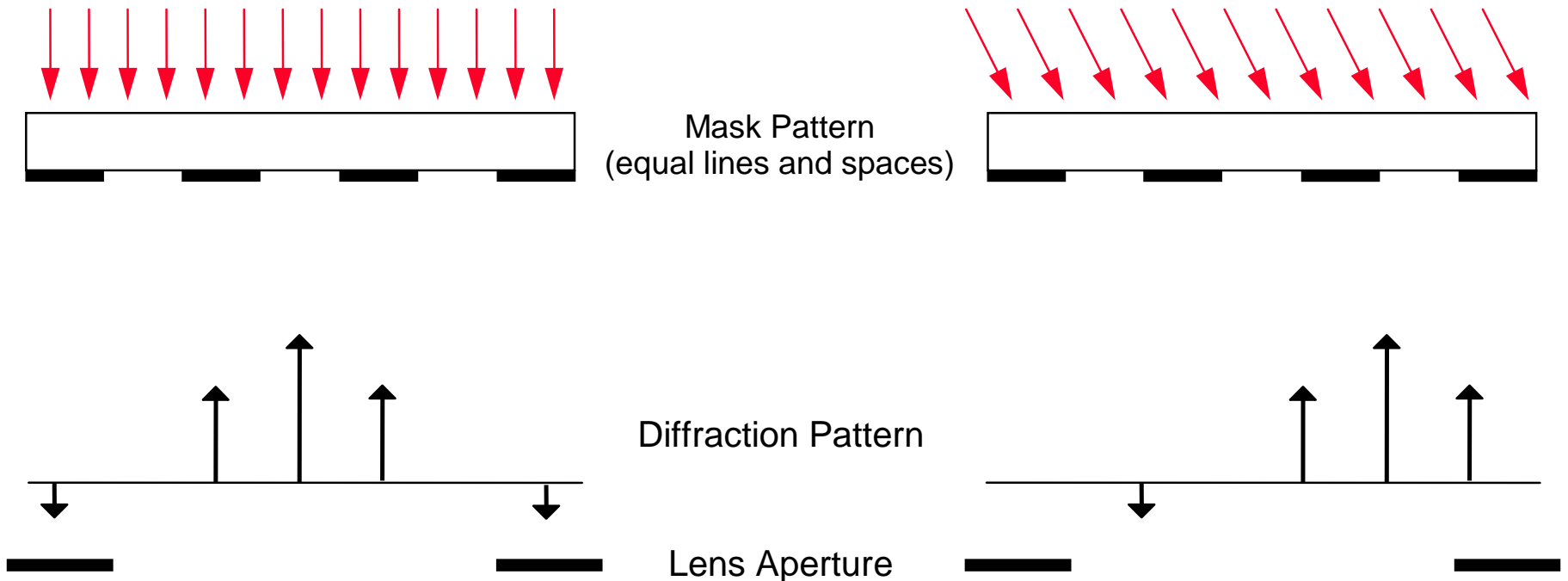


Aerial Imaging – Part II

Coherence, Aberration and Defocus

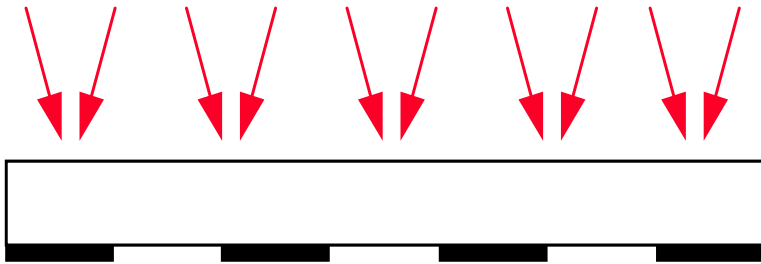
Coherence

- Previous analysis assumes light arrives in one direction (Spatial Coherence)



