Aperture-aware Lens Design

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https://imaging.cs.cmu.edu/aperture_aware_lens_design

Optimizing for speed

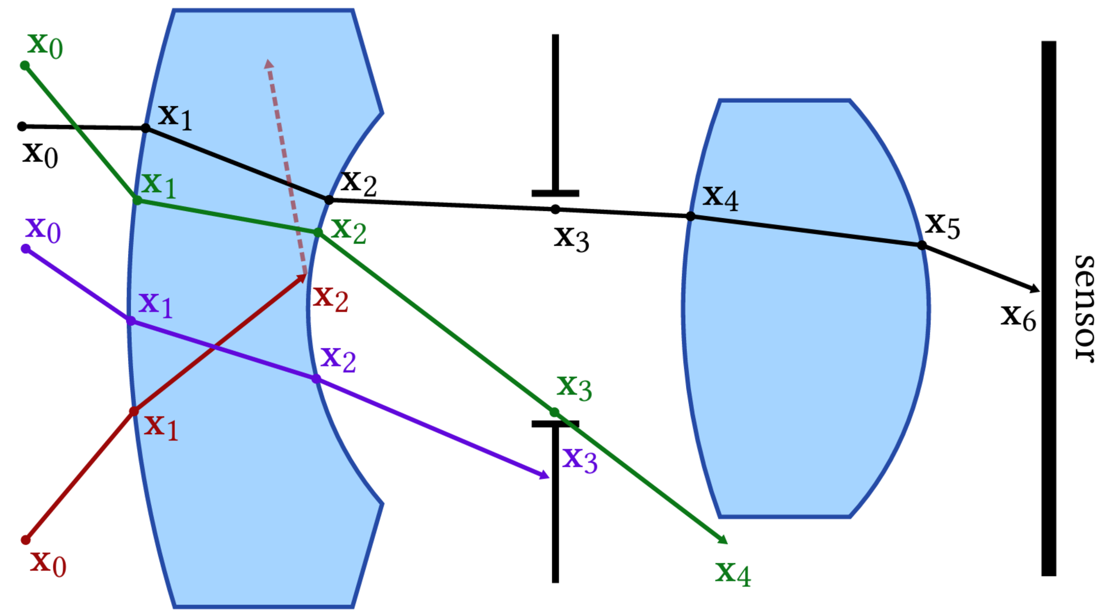
focus loss | speed loss

$$\mathcal{L}(\pi) = \int_{\Omega(\pi)} f(\mathbf{x})\, \mathrm{d}\omega - \lambda \int_{\Omega(\pi)} \mathrm{d}\omega$$

Unbiased gradient of focus and speed loss

$$\frac{\mathrm{d}\mathcal{L}}{\mathrm{d}\pi} = \int_{\Omega(\pi)} \frac{\mathrm{d}f}{\mathrm{d}\pi}\, \mathrm{d}\omega + \int_{\partial\Omega(\pi)} (f-\lambda)\frac{\mathrm{d}g}{\mathrm{d}\pi}\, \mathrm{d}\omega$$

