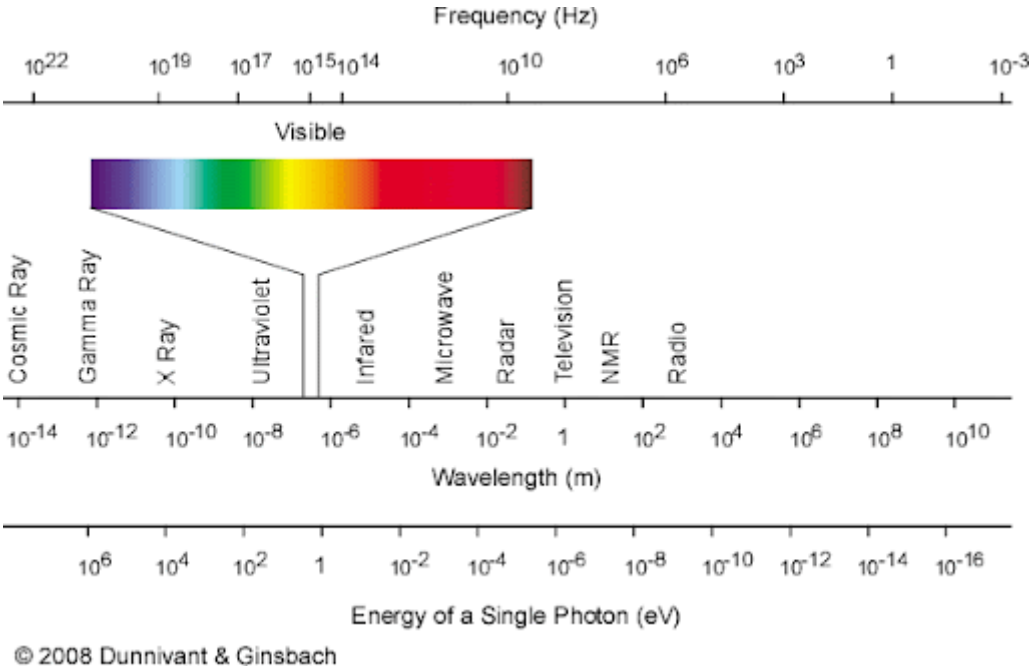
Optics

Properties of light

Wave particle duality:

Light is a wave

Image not found or type unknown



Absorption and Emission

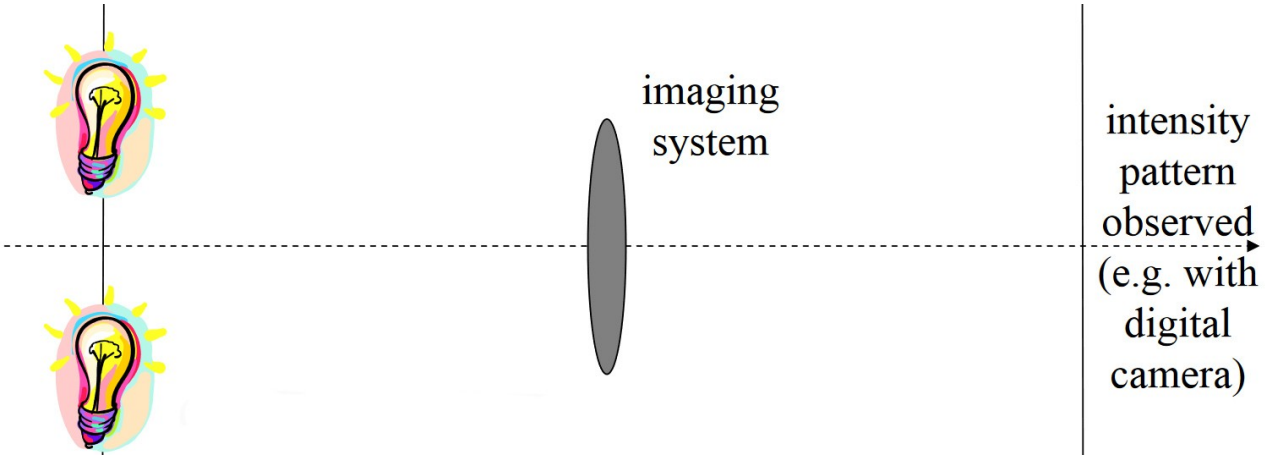
Beer's law

Refraction

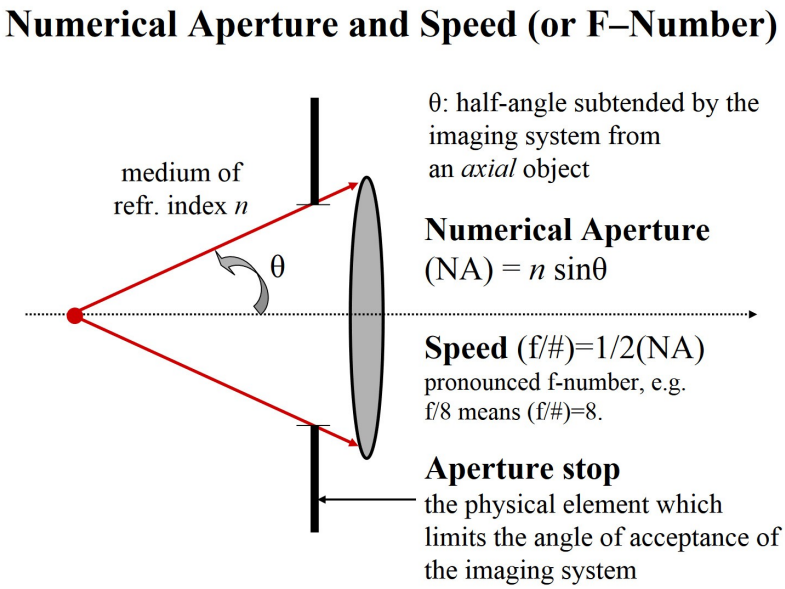
Ray tracing

Resolution

Resolution: The ability to separate two objects

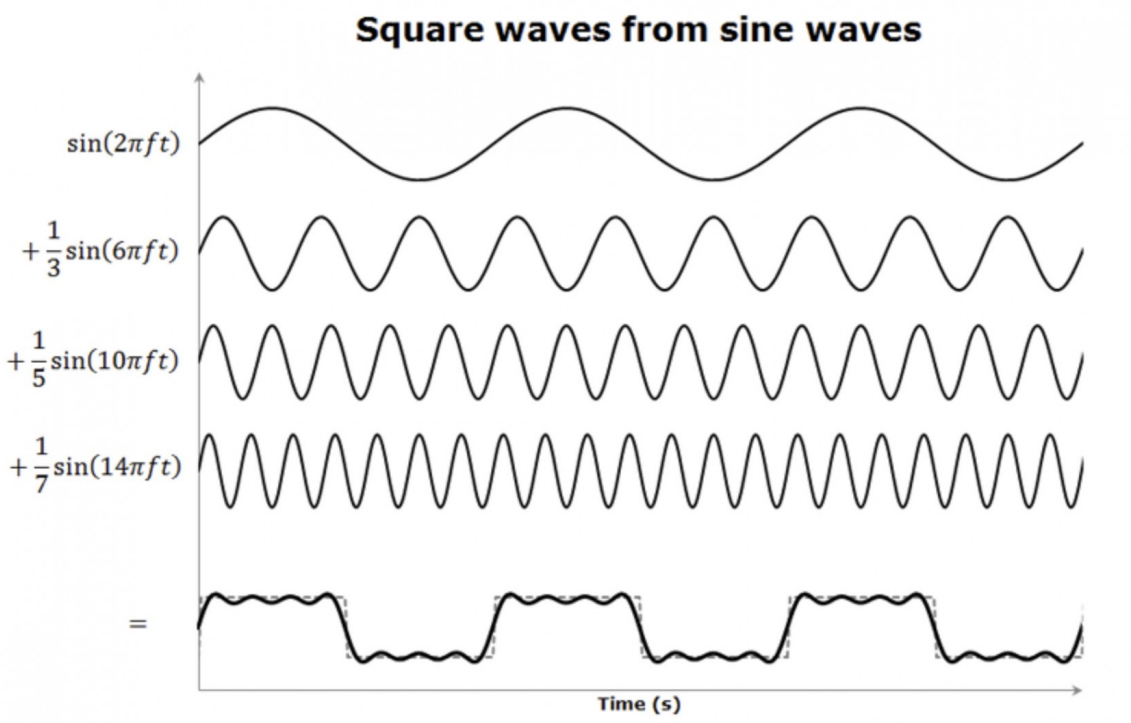


A definition of Numerical Aperture

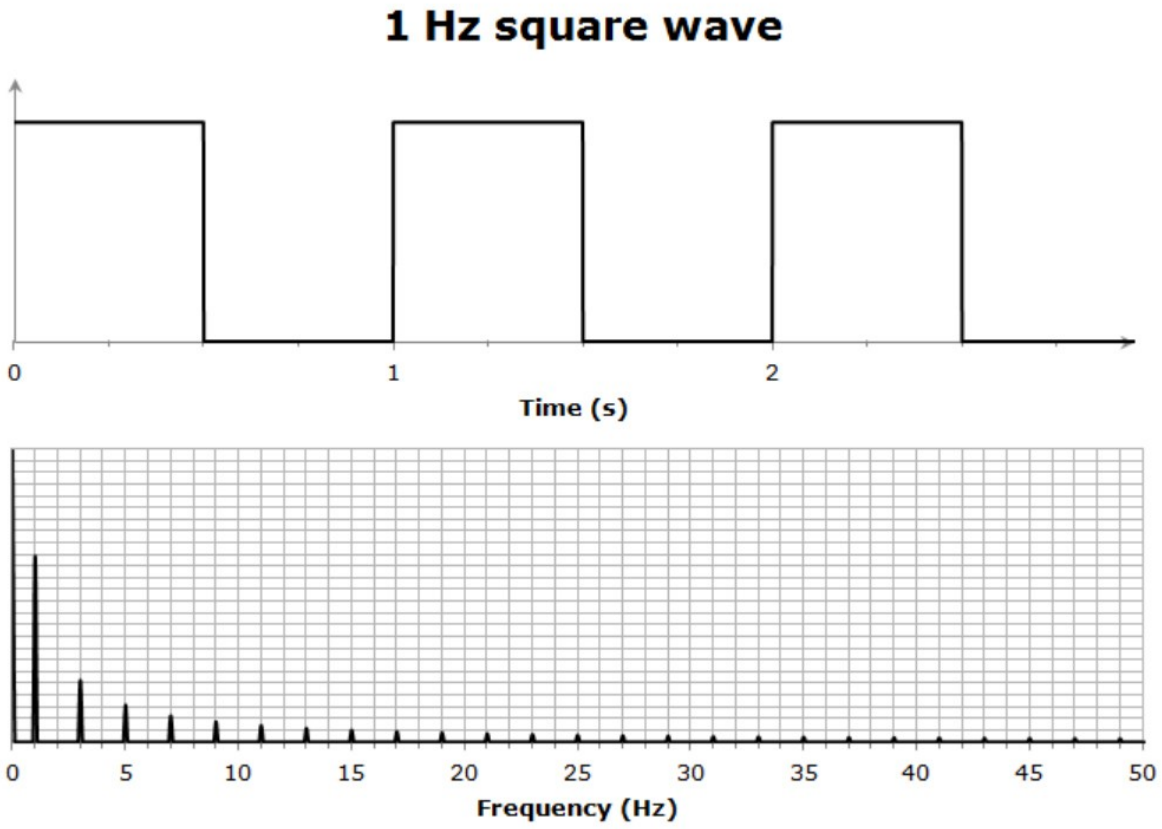


Fourier transform:

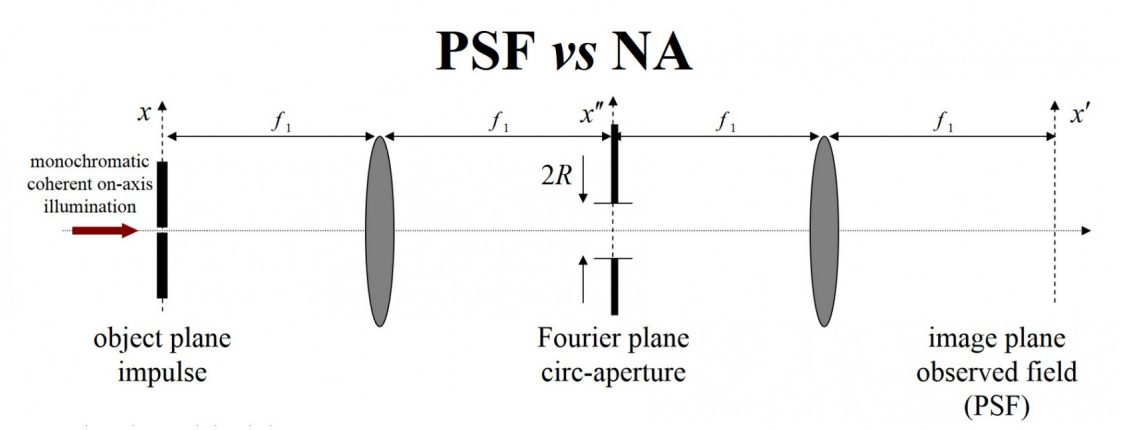
Transform from real space to frequency space



Now we look at a real square wave and frequency space



Look at a simple optical system:



Mathematical prediction of the Point Spread Function (PSF)

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

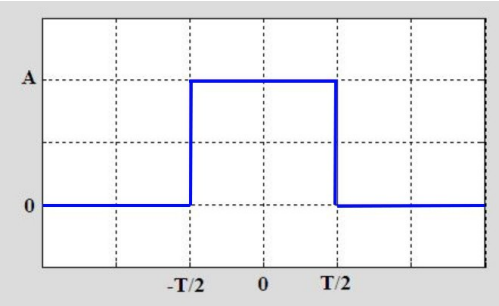
$$g_{\text{in}}(x,y) = \delta(x)\delta(y)$$

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

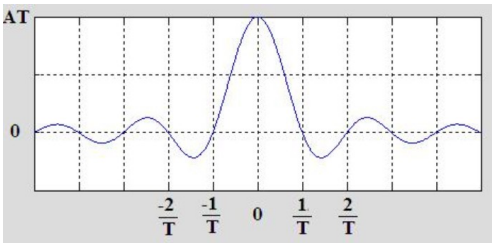


this has the same intensity at all points inside the aperture and zero outside. The second lens is now taking a Fourier transform on a box function the width of the aperture.

$$\text{jinc}(.,.) \equiv 2\frac{\mathrm{J}_1\left(2\pi \frac{R}{f_1}\frac{r'}{\lambda}\right)}{2\pi \frac{R}{f_1}\frac{r'}{\lambda}}$$

(unit magnification)

