

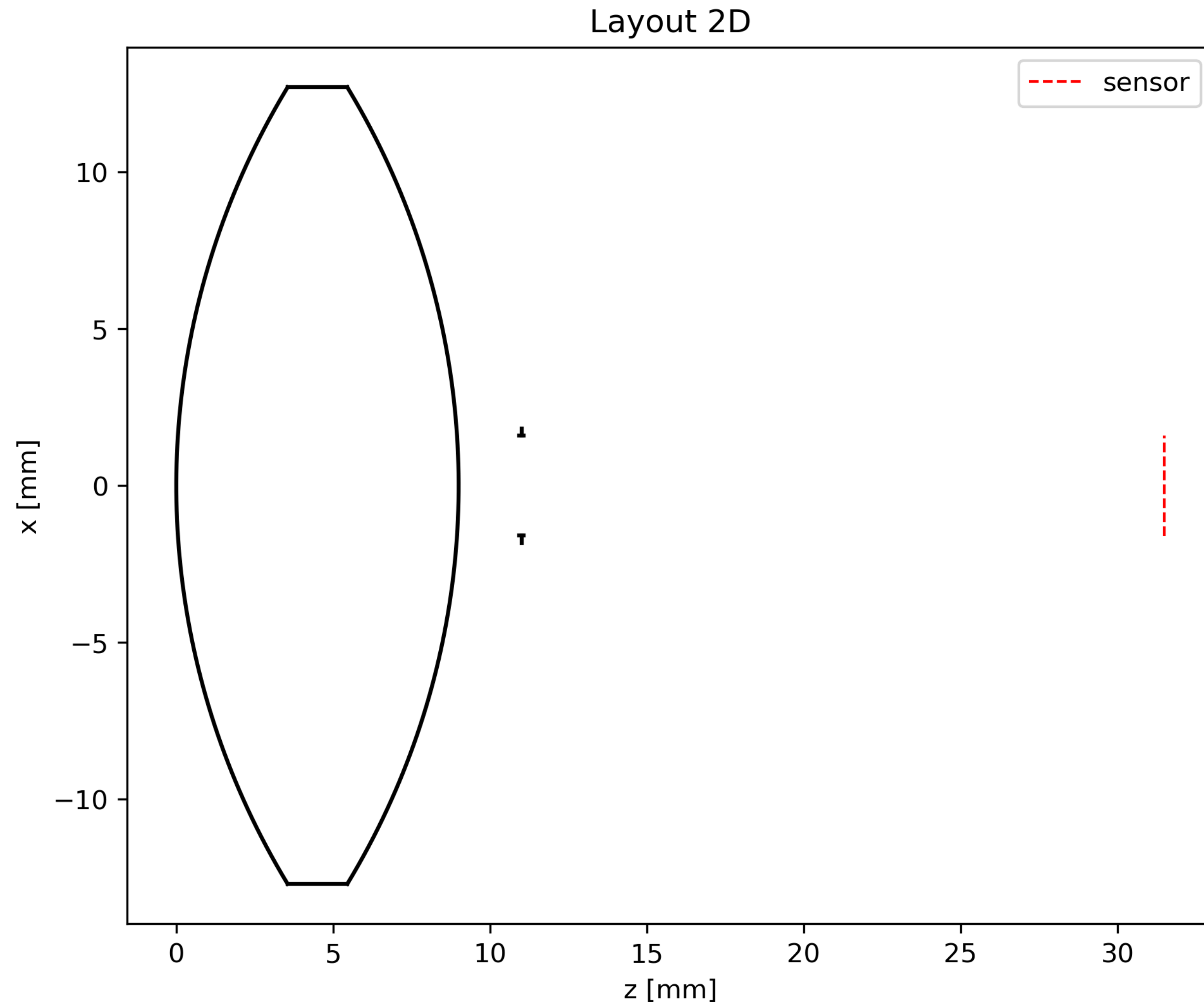
Optical Simulation

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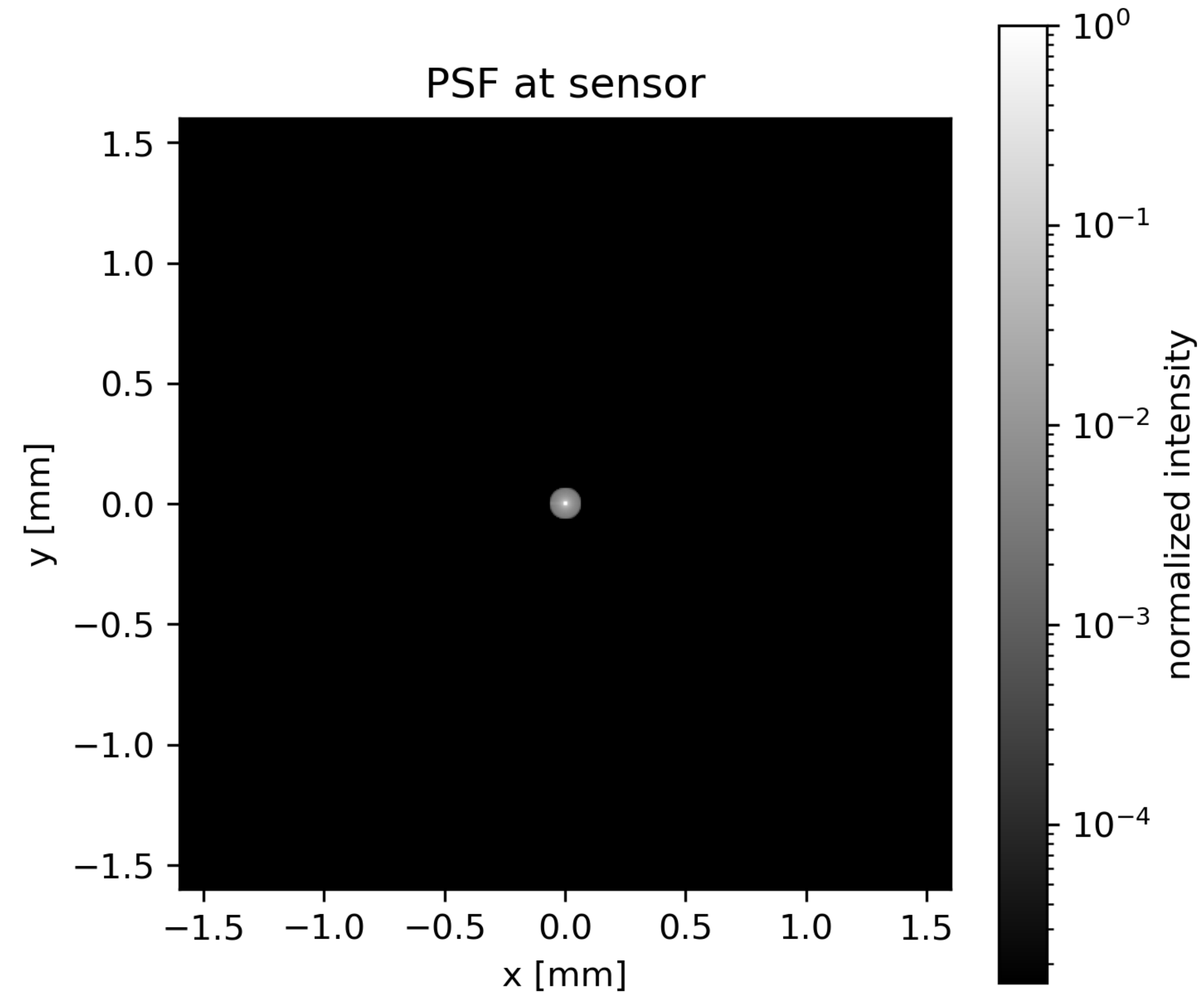
Experiment Briefs

- Lens: Throlabs LB1761 BK7 biconvex lens (f/8 aperture, 2 mm from the 2nd surface)
- Parameters: $R1 = 24.5$, $T = 9$, $R2 = -24.5$, $D2 = 22.2$, $OD = 3.175$ mm
- Experiments:
 - Function test
 - Layout & Ray visualization
 - Focus estimation
 - N , λ , $D2$, OD sweep
 - Off-axis sweep

