

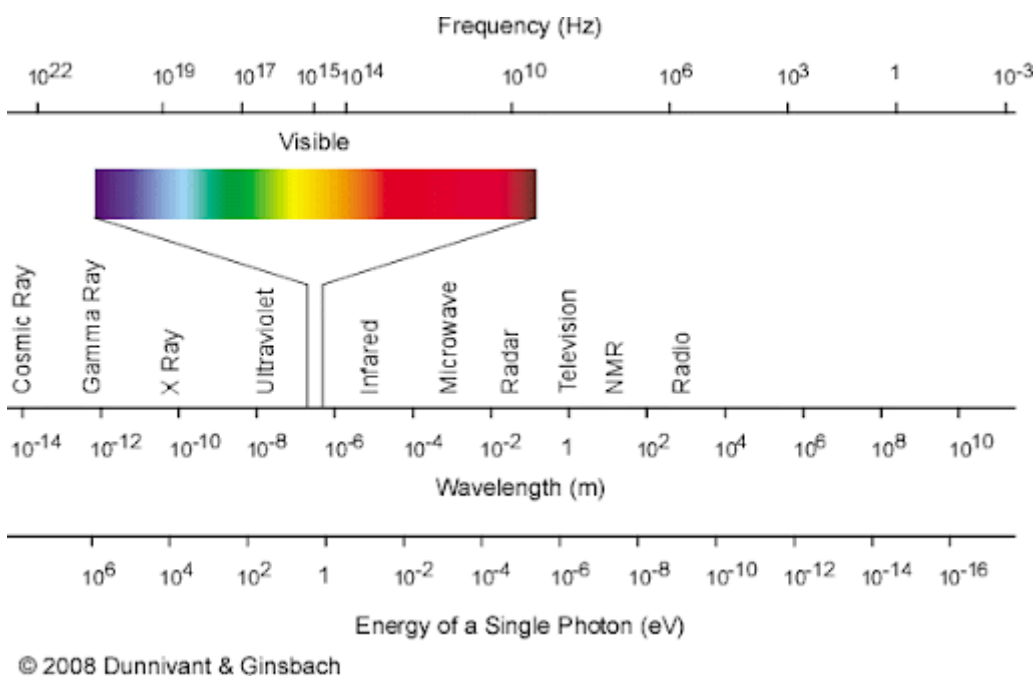
Optics

Properties of light

Wave particle duality:

