PHYSICS 411 – *interferometry*

Andreas E. Vasdekis

andreasv@uidaho.edu

www.aevlab.org

208-885-6099

E&P: 315

structure

1. today: in-person lecture;

2. Thursday: experiments
(handouts/data provided);

interferometry

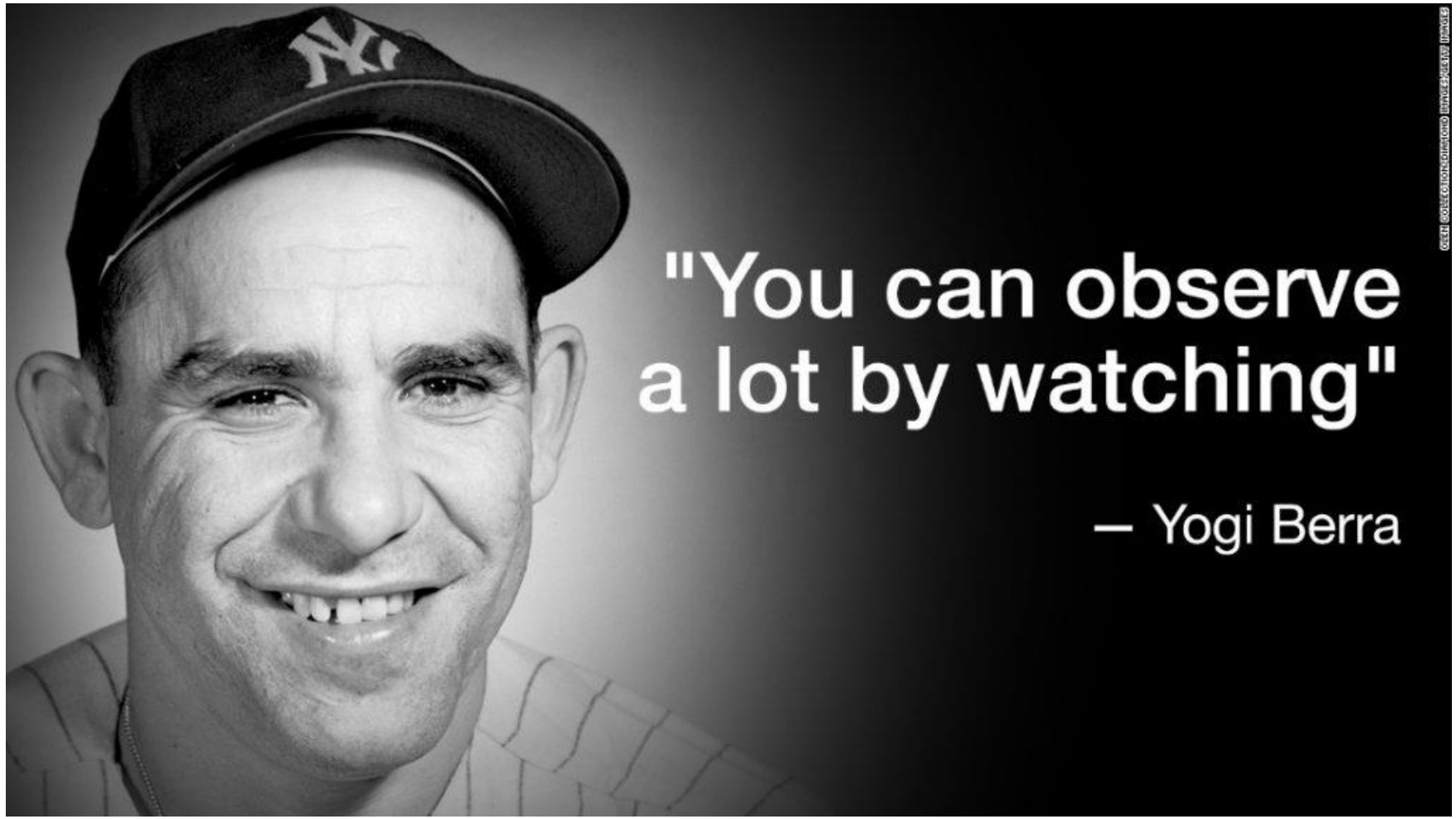
1. Physics of Optical Imaging (*an intro to…*);

2. wave interference and interferometry;

3. interferometric imaging;

