ABCs

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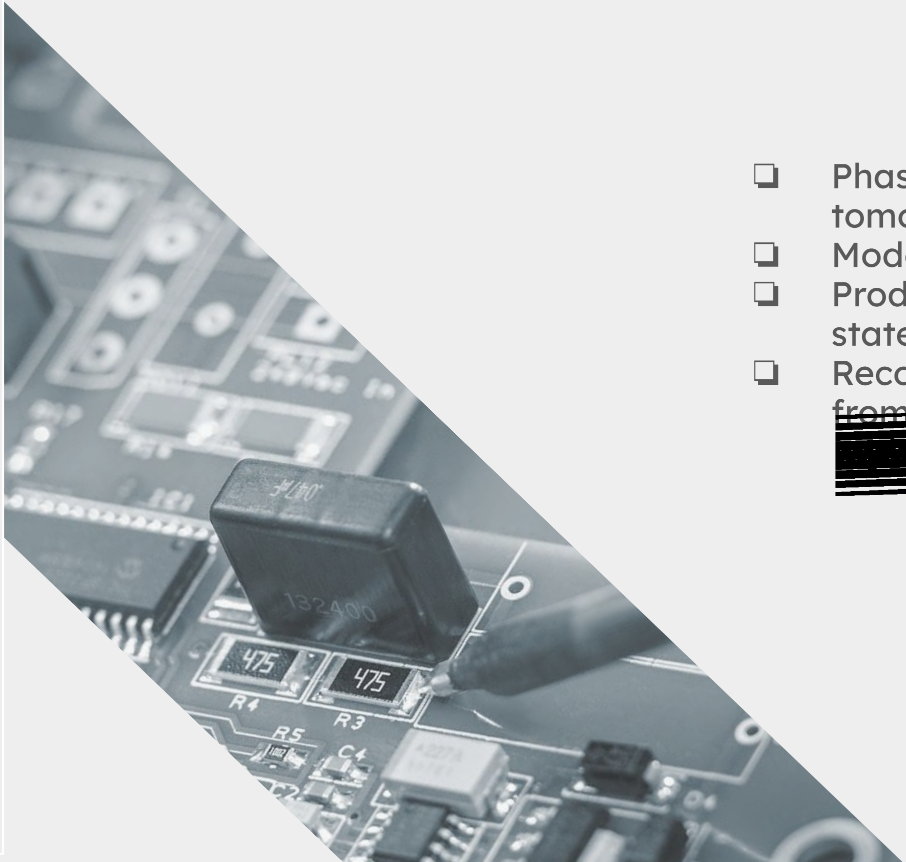
Overview



- Phase-space techniques for quantum state tomography
- Model dissipative dynamics
- Produce Wigner functions for quantum states
- Reconstruct the underlying density matrices from distorted or noisy data

Status

Task 1

- Static Wigner function plots for each state.
- A GIF animation showing the evolution of the dissipative cat state's Wigner function.
- A function or notebook that demonstrates the reconstruction process from $W\rho(x,p)$ to $\rho\sim$.
- Fidelity Tables or Plots comparing ρ vs $\rho\sim$ for each state type (Fock, coherent, cats..).
- Compare ρ and $\rho\sim$ using at least one additional method beyond fidelity.
- Plots of fidelity $F(\rho,\rho\sim)$ vs. noise level σ for different states.
- A comparison between reconstructions from simulated and real Wigner data.