Light is a wave

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Absorption and Emission

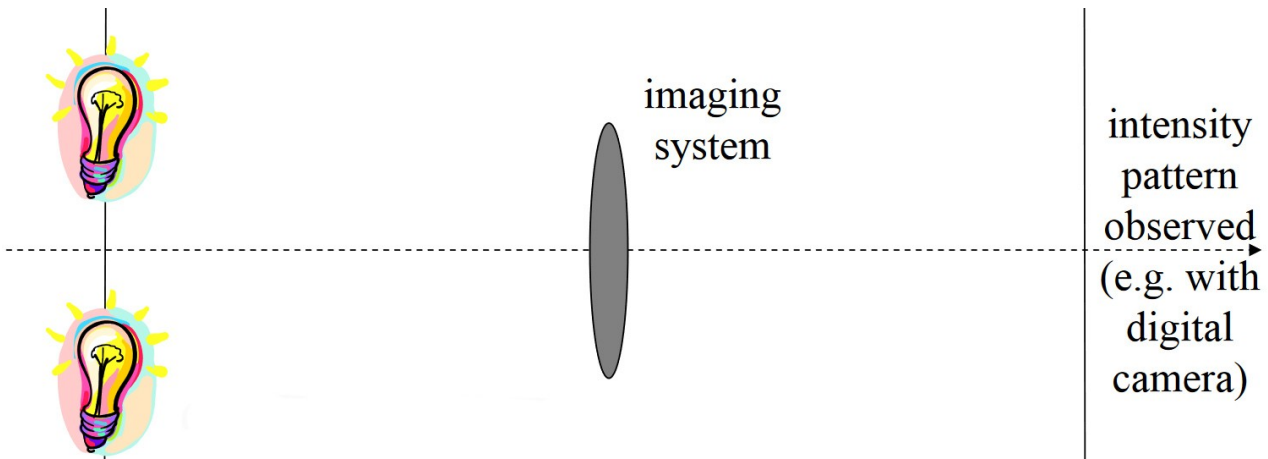
Beer's law

Refraction

Ray tracing

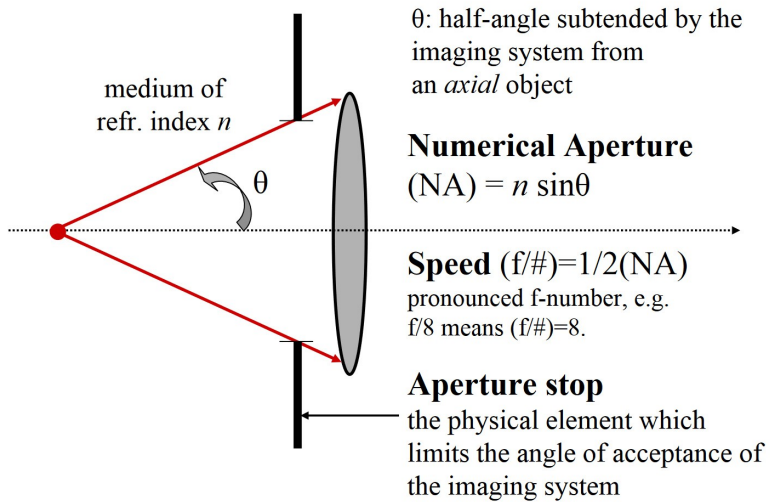
Resolution

Resolution: The ability to separate two objects



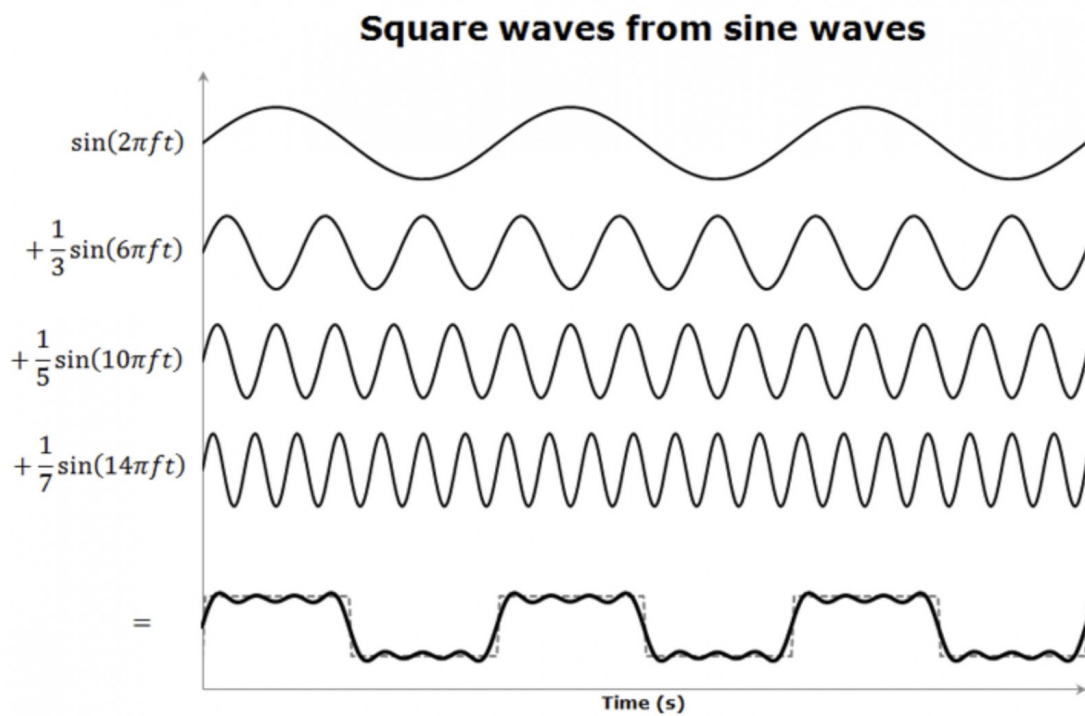
A definition of Numerical Aperture

Numerical Aperture and Speed (or F-Number)



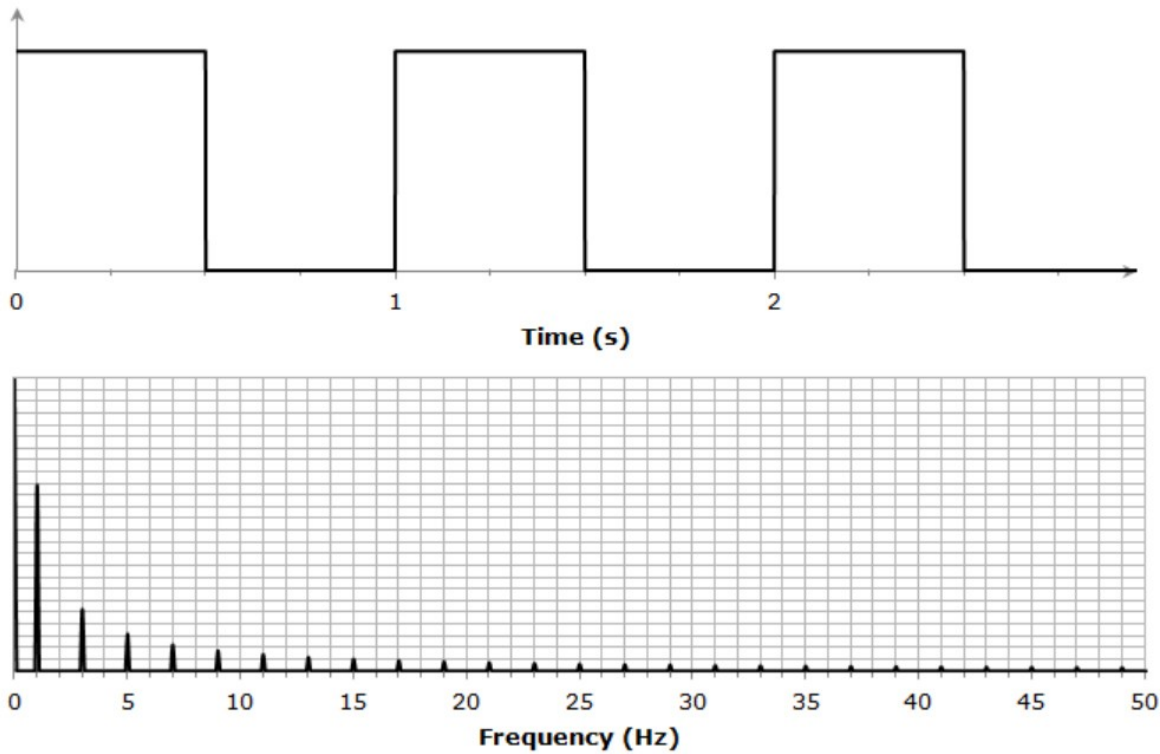
Fourier transform:

Transform from real space to frequency space



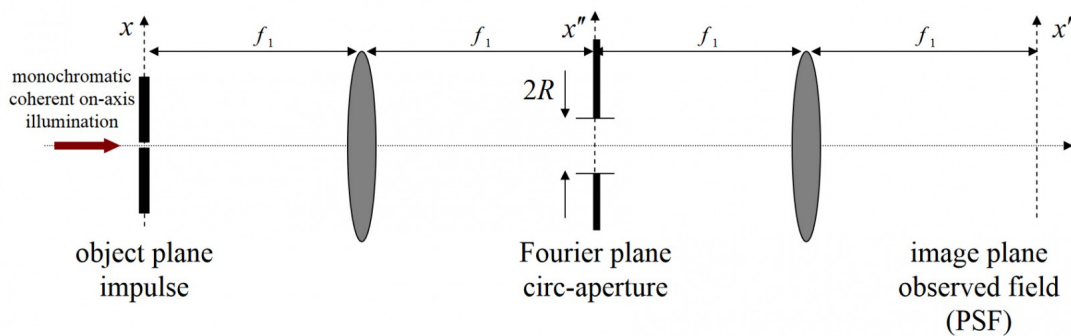
Now we look at a real square wave and frequency space

1 Hz square wave



Look at a simple optical system:

PSF vs NA



Mathematical prediction of the Point Spread Function (PSF)

on the left we have the mathematical point source know as a delta function.

$$g_{\text{in}}(x, y) = \delta(x)\delta(y)$$

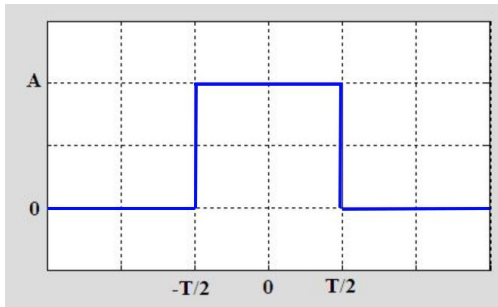
were

$$\delta(x) = \begin{cases} 0, & x \neq 0, \\ \infty, & x = 0, \end{cases}$$

the intensity at the Fourier plain can be found by taking the Fourier transform of this function.

$$F(\omega) = \mathcal{F}(\delta(x)) = \frac{1}{2\pi} \int_{-\infty}^{\infty} \delta(x) e^{i\omega x} dx = \frac{1}{2\pi}.$$

or

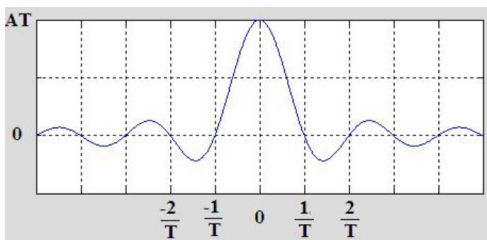


this has the same intensity at all points inside the aperture and zero outside. The second lens is now taking a Fourier transform on a box function the width of the aperture.

$$\text{jinc}(\cdot, \cdot) \equiv 2 \frac{J_1\left(2\pi \frac{R}{f_1} \frac{r'}{\lambda}\right)}{2\pi \frac{R}{f_1} \frac{r'}{\lambda}}$$

(unit magnification)