physics of optical imaging

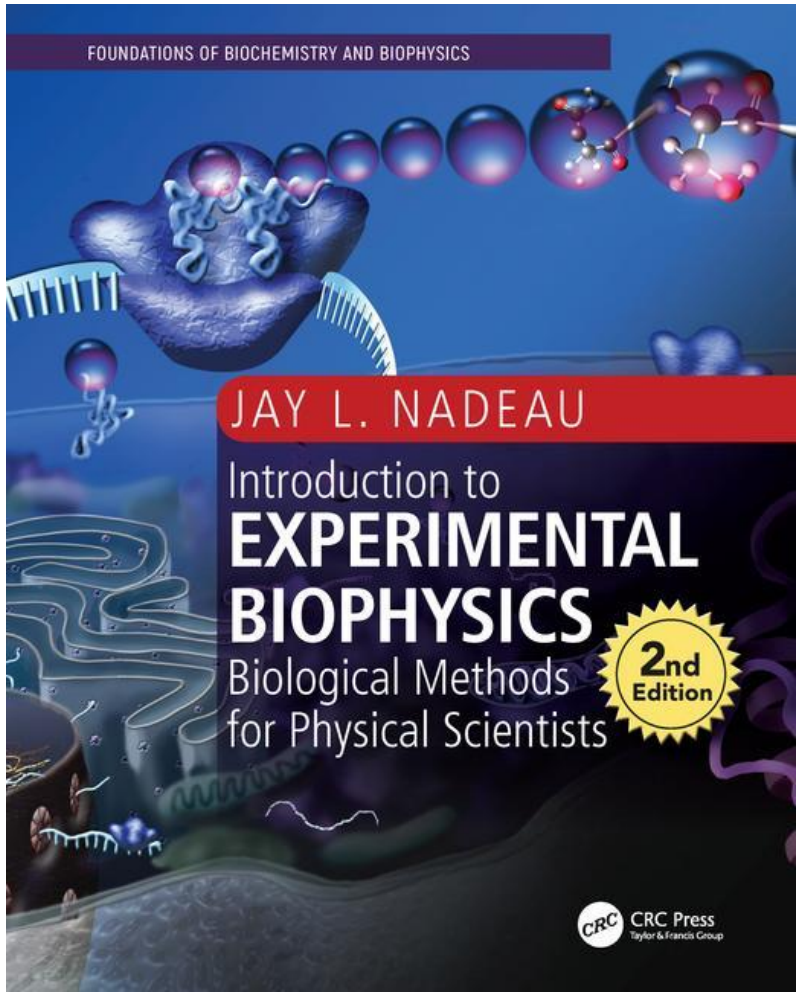
why optical imaging?

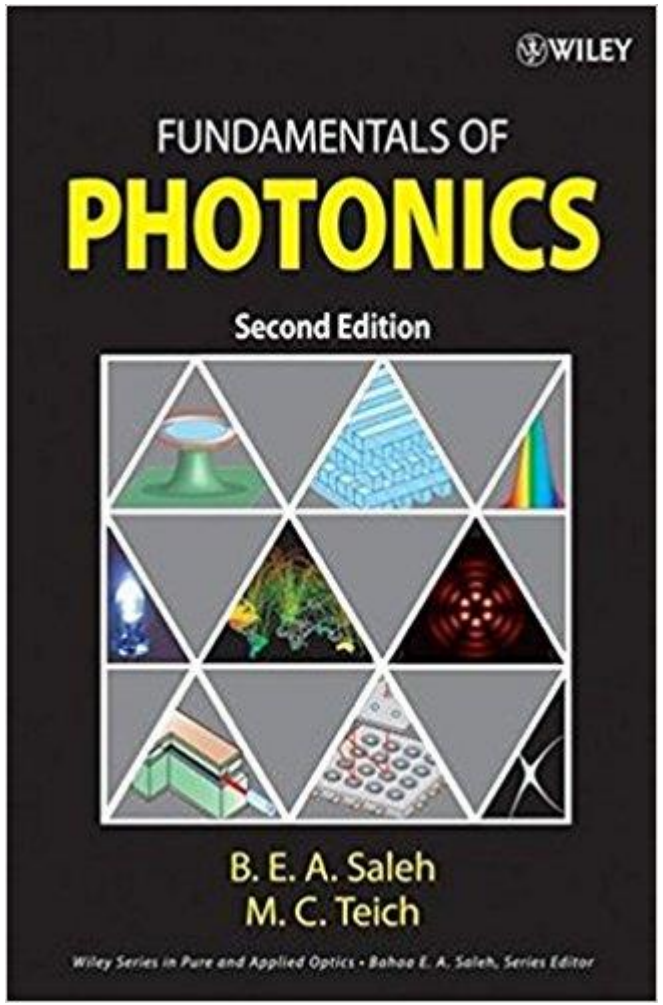


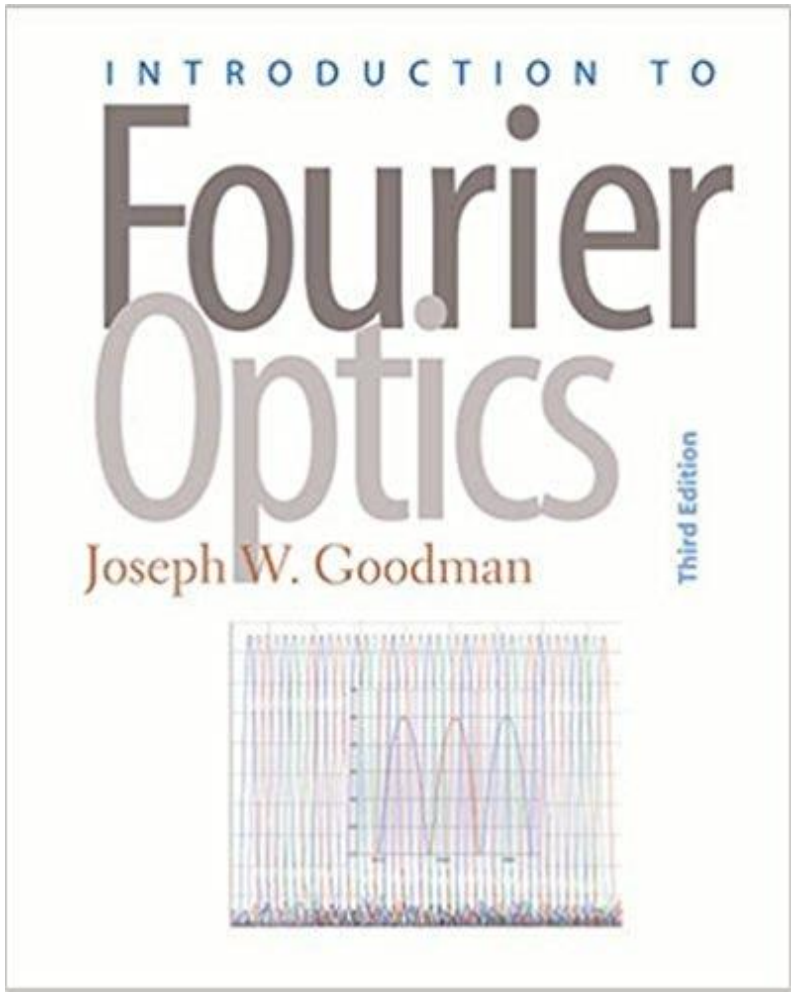
why optical imaging?