Lens Visualization

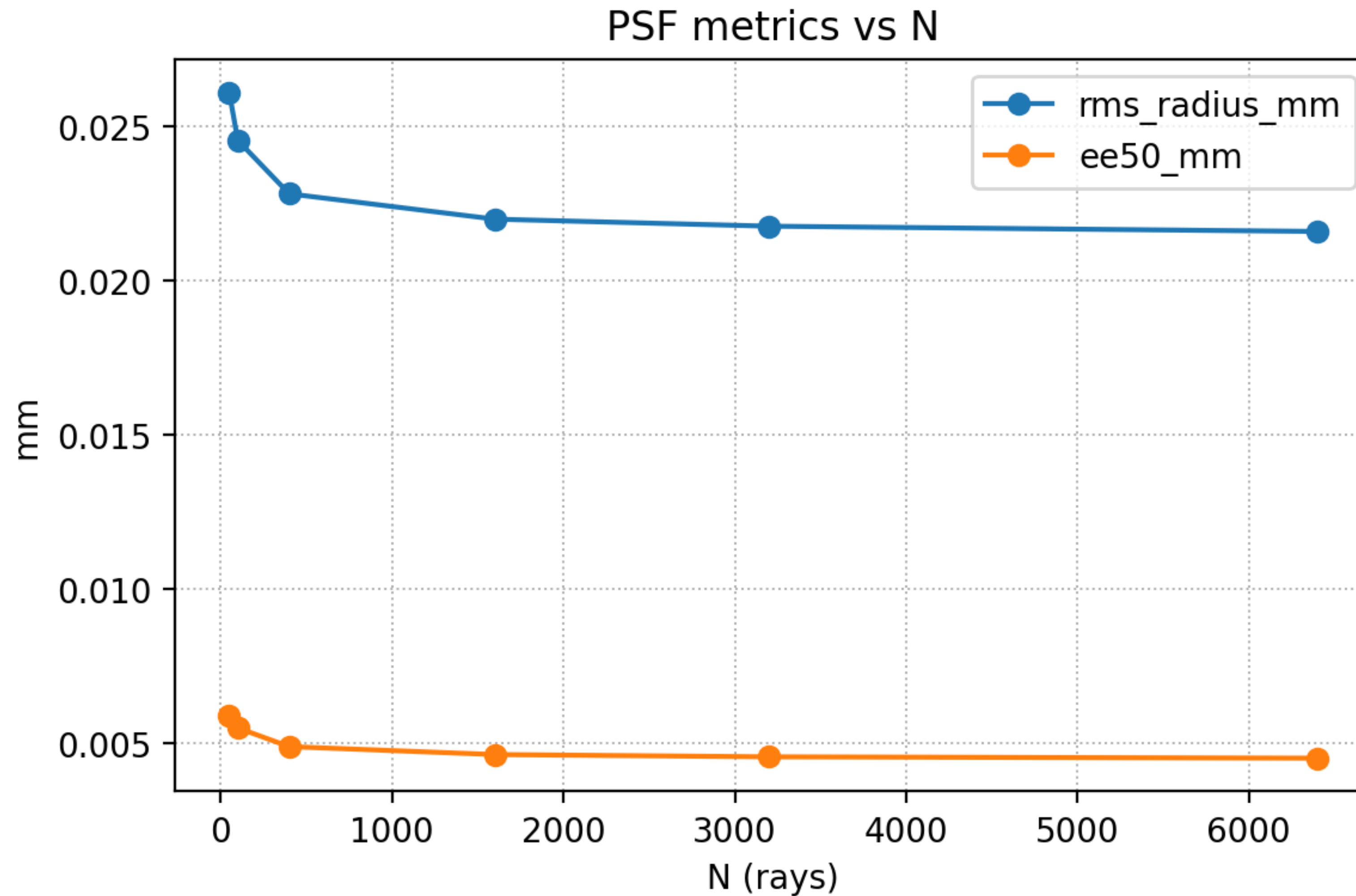


PSF Examples



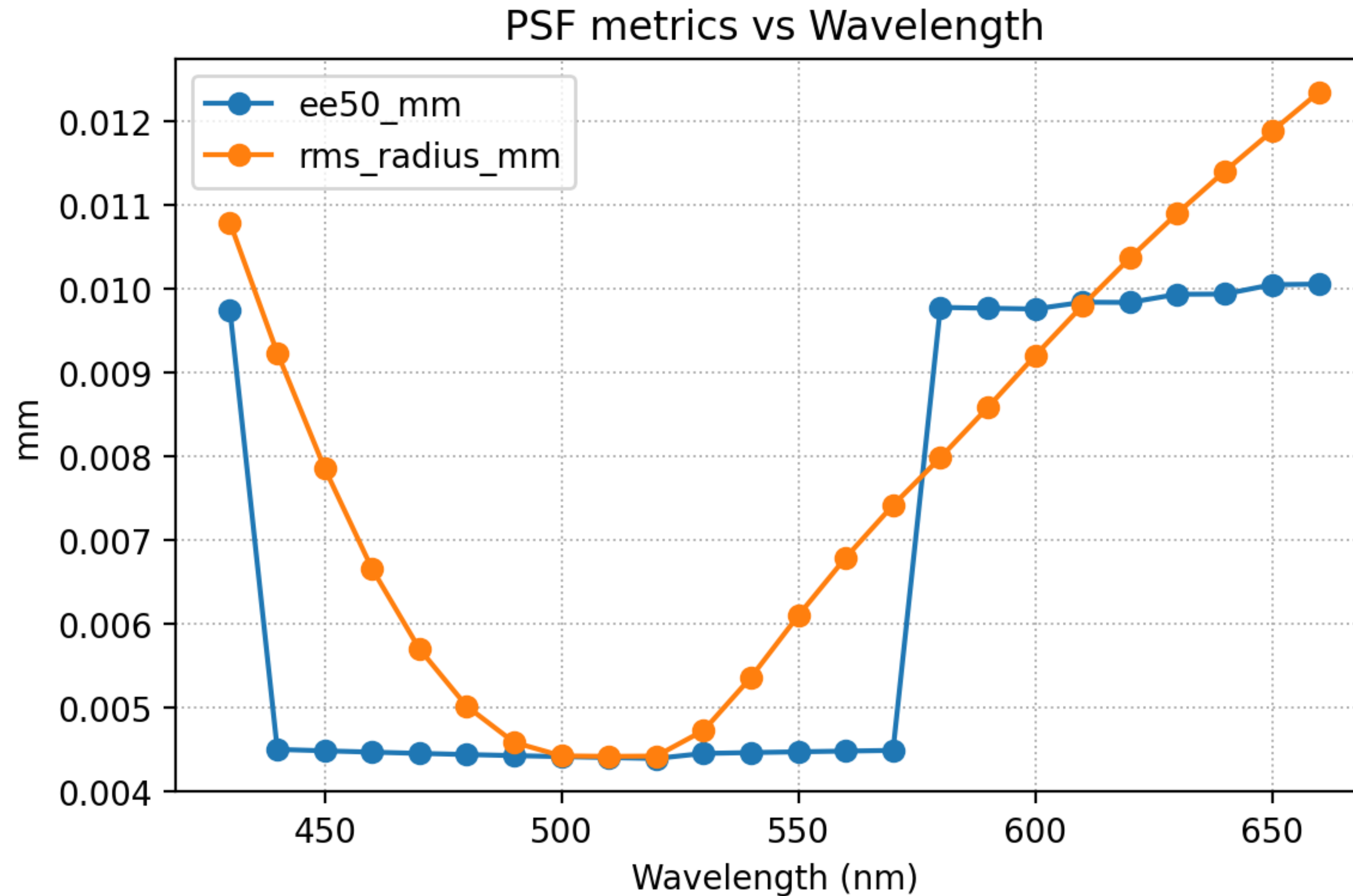
$R1 = 24.5$, $T = 9$, $R2 = -24.5$, $D2 = 22.2$, $OD = 6.35$ mm, $N = 3200$

