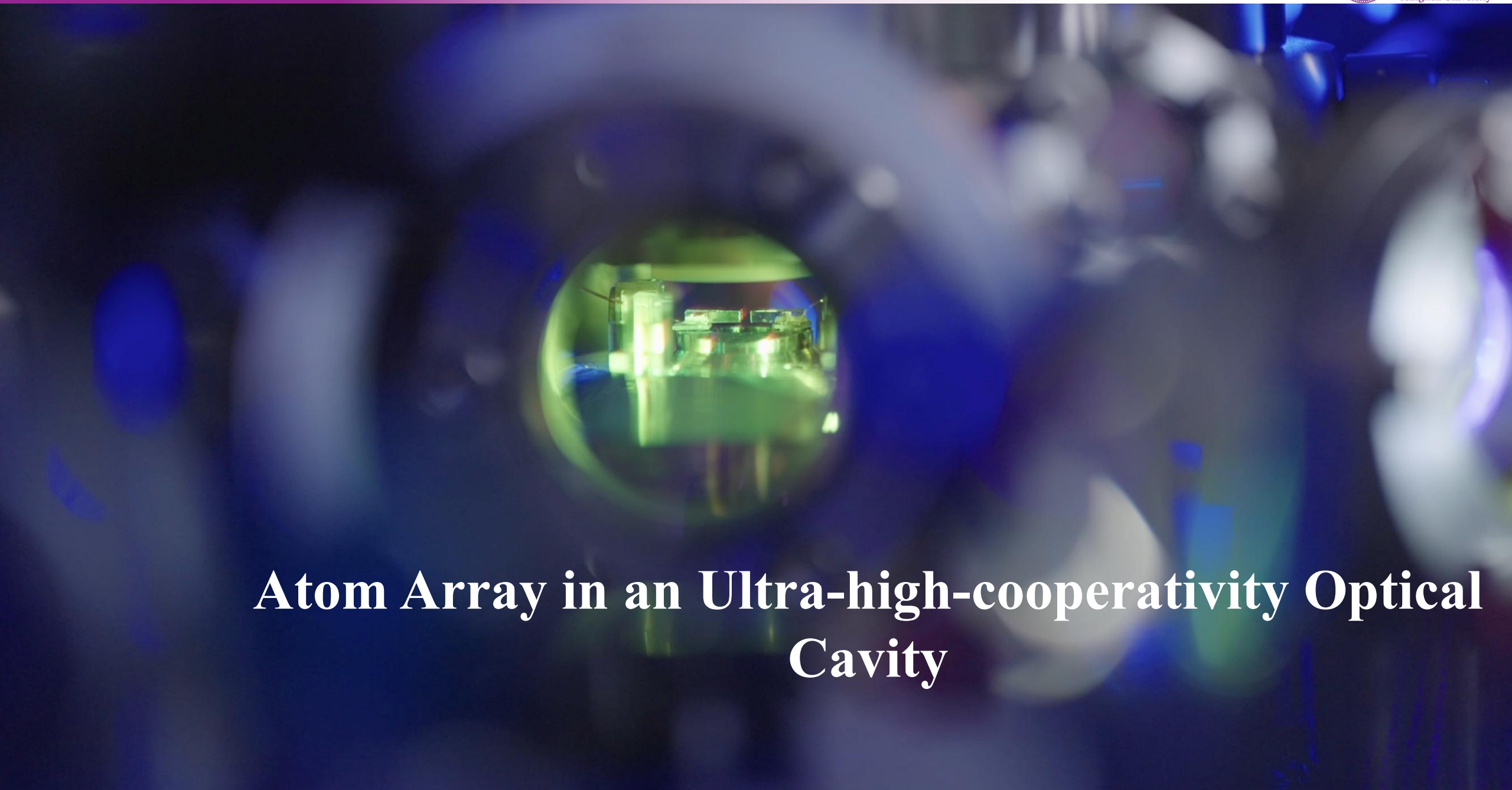
>12.2W (15 W)

0.67mW (0.8 mW) per tweezer

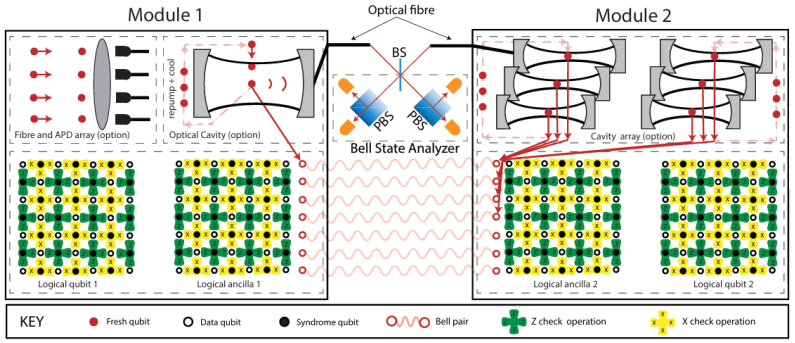
0.4 mK (0.3 mK)

