
Fast SLM Rearrangement

SUMMARY OF SUMMER RESEARCH

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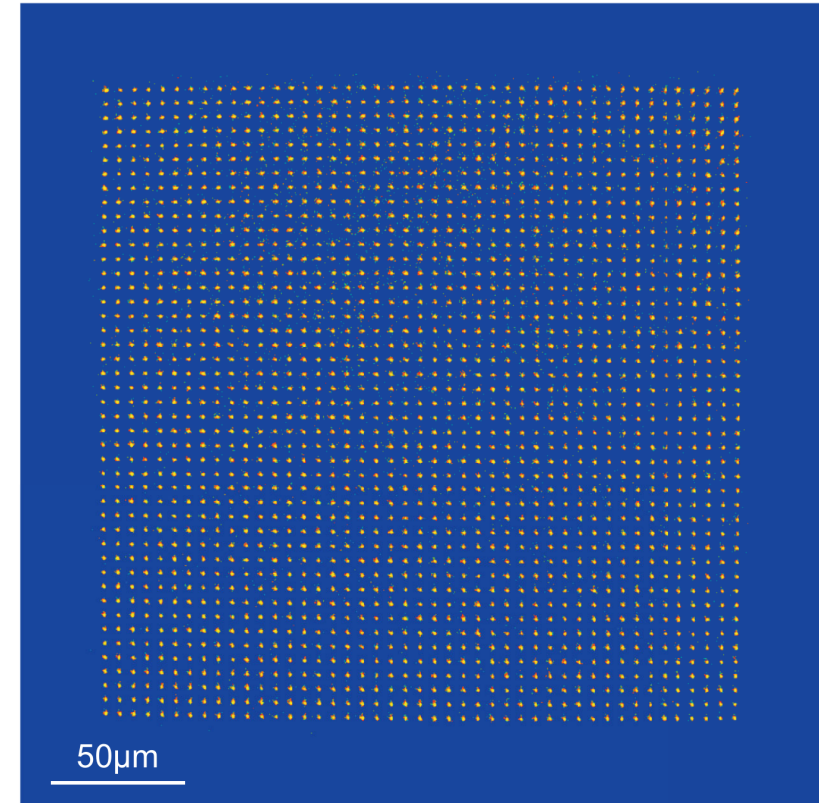
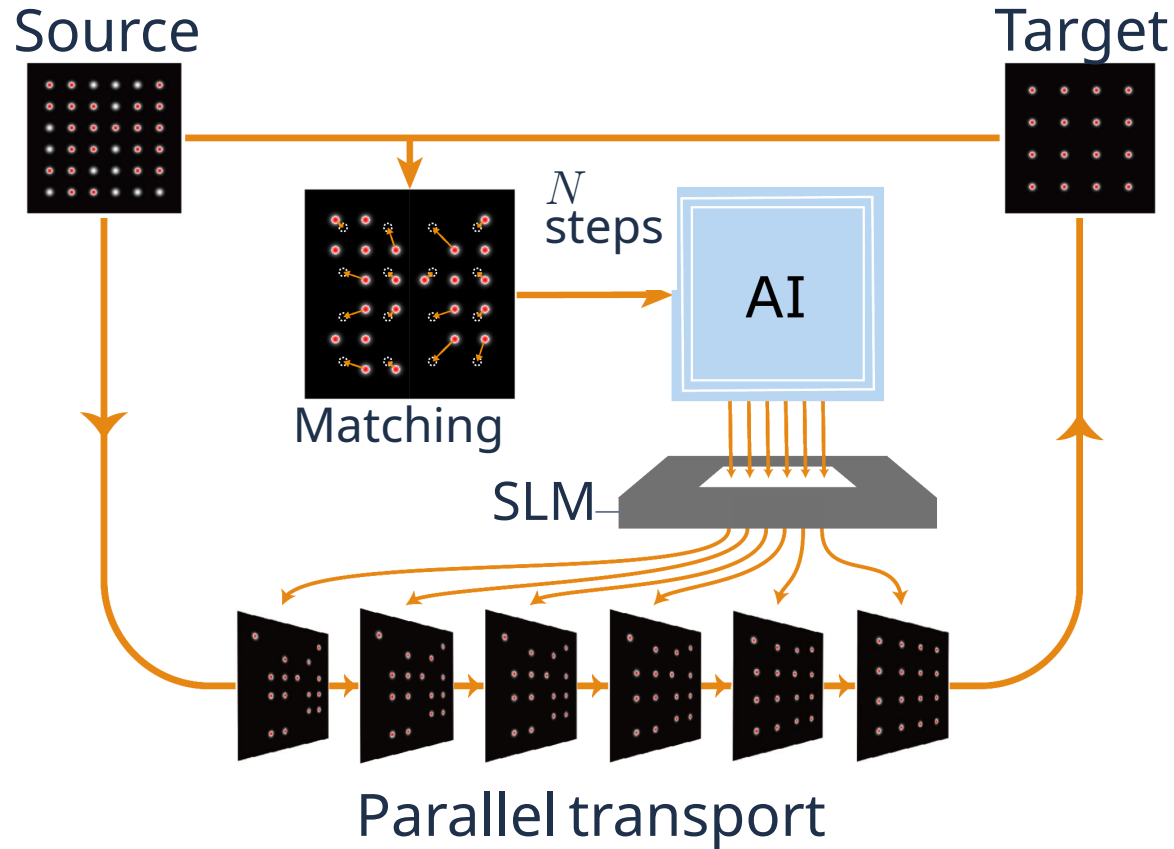
September 10th