Sampling N Sweep



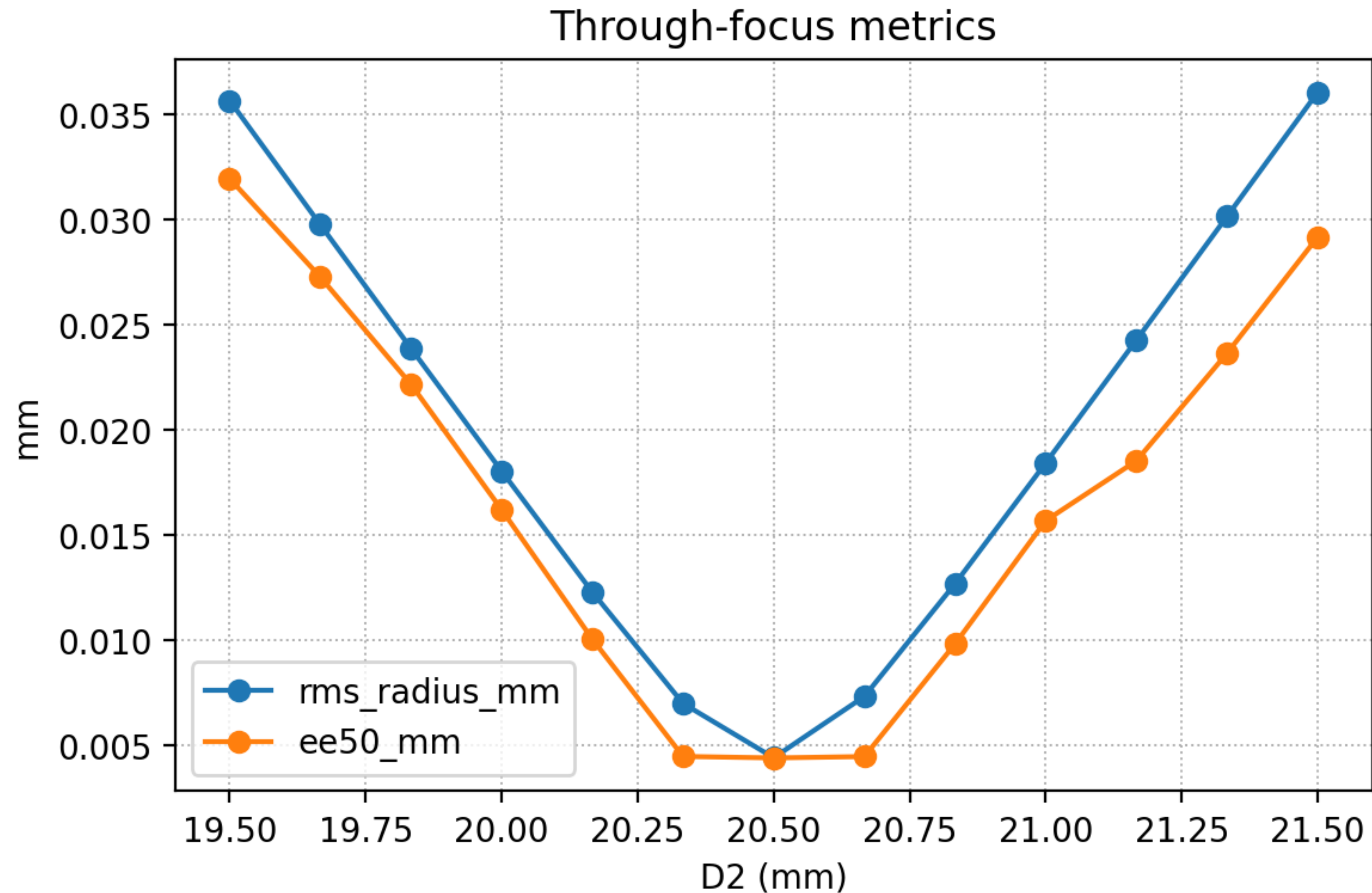
The convergence begins around $N \geq 1600$, where the RMS and EE50 values stabilize to ~ 0.045 mm and ~ 0.021 mm, respectively — indicating sufficient ray sampling density for accurate PSF estimation. To get better simulation, we choose $N=3200$ for the rest of experiments.