08 Possible solution for moving tweezers



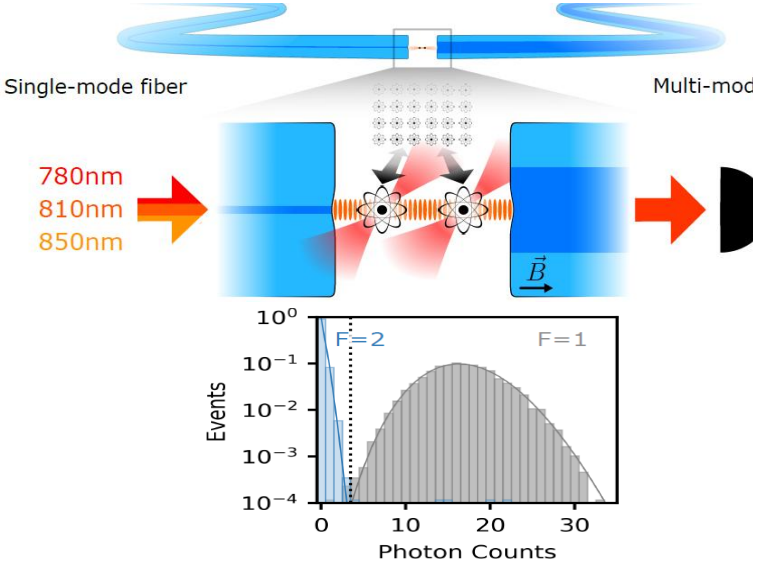


Atom Array in an Ultra-high-cooperativity Optical Cavity



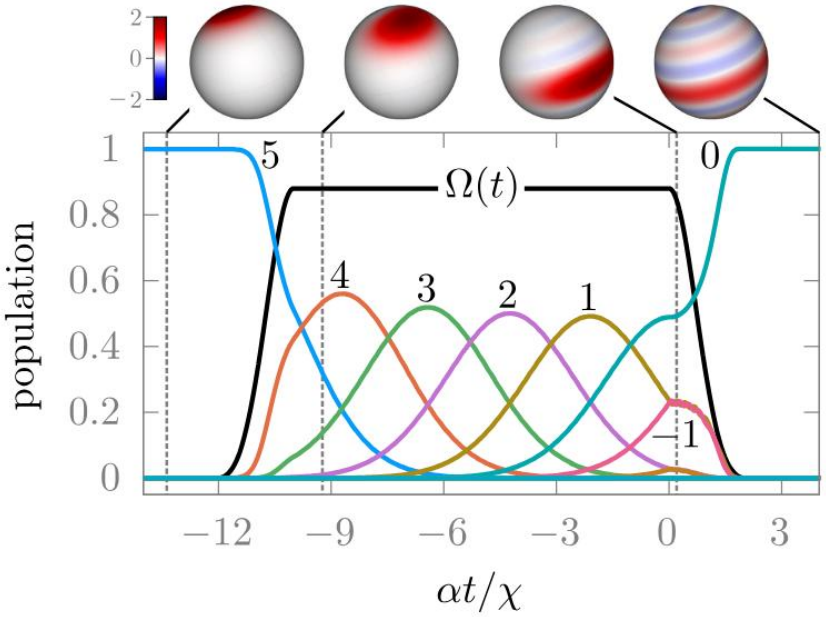
Phys. Rev. Research **7**, 013313 (2025)

Error-corrected quantum networking



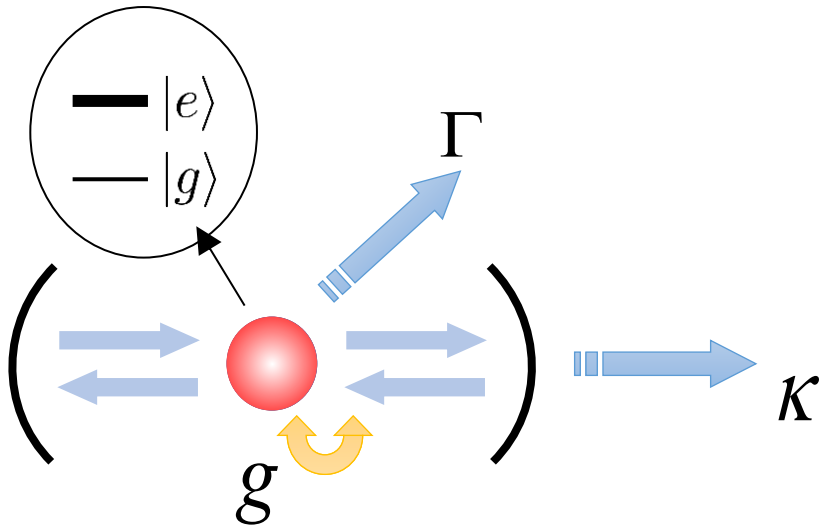
Science **387**, 1301 (2025)
Phys. Rev. Lett. **134**, 240802 (2025)

Quantum state measurement



Nature Physics **20**, 1648 (2024)
Phys. Rev. Lett. **132**, 153603 (2024)
Phys. Rev. Lett. ***136***, *120401 (2026)*