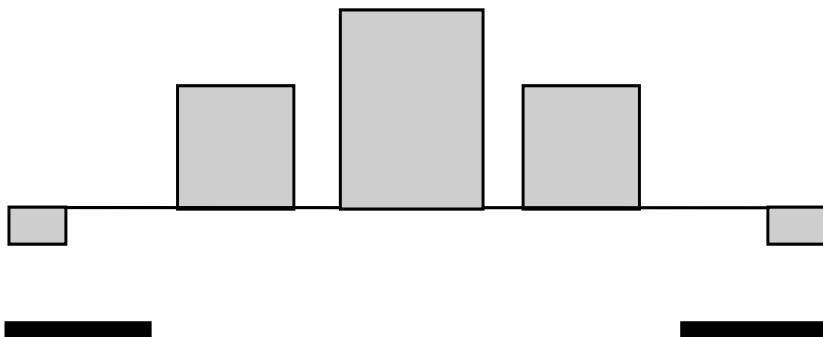
Partial Coherence

- Light comes from range of angles -> Broadened diffraction orders



$$\sigma = \frac{n \sin \theta_{max}}{NA} = \frac{\text{source diameter}}{\text{lens diameter}}$$

Mask Pattern
(equal lines and spaces)



Diffraction Pattern

Lens Aperture

Abbe's Method

- Arbitrary source divided into independent point sources
- Each point a source of spatially coherent illumination
- Two point sources do not interact coherently

$$I_{total}(x, y) = \frac{\iint I(x, y, f_x, f_y) S(f_x, f_y) df_x df_y}{\iint S(f_x, f_y) df_x df_y}$$

where $S(f_x, f_y)$ is intensity of source as a function of position

Simplifications for Litho simulations

Hopkin's Equation

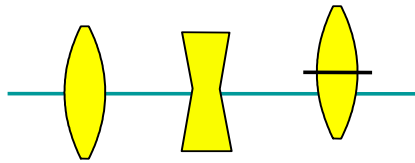
$$I_{total}(x) = \iint TCC(f_x, \tilde{f}_x) T_m(f_x) \dot{T}_m(\tilde{f}_x) df_x d\tilde{f}_x$$

SOCS Approach

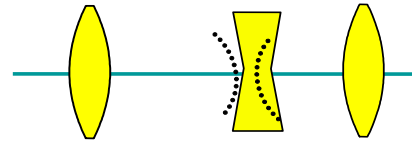
$$I(x) = \sum_{n=1}^{\infty} \omega_n |\varphi_n(x) * t_m(x)|$$

Aberrations

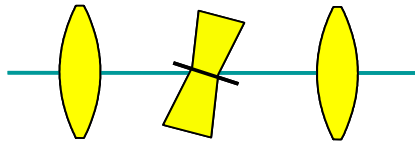
- Aberrations of construction, design and use