We need to define the boundary

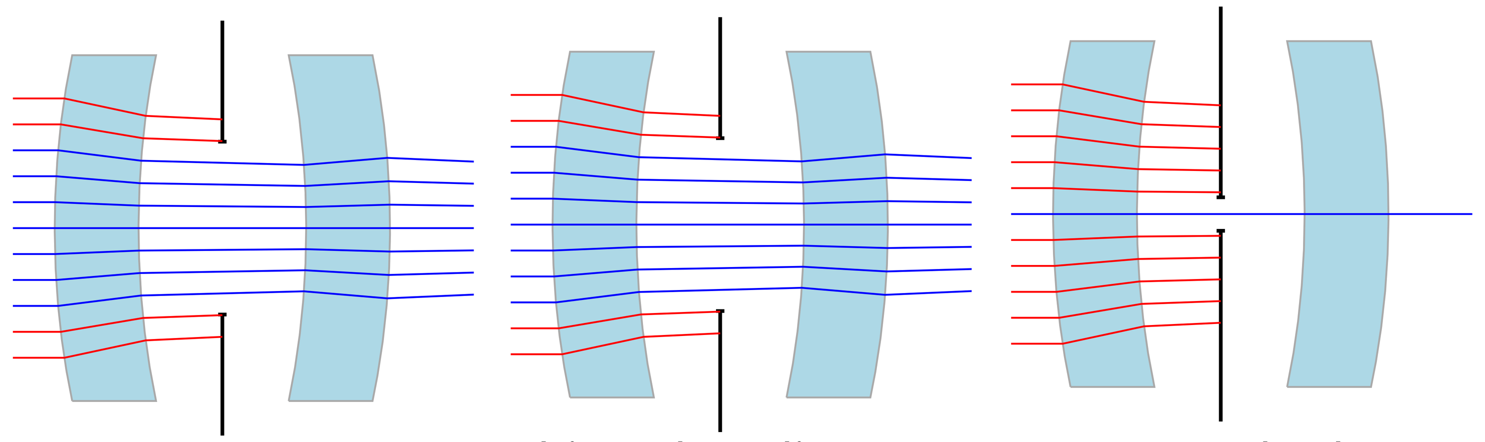


$$g^{\text{semi}}(\mathbf{x}) = \text{dist}(\mathbf{x}) - R(\pi)$$
$$g^{\text{TIR}}(\mathbf{x}) = \cos(\phi^{\text{crit}}(\pi))^2 - \langle \mathbf{v}, \hat{\mathbf{n}}(\mathbf{x},\pi)\rangle$$