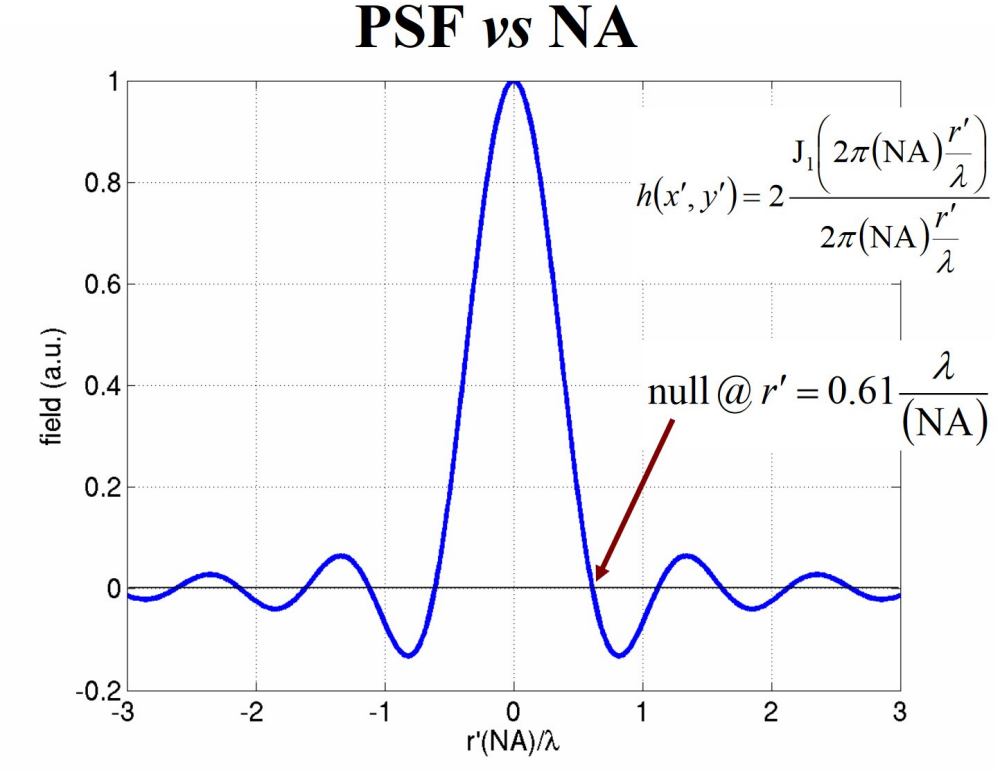
or

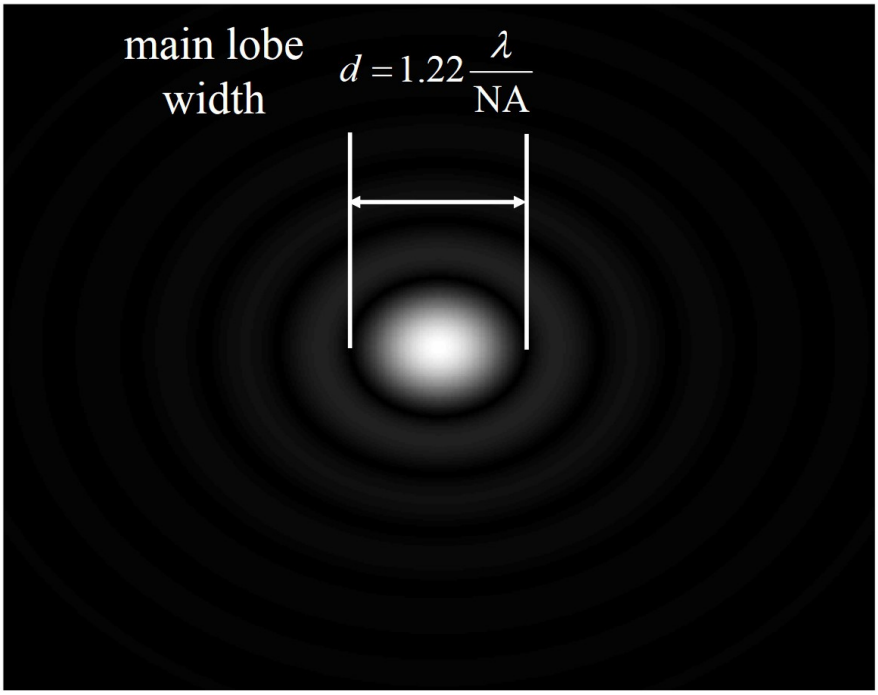


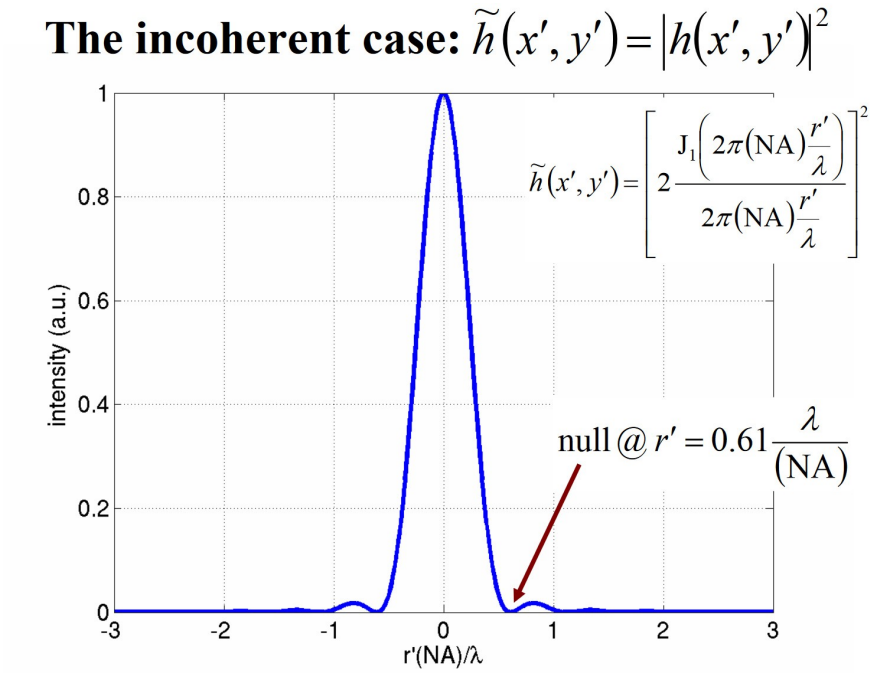
Substituting in the definition for NA

Numerical Aperture (NA) by definition: $(\text{NA}) \equiv \frac{R}{f_1}$

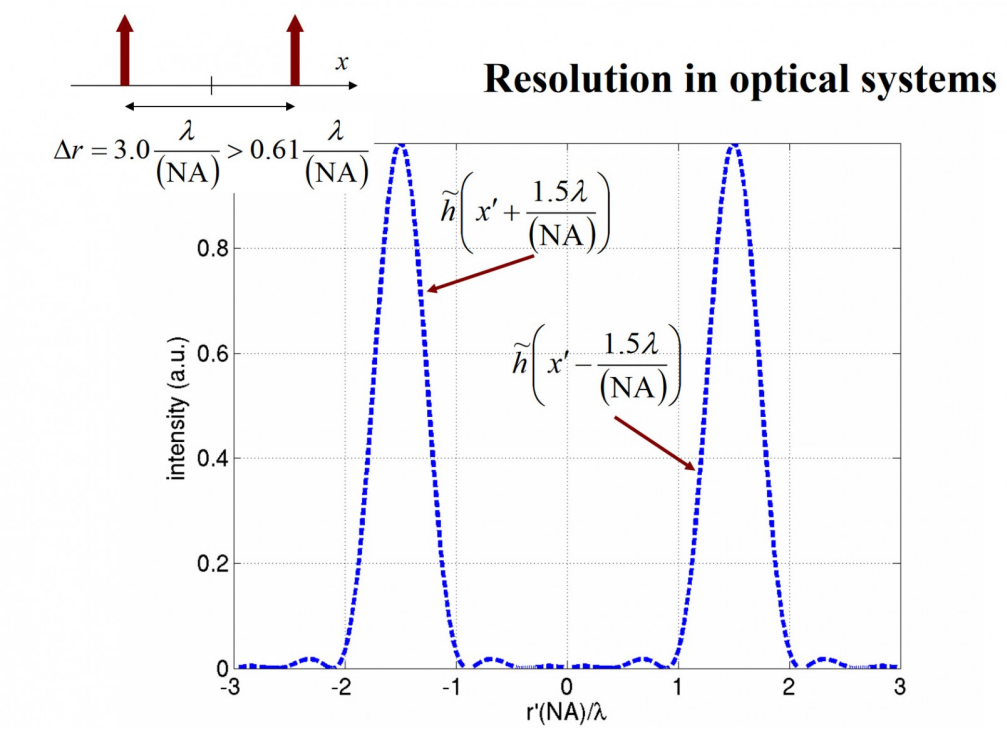
PSF *vs* NA


$h(x', y') = 2\frac{J_1\left(2\pi(\mathrm{NA})\frac{r'}{\lambda}\right)}{2\pi(\mathrm{NA})\frac{r'}{\lambda}}$