Task 2

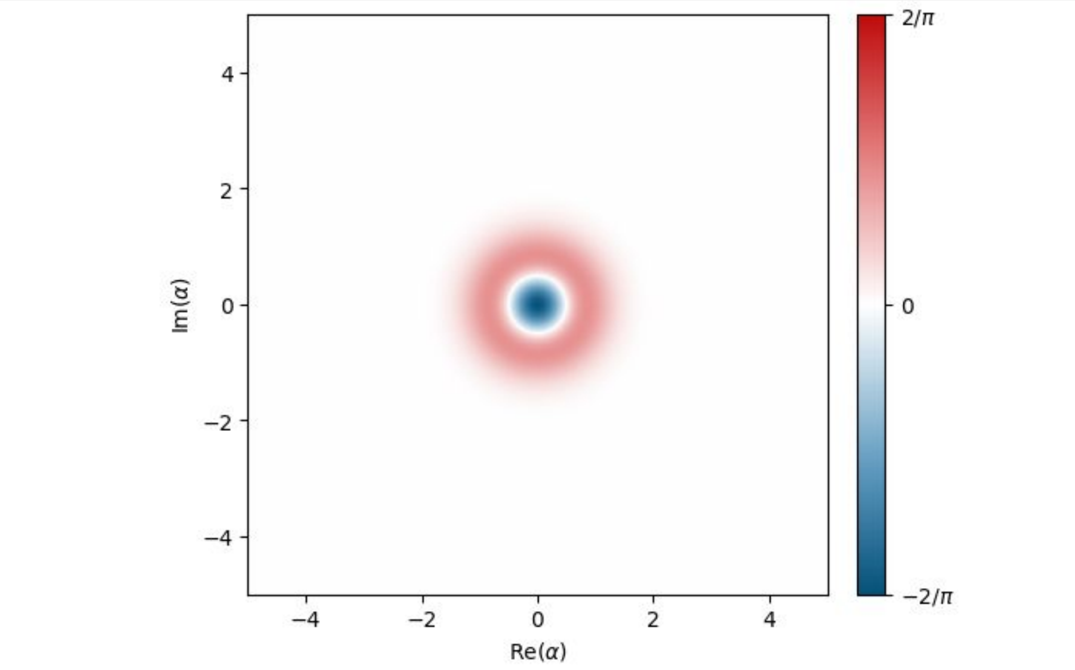
- Correction & Denoising Code: A script or notebook that performs:

  Affine correction (estimation and removal of a and b)