Without speed, the optimal focused lens is a pinhole

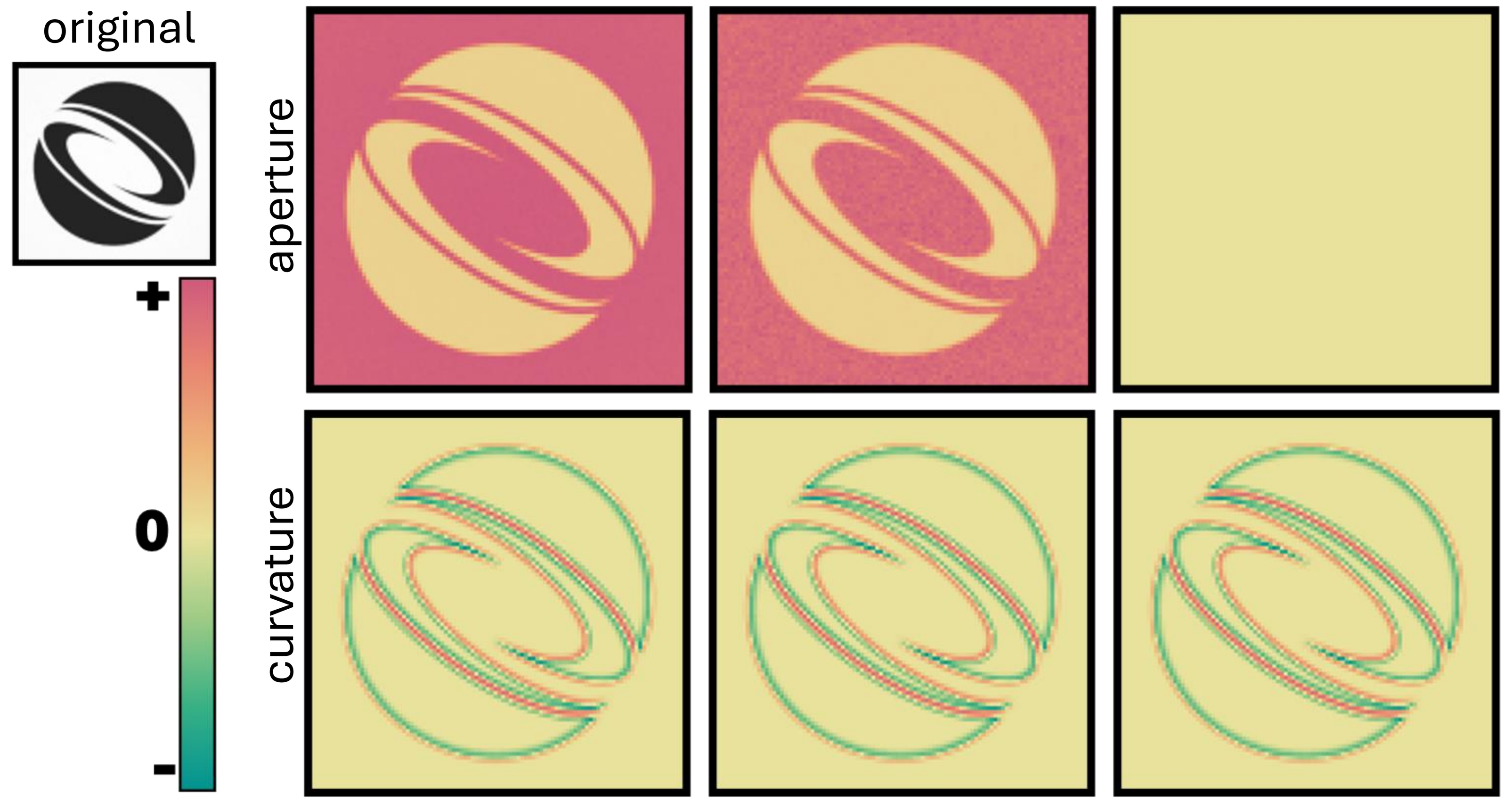
$\lambda = 0$

π : radius of aperture stop