$\text{null} @ r' = 0.61\frac{\lambda}{(\mathrm{NA})}$
field (a.u.)
r'(NA)/λ
1
0.8
0.6
0.4
0.2
0
-0.2
-3
-2
-1
0
1
2
3


main lobe width
$d = 1.22\frac{\lambda}{\mathrm{NA}}$



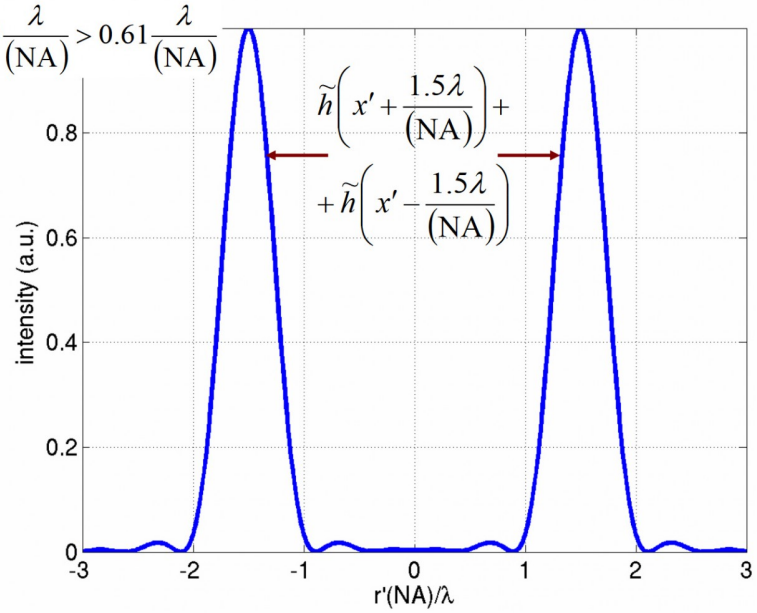
Now we go back to Resolution. How close together we can position two points and still distinguish them



