Simulation of the multi-view imaging system with differentiable ray tracing

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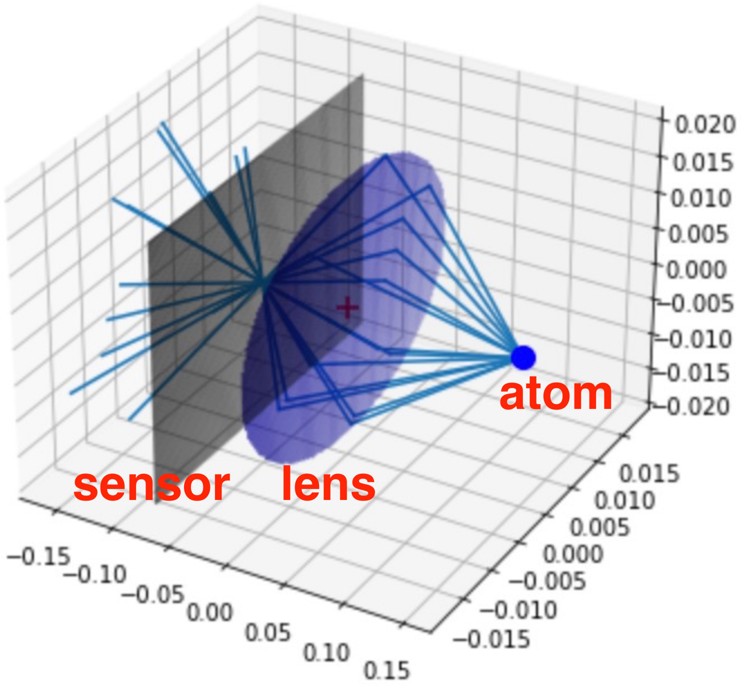
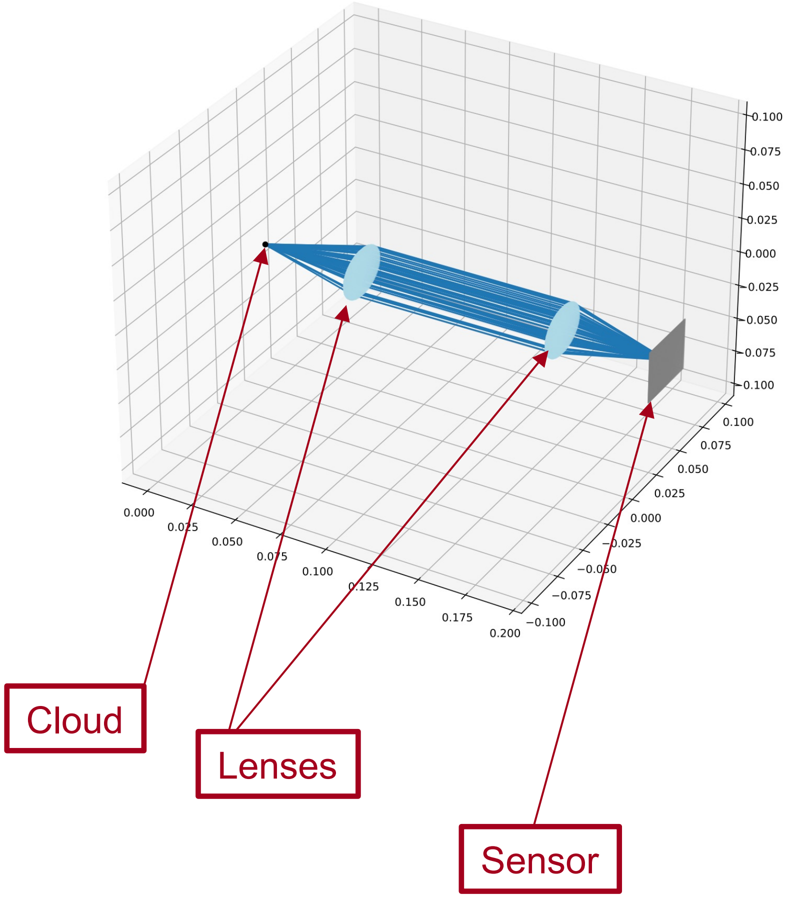
U.S. DEPARTMENT OF
ENERGY
Office of Science