Background: AI-enabled parallel rearrangement

Parallel transport with an SLM

2,024 atoms 60 ms

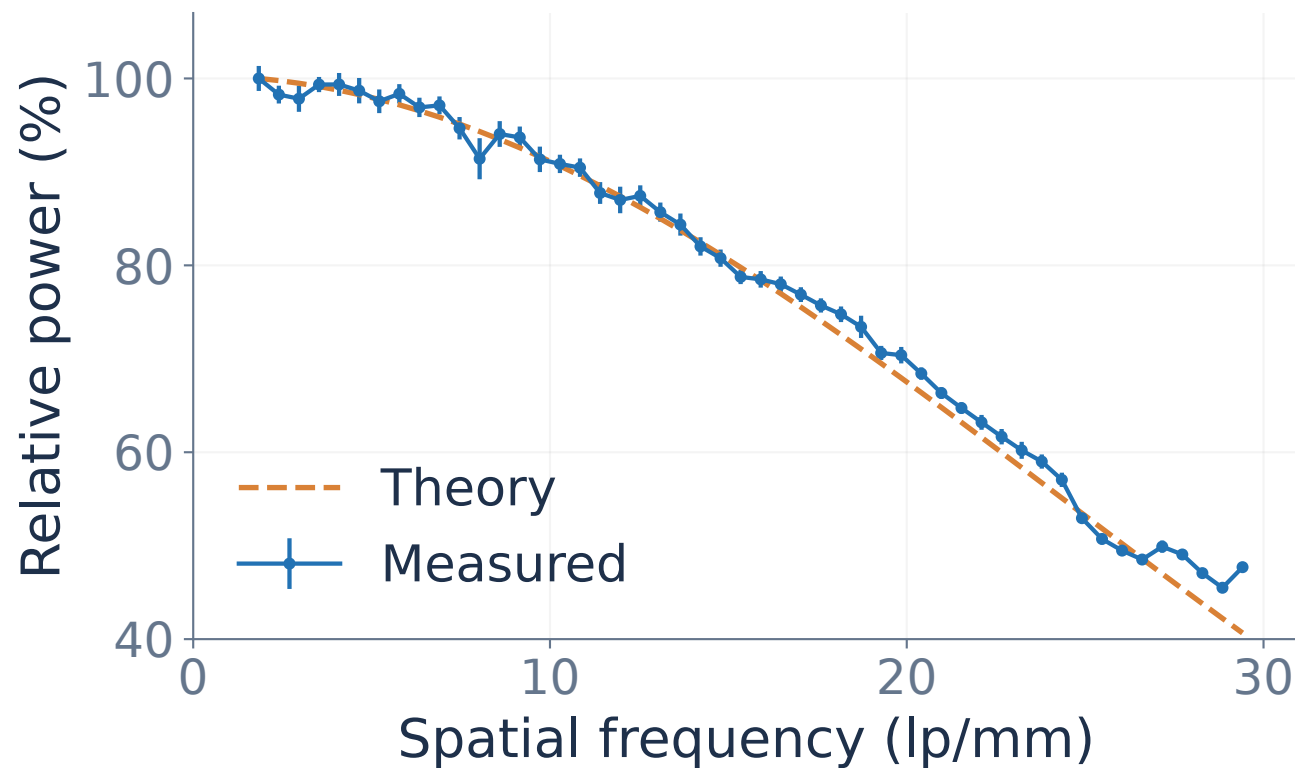


Control both position and phase during every step.

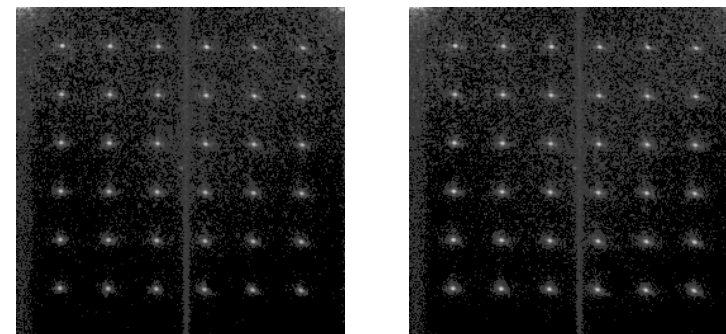
Lin et al., *Phys. Rev. Lett.* 135, 060602 (2025). Figures 1 and 4(a).

Fast SLM test: diffraction efficiency

852 nm • 50 spatial frequencies • 7 repeats per point



Intensity correction



Before

After

Common display gamma: 0.5

Spatial CV 6×6 array

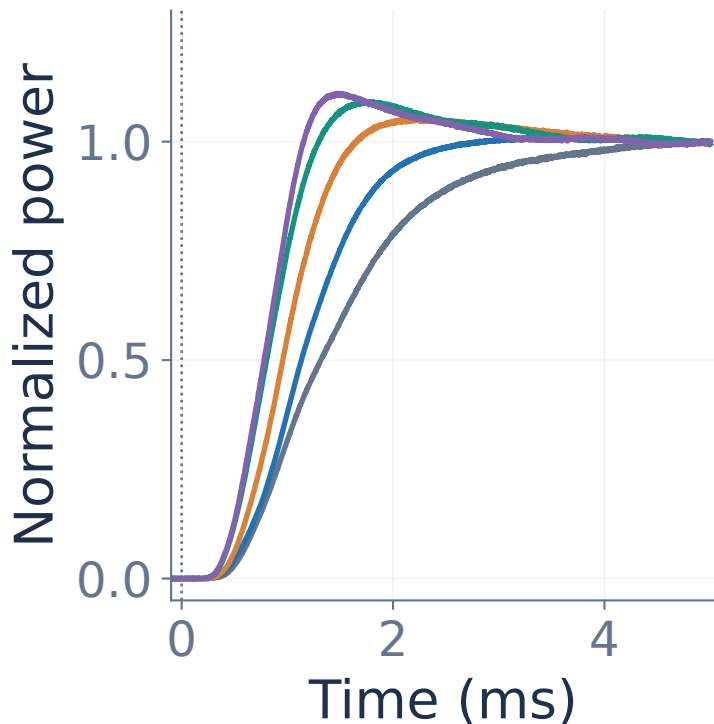
16.14% → 5.34%

First-order power, normalized to the zero-frequency reference. Error bars: repeatability (1σ).

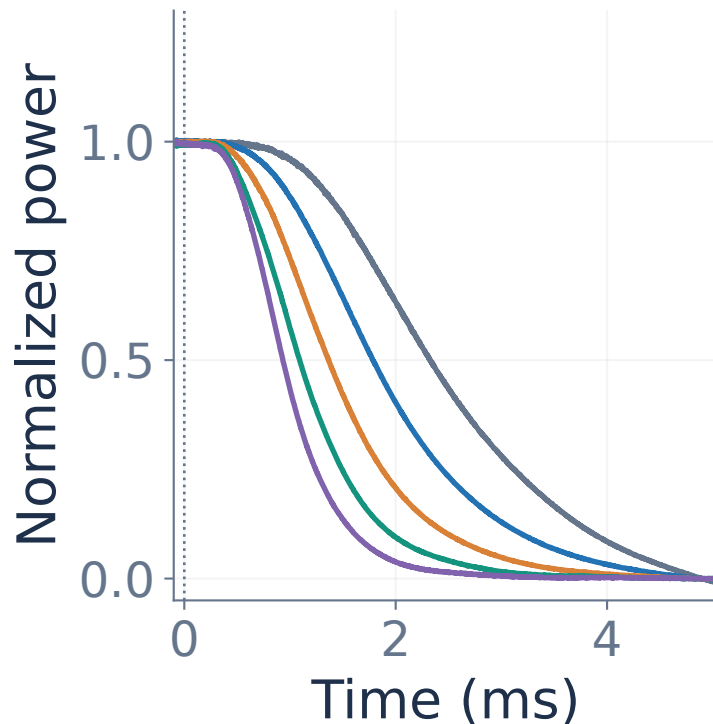
Fast SLM test: response time and fluctuation