Wavelength λ Sweep



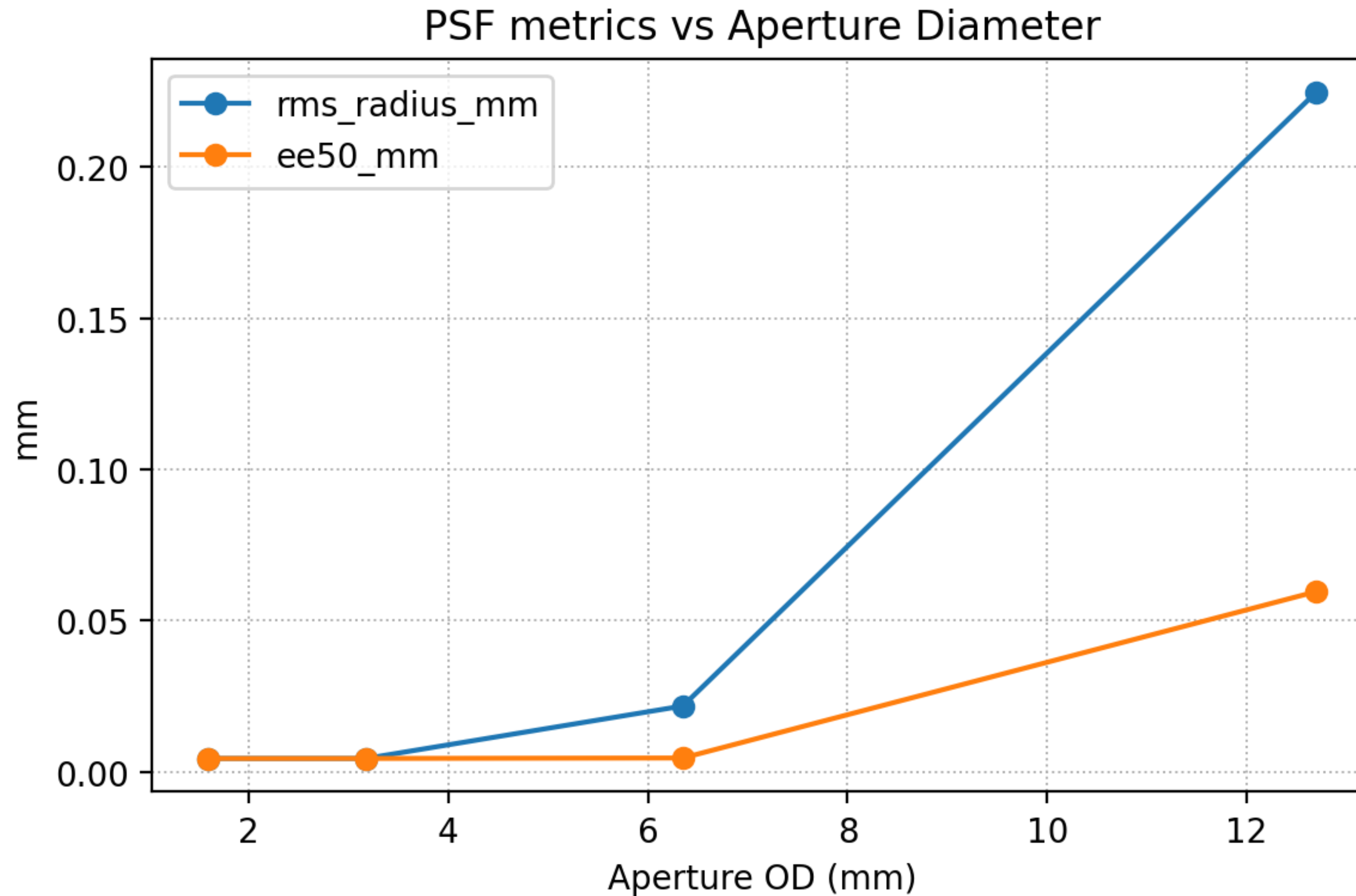
With BK7 dispersion enabled, the smallest PSF occurs near ~ 500 nm and grows toward both spectral ends. This matches expectation: the effective focal length shifts with λ (chromatic focus), so a single sensor position cannot be perfectly focused for all wavelengths. (EE 50 has limitation here)