SLAC NATIONAL
ACCELERATOR
LABORATORY

Comparisons w/ single-lens & 4F system



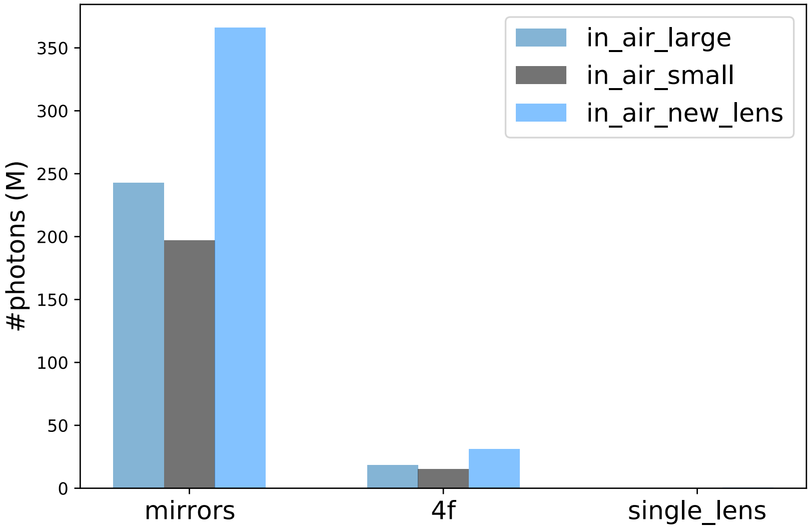


Cloud

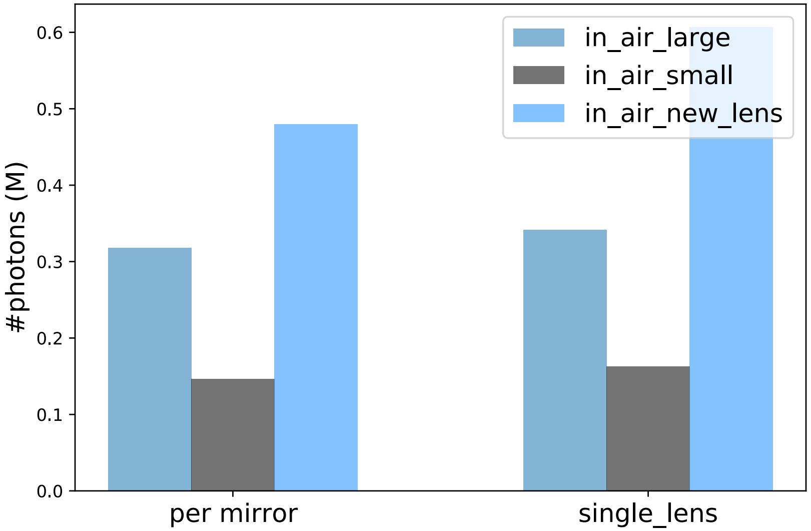
Lenses

Sensor

Amount of light

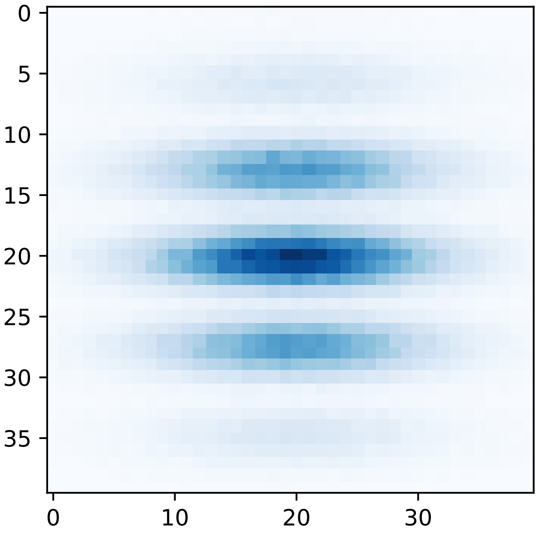


Total amount of light