Entanglement engineer

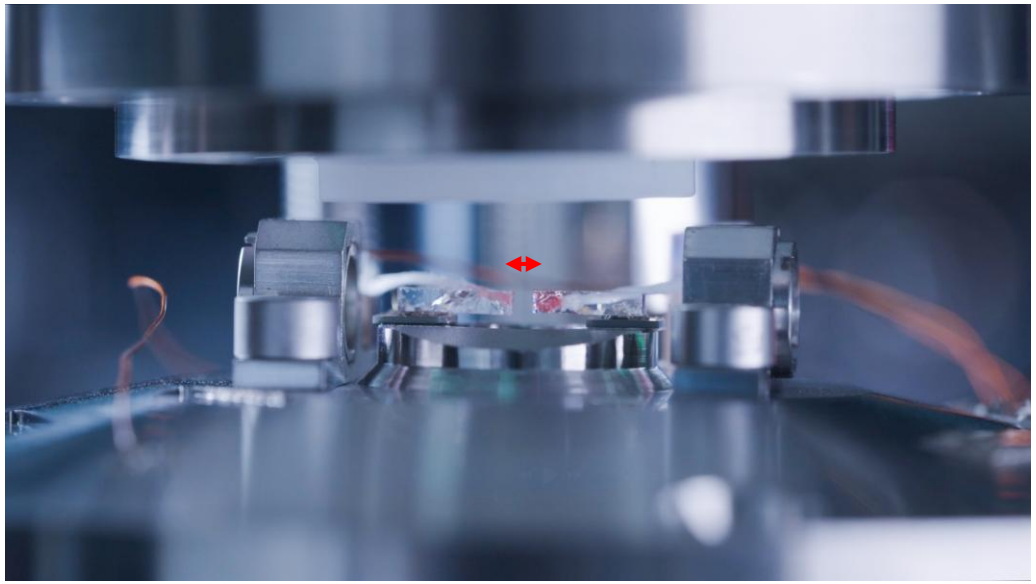


$$\eta = \frac{4g^2}{\kappa\gamma} = \frac{24\,\mathcal{F}}{\pi\,k^2 w^2}$$

g : Single-photon Rabi frequency
γ : Atomic linewidth
κ : Cavity linewidth

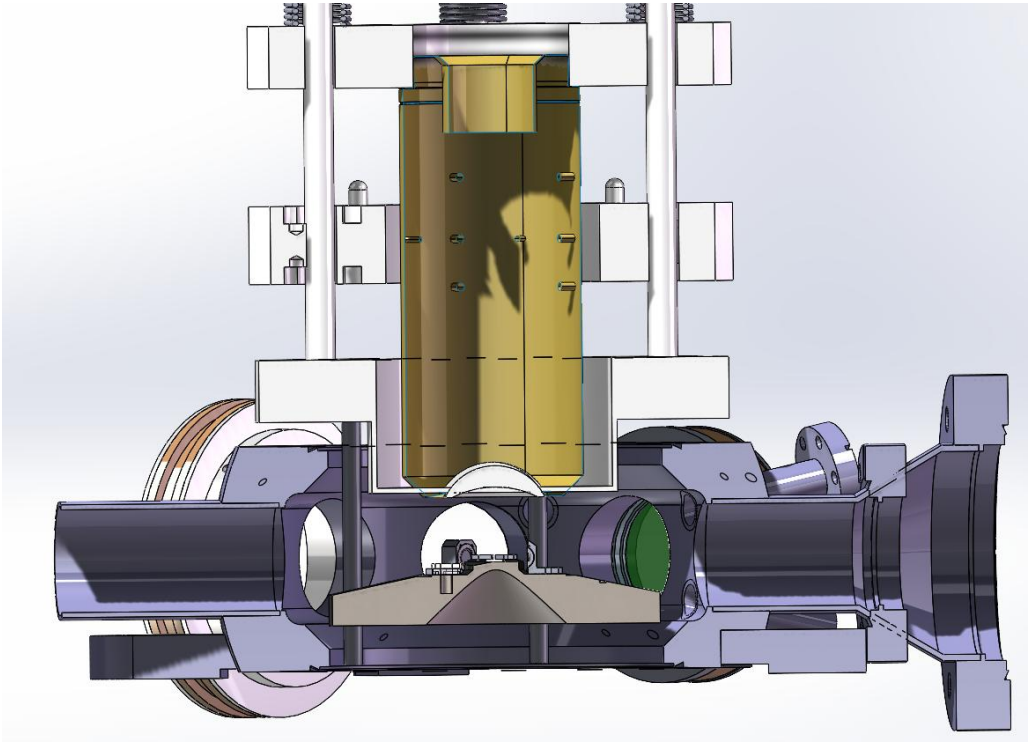
$N\eta \gg 1 \rightarrow \eta \gg 1$

Atomic ensemble
→
atoms in tweezer array



Microscope NA： 0.65

Field of view： 100 μm



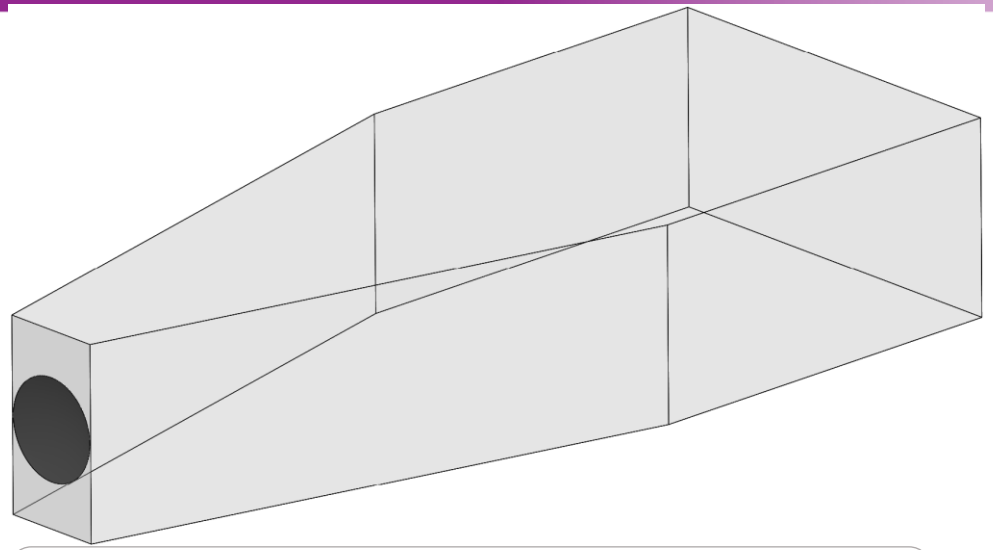
Y. Tian et al, Opt. Expr. 30, 36912 (2022)

High-cooperativity cavity

+

Atoms in tweezers arrays (N~100)