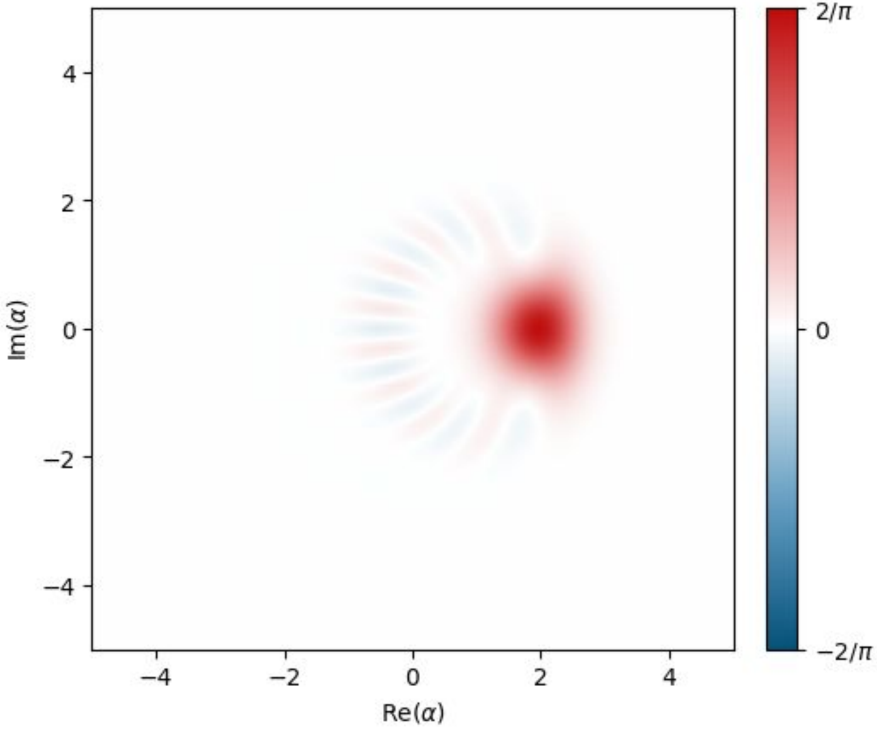
  Gaussian filtering

- Benchmarking Module: A section that runs the full reconstruction pipeline on:
  - Raw noisy Wigner data
  - Corrected and/or denoised Wigner data
  - Then compares both against the clean reference using fidelity.
- Metrics & Plots
  - Fidelity Comparison: Table or plot showing F-raw and F-denoised for each test case.
  - Fidelity vs. Noise: Curves showing how performance degrades or improves with varying noise width σ, for different Wigners.
  - Before vs. After Wigner Plots: Visual side-by-side of W-measured and W-clean
- Experimental Test Case: Apply your correction pipeline to the experimental Wigner data and include a short discussion or plot illustrating its effect (no fidelity comparison needed here).