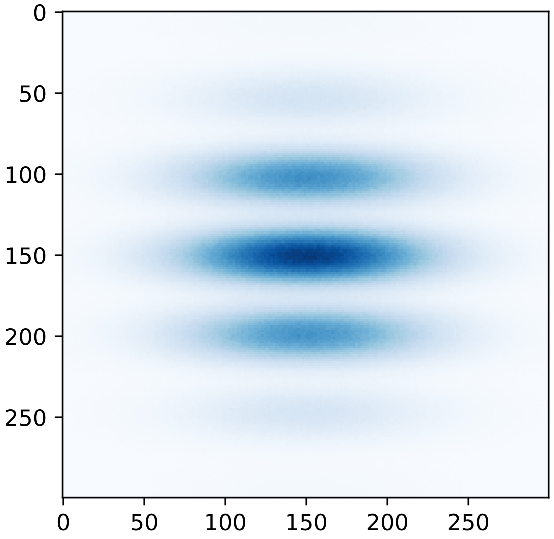
Amount of light per view

Resolution



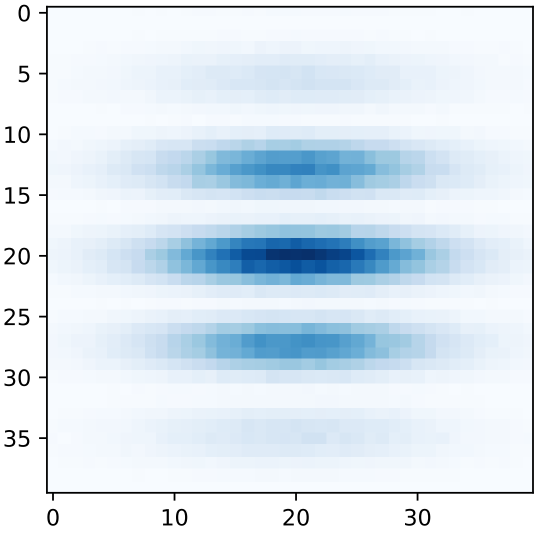
Ours

40 x 40 px



4F

300 x 300 px

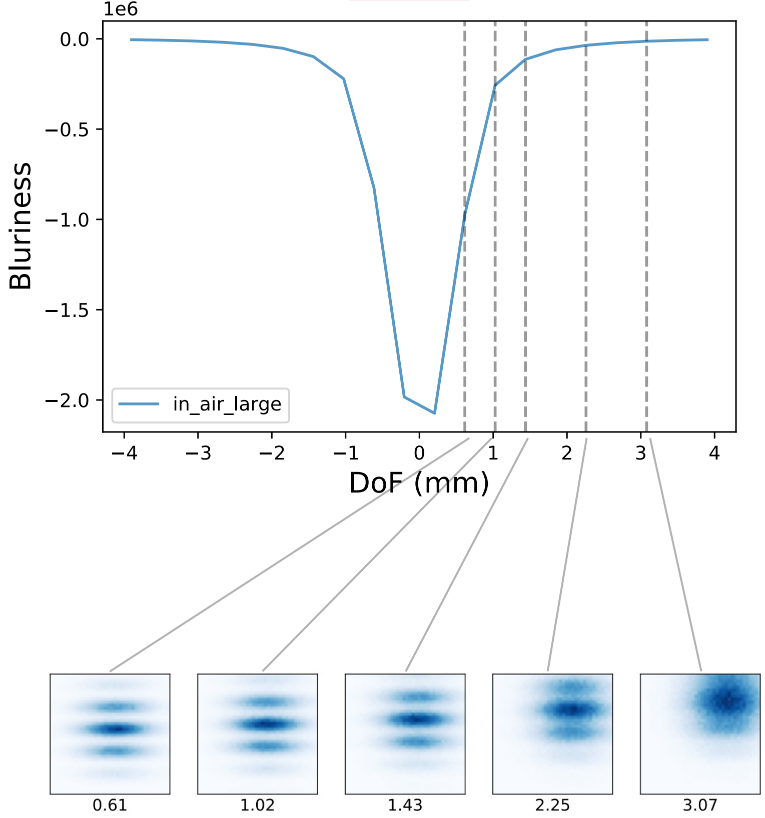


Single-lens

40 x 40 px

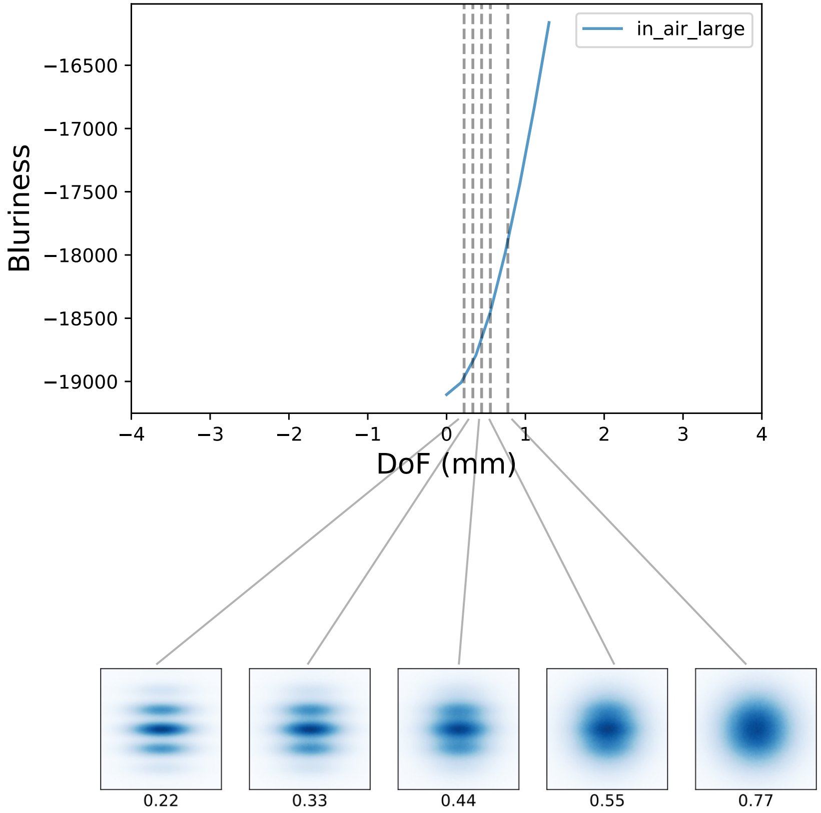
DoF

Ours



1e6
0.0
−0.5
−1.0
−1.5
−2.0