13 Home-made cavity mirrors



Radius of curvature: 1mm

Rayleigh Length: 371μm

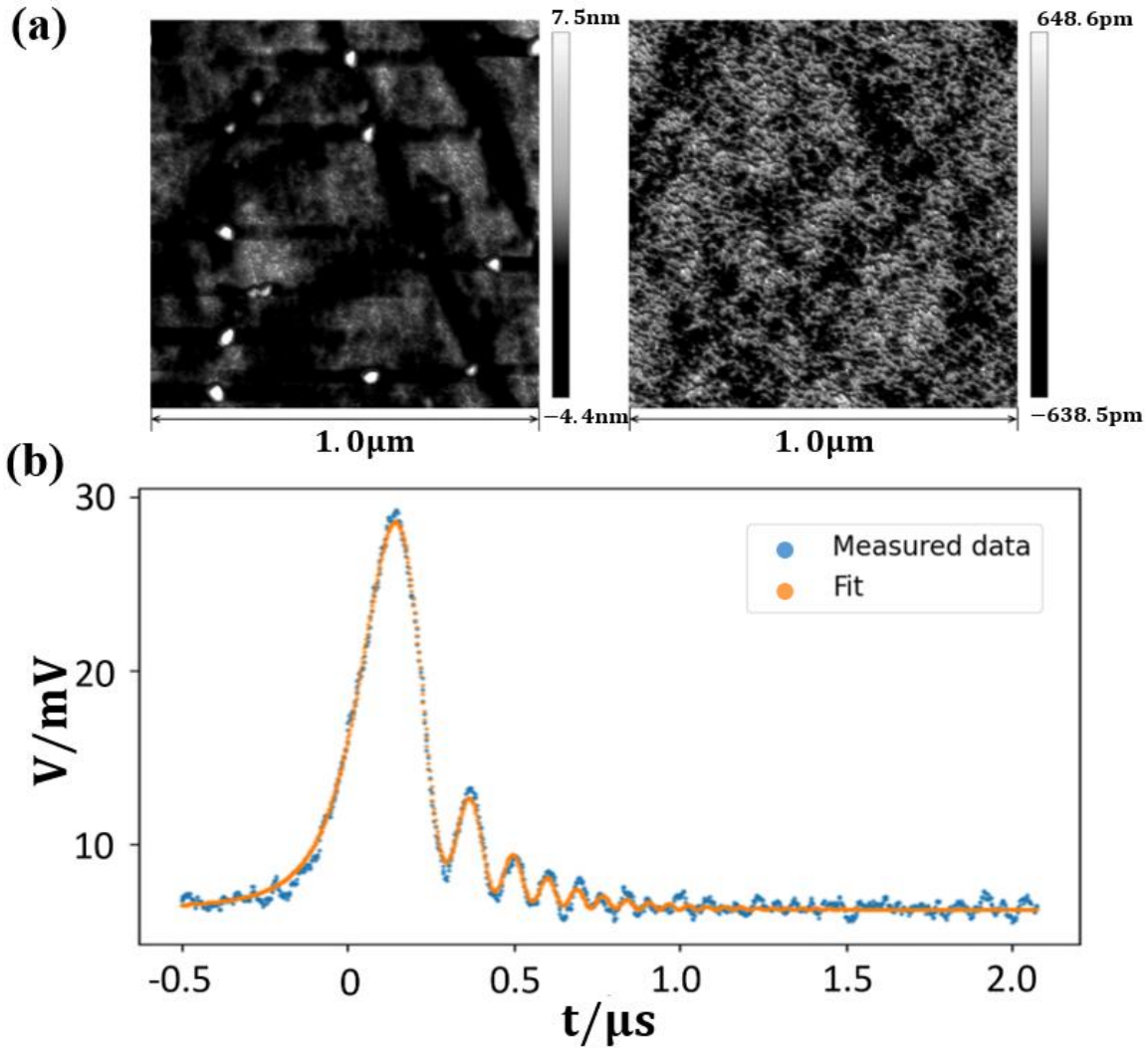
Cavity Length: 1.667mm

Cavity Decay Constant: $2\pi \times 0.916$MHz

Cavity Finesse: 0.98×10^5

Cavity waist(@780nm): 9.6μm

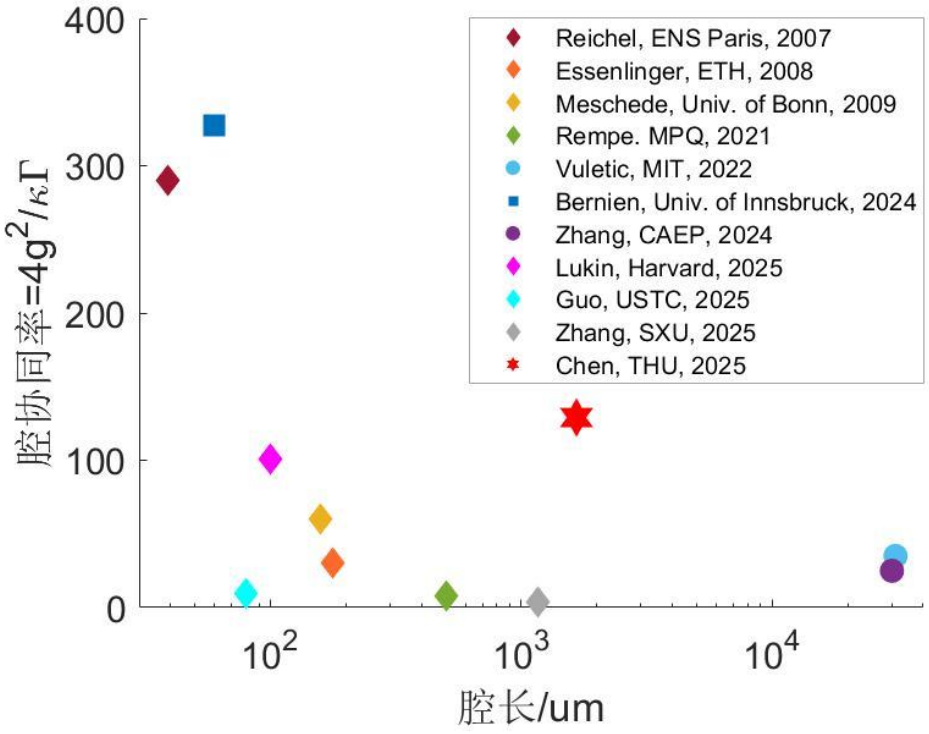
Cooperativity(@780nm): 125

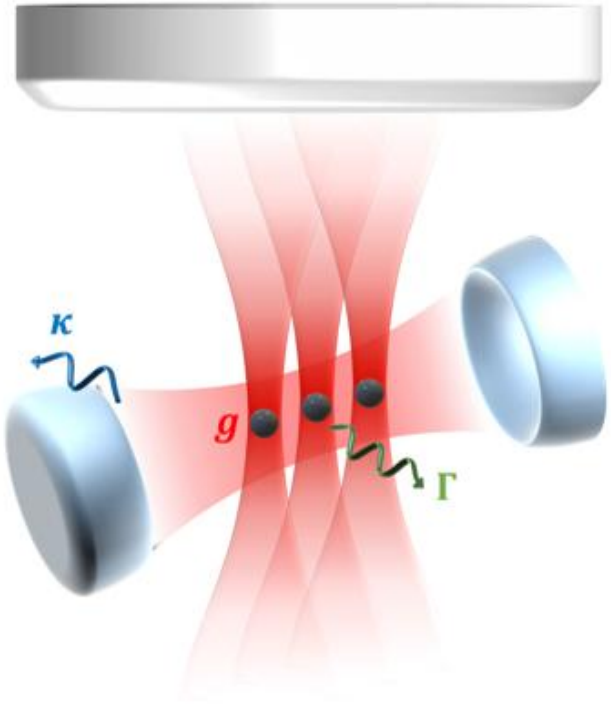


Jakob Reichel group, Applied Physics Letters 89, 111110 (2006)

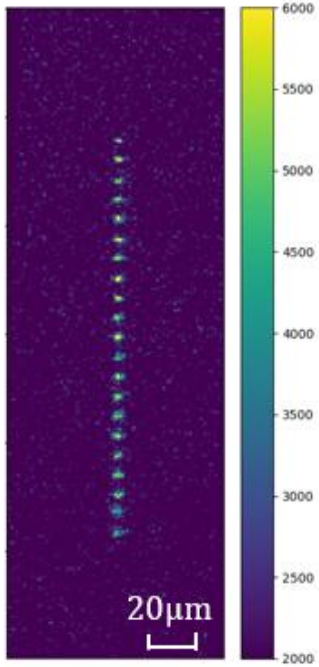
Atom array in the high-cooperativity cavity

- Optical cavity cooperativity **125**
- Individually controller atom number **20**