or

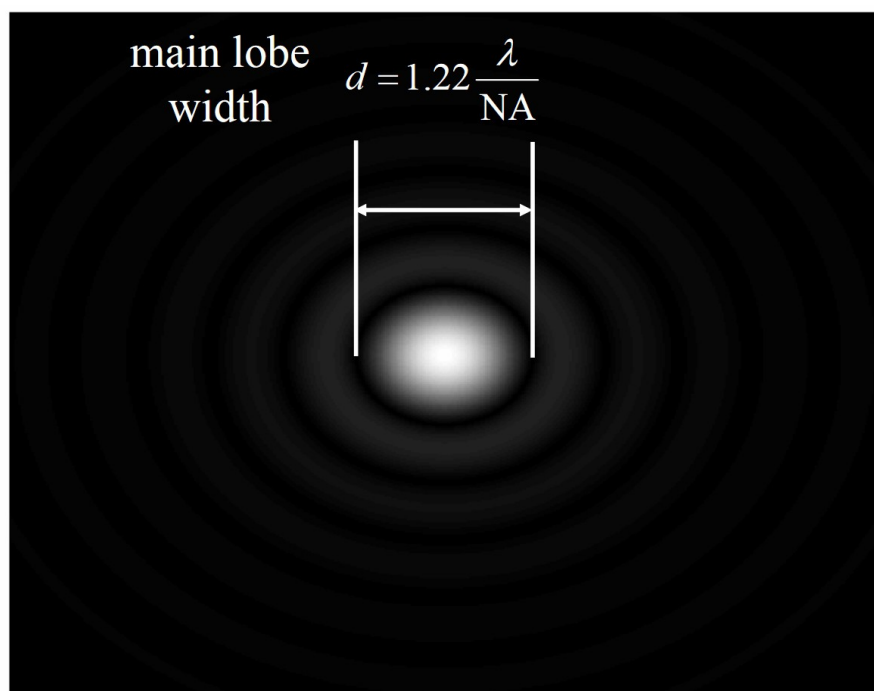
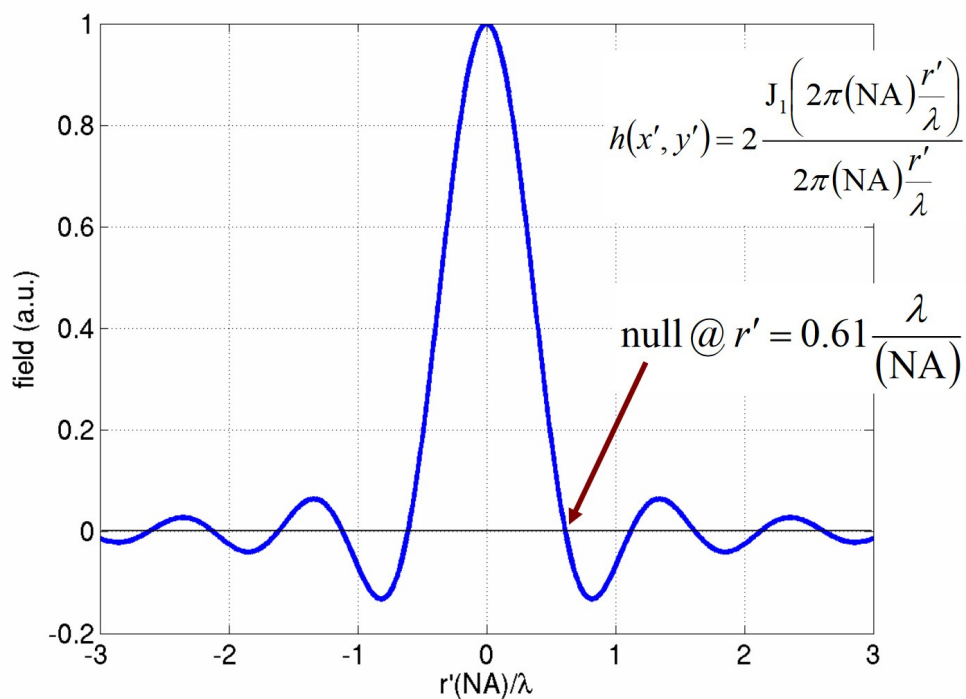


Substituting in the definition for NA

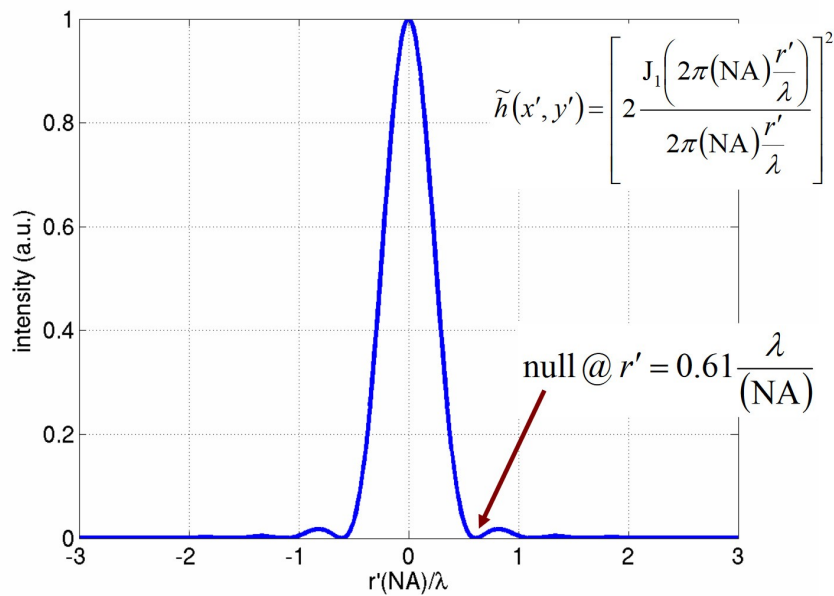
Numerical Aperture (NA) by definition:

$$(NA) \equiv \frac{R}{f_1}$$

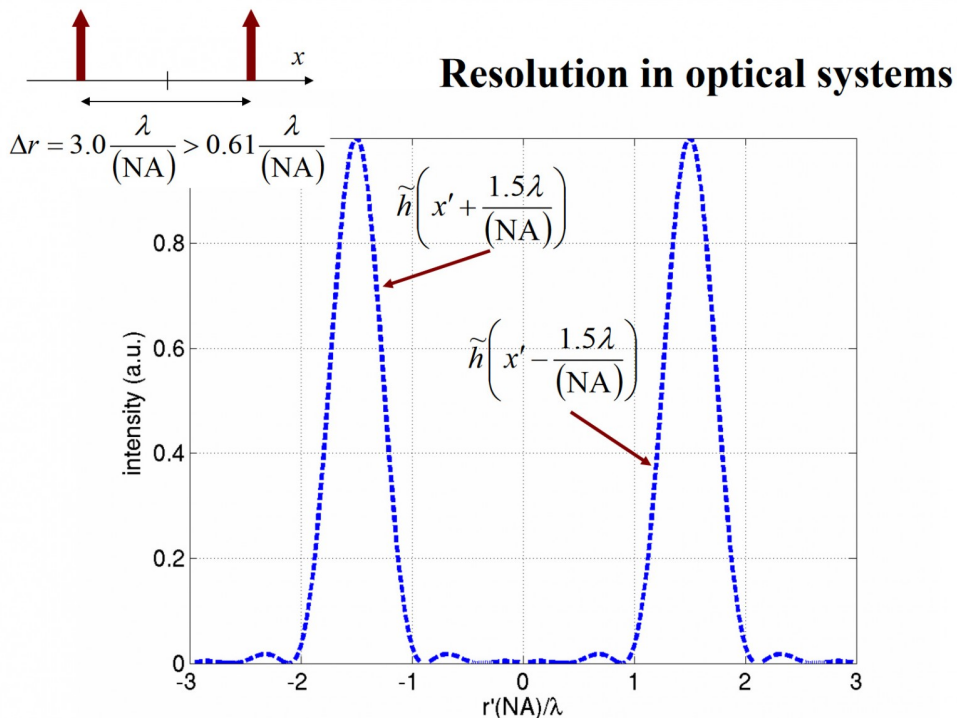
PSF *vs* NA

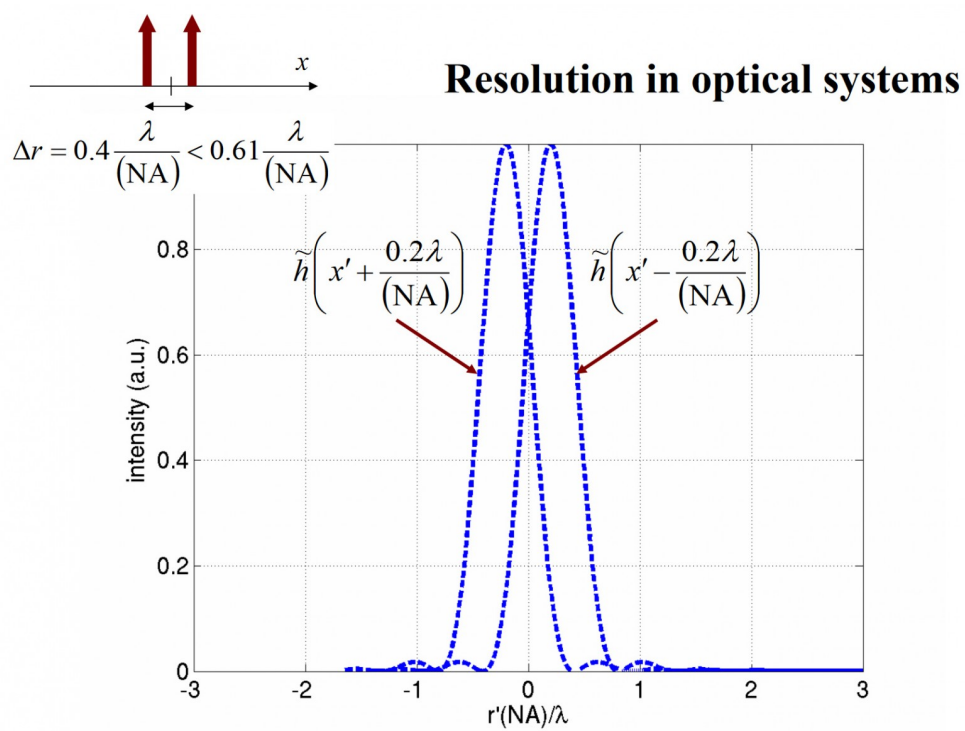
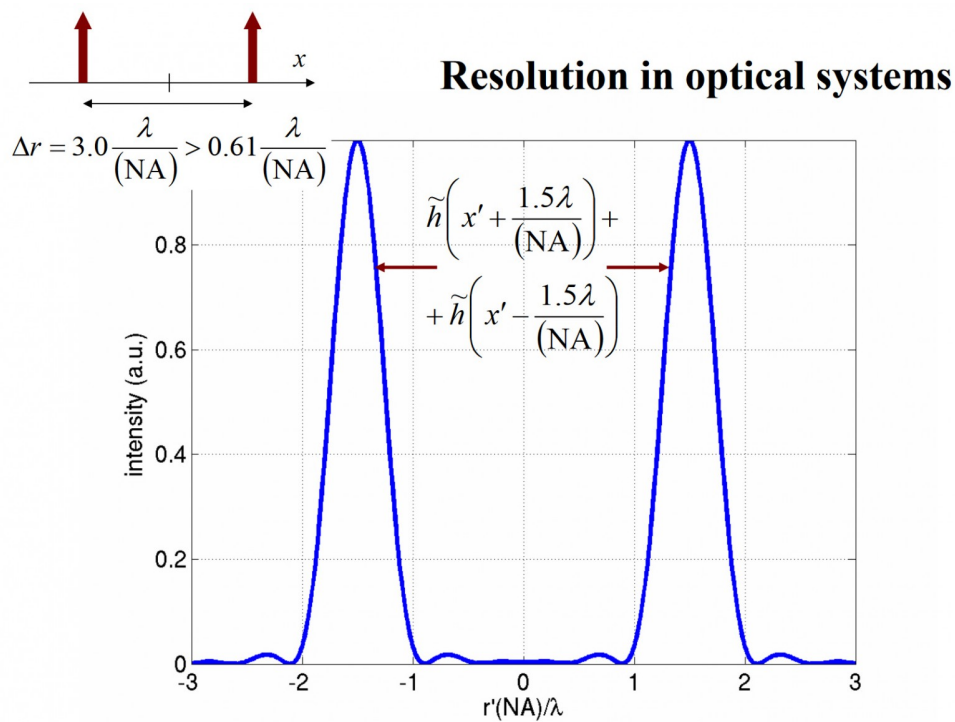