Bluriness
in_air_large
−4
−3
−2
−1
0
1
2
3
4
DoF (mm)
0.61
1.02
1.43
2.25
3.07

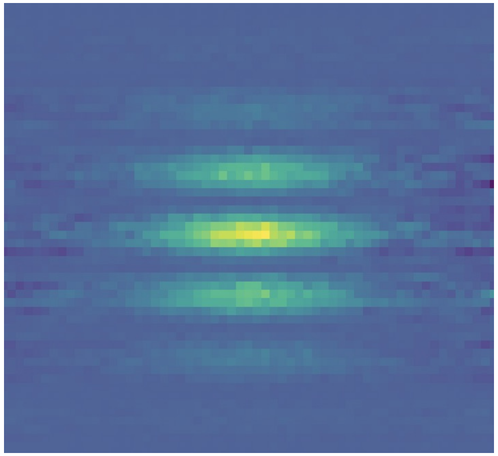
4F



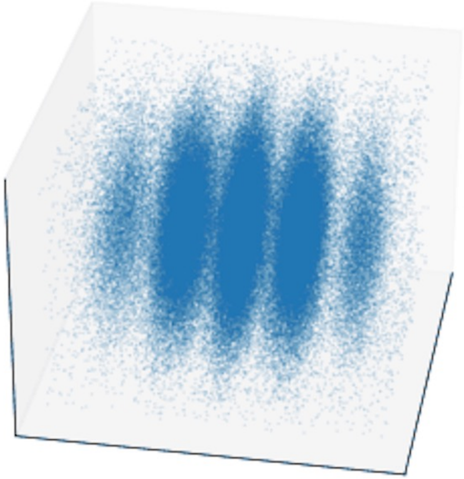
−16500
−17000
−17500
−18000
−18500
−19000
Bluriness
in_air_large
−4
−3
−2
−1
0
1
2
3
4
DoF (mm)
0.22
0.33
0.44
0.55
0.77