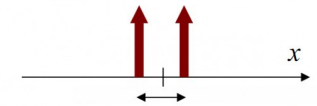
Resolution in optical systems



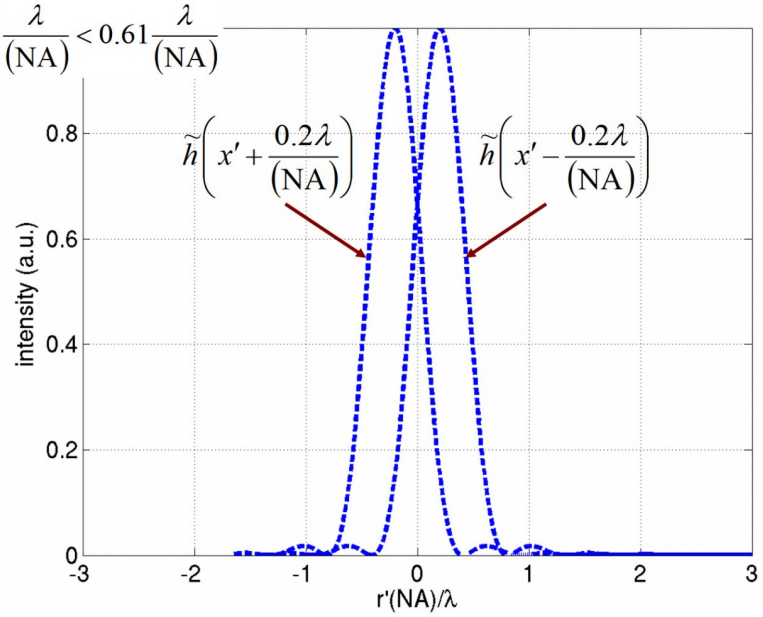
$$\Delta r = 3.0\frac{\lambda}{(\mathrm{NA})} > 0.61\frac{\lambda}{(\mathrm{NA})}$$



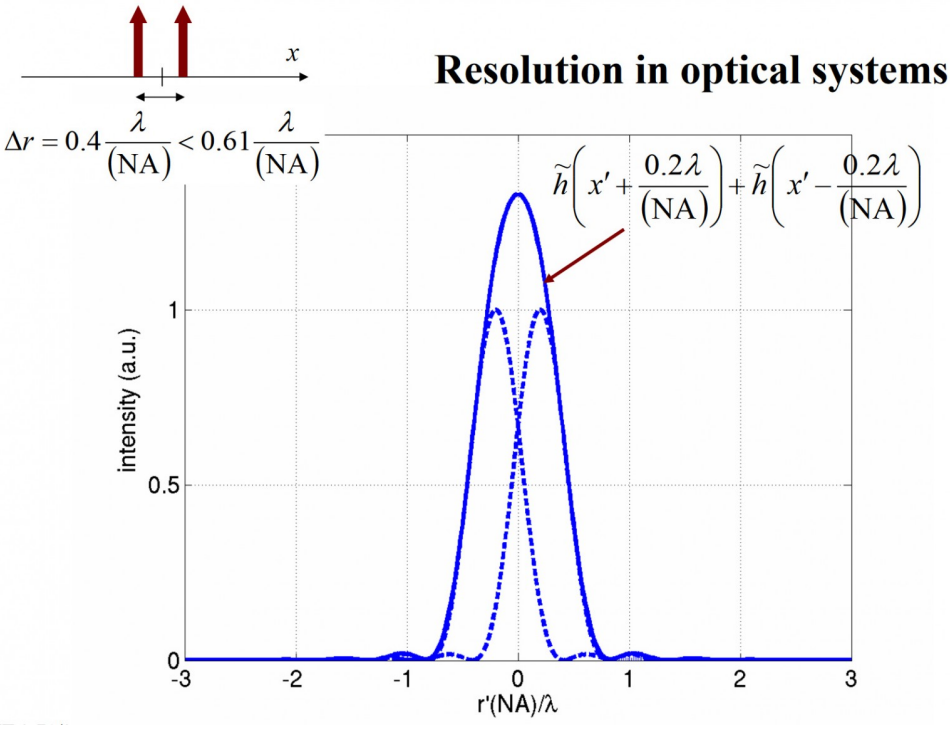
Resolution in optical systems



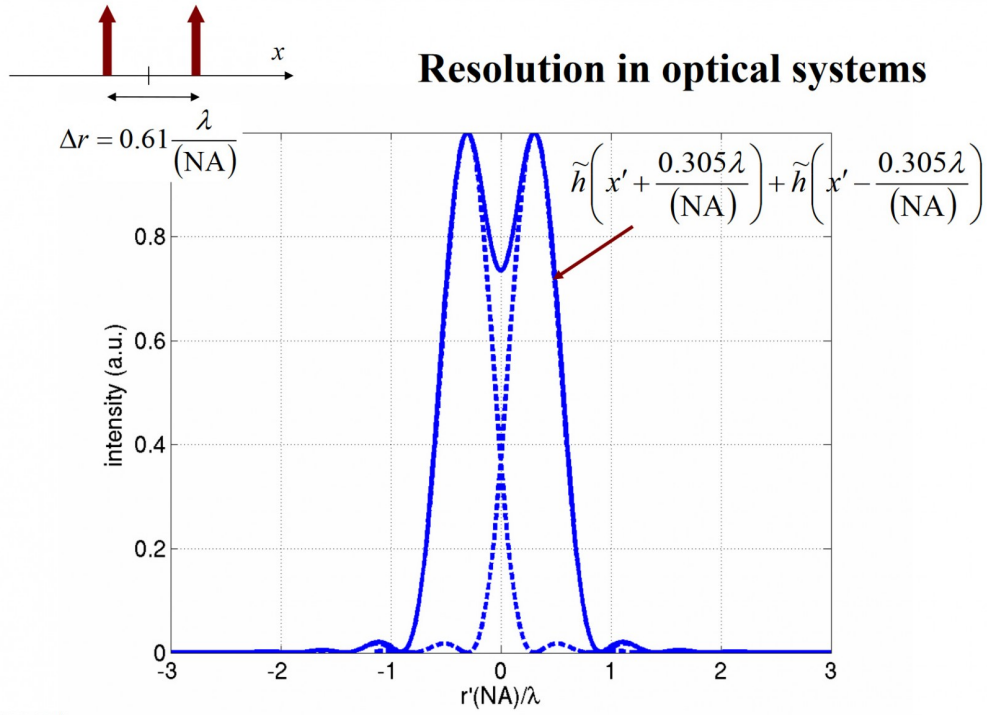
$$\Delta r = 0.4\frac{\lambda}{(\mathrm{NA})} < 0.61\frac{\lambda}{(\mathrm{NA})}$$