Focus D2 Sweep



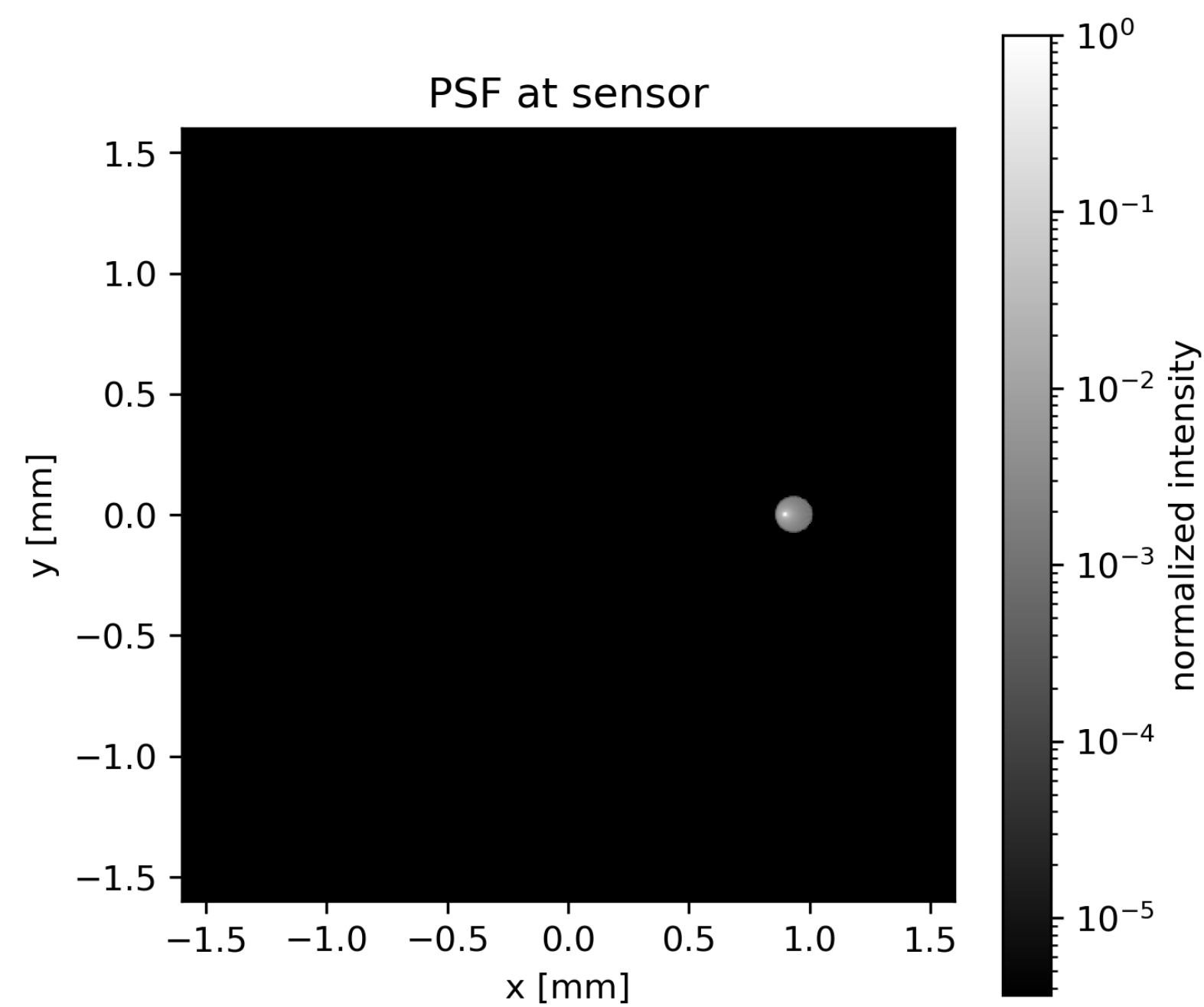
As we move away from 20.5 mm (toward 20.33 or 20.66 and beyond), RMS and EE50 grow smoothly, indicating increasing defocus blur. The growth is slightly asymmetric—typical once real lens aberrations are present. The sweep cleanly identifies 20.5 mm as the optimal aperture-to-sensor distance for this configuration, with predictable defocus behavior on either side.