Single trap • Five temperatures • 100 transitions per direction

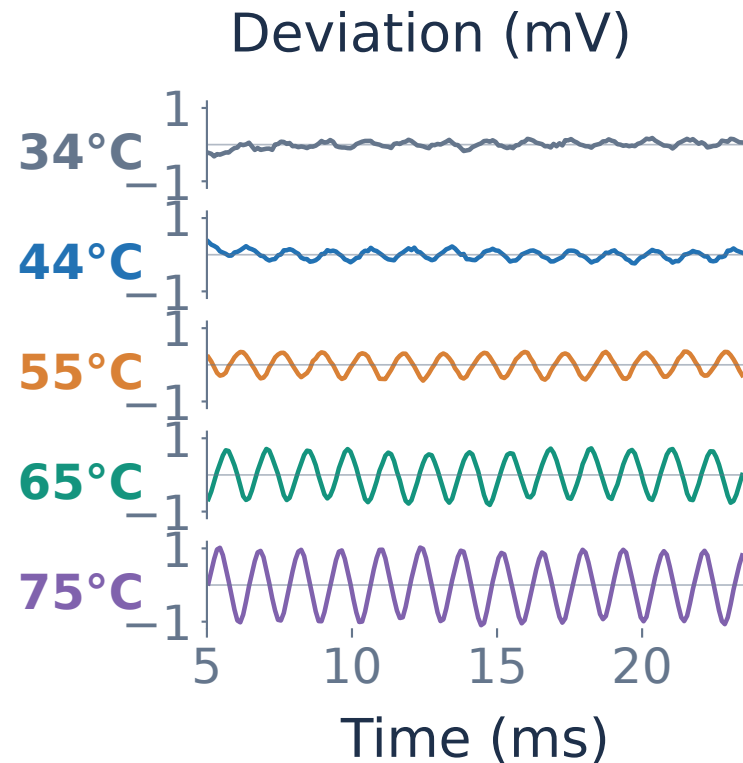
Dark → bright
34 °C 44 °C 55 °C 65 °C 75 °C



Bright → dark



Fluctuation

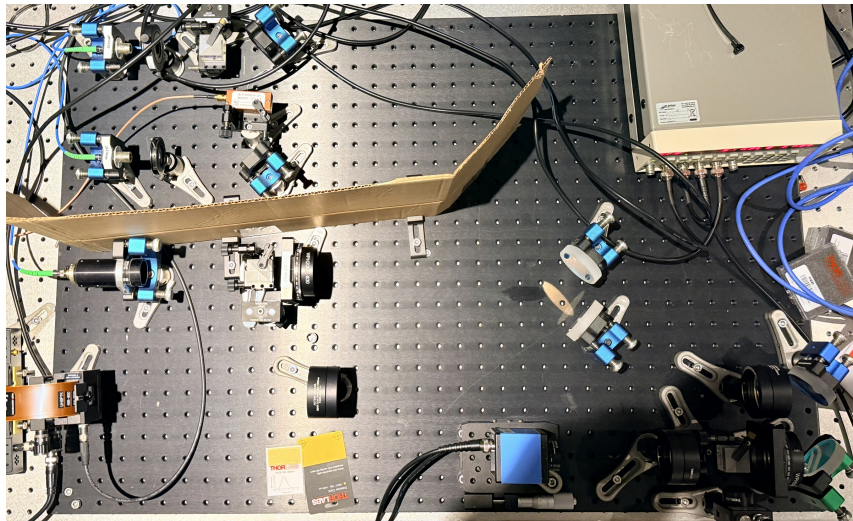


Faster switching at higher temperature; larger steady-state fluctuation.

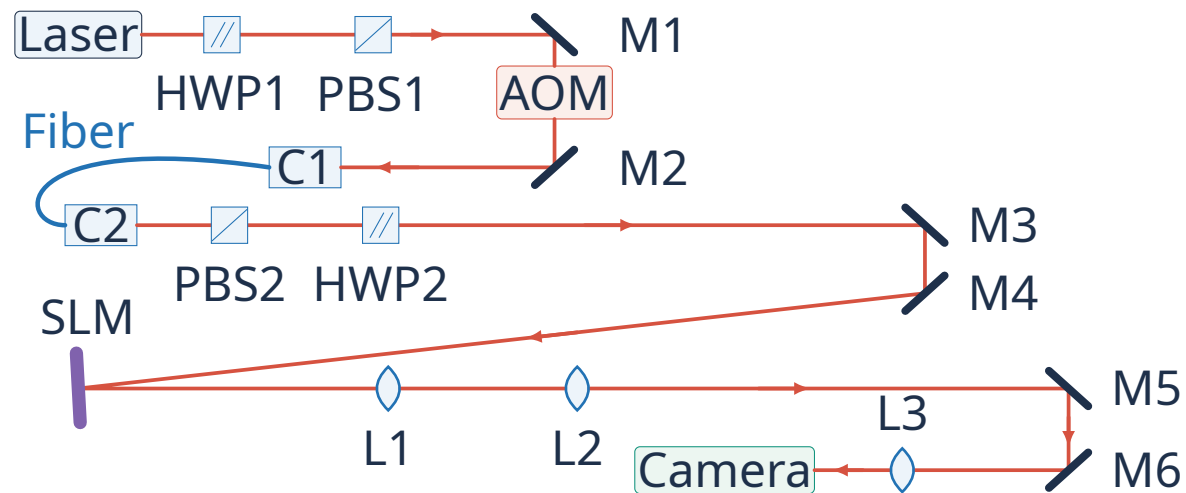
Fixed 35 °C LUT. Response: mean traces. Fluctuation: 100 μ s averages; common vertical scale.