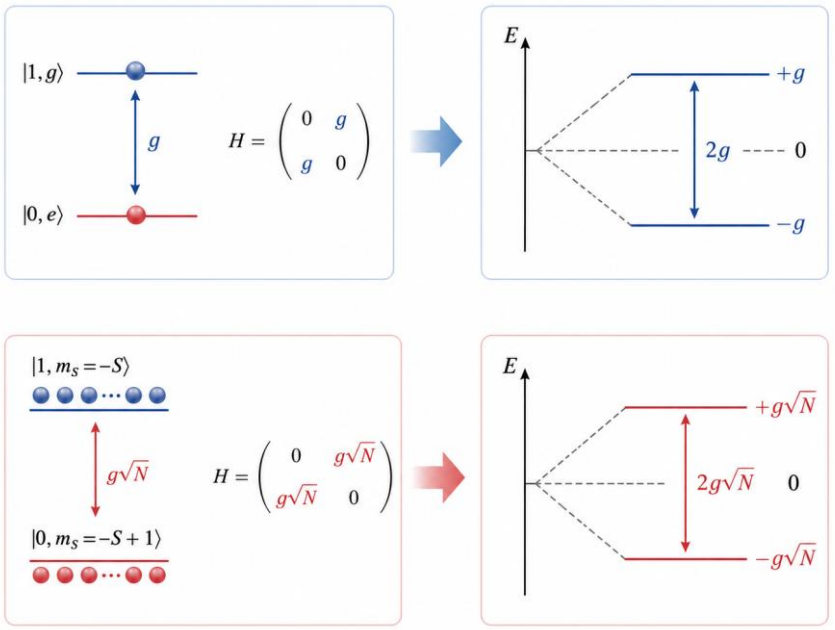


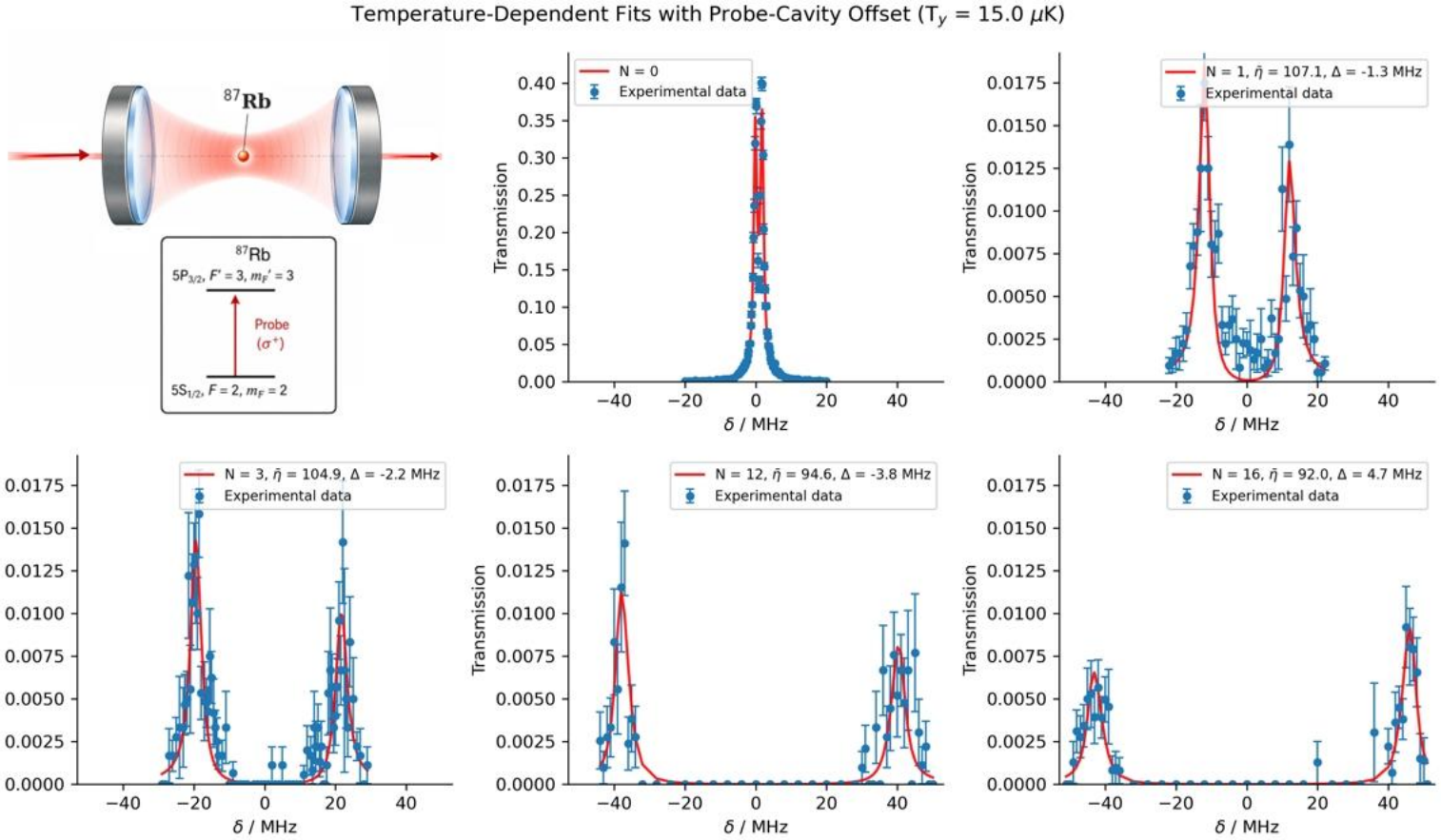


(c)

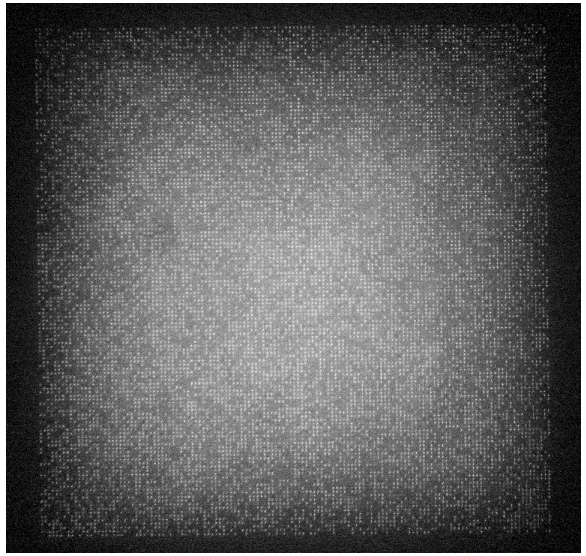


- Atom observed cooperativity >**100**
- **16** individually controlled atoms coupled to the cavity antinode