why optical imaging?

sources…

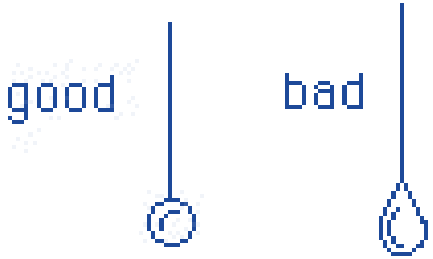

FOUNDATIONS OF BIOCHEMISTRY AND BIOPHYSICS
JAY L. NADEAU
Introduction to
EXPERIMENTAL
BIOPHYSICS
Biological Methods
for Physical Scientists
2nd Edition
CRC Press
Taylor & Francis Group


WILEY
FUNDAMENTALS OF
PHOTONICS
Second Edition
B. E. A. Saleh
M. C. Teich
Wiley Series in Pure and Applied Optics • Bahaa E. A. Saleh, Series Editor


INTRODUCTION TO
Fourier
Optics
Joseph W. Goodman
Third Edition

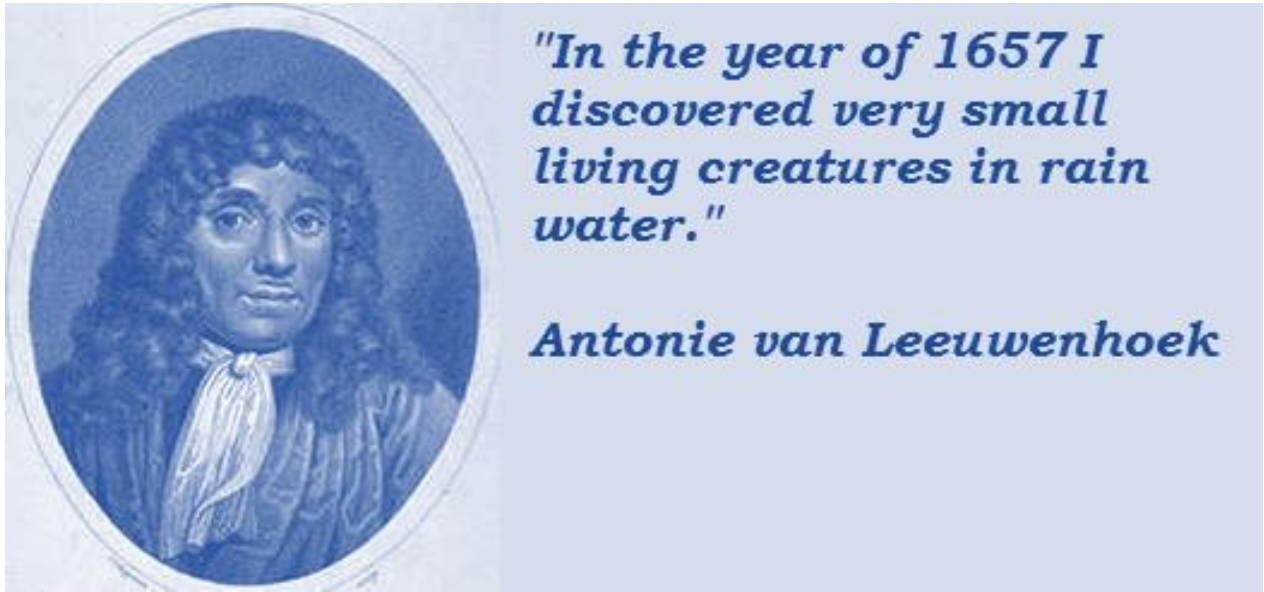
the beginning….