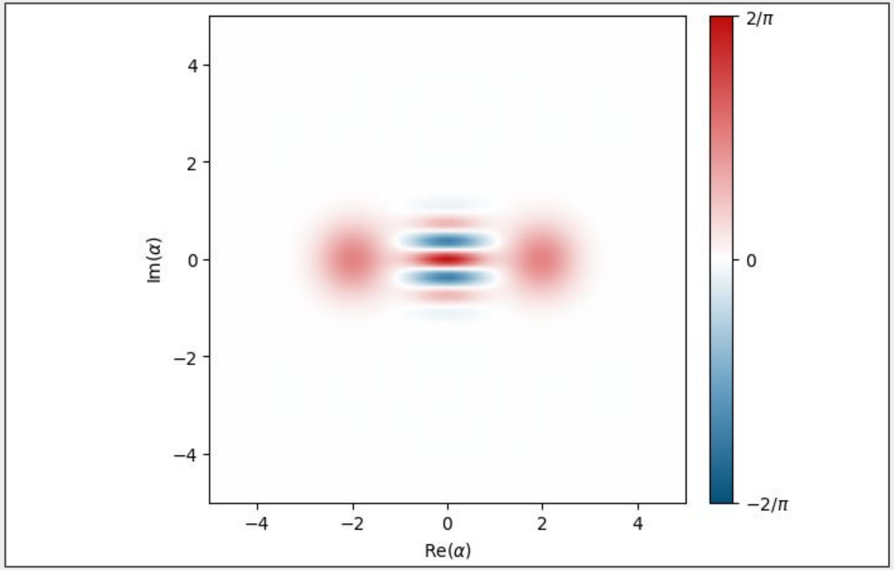
Fock State Type

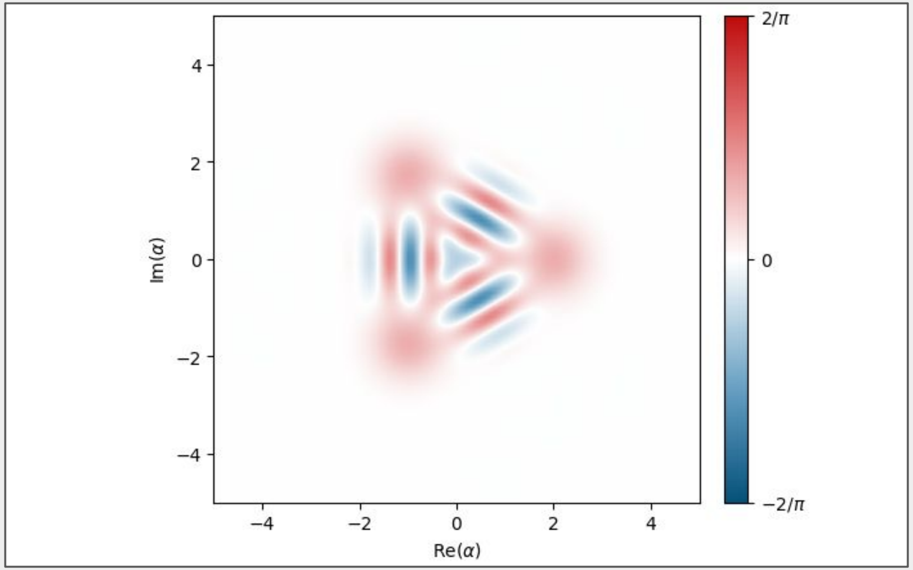


Coherent State Type

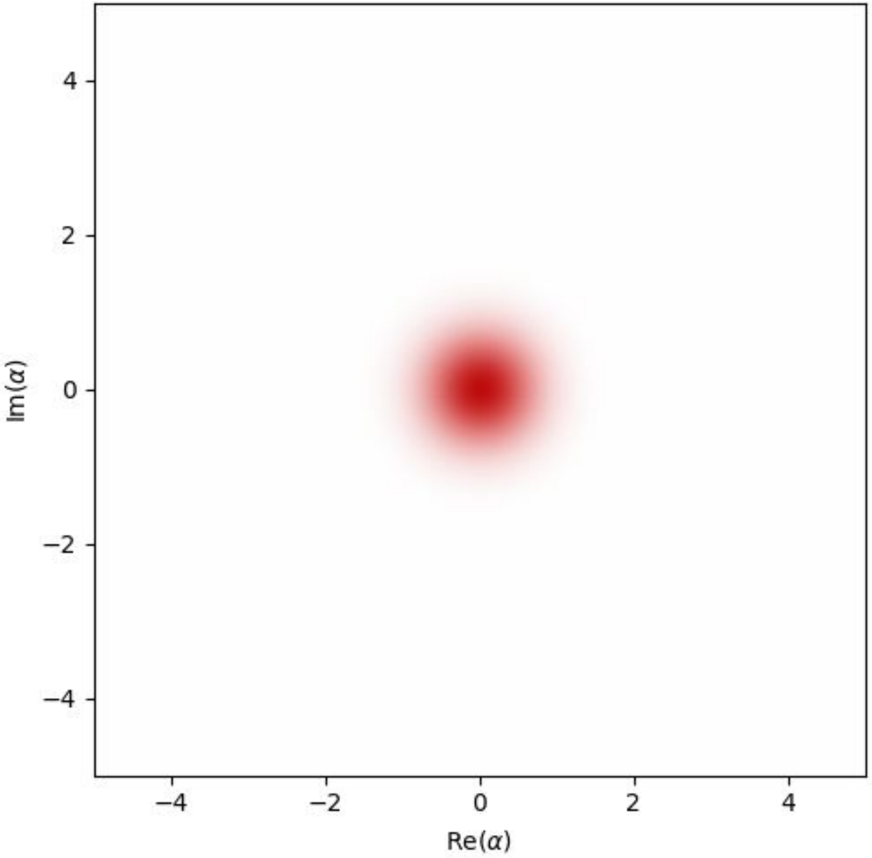


Cat State Type





Dissipative Cat State from a Two-Photon Exchange Hamiltonian



Wigner Function → Density Matrix

$$p_\alpha = \mathrm{Tr}(E_\alpha \rho) = \frac{1}{2}(1 + \frac{\pi}{2} W(\alpha))$$

$$E_\alpha = \frac{1}{2}(\mathbb{I} + D(\alpha) P D^\dagger(\alpha))$$

$$\min_{\rho \in \mathcal{M}} \sum_k \left| \mathrm{Tr}(E_{\alpha_k} \rho) - w_k \right|^2$$

Convex Optimization problem

Utilize cvxpy with constraints:

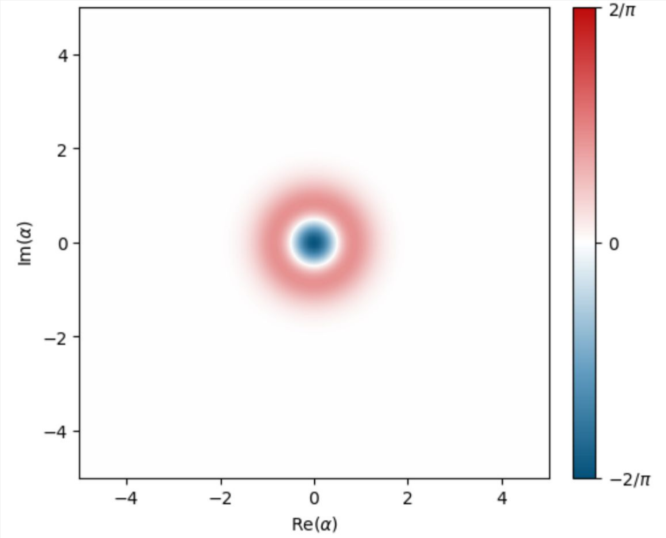
- Hermitian
- Positive semidefinite
- Trace = 1 (normalized)

Optimize observable calculations with JAX - 30x speedup

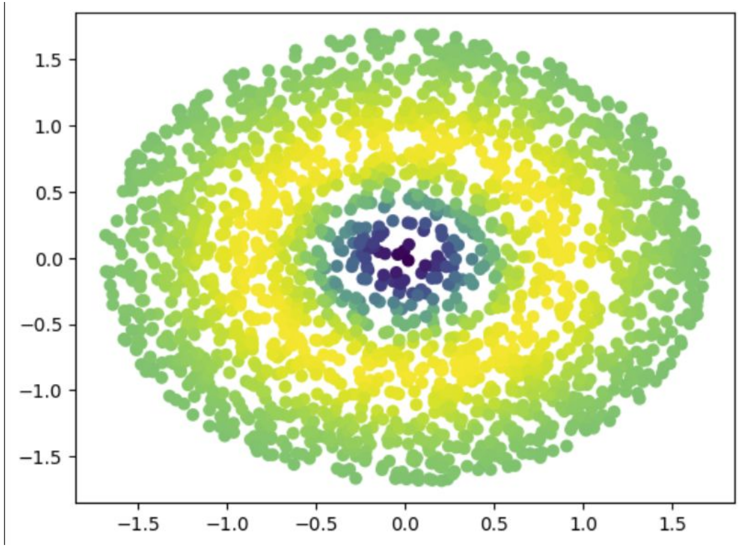
Batching to conserve memory and speedup minimization