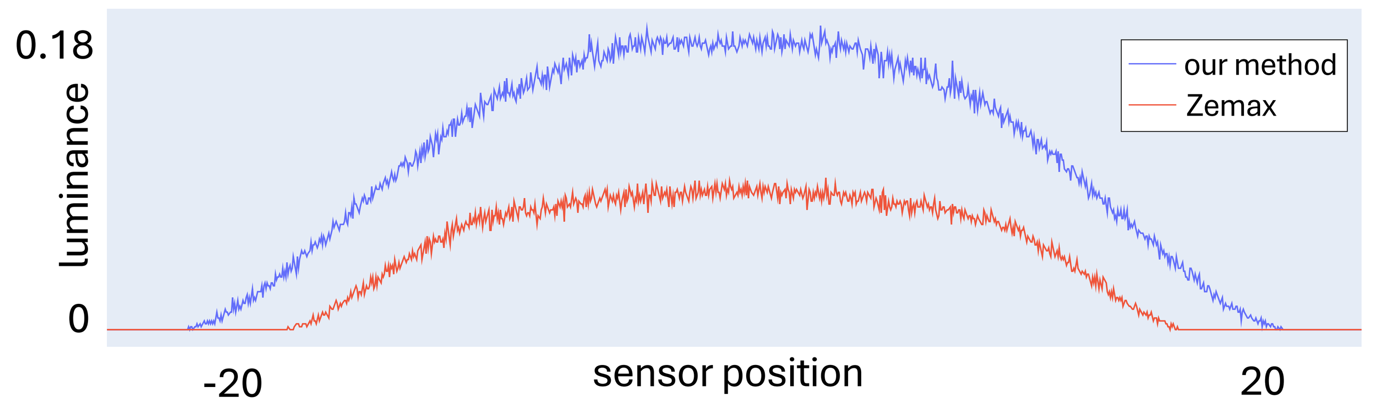
initial | biased gradient | our method

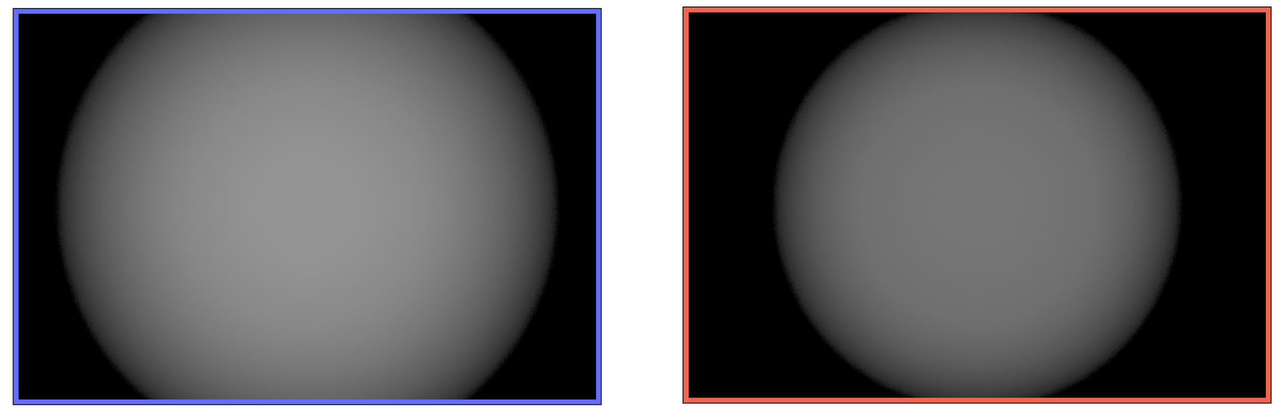
Aperture-aware gradients follow finite differencing