Optical setup and stroboscopic timing

Optical bench



Beam path



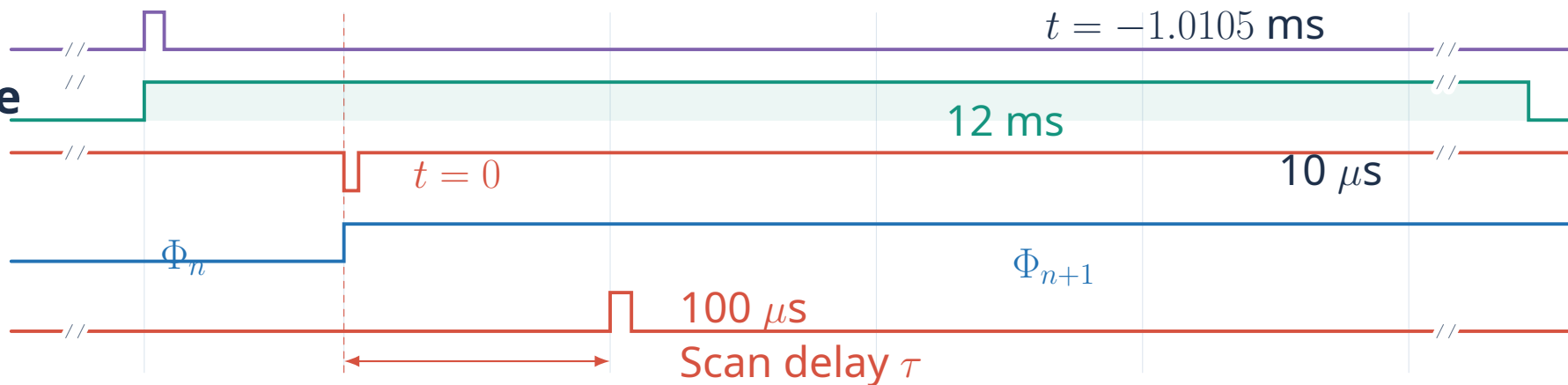
Camera trigger

Camera exposure

SLM trigger

SLM frame

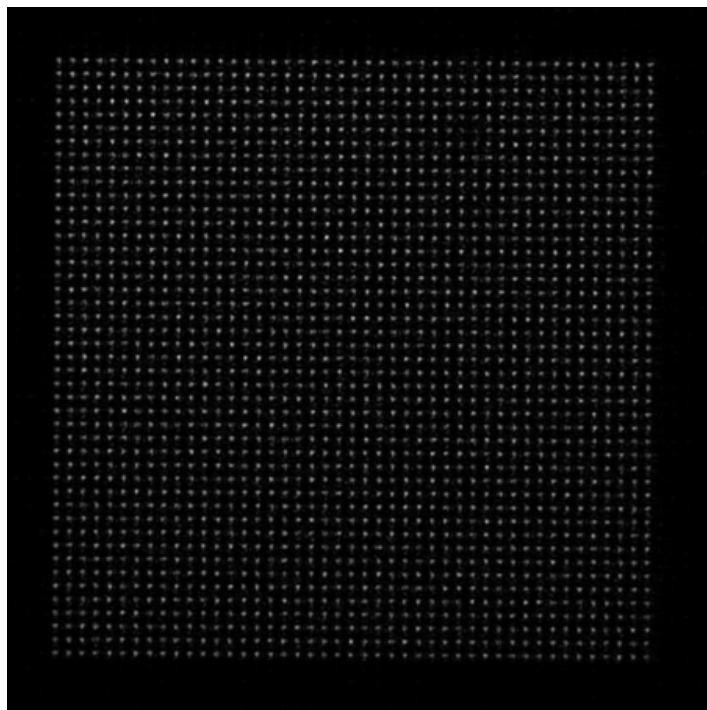
AOM gate



Scan $\tau = -1$ to $+5$ ms; not to scale.

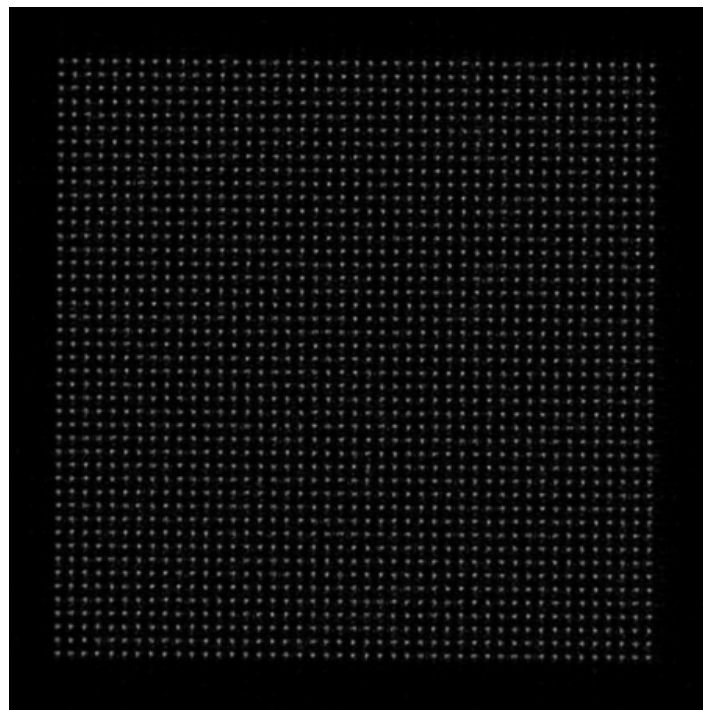
Optical calibration and camera feedback

Before feedback



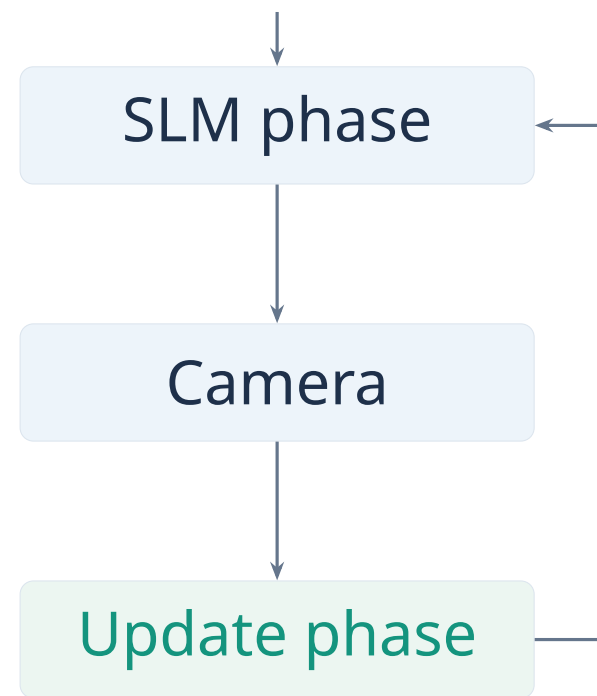
CV **14.52%**

After feedback



CV **0.32–0.37%**

Focus + aberration

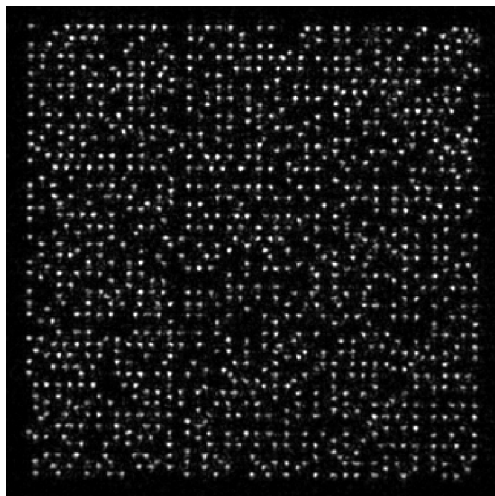


45×45 target; offline

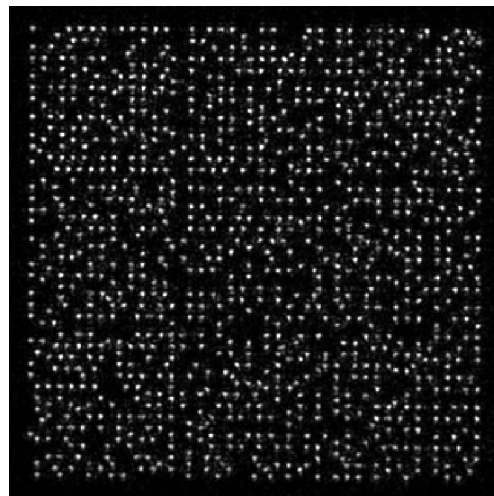
Single frames; common scale. CV: 512 registered + normalized exposures; 3 checks.