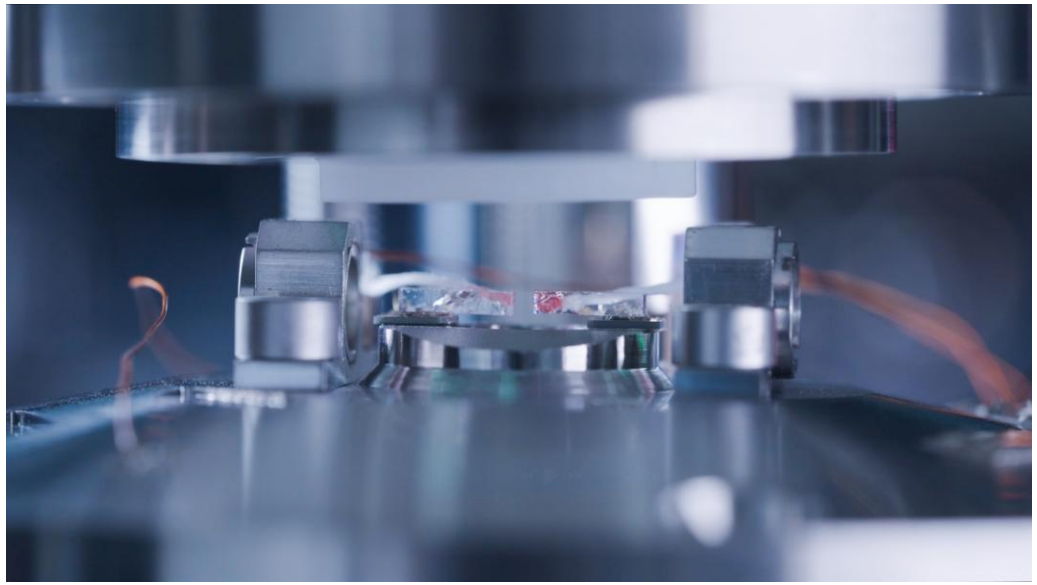


To appear on arXiv soon



Metasurface

- Stable loading of over **11,000** single atoms
- Metasurface is practical and **power-efficient** to **directly** generate static tweezer array



Atom array in the high-cooperativity cavity

- Optical cavity cooperativity **125**
- Individually controller atom number **20**

Hui Zhai
Tsinghua

Yingfei Gu
Tsinghua

Jiazhong Hu
QSCGBA

Xue Feng
Tsinghua

Chengshu Li
Hanteng Wang
Yajuan Zhao
Ye Tian
Jilai Ye
Zhihao Chi
Shuyao Mei
Xiaoyu Li
Luming Ma
Hefan Chen

Wenjun Zhang
Tao Zhang
Yuqing Wang
Zhongchi Zhang
Ziqi Li
Angrui Du
Yujia Wu
Yushuo Huang
Yuxuan Liao
Binjie Ji
Youjia Huang

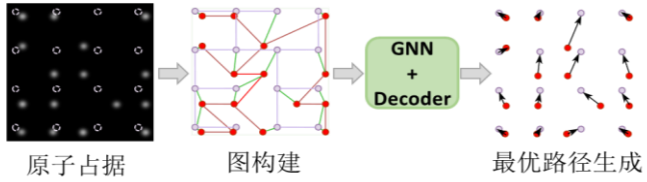
www.ultracold.cn

Tsinghua University

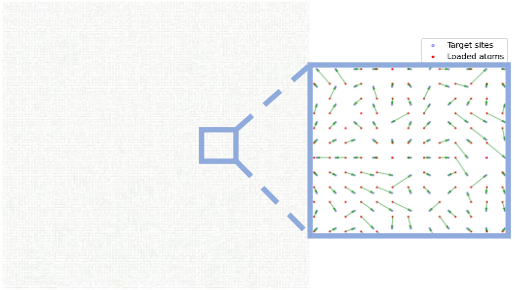
已开发耗时小于**15毫秒**的万原子无缺陷阵列重排算法，包括路径规划和相位生成部分