our method | finite differencing | DiffOptics [2022]

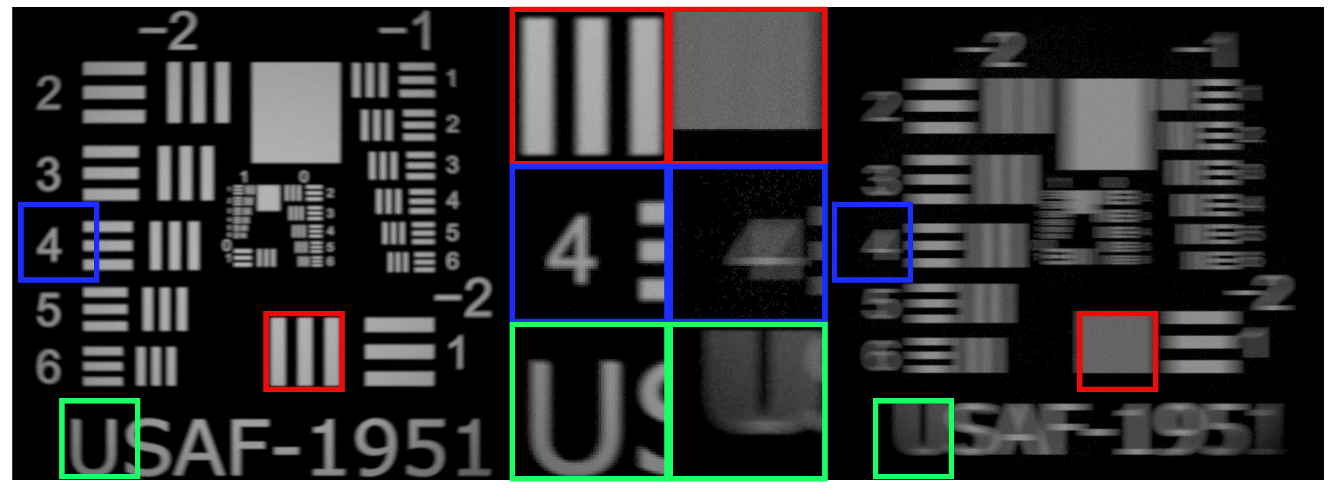
Speed optimized lenses have less vignetting,