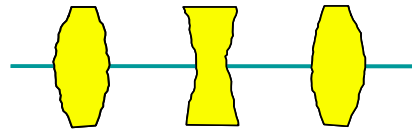
Decentered



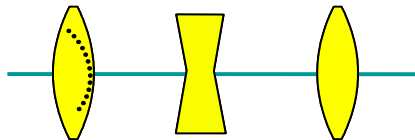
Incorrect spacing or thickness



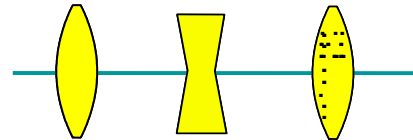
Tilt



Rough surfaces

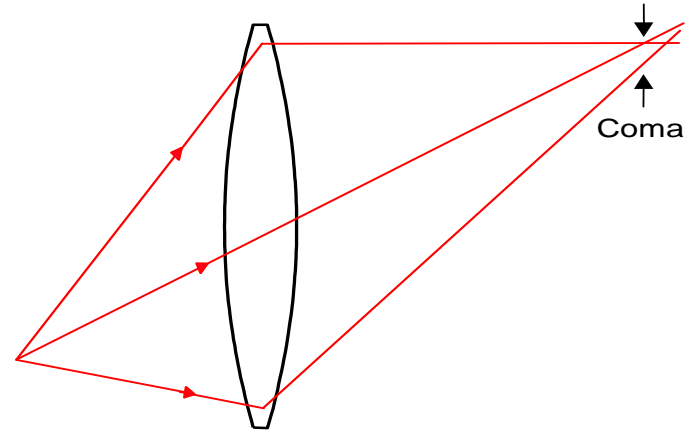
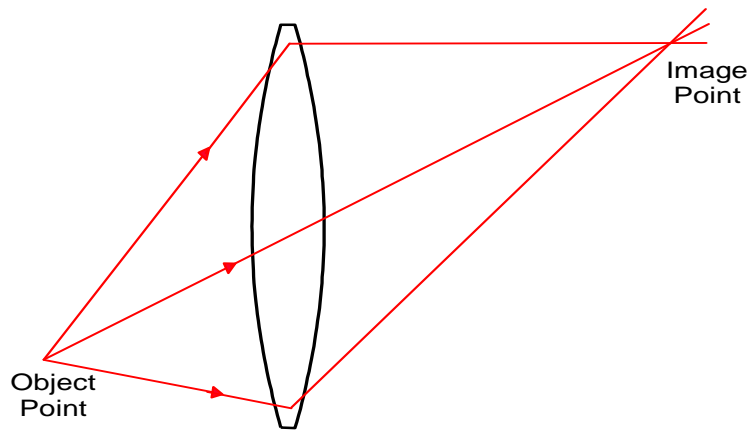


Incorrect Curvature



Glass inhomogeneity or strain

Modeling Aberrations-Zernike Polynomials

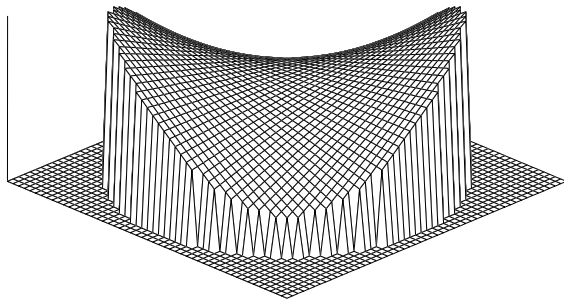


$$W(R, \varphi) = \frac{OPD}{\lambda} = \sum_{i=0}^{\infty} Z_i F_i(R, \varphi)$$

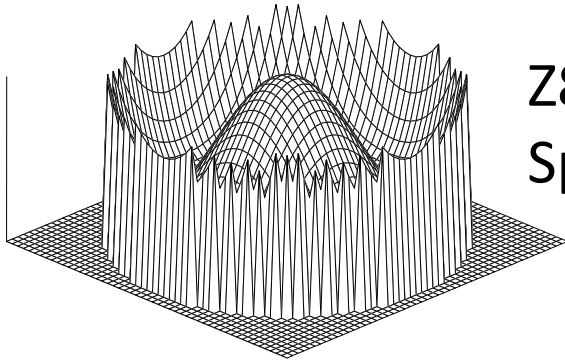
$$f_x = \frac{NA}{\lambda} R \cos \varphi, f_y = \frac{NA}{\lambda} R \sin \varphi$$