路径规划

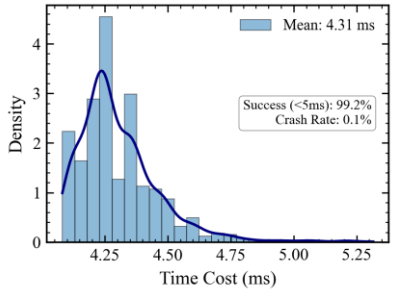
流程：



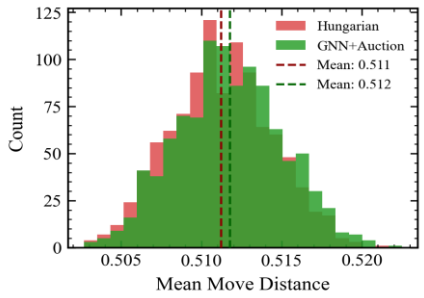
原子占据　图构建　最优路径生成

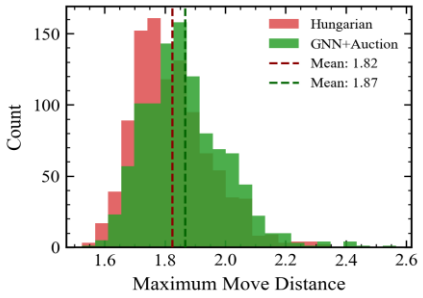


万原子重排的路径规划结果



算法耗时分布：5ms成功率＞99%

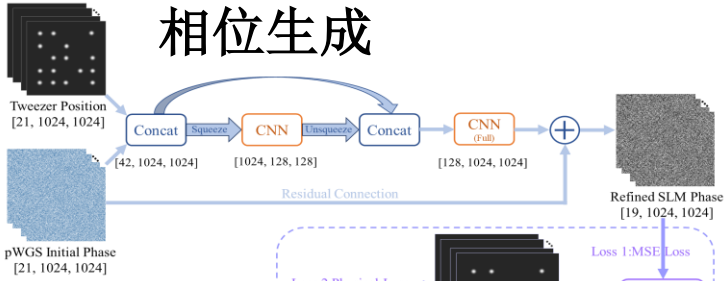


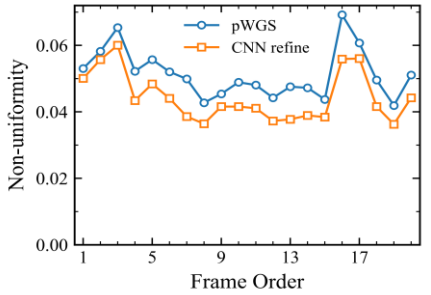


万原子比特规模下，我们的路径规划算法相较于全局最优的匈牙利算法，耗时缩短3000倍的同时，平均移动距离和最大移动距离仅分别相差0.1%和3%

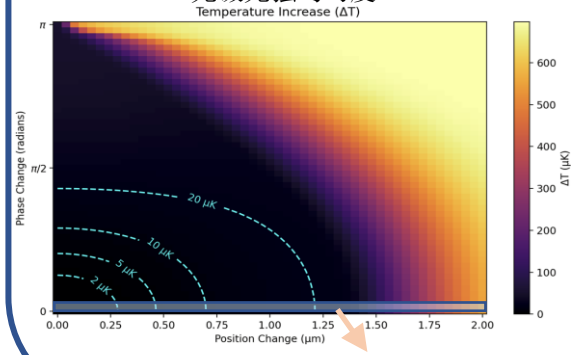
相位生成

流程：

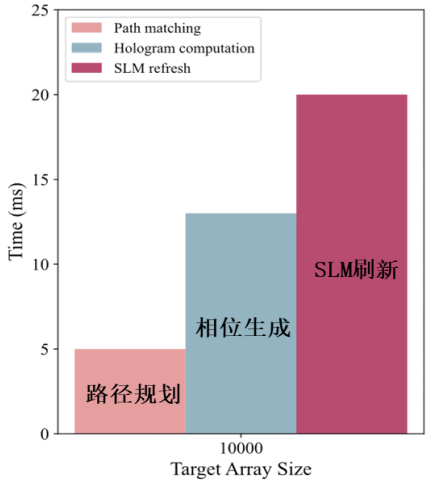




光镊光强均匀度



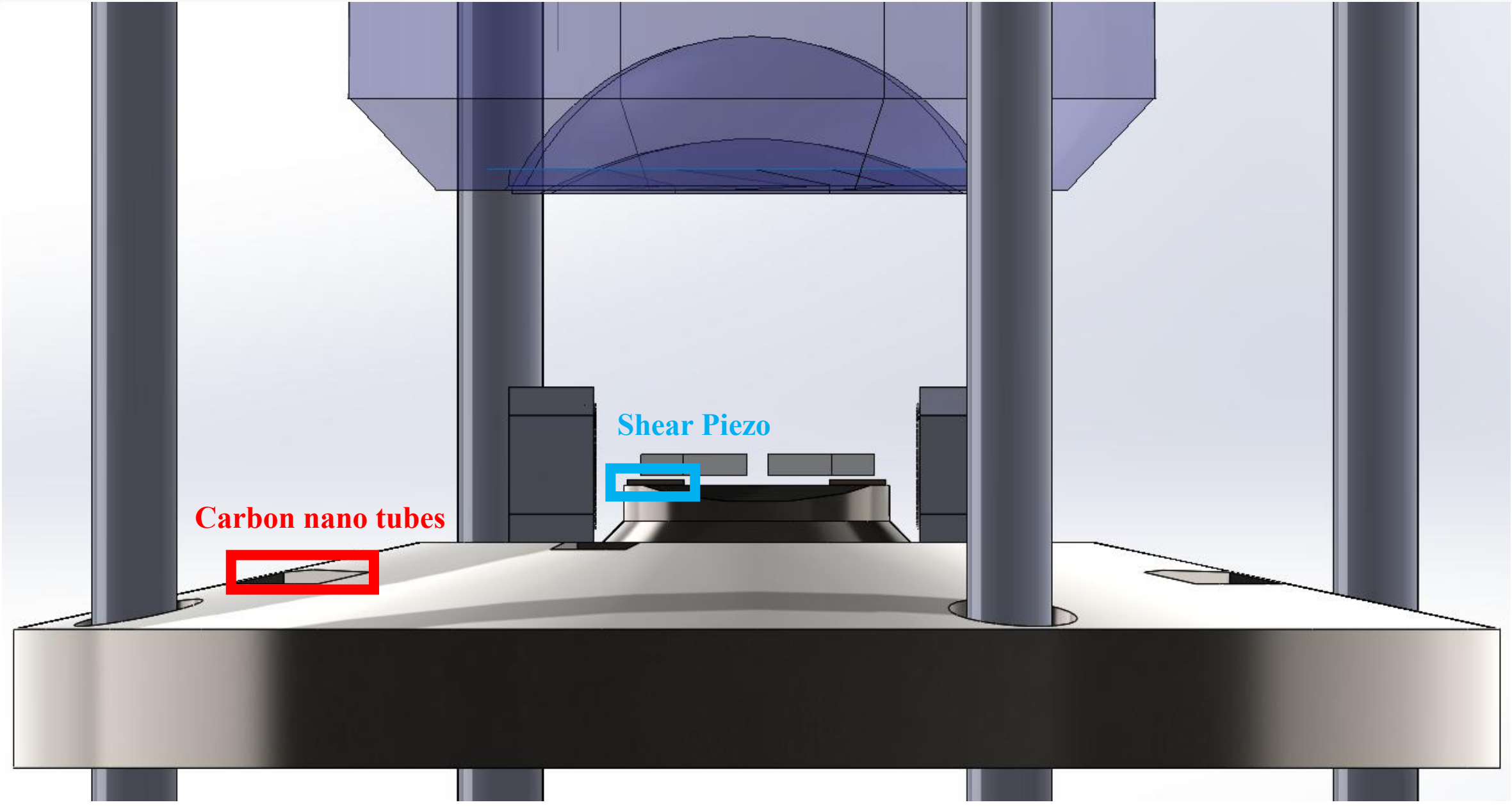
相位生成算法连续性：$\Delta\phi < 0.03\pi$