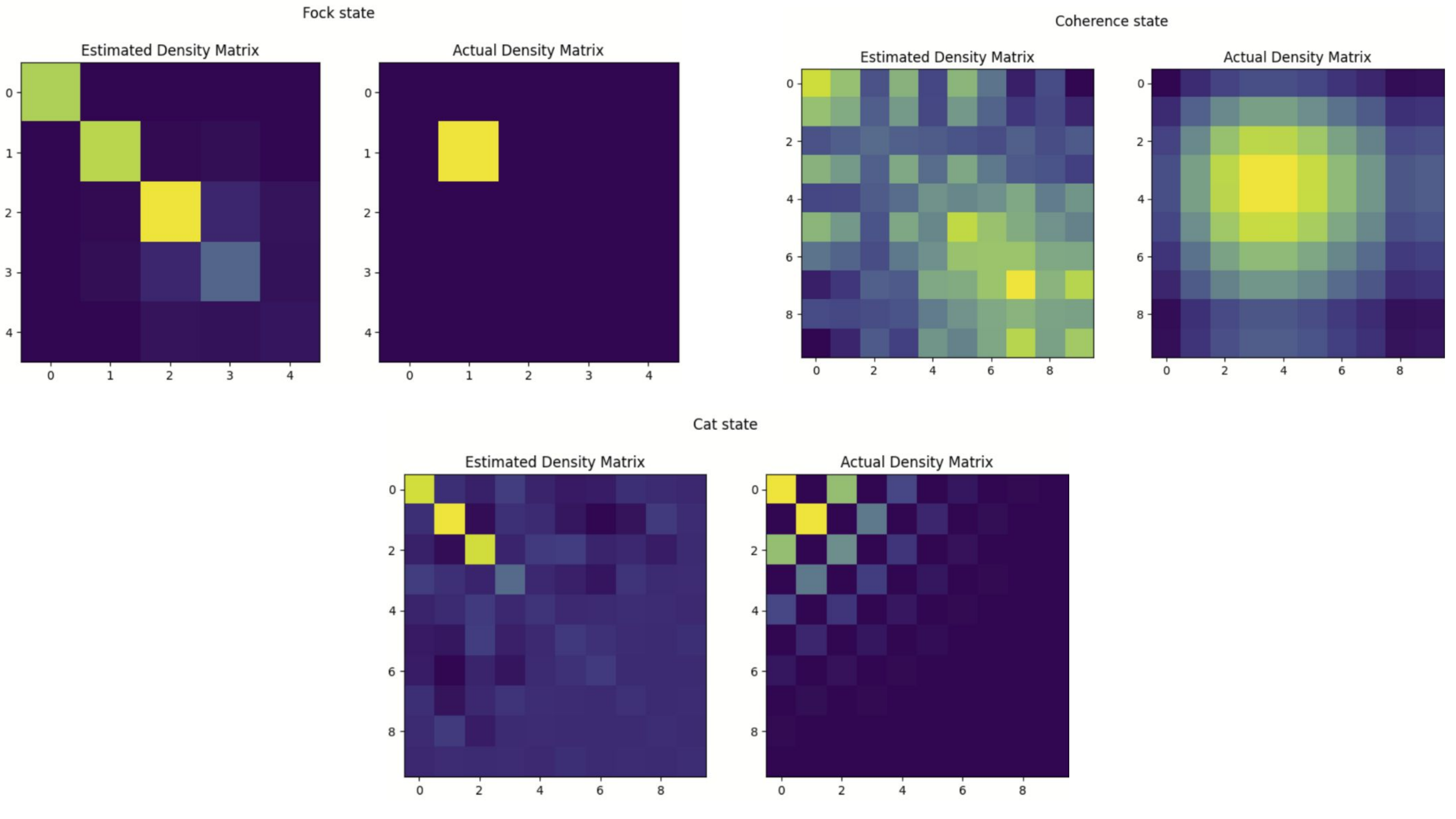
Sampling

- Need to sample W
  - Capture behavior of function with small sample size



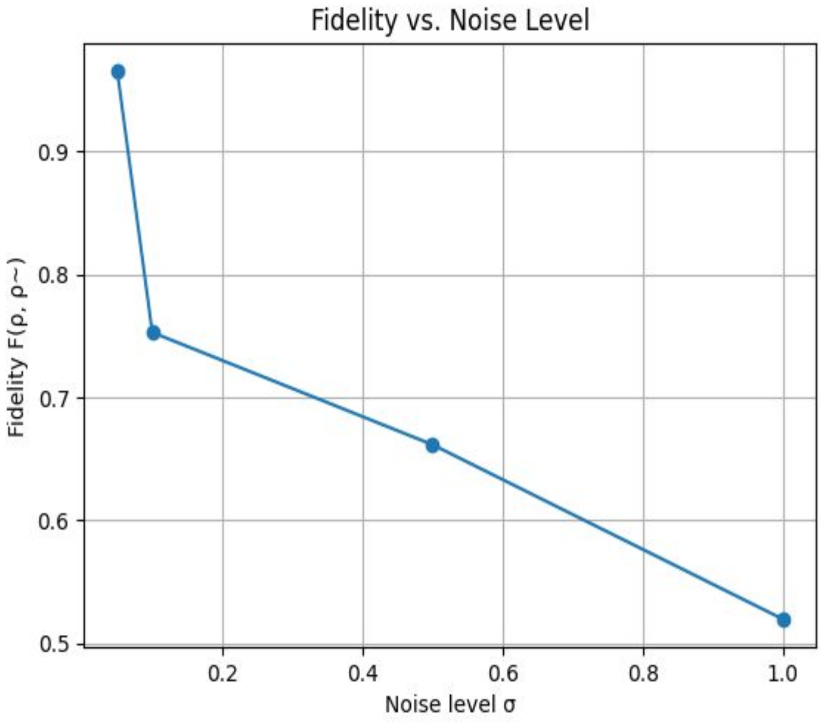
- Sample in circle around center





Fock state
Estimated Density Matrix
Actual Density Matrix
Coherence state
Estimated Density Matrix
Actual Density Matrix
Cat state
Estimated Density Matrix
Actual Density Matrix