Why phase continuity matters

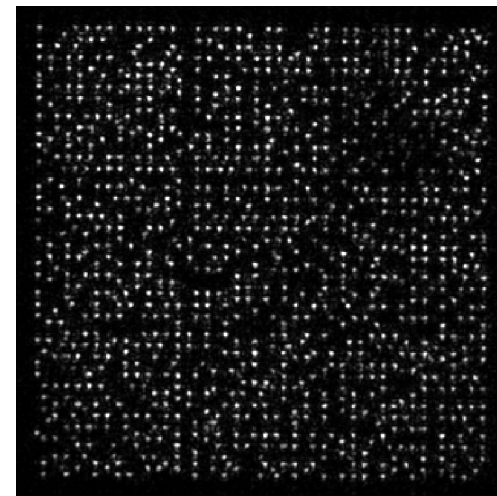
CNN



Dirichlet (3 it.)



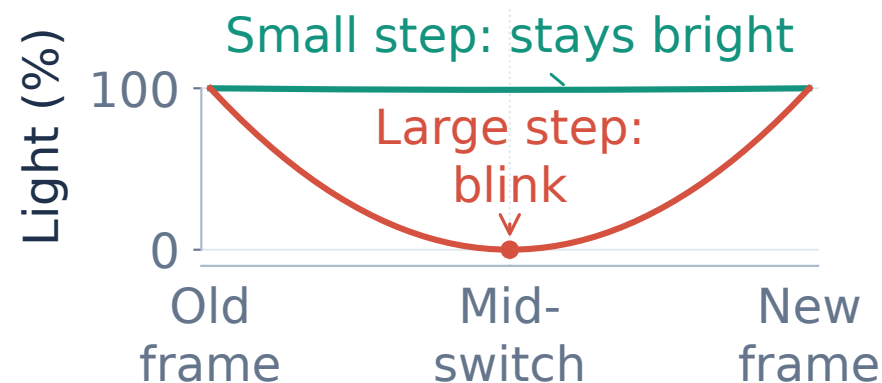
Fast WGS



► Play / restart

Small phase steps reduce blinking.

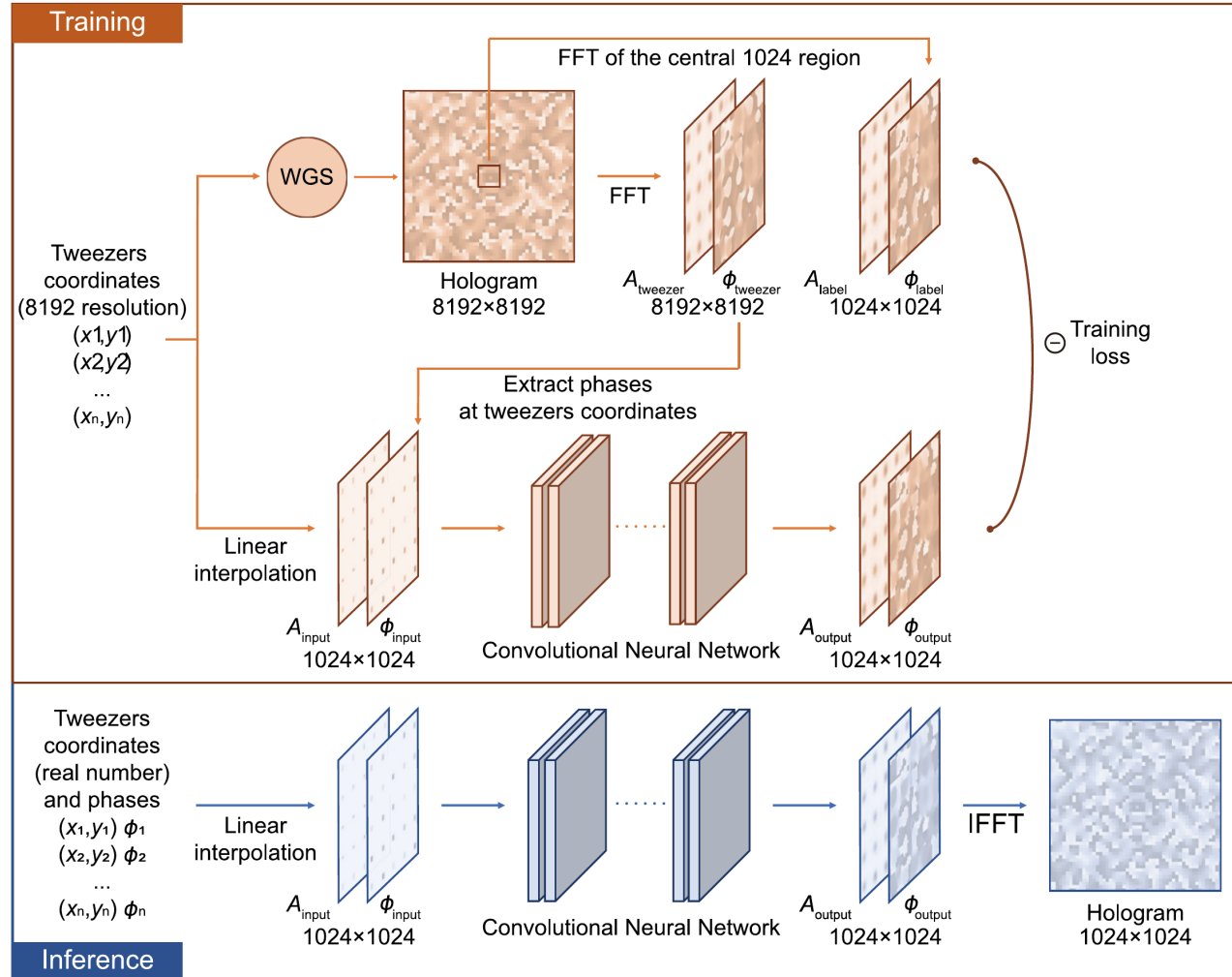
$$I_{\text{mid}}/I_{\text{end}} = \cos^2(\Delta\phi/2)$$