耗时受限于SLM刷新率，而非算法

T. Zhang et al, arXiv:2604.08669 (2026)

Designs of the cavity

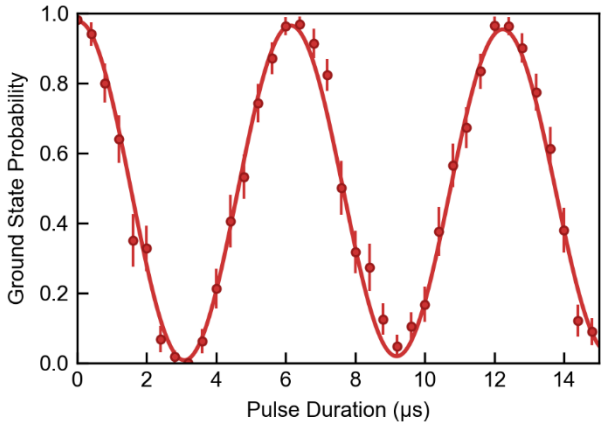


SPAM fidelity **97%**

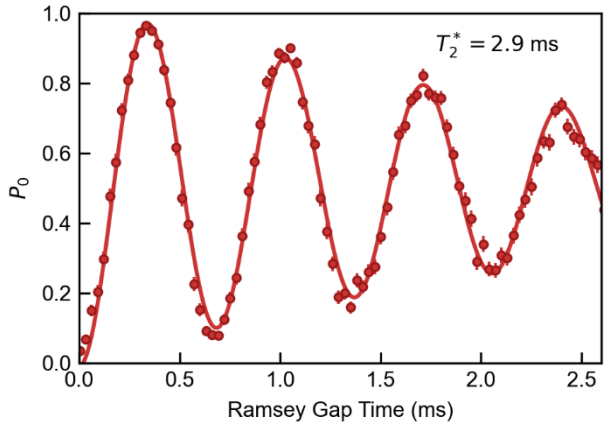
Single qubit gate fidelity **99.93%**

- Ground state T_2^* **2.9** ms

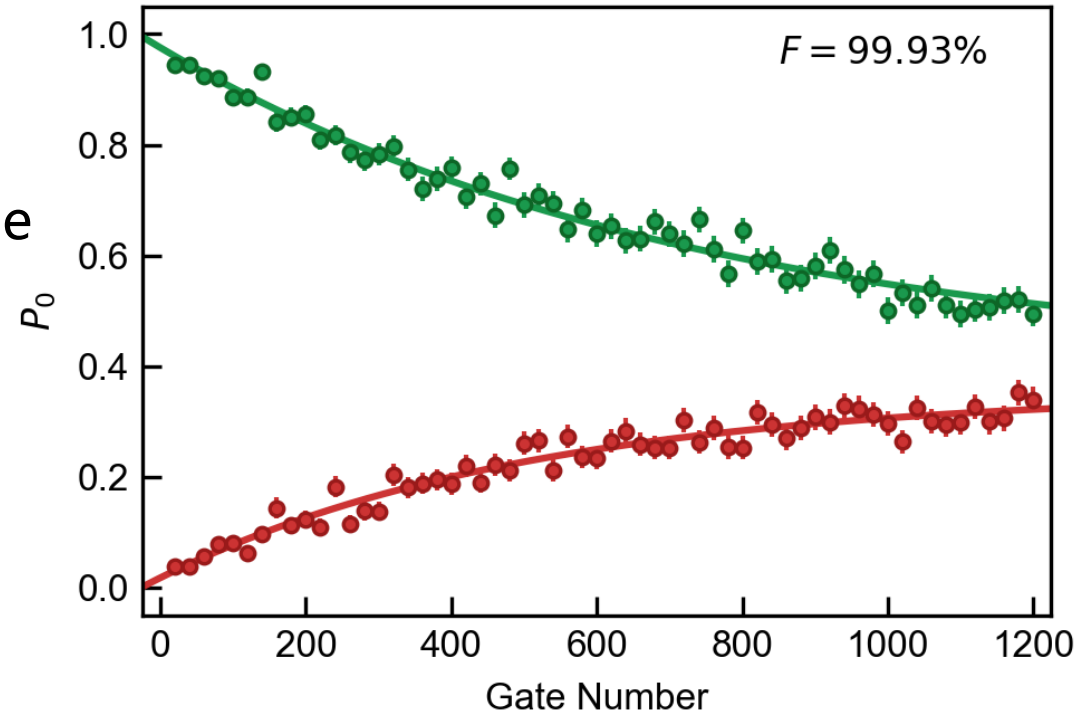
Rabi oscillation



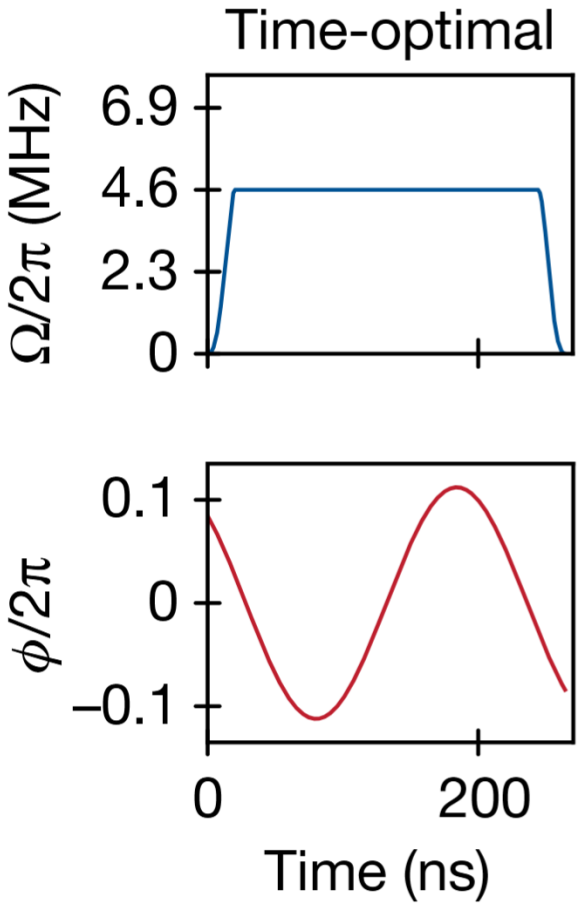
Ground state coherent time

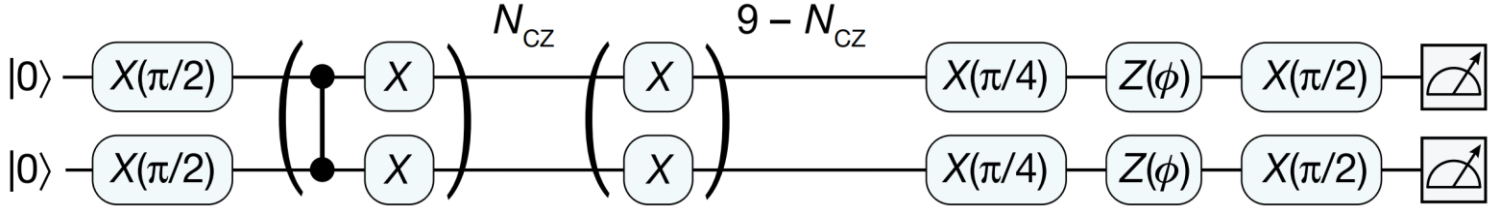


Single qubit gate fidelity



Two qubit gate fidelity **99.50(6)%**





两比特门保真度