The incoherent case: $\tilde{h}(x', y') = |h(x', y')|^2$

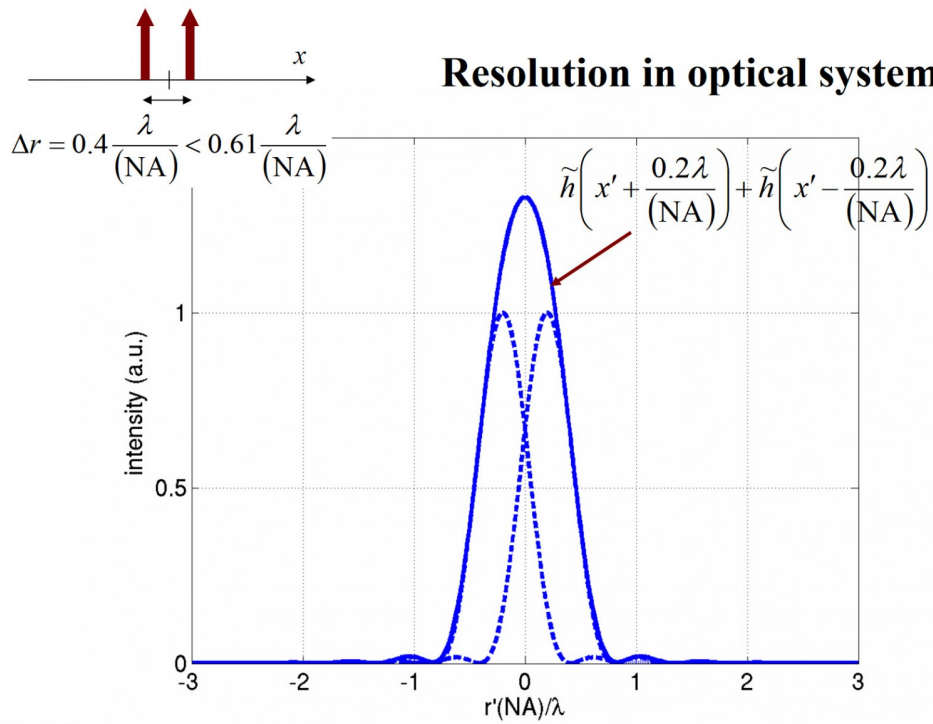


Now we go back to Resolution. How close together we can position two points and still distinguish them