Reconstruction

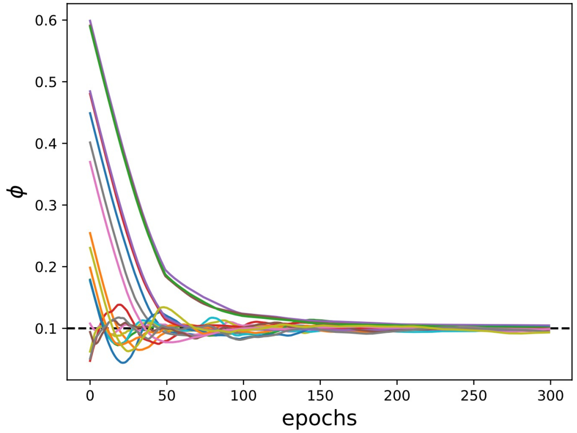
Current baselines



Filtered Backprojection



Voxel-based Reconstruction



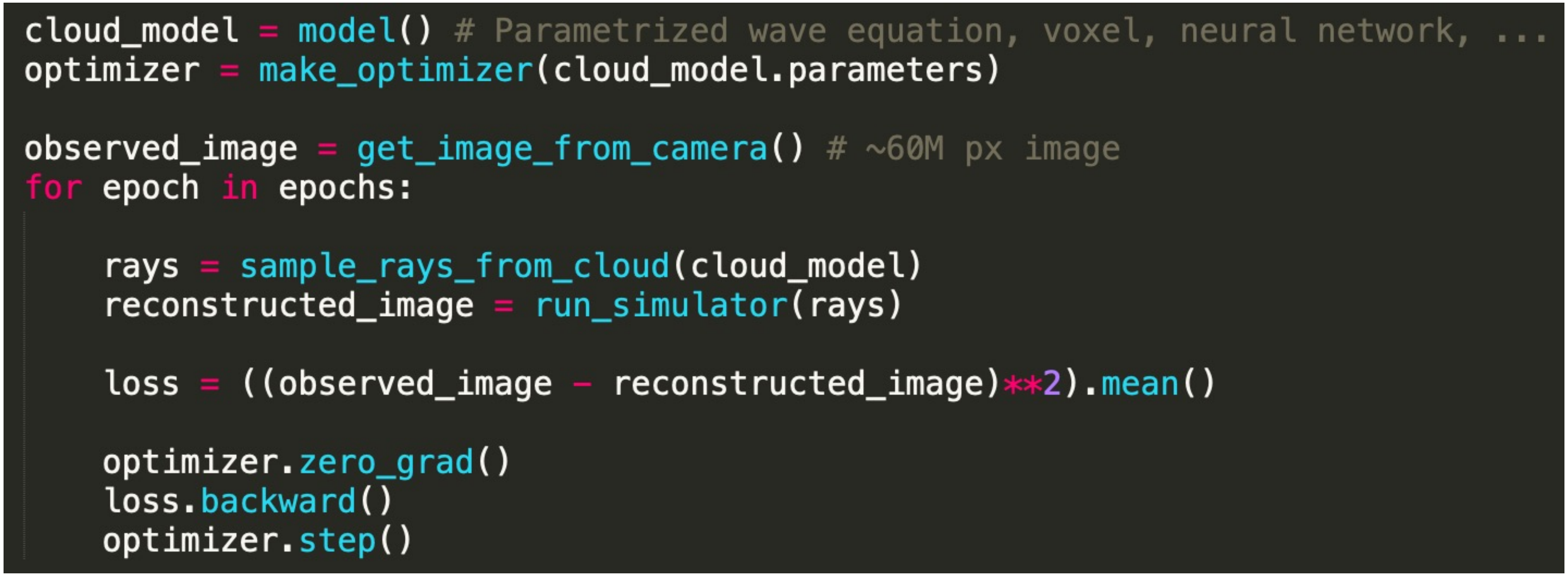
MLE Fit

Next steps

- Quantify baselines (Fourier ring correlation, uncertainty, …).
- NN-based reconstruction (implicit functions & normalizing flows).
- Add aberrations.