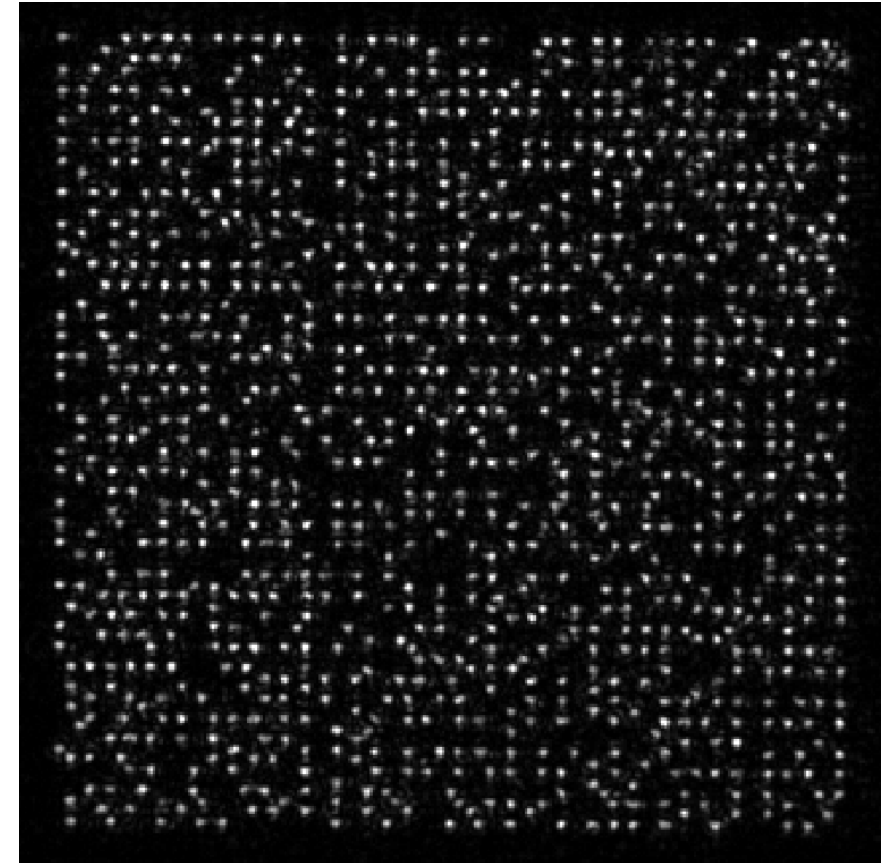
Fast WGS: phase-locked. Equal-field model: Lin et al. (2025).