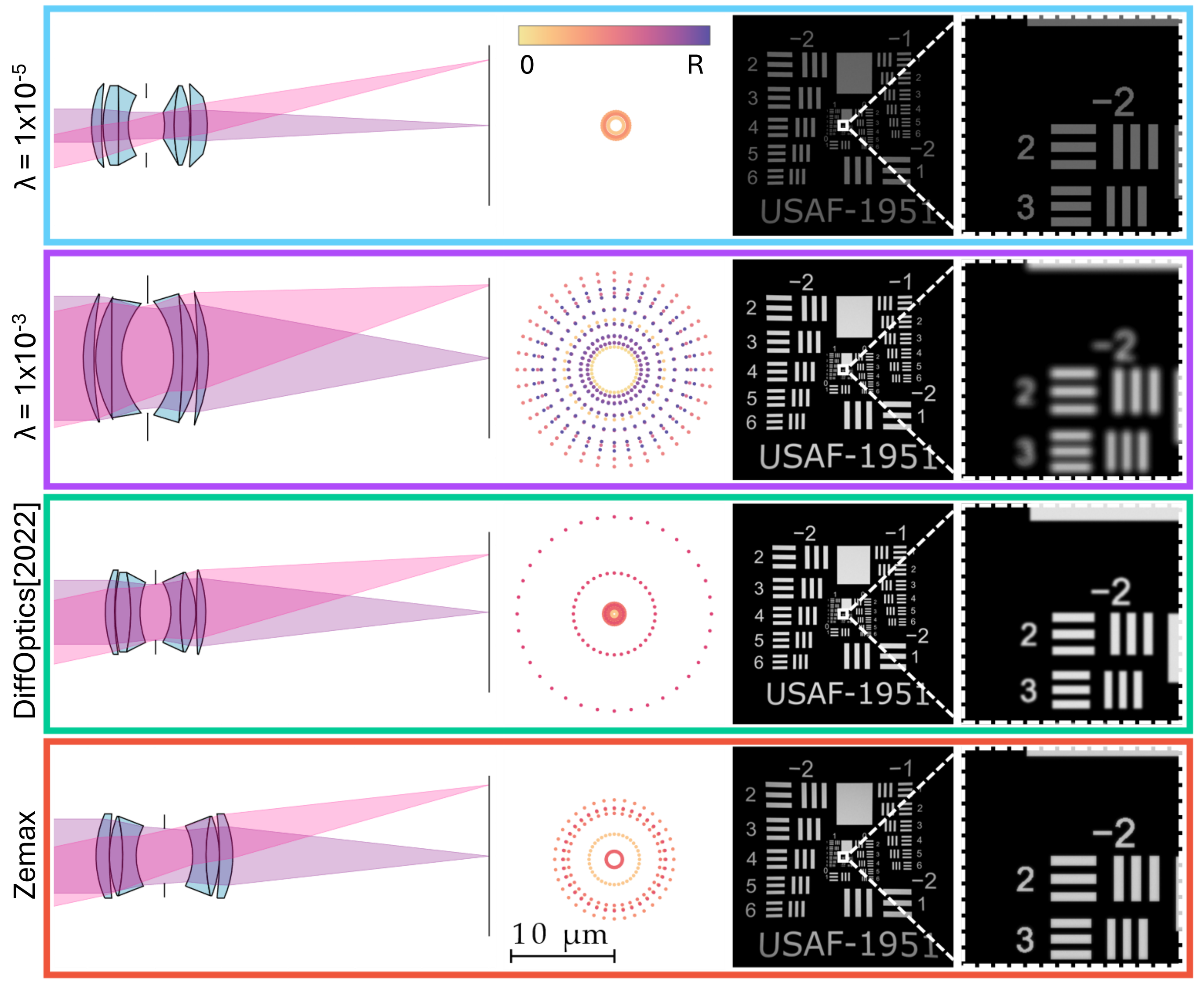
Our method | Zemax

...and less motion blur.