Reconstruction

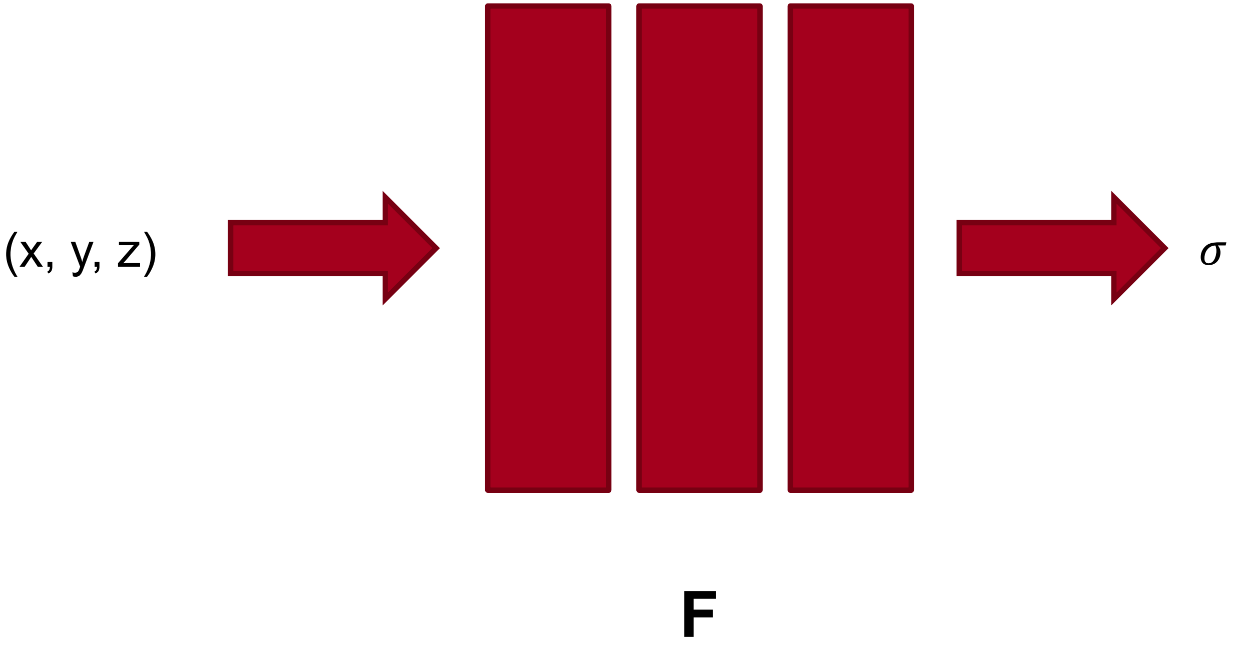
- General reconstruction algorithm.



```
cloud_model = model() # Parametrized wave equation, voxel, neural network, ...
optimizer = make_optimizer(cloud_model.parameters)

observed_image = get_image_from_camera() # ~60M px image
for epoch in epochs:

    rays = sample_rays_from_cloud(cloud_model)
    reconstructed_image = run_simulator(rays)

    loss = ((observed_image - reconstructed_image)**2).mean()

    optimizer.zero_grad()
    loss.backward()
    optimizer.step()
```

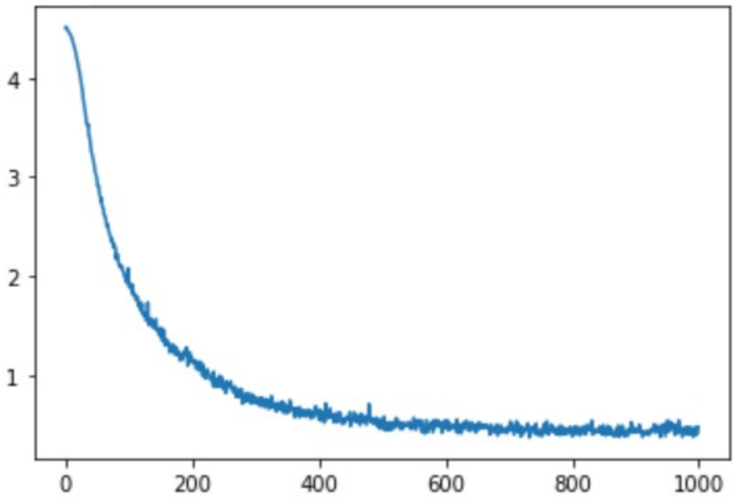
NN-based reconstruction (using implicit functions)

- Modeling the cloud with a neural network $x \in R^3 \rightarrow \sigma \in R$.
  - ~ Infinite-dimensional.
  - Scales better.
  - Better at capturing aberrations.