CNN: training and inference

Inputs **WGS supervision** **CNN prediction**



CNN — camera recording

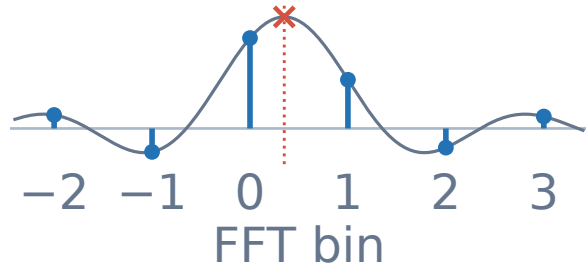


► Play / restart

Dirichlet WGS: subpixel traps in 3 iterations

Place traps between FFT bins

Trap at 0.35 bin



$$D_N(\delta) = \frac{\sin(\pi\delta)}{N \sin(\pi\delta/N)}$$

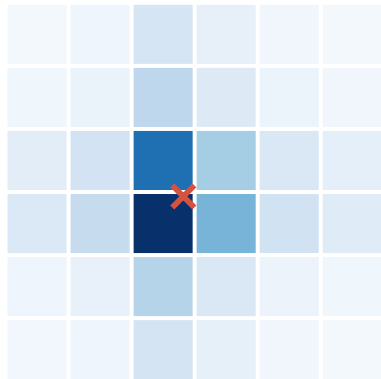
Sample + normalize
6×6 bins → patch K_j

$$\Phi_{\text{SLM}} = \arg \mathcal{F}^{-1} \{ \sum_j w_j e^{i\theta_j} K_j \}$$

Weight w_j

Fixed phase θ_j

Trap patch K_j



6×6 Dirichlet patch

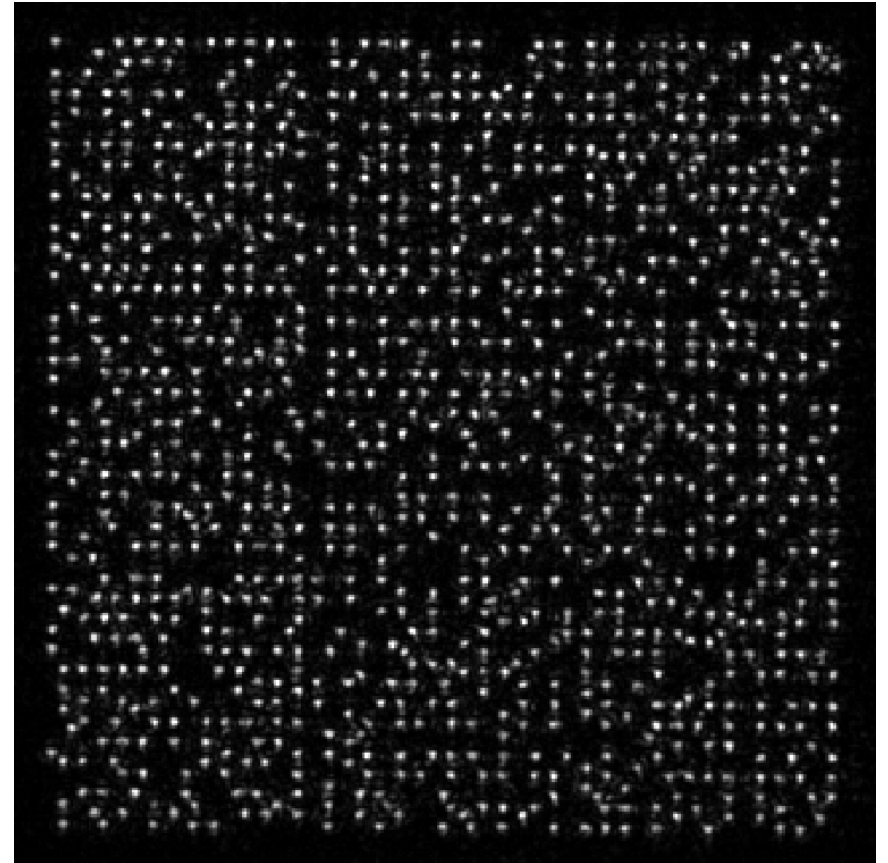
× Trap position

■ Magnitude $|K_j|$

3 weight updates



Dirichlet — camera recording



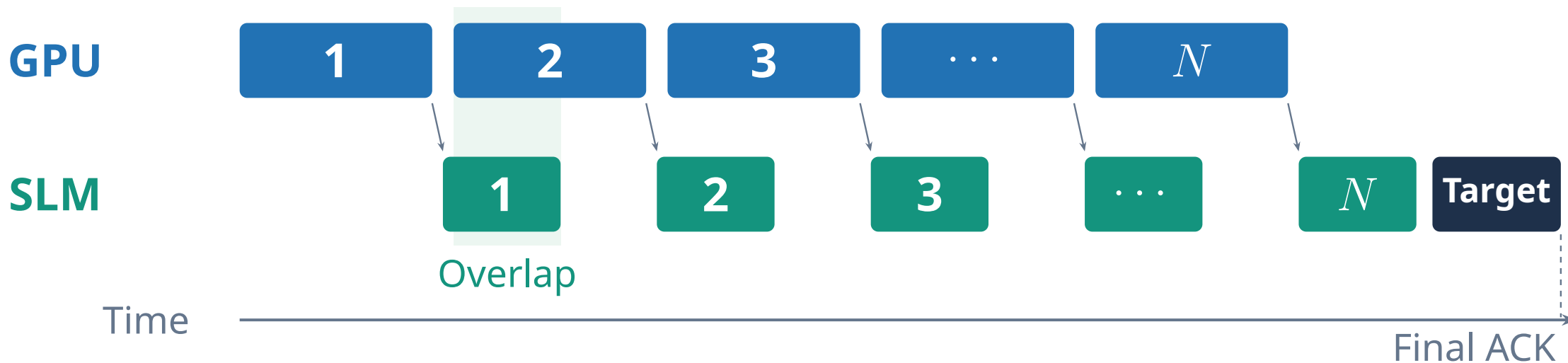
► Play / restart

1,024×1,024 FFT, no padding. Three updates + final synthesis.

From matching to the final SLM frame



Generate frame $n + 1$ while displaying frame n



C++ / CUDA • Asynchronous transfer • Schematic, not to scale

Measured time and transition dynamics

Total time for 2,025 traps Matching → final SLM ACK; median of 30 random loads

CNN **50.11 ms**

22 frames; uncompensated

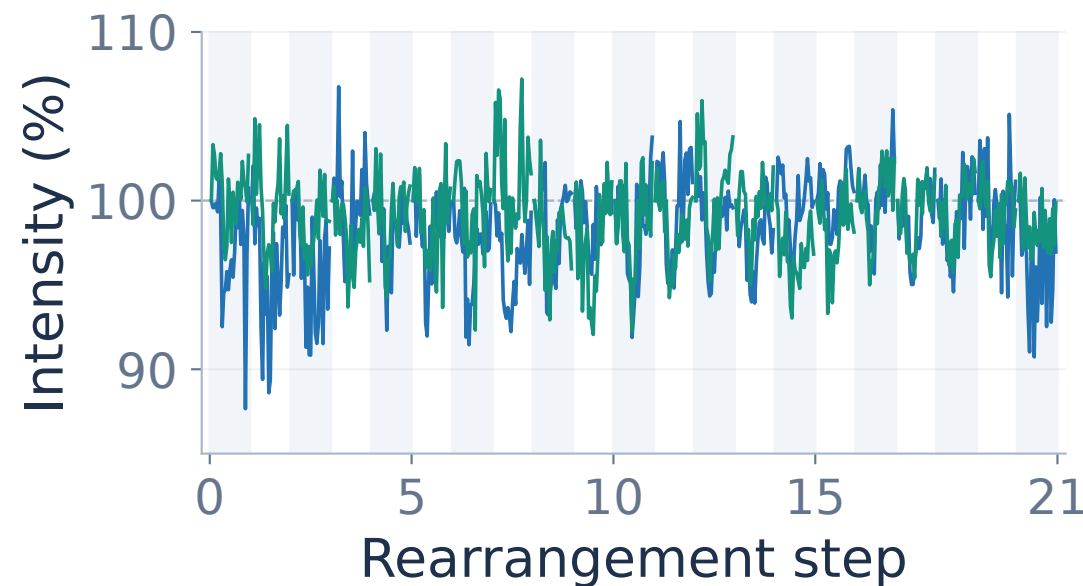
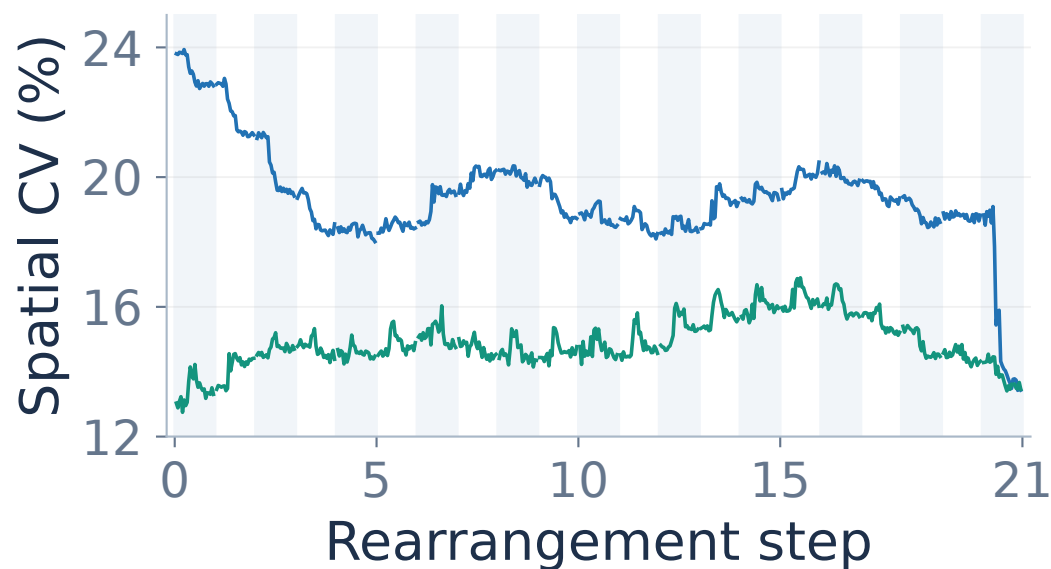
Dirichlet **38.68 ms**

3 iterations; 22 frames; uncompensated

Full rearrangement: 1,024 traps

CNN

Dirichlet (3 it.)