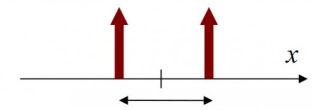
Resolution in optical systems



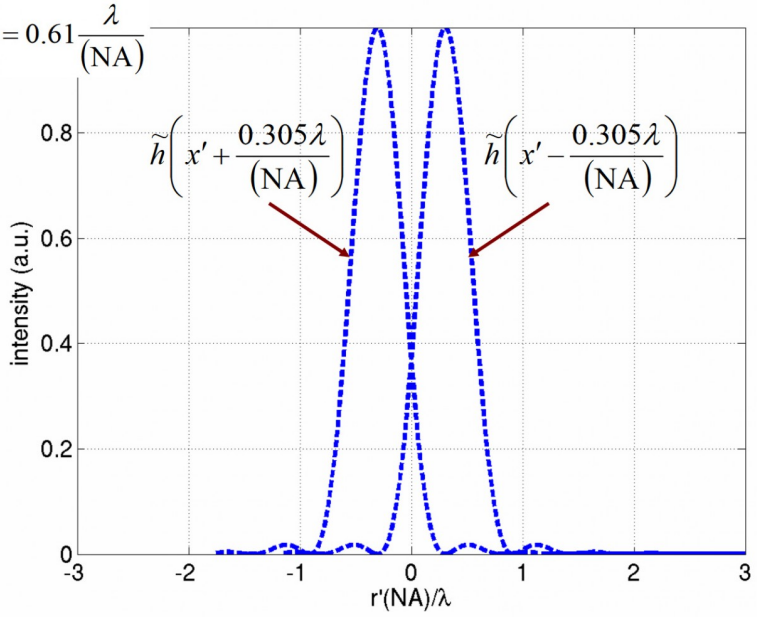
Resolution in optical systems



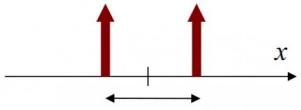
Resolution in optical systems



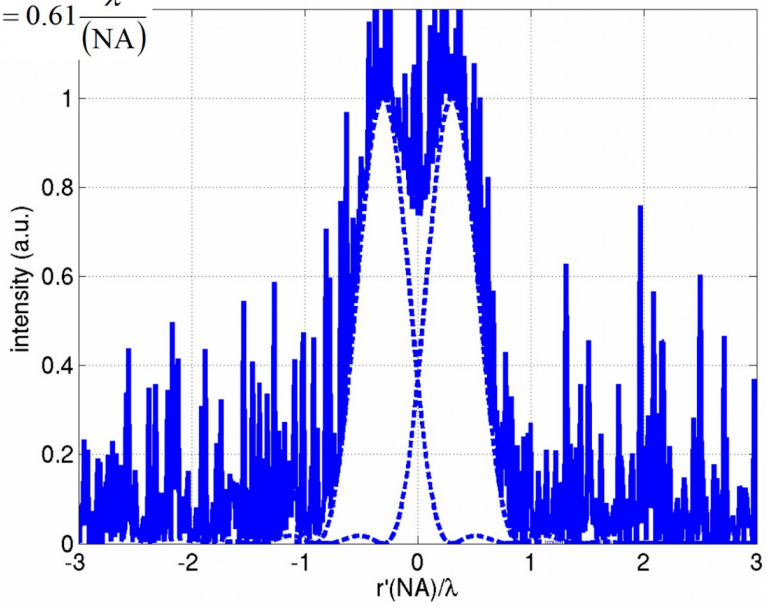
$$\Delta r = 0.61\frac{\lambda}{(\mathrm{NA})}$$