Antony van Leeuwenhoek (1632-1723)

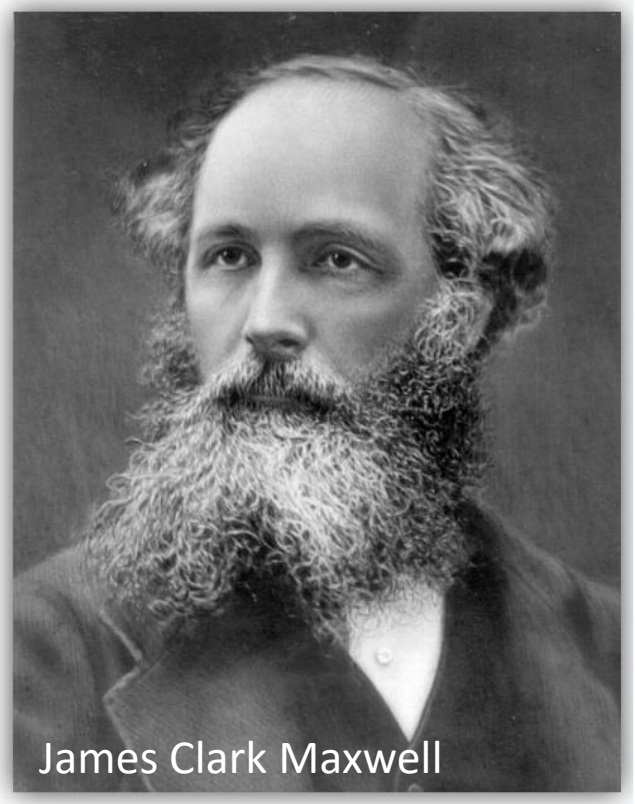


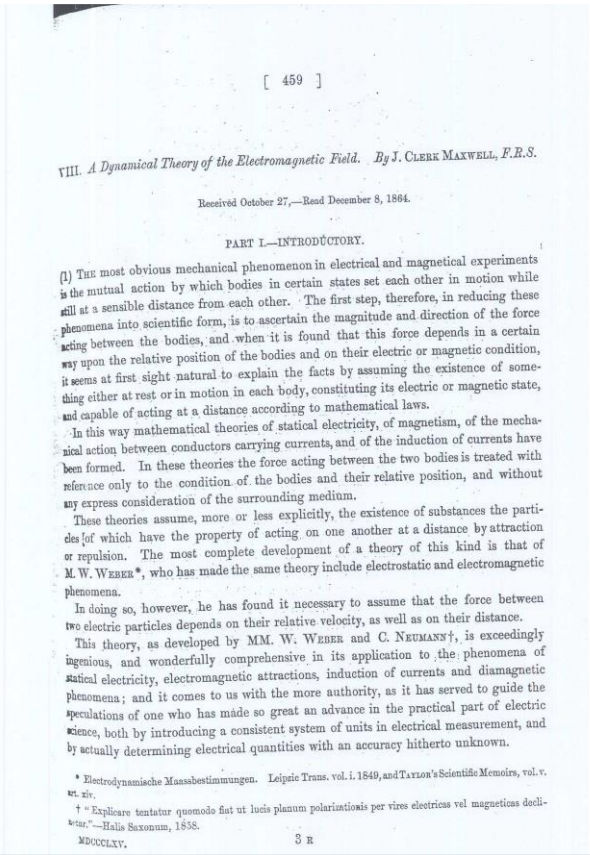
http://www.ucmp.berkeley.edu/history/leeuwenhoek.html

the beginning….



the present….





[459]

VIII. *A Dynamical Theory of the Electromagnetic Field.* By J. CLERK MAXWELL, *F.R.S.*

Received October 27,—Read December 8, 1864.

PART I.—INTRODUCTORY.

(1) THE most obvious mechanical phenomenon in electrical and magnetical experiments is the mutual action by which bodies in certain states set each other in motion while still at a sensible distance from each other. The first step, therefore, in reducing these phenomena into scientific form, is to ascertain the magnitude and direction of the force acting between the bodies, and when it is found that this force depends in a certain way upon the relative position of the bodies and on their electric or magnetic condition, it seems at first sight natural to explain the facts by assuming the existence of something either at rest or in motion in each body, constituting its electric or magnetic state, and capable of acting at a distance according to mathematical laws.

In this way mathematical theories of statical electricity, of magnetism, of the mechanical action between conductors carrying currents, and of the induction of currents have been formed. In these theories the force acting between the two bodies is treated with reference only to the condition of the bodies and their relative position, and without any express consideration of the surrounding medium.

These theories assume, more or less explicitly, the existence of substances the particles of which have the property of acting on one another at a distance by attraction or repulsion. The most complete development of a theory of this kind is that of M. W. WEBER*, who has made the same theory include electrostatic and electromagnetic phenomena.

In doing so, however, he has found it necessary to assume that the force between two electric particles depends on their relative velocity, as well as on their distance.

This theory, as developed by MM. W. WEBER and C. NEUMANN†, is exceedingly ingenious, and wonderfully comprehensive in its application to the phenomena of statical electricity, electromagnetic attractions, induction of currents and diamagnetic phenomena; and it comes to us with the more authority, as it has served to guide the speculations of one who has made so great an advance in the practical part of electric science, both by introducing a consistent system of units in electrical measurement, and by actually determining electrical quantities with an accuracy hitherto unknown.

* Electrodynamische Maassbestimmungen. Leipzic Trans. vol. i. 1849, and TAYLOR's Scientific Memoirs, vol. v. art. xiv.

† "Explicare tentatur quomodo fiat ut lucis planum polarizationis per vires electricas vel magneticas declinetur."—Halis Saxonum, 1858.