$$P(f_x, f_y) = P_{ideal}(f_x, f_y) e^{i2\pi W(R, \varphi)}$$

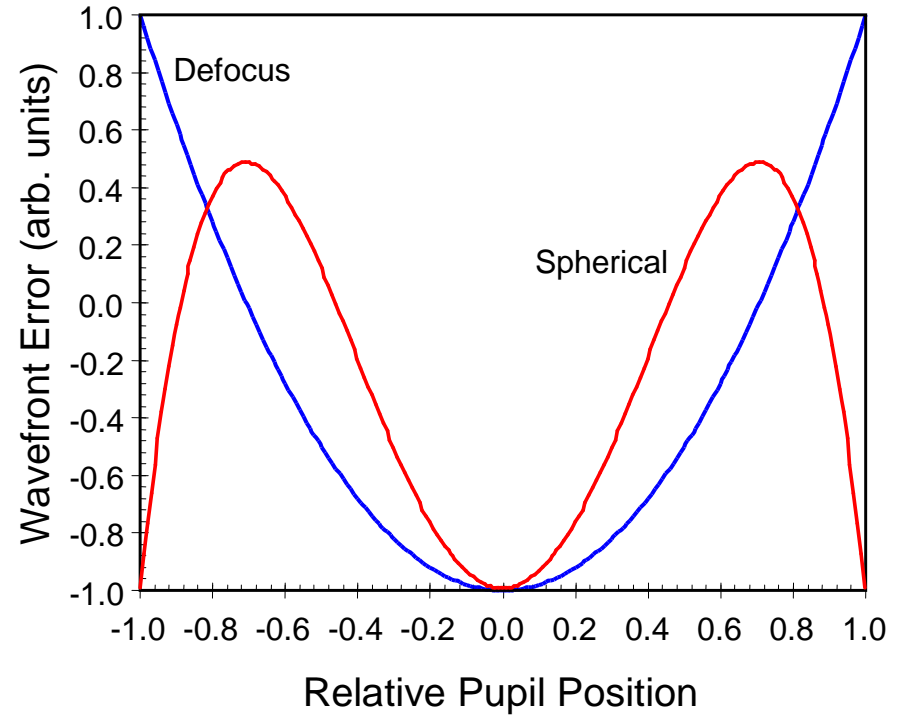
Aberration Examples



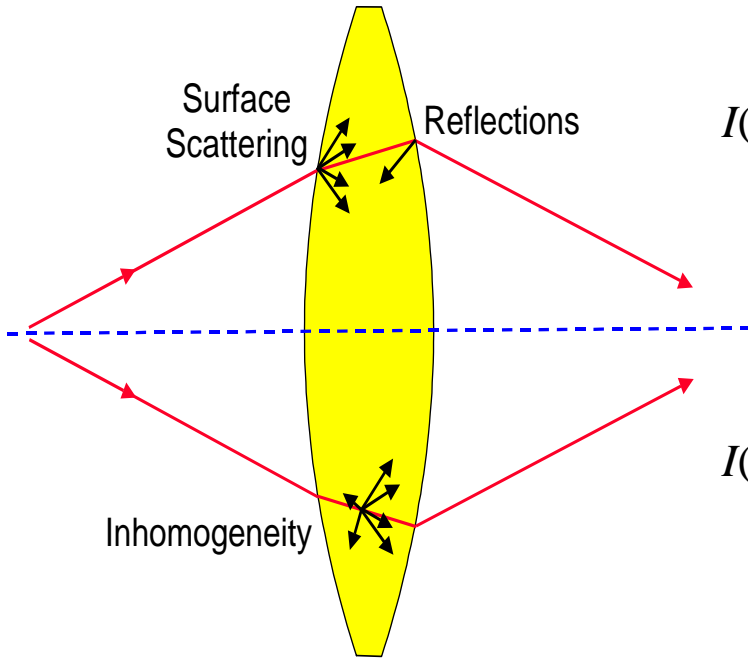