Aperture OD Sweep

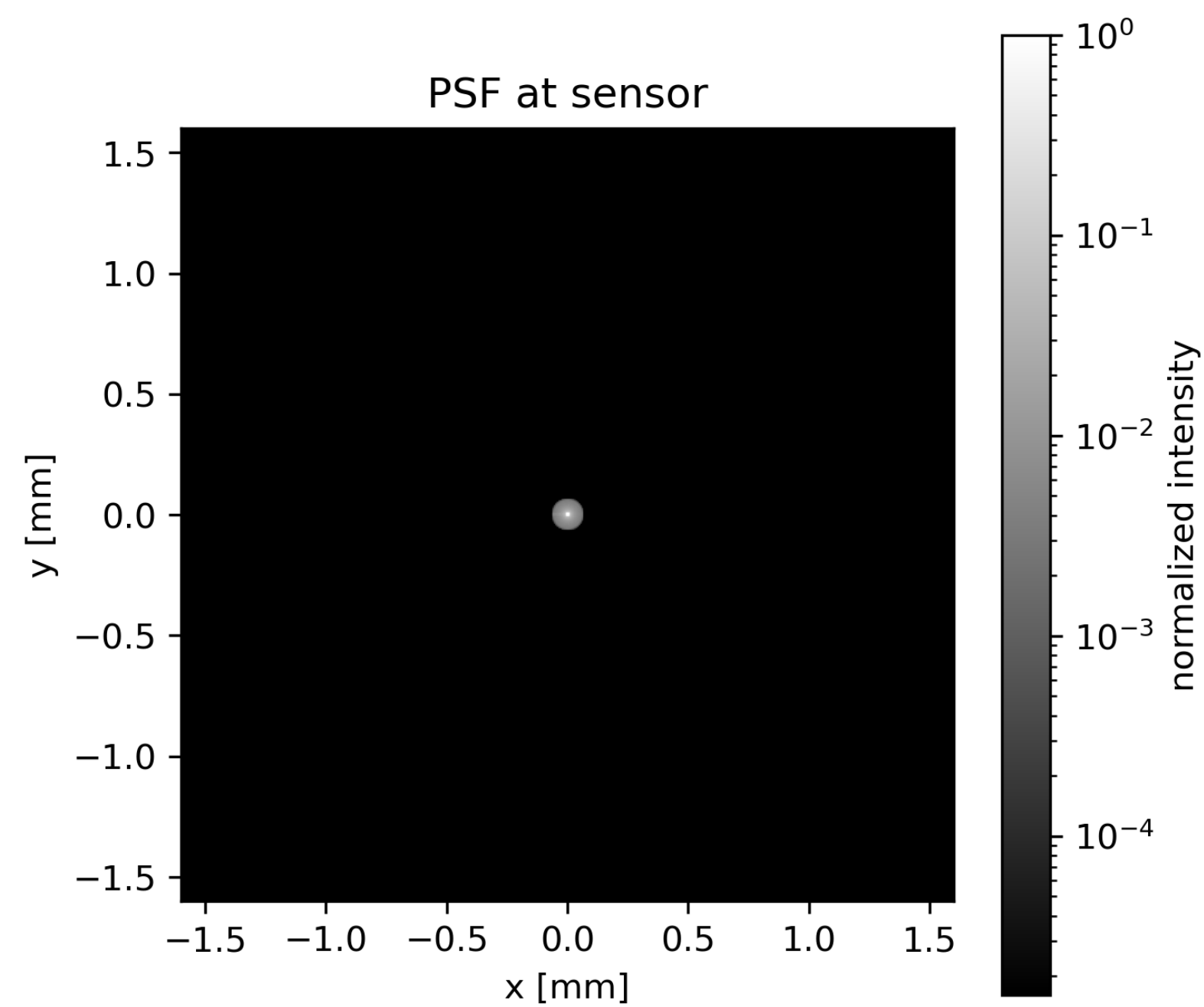


As aperture increases from $\sim 1.6 \rightarrow 12.7$ mm, the PSF's core (EE50) stays nearly constant at small–moderate apertures while the halo (RMS) grows rapidly—and at the largest aperture both EE50 and RMS spike—so the sharpest results occur with small apertures ($\sim 1.6\text{--}3.2$ mm).