MDCCCLXV. 3 R

$$\frac{\partial^2 \mathrm{E}}{\partial \mathrm{x}^2} = \mu_o \cdot \varepsilon_o \cdot \frac{\partial^2 \mathrm{E}}{\partial \mathrm{t}^2}$$

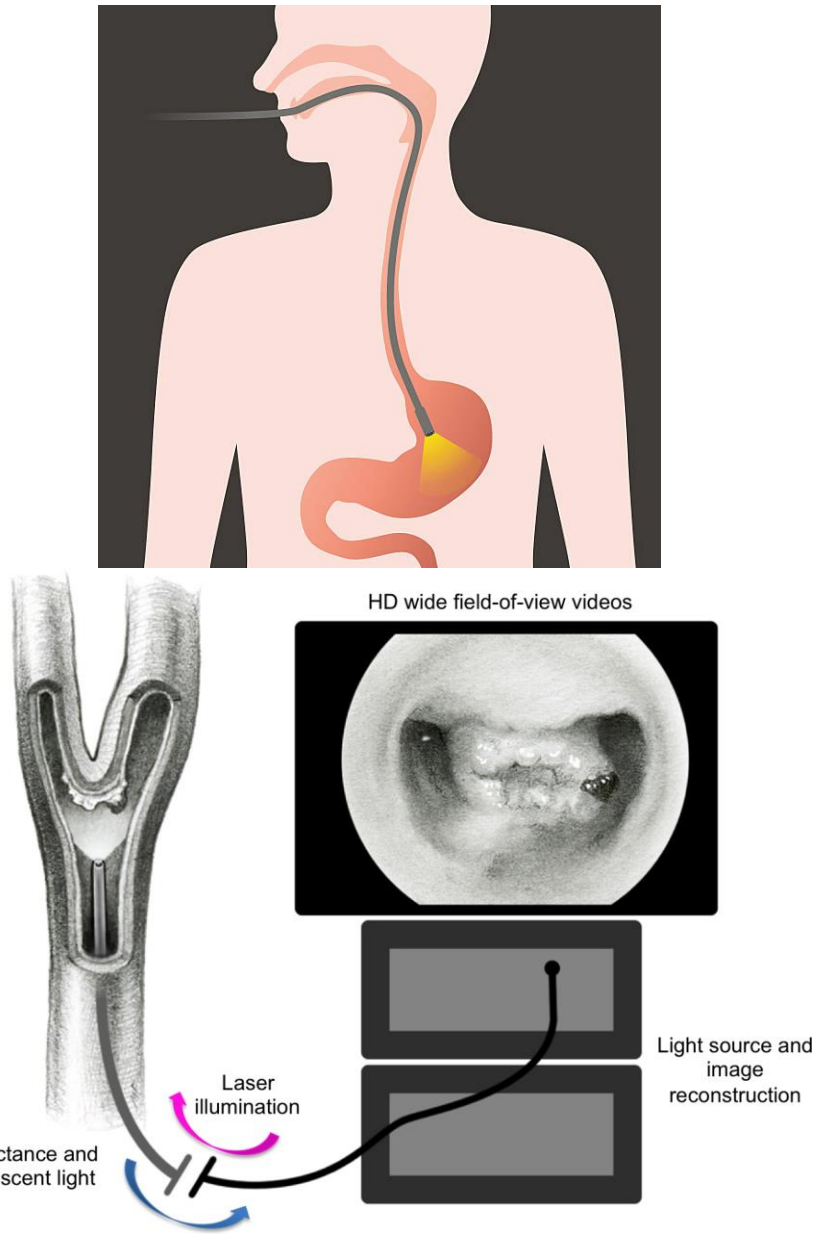
$$\frac{\partial^2 \mathrm{B}}{\partial \mathrm{x}^2} = \mu_o \cdot \varepsilon_o \cdot \frac{\partial^2 \mathrm{B}}{\partial \mathrm{t}^2}$$