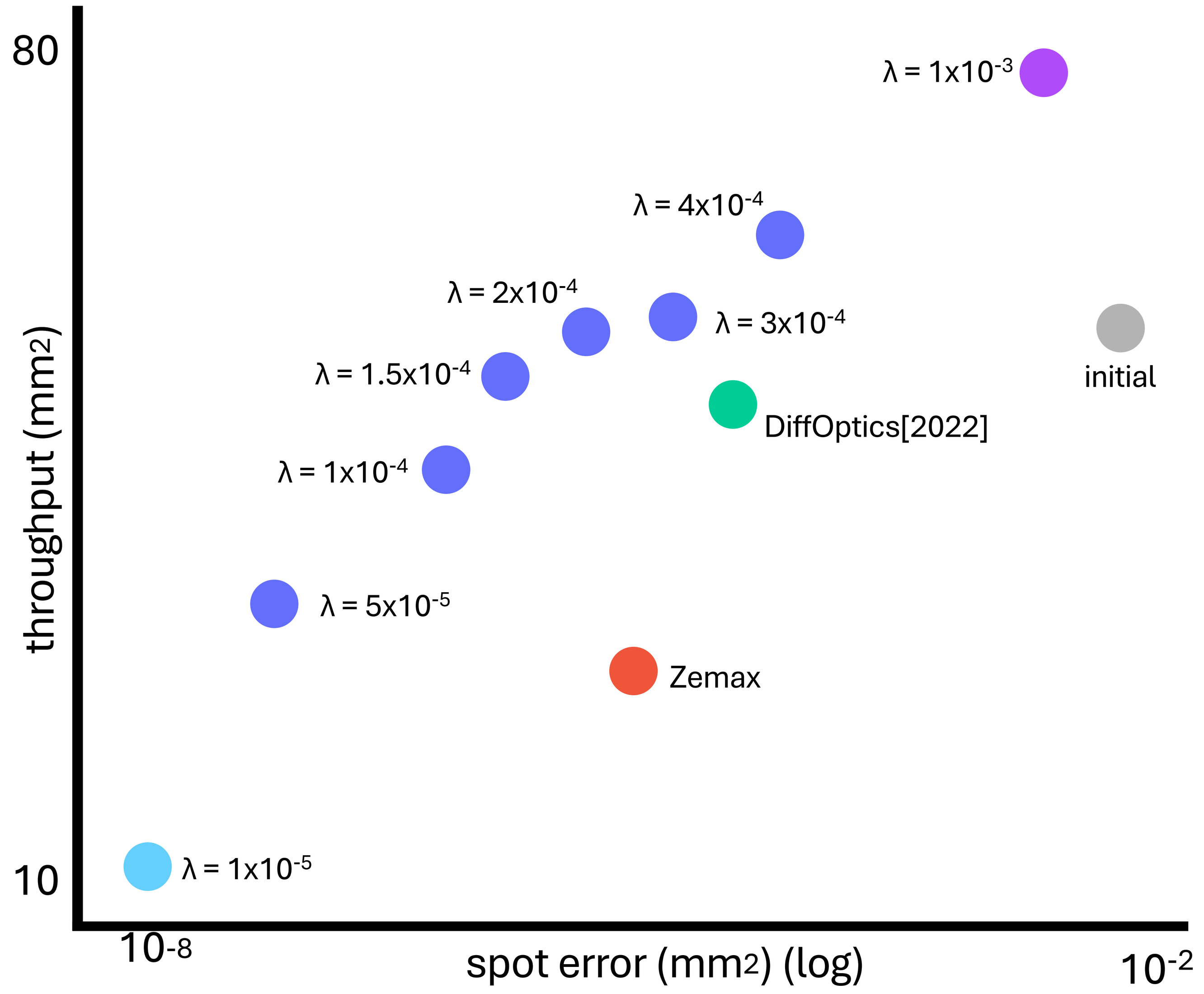


high speed optimized | low speed optimized

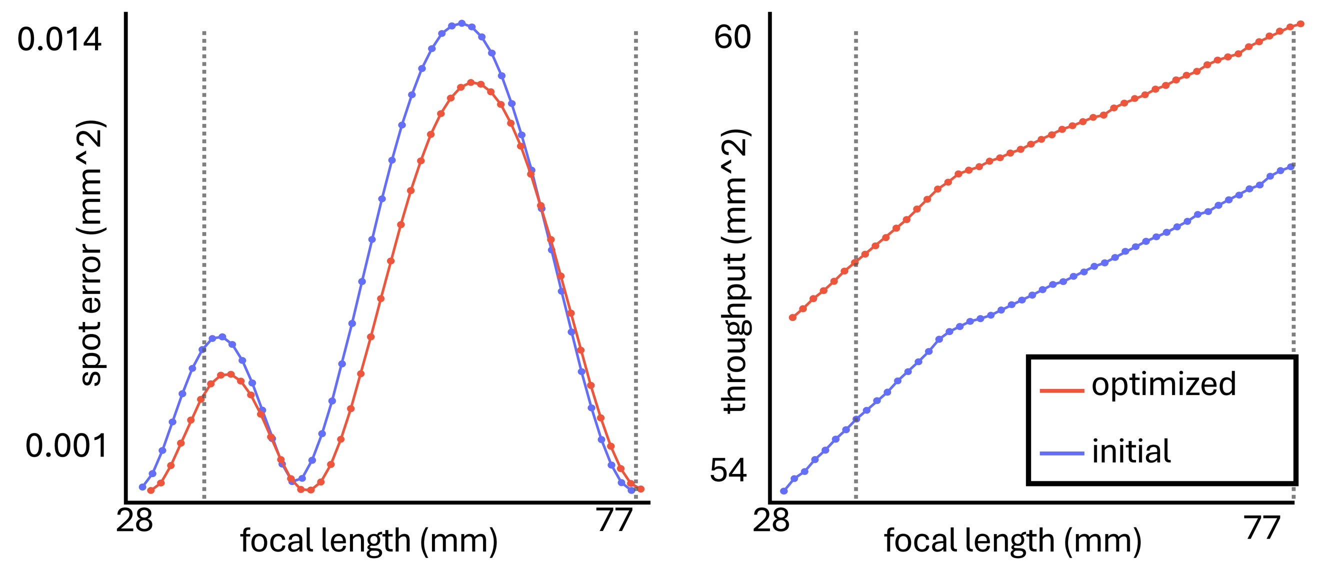
Exploring the sharpness-throughput trade off