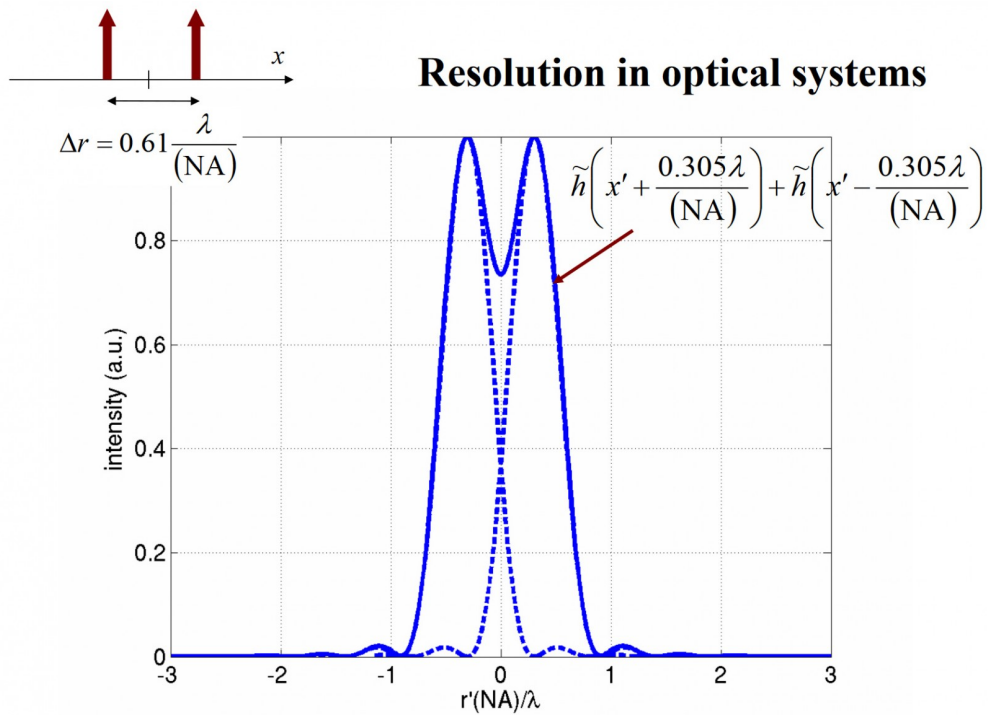


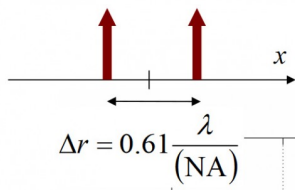


Resolution in optical systems

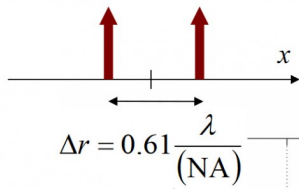
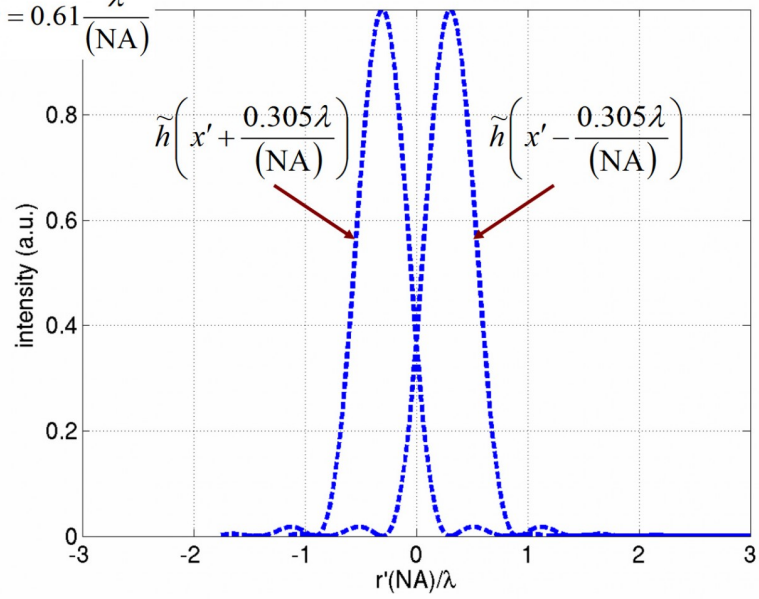


Resolution in optical systems

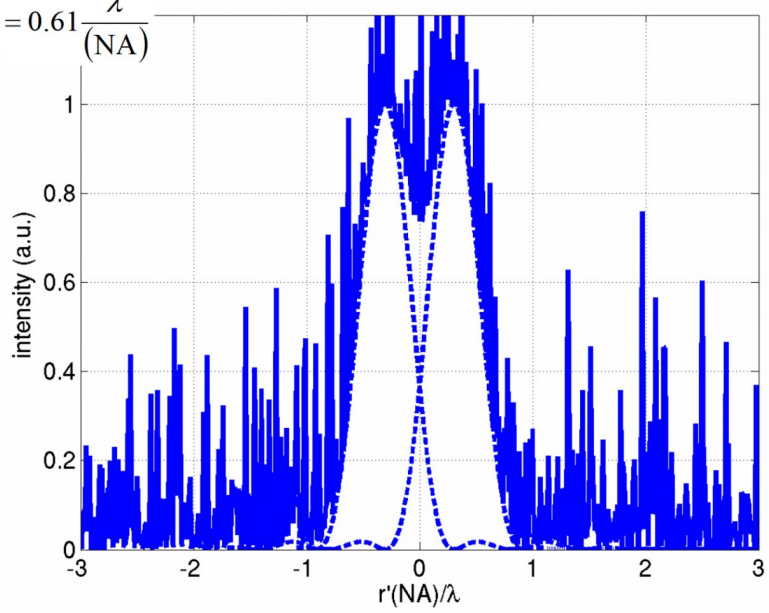


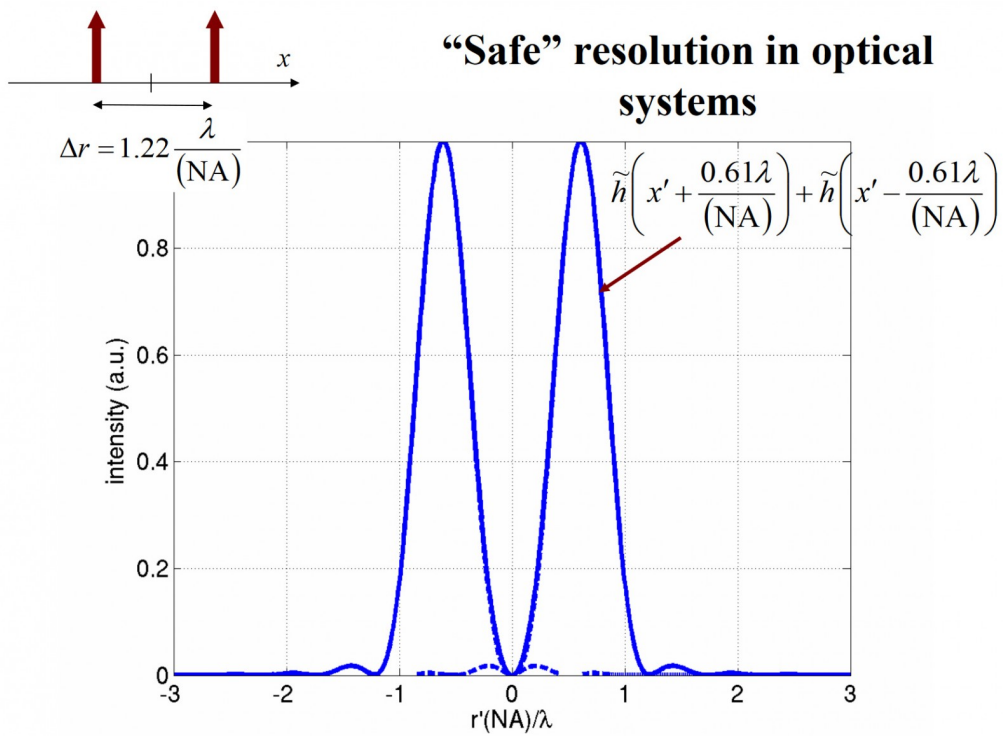


Resolution in optical systems



Resolution in noisy optical systems





Theoretical maximal resolution d_0

$$d_0 = \frac{\lambda}{n \cdot A_{\text{Objective}} + n \cdot A_{\text{Condenser}}}$$