Z3: Defocus



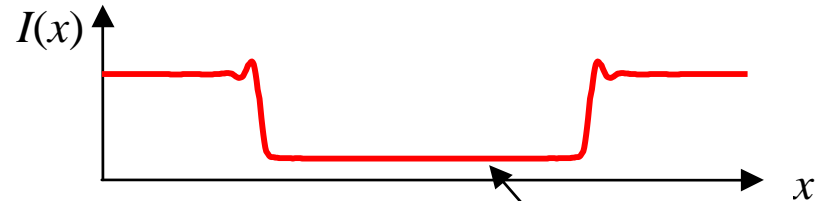
Z8: 3rd Order Spherical



Flare



Aerial Image with No Flare



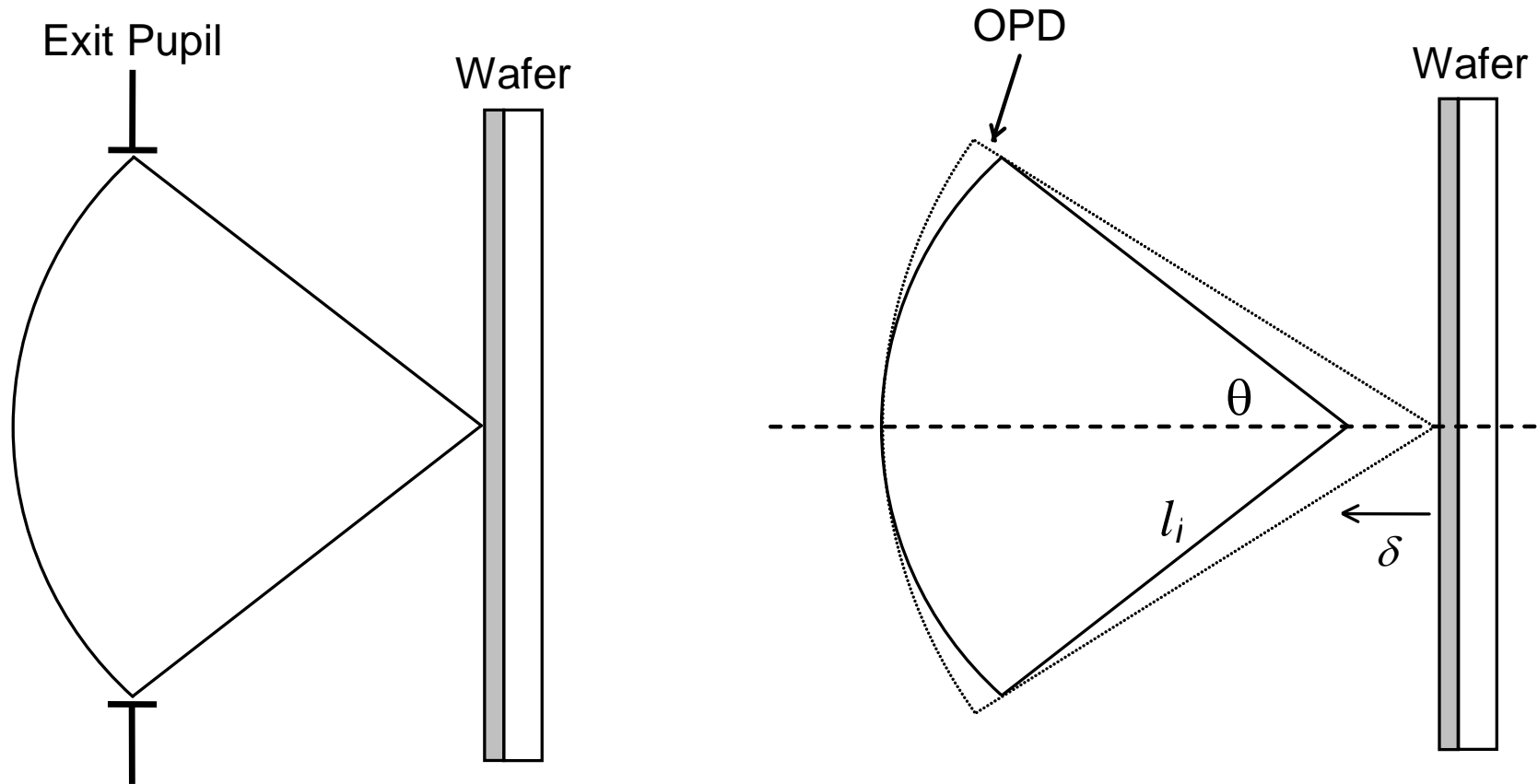
Aerial Image with Flare