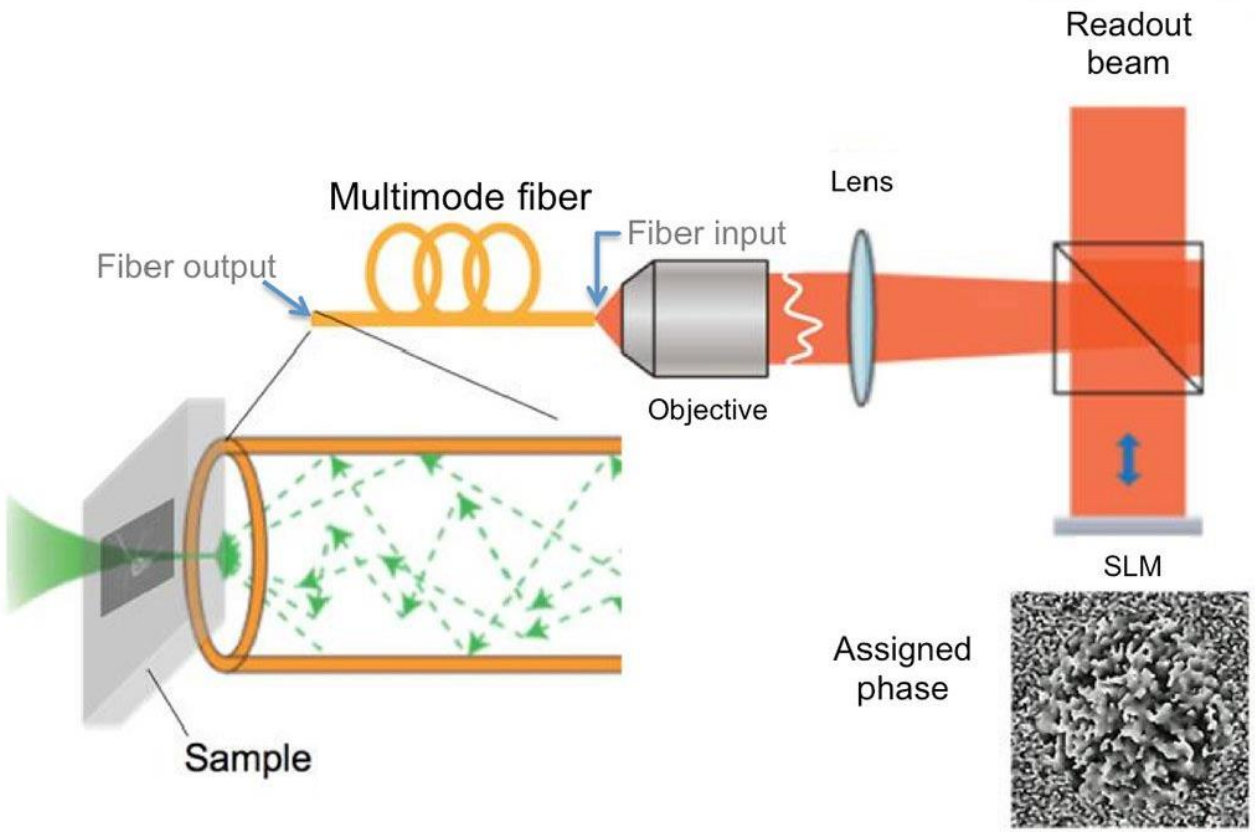
- E, B orthogonal oscillating waves
- travelling wave velocity
- momentum
- energy

https://www.olympus-lifescience.com/fr/microscope-resource/primer/anatomy/components

the present….