Adding Gaussian Noise and Comparing



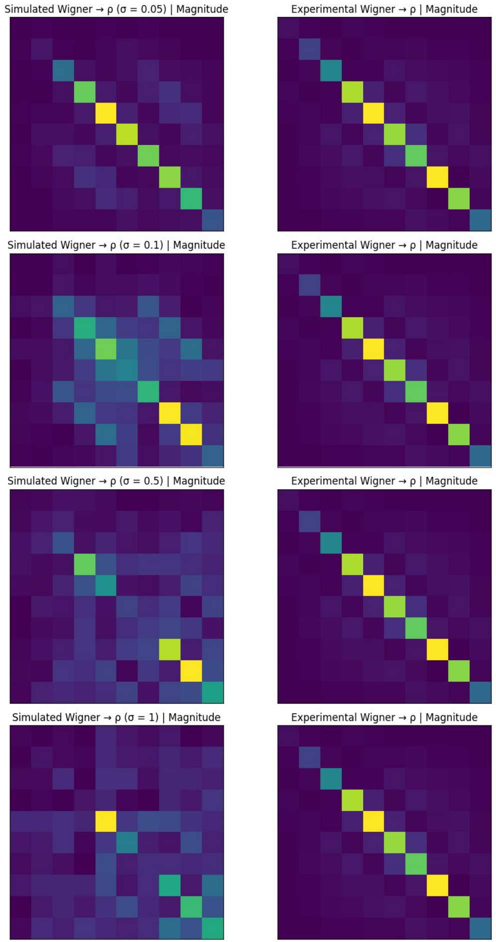
Sigmas:

.05

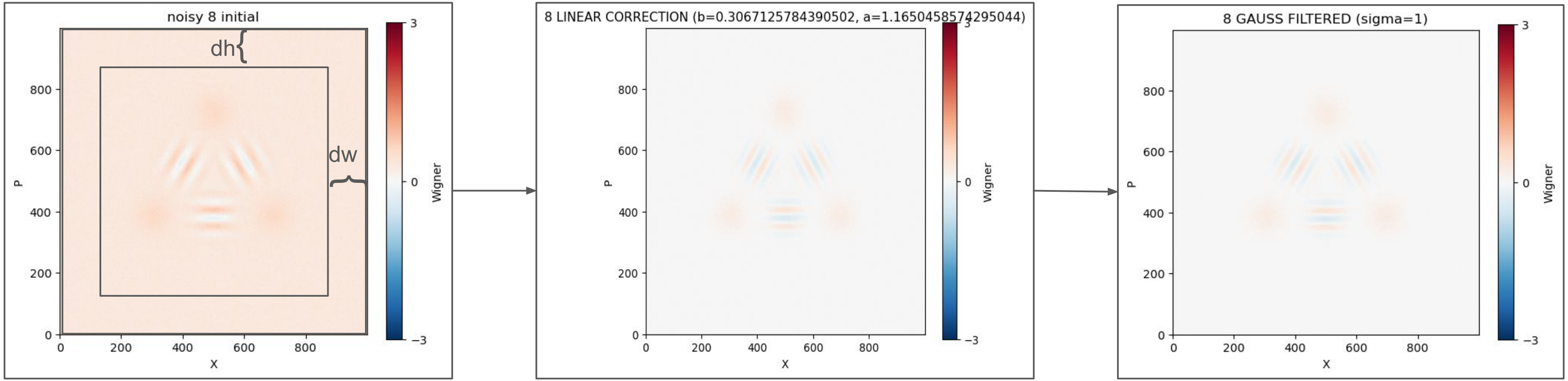
.1

.5

1



Denoising the Measured Wigner Function



Assume W tends towards 0 at the bounds.
Find average Wigner value within a frame to estimate b.