Stray Light

Dark-field reticle -> less flare

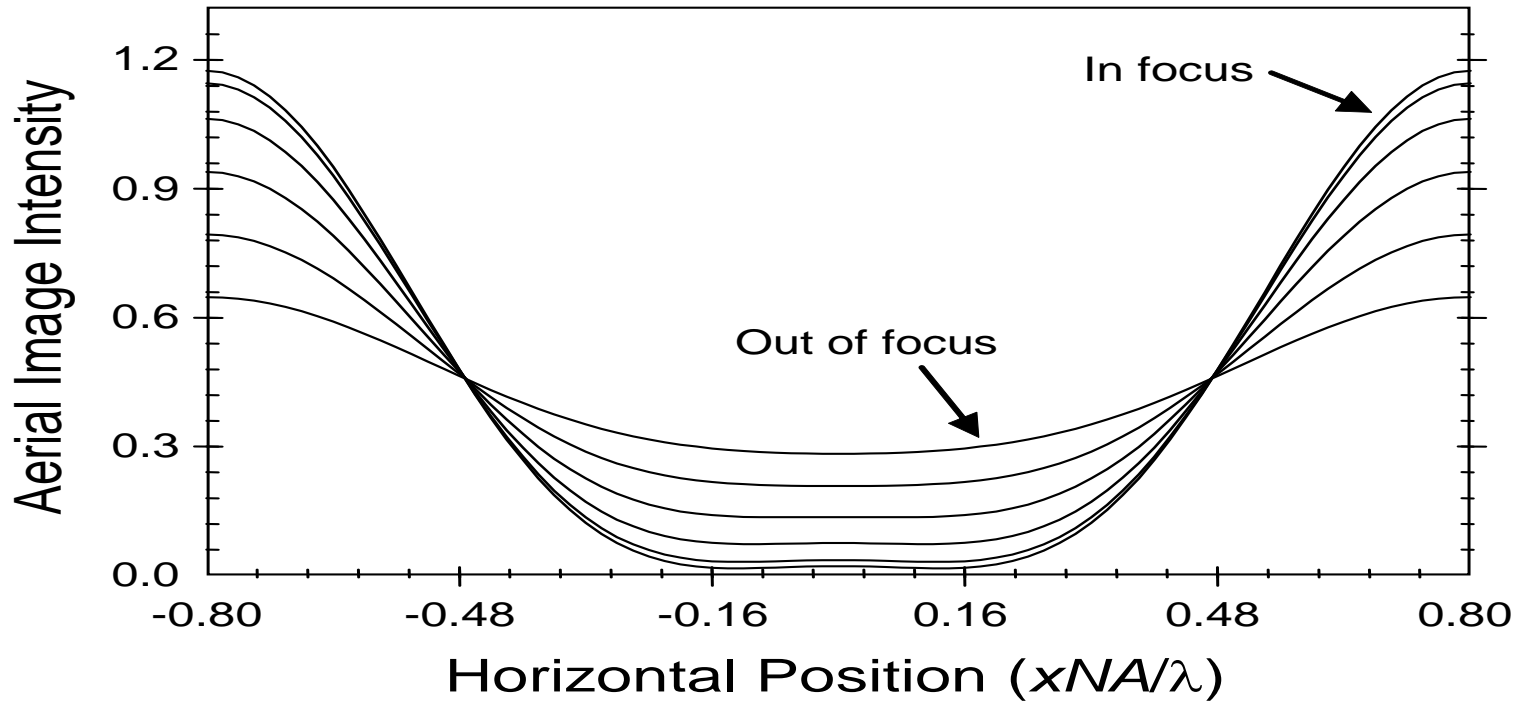
$$I(x, y) = SF * CF + (1-SF)I_o(x, y)$$

Defocus



$$OPD = n\delta(1 - \cos \theta) = \frac{1}{2}n\delta \sin^2 \theta$$

Defocus Example: Dense Lines



3-beam imaging

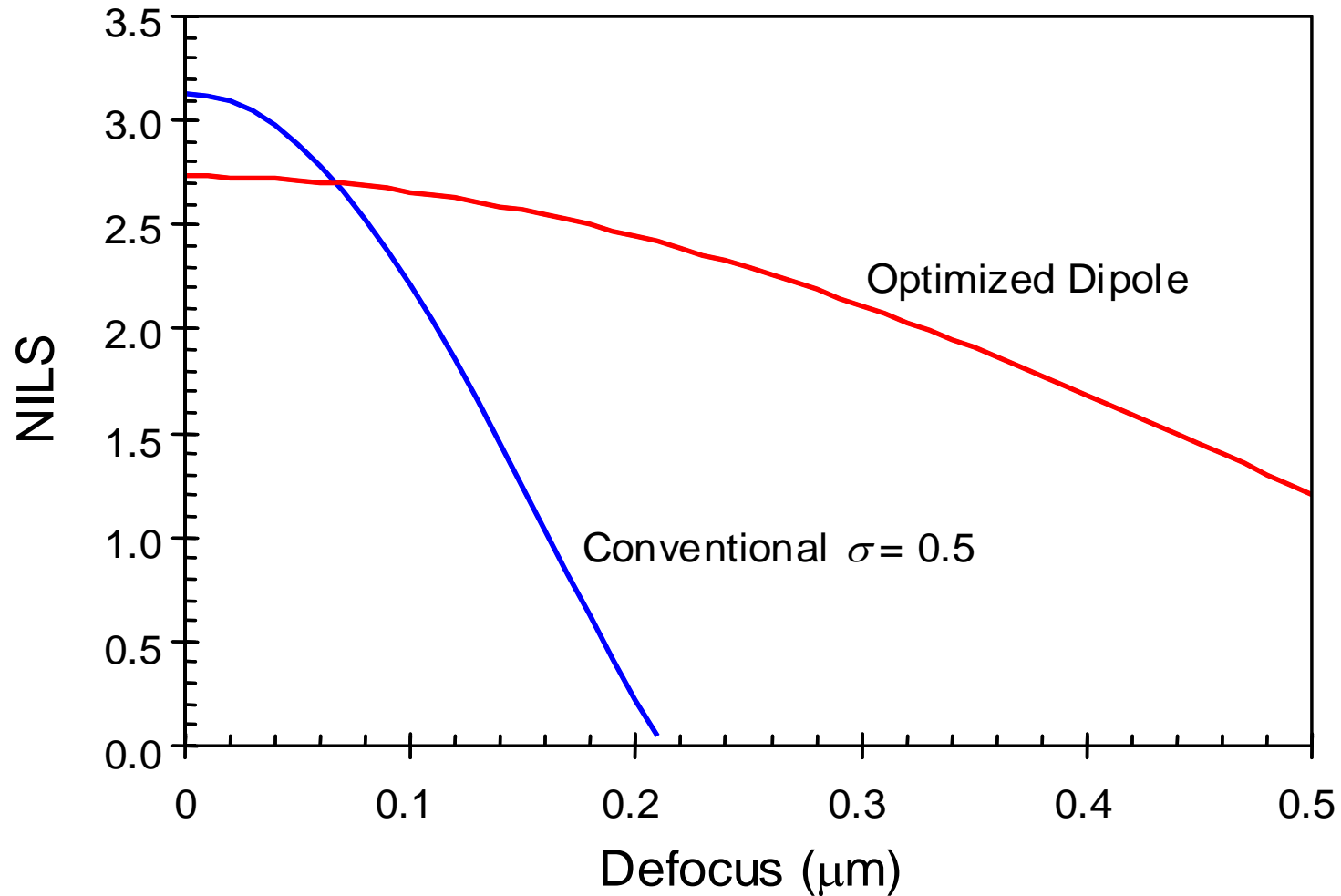
$$I(x, \delta) = I(x, 0) - \delta^2 f(x)$$