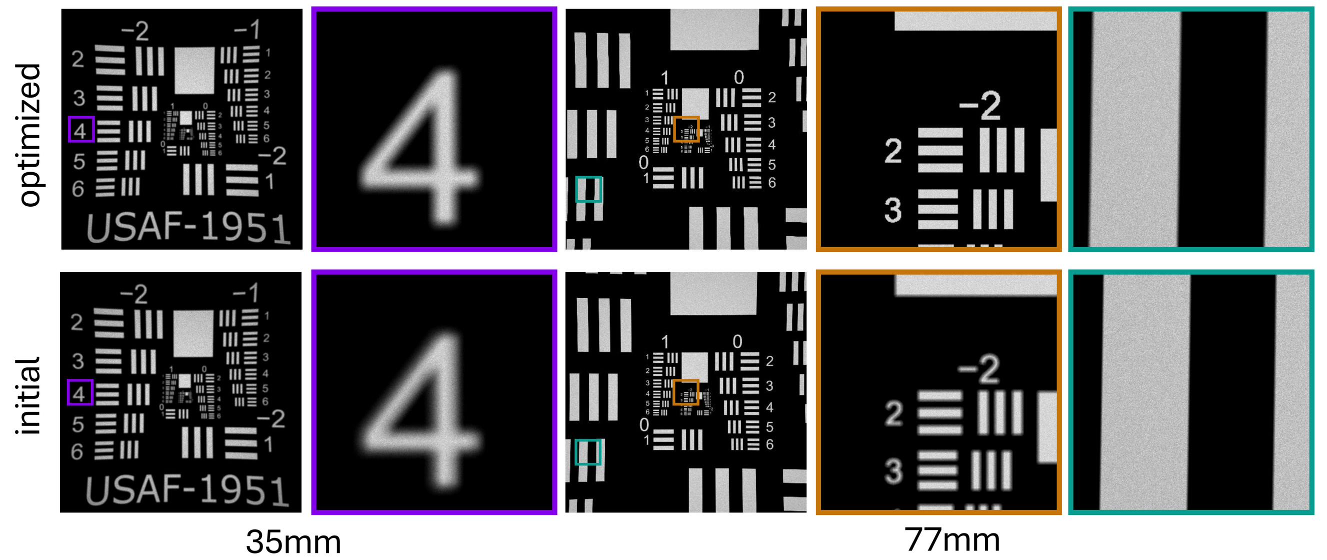


lens layout | spot diagram | render | incut

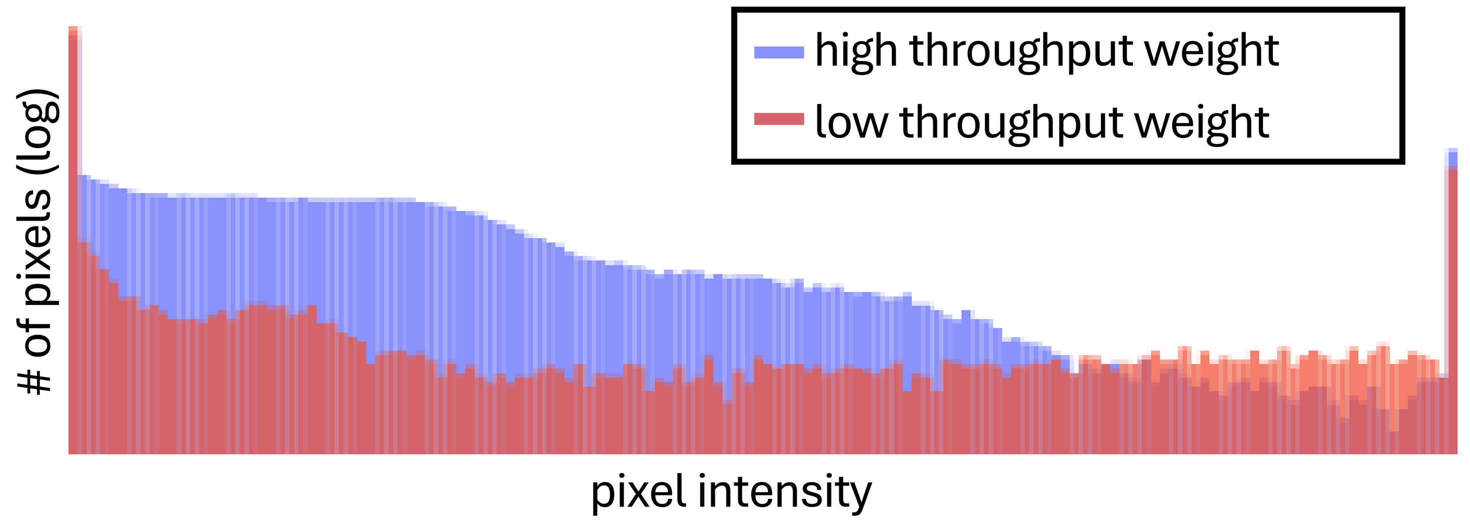


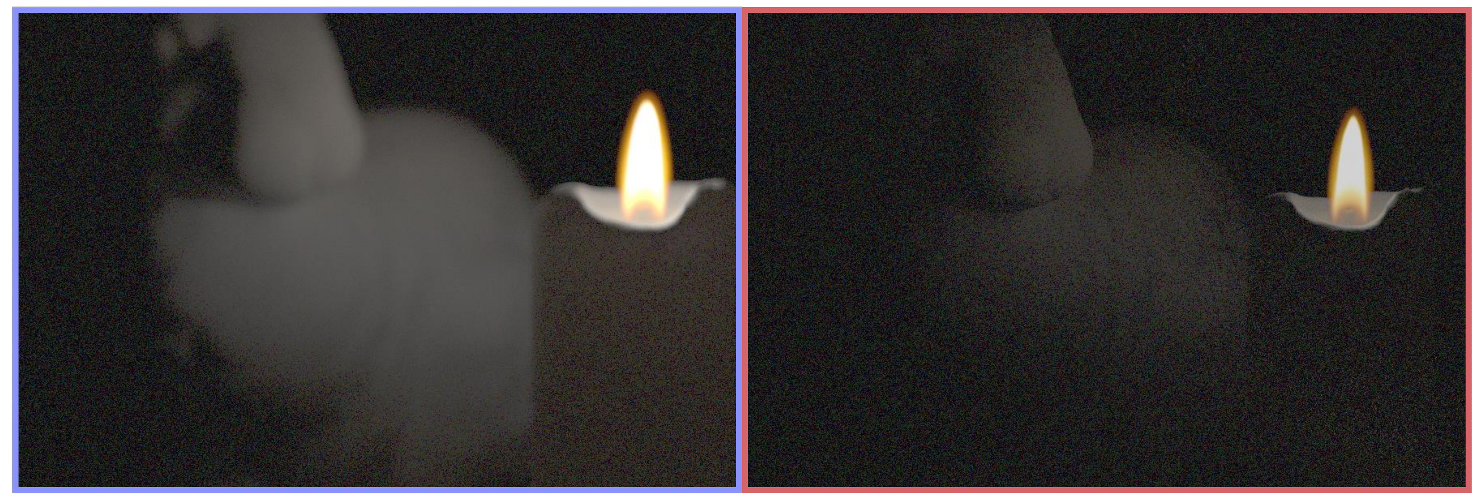
Optimizing a zoom lens





Low light scene with sensor noise





high speed weight 46.85dB | low speed weight 35.86dB