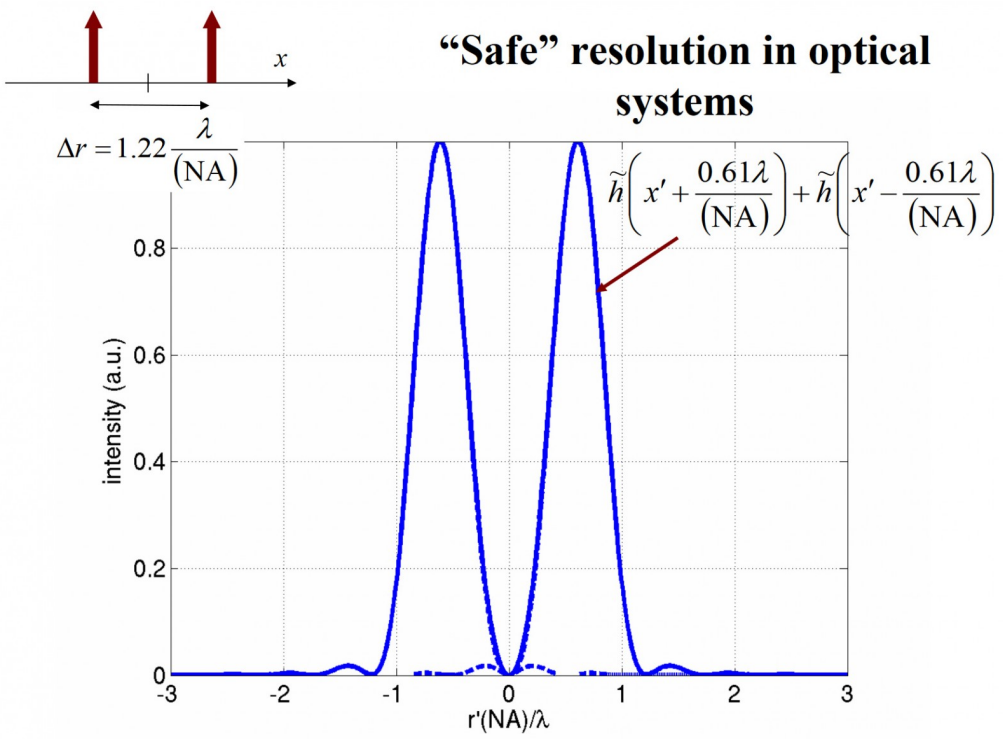


Resolution in noisy optical systems



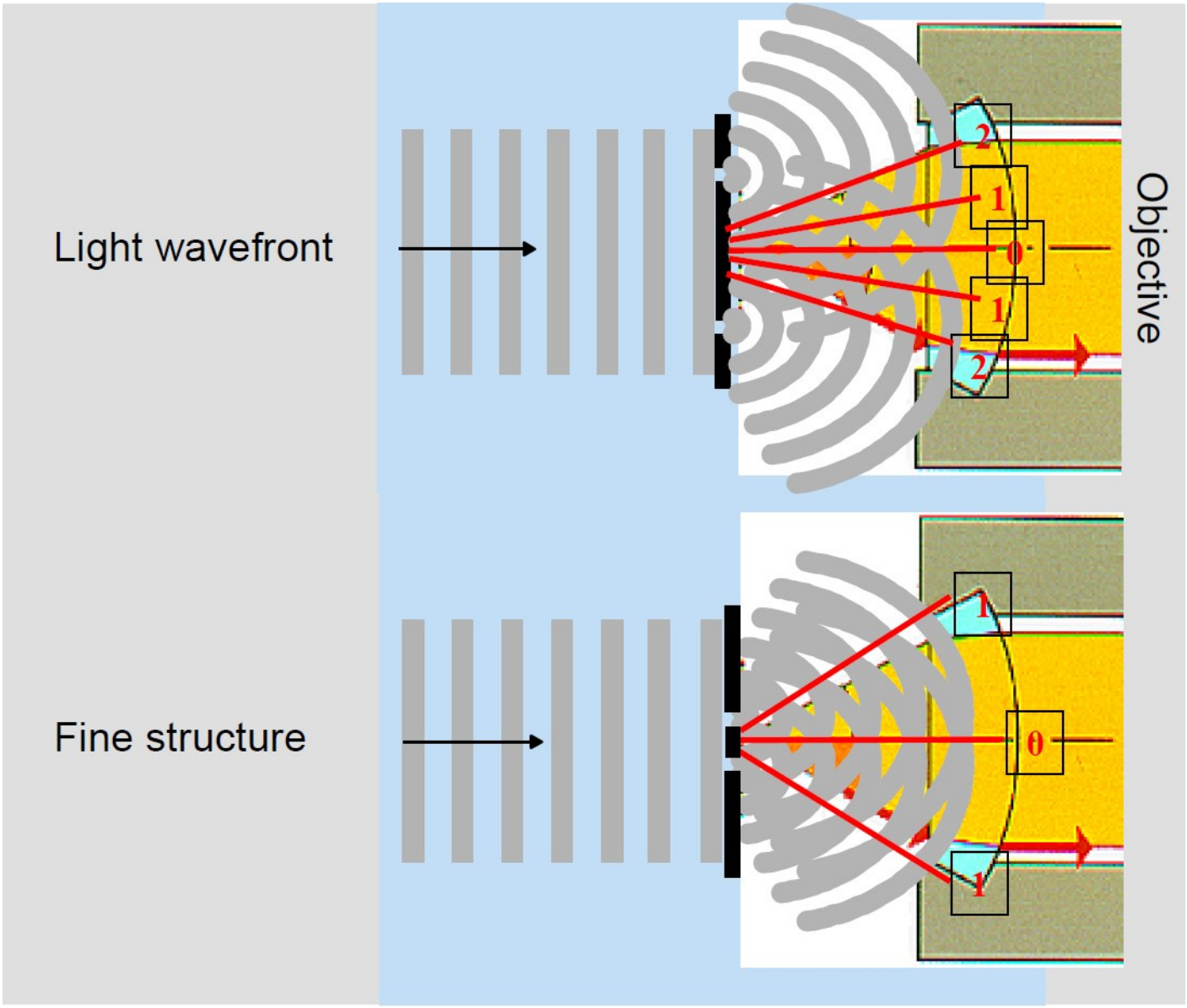
$$\Delta r = 0.61\frac{\lambda}{(\mathrm{NA})}$$





Theoretical maximal resolution d_0	$d_0 = \frac{\lambda}{\text{n. A.}_{\text{Objective}} + \text{n. A.}_{\text{Condenser}}}$
Simplified formula (wo condensor) for resolution d_0	$d_0 = \frac{\lambda}{2\ \text{n. A.}_{\text{Objective}}}$
Maximal resolution d_0 in reality	$d_0 = \frac{1.22 \times \lambda}{2\ \text{n. A.}_{\text{Objective}}}$
Example	**Green light λ = 550 nm, n. A. = 1.4 (Oil immersion)** **d_0 = 671 nm / (2 x 1.4) = 239 nm = 0.239 µm**

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

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