2-beam imaging

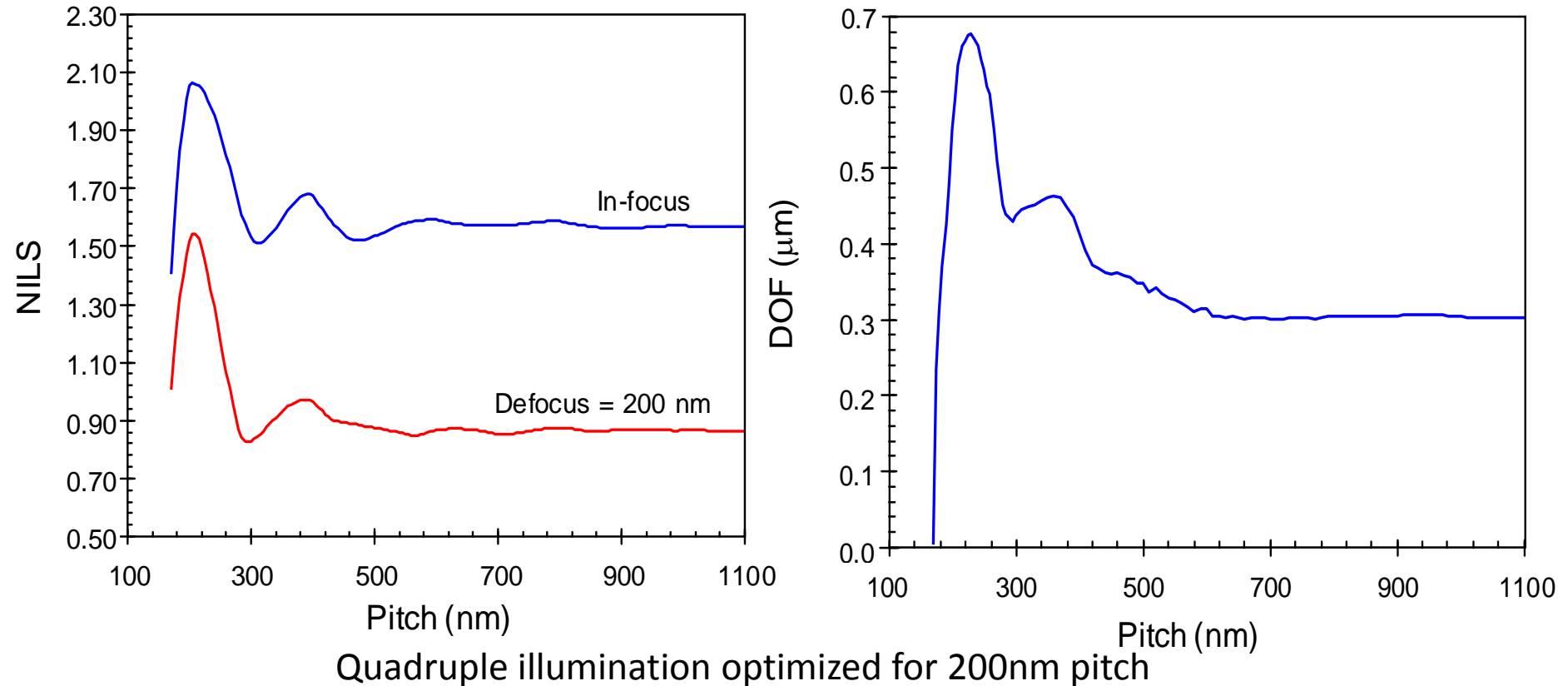
$$I(x) = a_0^2 + a_1^2 + 2a_0 a_1 \cos(\varphi_1 - \varphi_0) \cos 2\pi x/p$$

(After compensating for telecentricity)

Off-Axis Illumination



Forbidden Pitches



- SRAFs can be inserted if pitch > 1.7 times minimum pitch
- 1.3-1.7 times minimum pitch is forbidden since poor DOF & NILS