Simplified formula (wo condensor) for resolution d_0

$$d_0 = \frac{\lambda}{2 n \cdot A_{\text{Objective}}}$$

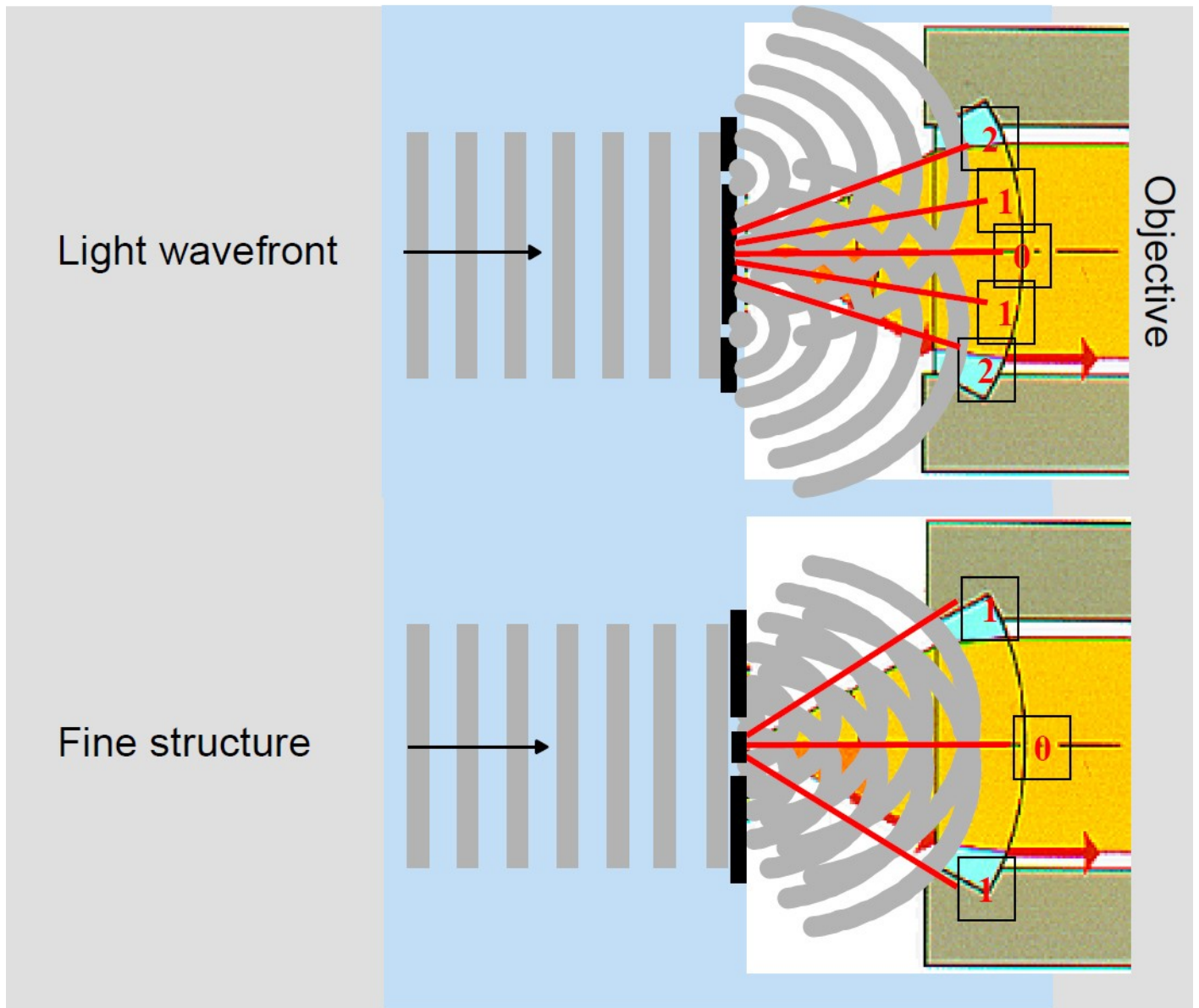
Maximal resolution d_0 in reality

$$d_0 = \frac{1.22 \times \lambda}{2 n \cdot A_{\text{Objective}}}$$

Example

Green light $\lambda = 550 \text{ nm}$, $n \cdot A = 1.4$ (Oil immersion)
 $d_0 = 671 \text{ nm} / (2 \times 1.4) = 239 \text{ nm} = 0.239 \mu\text{m}$

More intuitive approach



Notes from:

<http://web.mit.edu/2.710/Fall06/2.710-wk12-b-sl.pdf>

<https://links.uwaterloo.ca/amath353docs/set11.pdf>

<https://www.thefouriertransform.com/pairs/box.php>

<http://www.phys.unm.edu/msbahae/Optics%20Lab/Fourier%20Optics.pdf>

Super Resolution Techniques

Revision #13

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