$$a = \Sigma_{x,p}[W_{measured}(x,p) - b]\Delta x \Delta p$$

$$W_{real}(x,p) = \frac{W_{measured}(x,p) - b}{a}$$

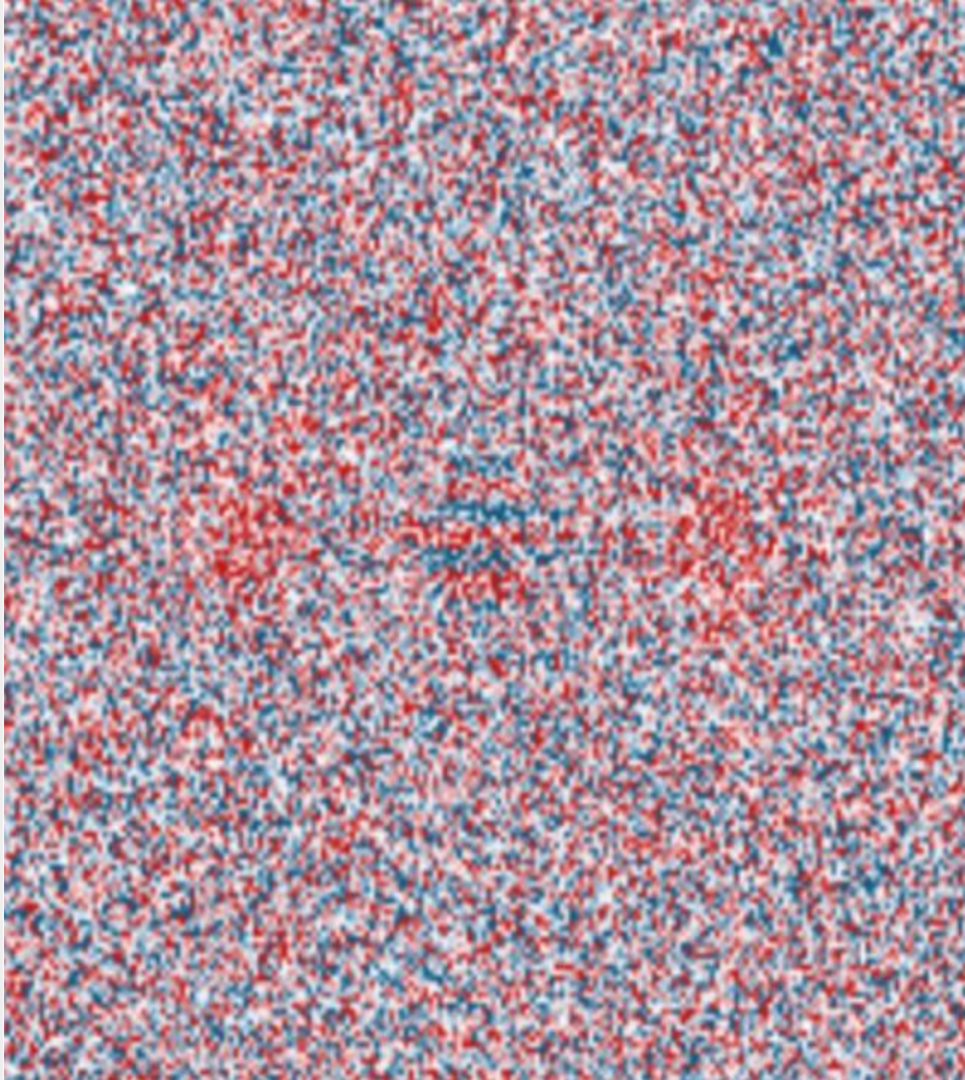
In detail: scipy.ndimage.gaussian_filter

Challenges

- Large calculations were difficult on our hardware

- Balance small sample size with capturing behavior of Wigner function

- Wigner to Density process was inconsistent between state types



Thank You

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ALICE & BOB

YQ

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