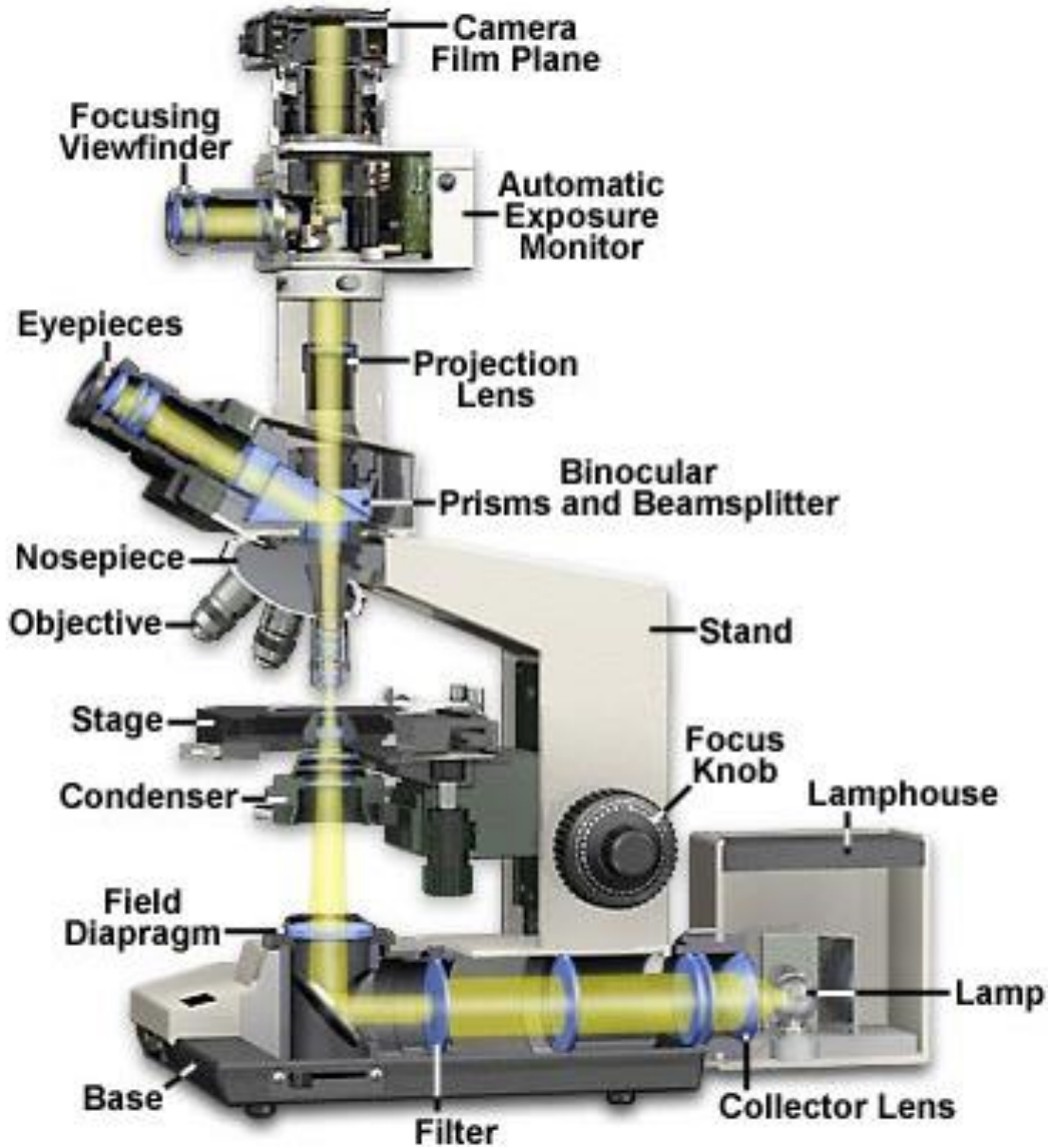
https://doi.org/10.1093/neuros/nyx322





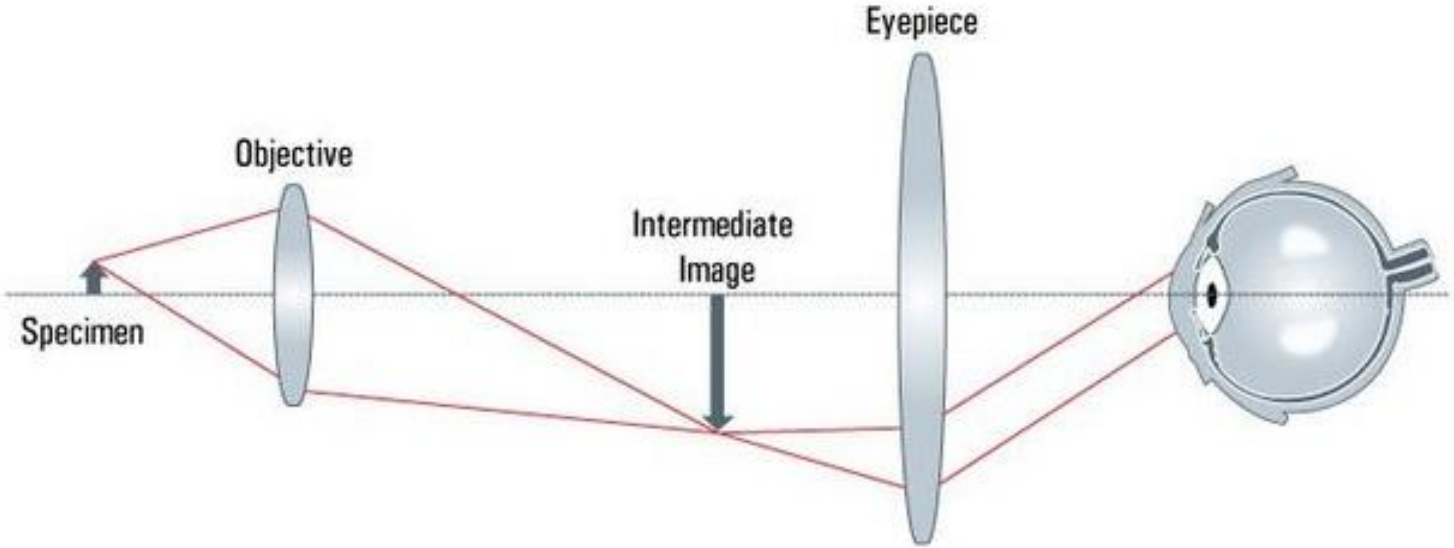
http://spie.org/newsroom/5170-shrinking-optical-endoscopes?ArticleID=x103748&SSO=1

the present….



https://www.olympus-lifescience.com/fr/microscope-resource/primer/anatomy/components

the present….

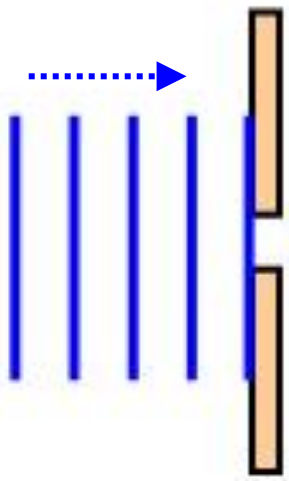


https://onlinelibrary.wiley.com/doi/epdf/10.1002/opph.201600002

the resolution limit….

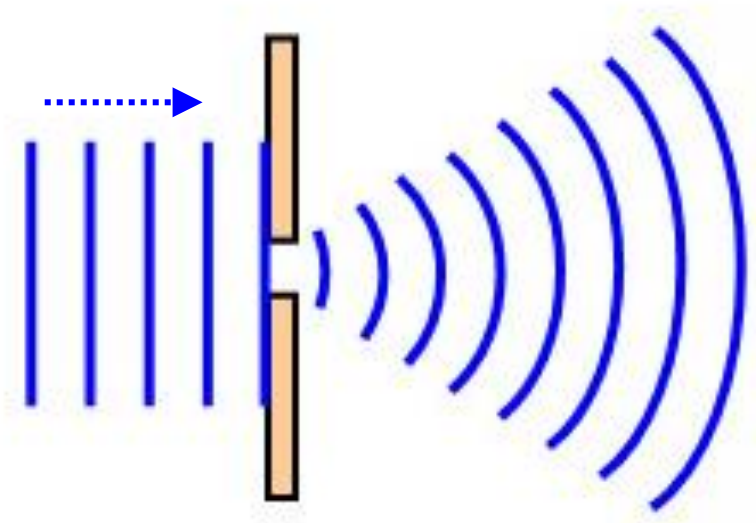
Quiz 1:

What happens when a light wave passes through a narrow aperture?