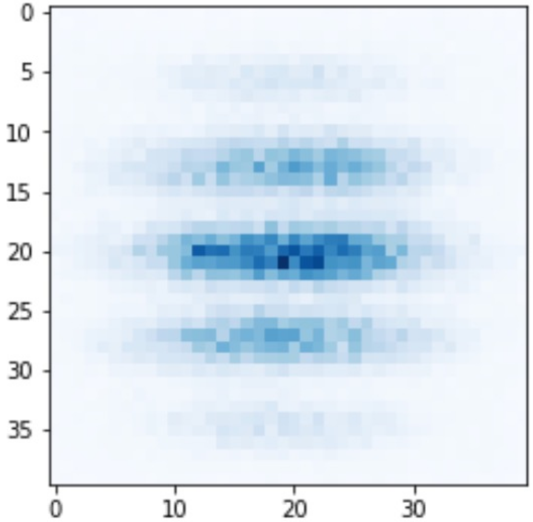


NN-based reconstruction (using implicit functions)

- Keep it simple: fitting the 2d marginal from a single viewing angle.



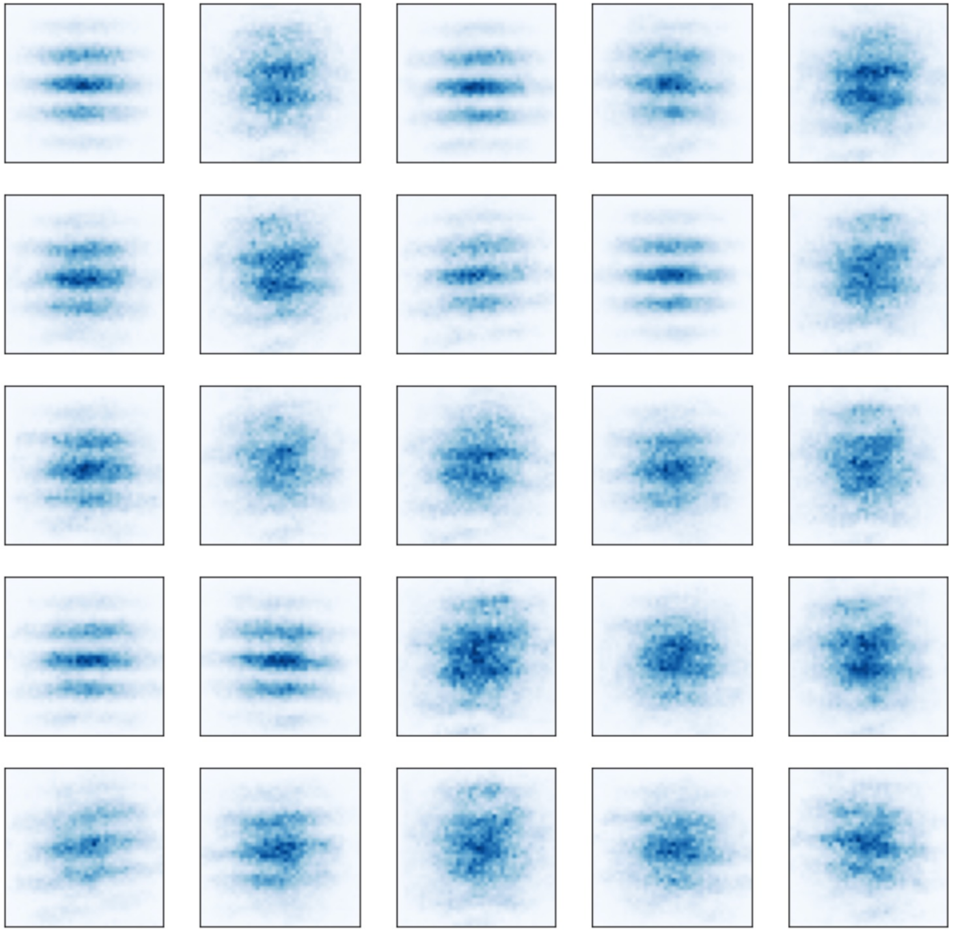
Training loss



Reconstructed image

NN-based reconstruction (using implicit functions)

- 3d visualization.



NN-based reconstruction (using implicit functions)

- Visualization over the course of optimization.