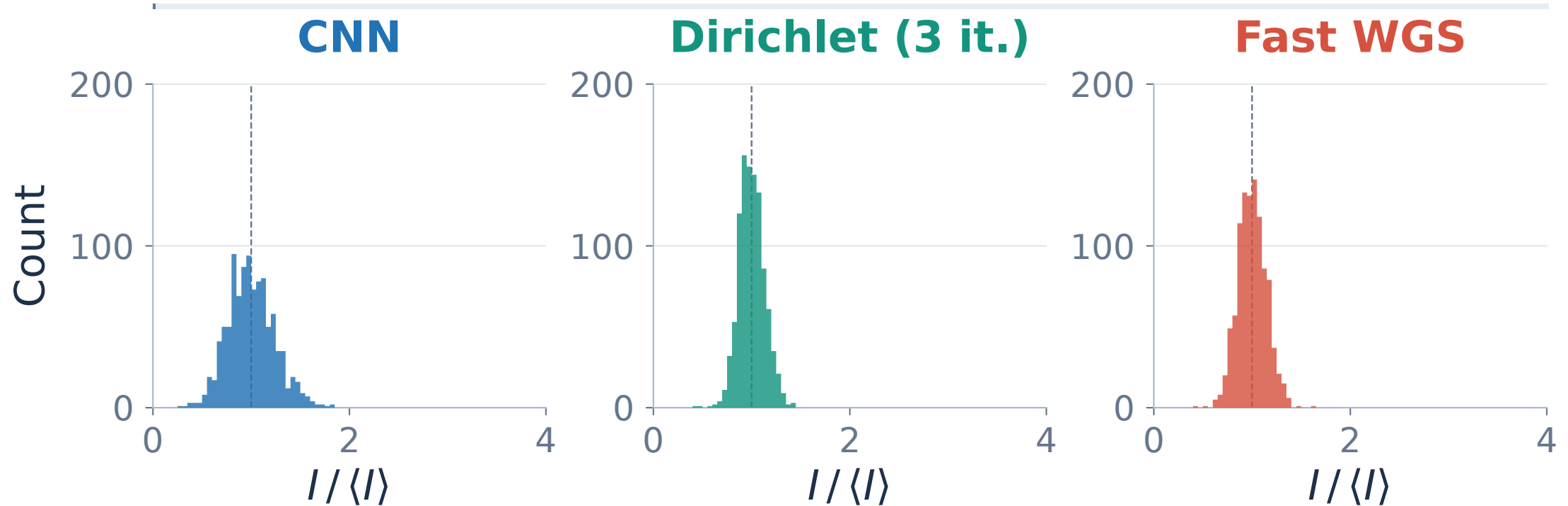


21 steps × 25 samples; independent strobe scans, 100 μ s gate.
Intensity normalized to the pre-trigger level of each step.

Intensity distributions during rearrangement

1,024 traps • Full sequence: 21 steps, 525 captured frames

Step 01 / 21 | Delay -1.00 ms

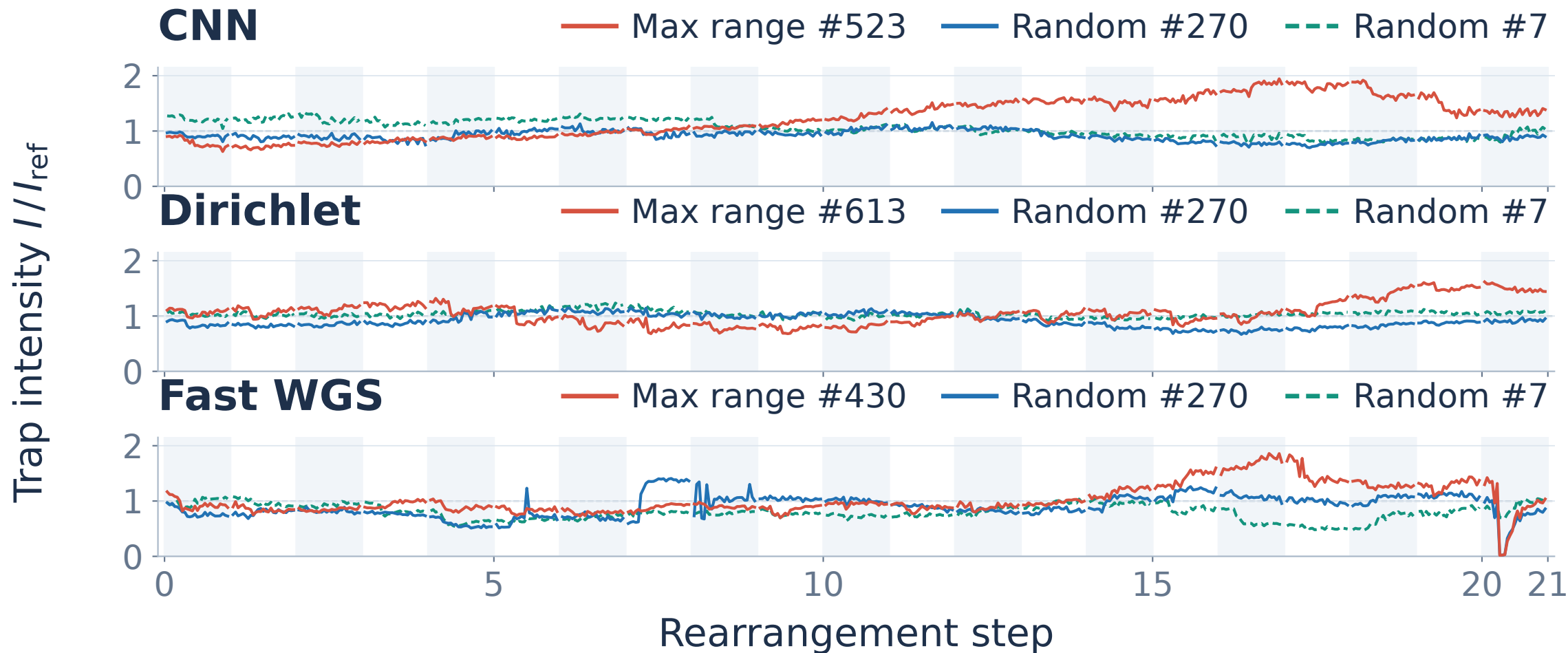


► Play / restart

Per-frame mean normalization; independent strobe scans. Fast WGS: phase-locked.

Tracking individual trap intensity

Fixed trap IDs • 21 steps, 525 samples • Max range: $I_{\max} - I_{\min}$



Fixed I_{ref} : all-trap mean before triggering. Independent strobe scans.

CNN and Dirichlet: performance summary

Key metric	CNN	Dirichlet (3 it.)
Total rearrangement time ↓ Median; 2,025 traps; 22 frames	50.11 ms	38.68 ms
Static intensity CV ↓ Median; 1,024 traps	19.4%	14.8%
Minimum relative array intensity ↑ Median trace; 1,024 traps	95.0%	96.4%

Dirichlet is faster and more uniform on our bench.

Time: matching to final SLM ACK.

Thankyou

Questions?

Jianshuo Gao • Fast SLM rearrangement