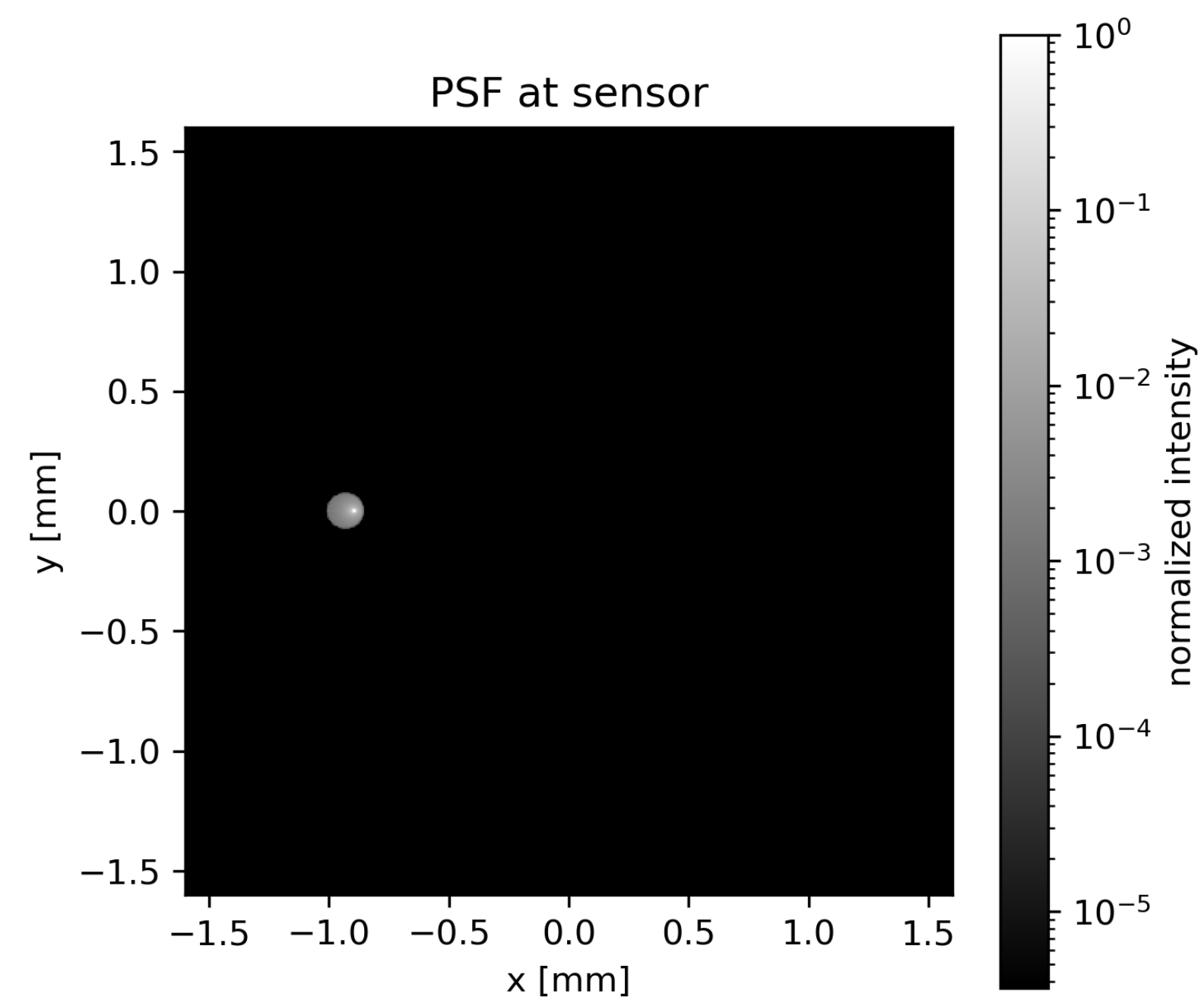
Off-axis sweep



$$X_{off} = -35\text{mm}$$

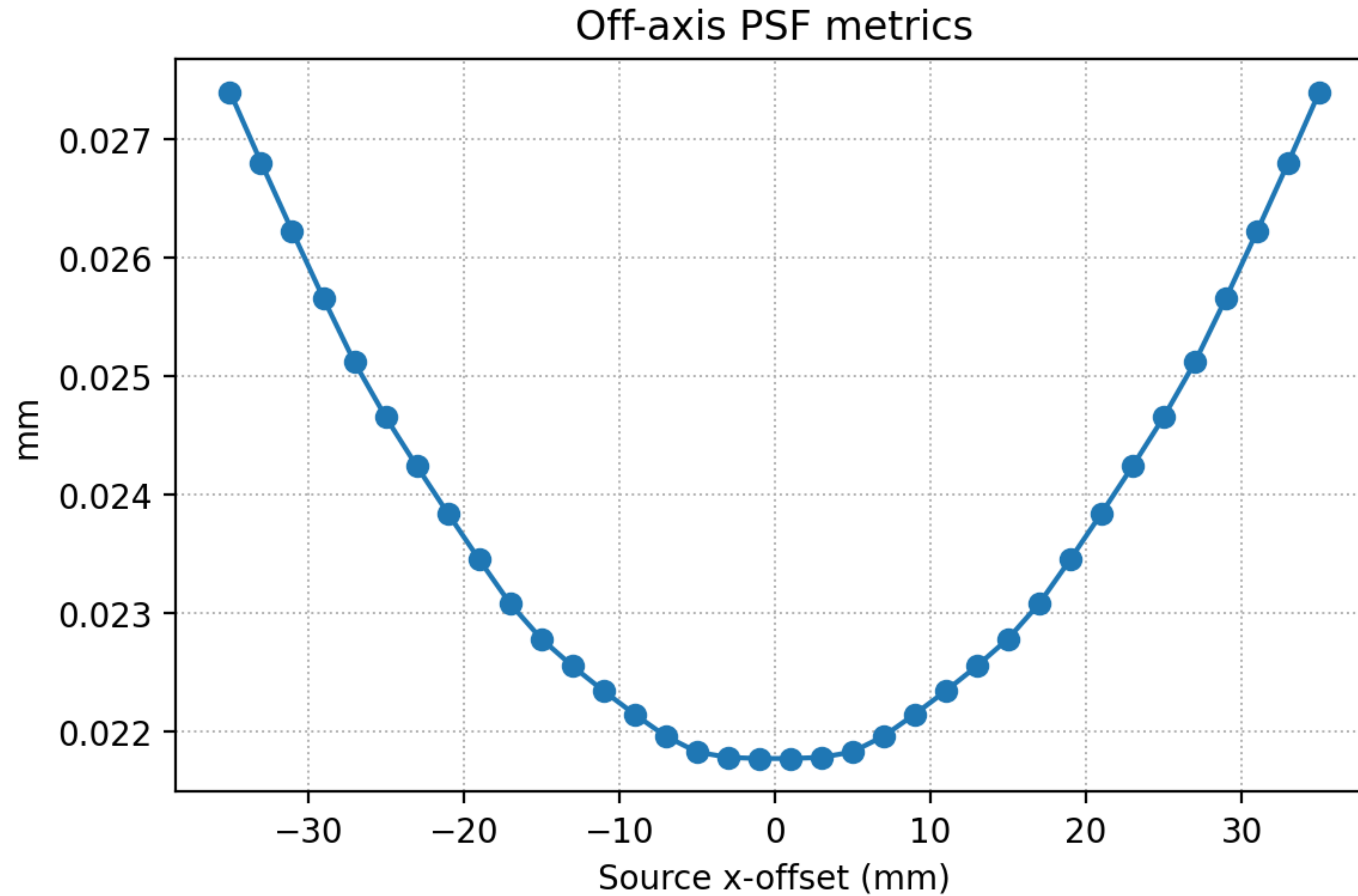


$$X_{off} = 0\text{mm}$$



$$X_{off} = 35\text{mm}$$

Off-axis sweep



As the source moves off-axis, the PSF centroid shifts roughly linearly with field while the core size stays nearly constant for small offsets, with only mild broadening/asymmetry (coma/astigmatism tails) appearing as the field angle increases.

Qualitative Analysis

- Sampling: convergence at $N \geq 1600$, aliasing at low N
- Wavelength: chromatic aberration
- Focus: symmetric degradation around best focus (20.5 mm)
- Aperture: sharpness
- Off-axis: coma

Aberration Correction Comparison

| Aspect | Classical Deconvolution | Neural Network Approach |
|-----------|--|---|
| Principle | Linear inversion (e.g., Wiener, RL) using known PSF | Data-driven mapping from blurred to sharp |
| Pros | Physically interpretable; predictable behavior; easy to regularize; no training data | Can handle complex, non-paraxial, chromatic, or field-dependent aberrations; flexible and adaptive. |
| Cons | Sensitive to noise and PSF mismatch; performance drops when aberrations vary across field. | Requires training data, risk of overfitting |
| Best use | Mild blur, stationary PSF | Complex senarios, data-rich pipelines. |

Comparison classical deconvolution method and neural network approach

Model Refinement

- Physical accuracy:
 - Add diffraction, pixel MTF, temperature tolerances
- Computational efficiency:
 - Vectorization of intersection, GPU acceleration
- Extensions:
 - Image rendering, multi-lens systems