→ light will diffract. According to the *Huygens-Fresnel* principle, every point on a light wave(front) acts as a source of wavefronts that interact with neighboring ones. As such, wavefronts at the edges of the slit generate new wavefronts at various directions (light bending at the slit's edges).

the resolution limit….

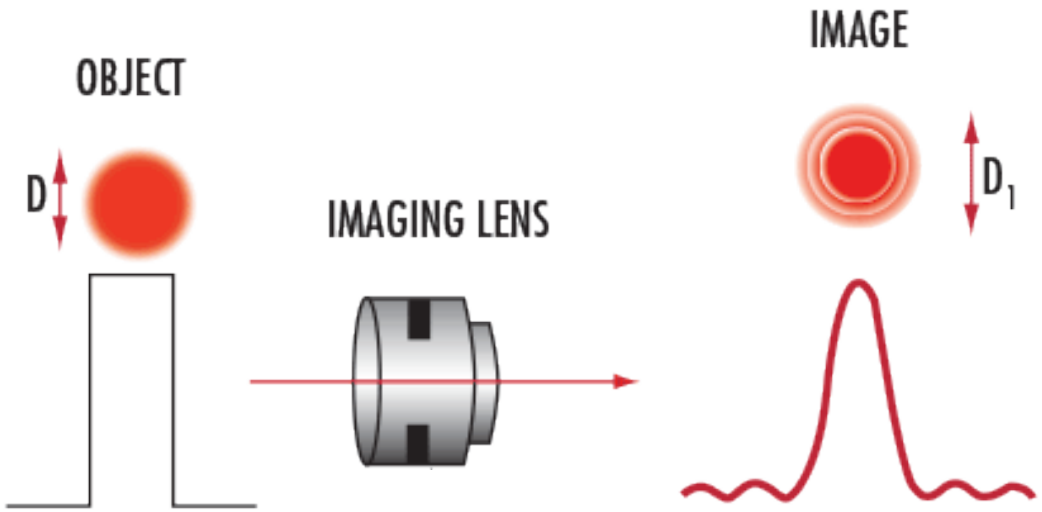


Quiz 2:

Back to the aperture, when does light diffract more, when passing through a small or large aperture?

→ smaller...

the resolution limit….



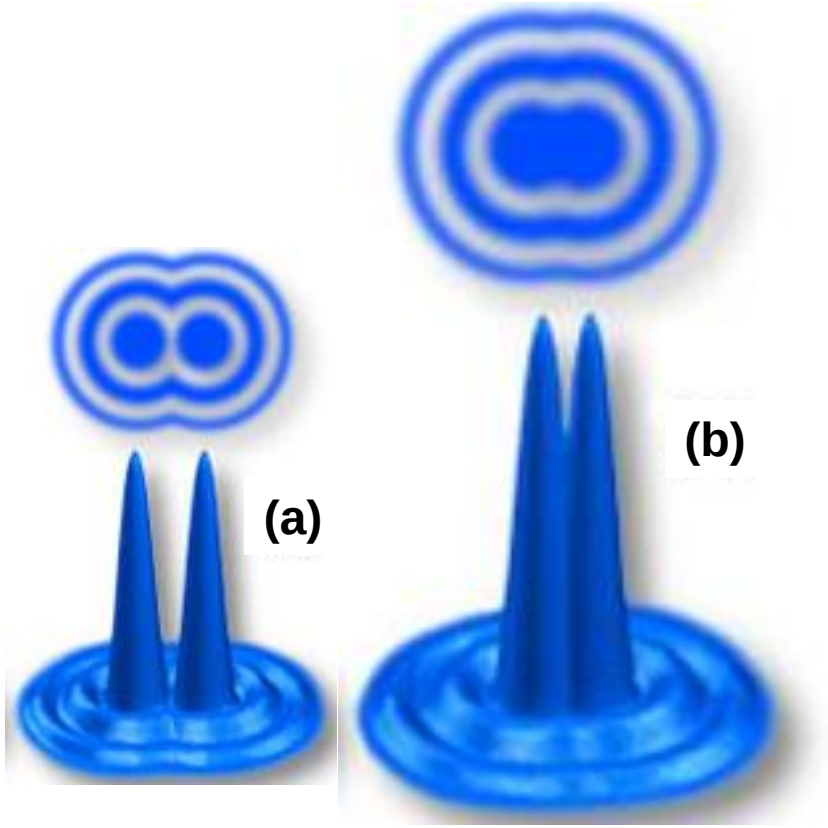
similar effects occur when light passes through a lens (all lenses or objectives are/have apertures) results in a ring shaped diffraction pattern, the *Airy* disk pattern.

the smaller the aperture of a lens the greater the diffraction mediated ‘spreading’ of light.

the resolution limit….

Quiz 3:

Two spherical objects are sitting on a transparent substrate at distance d. We use two different objectives to image them, each yielding a distinct Airy pattern shown in the figure. Which objective (a, or b) exhibits a larger aperture?

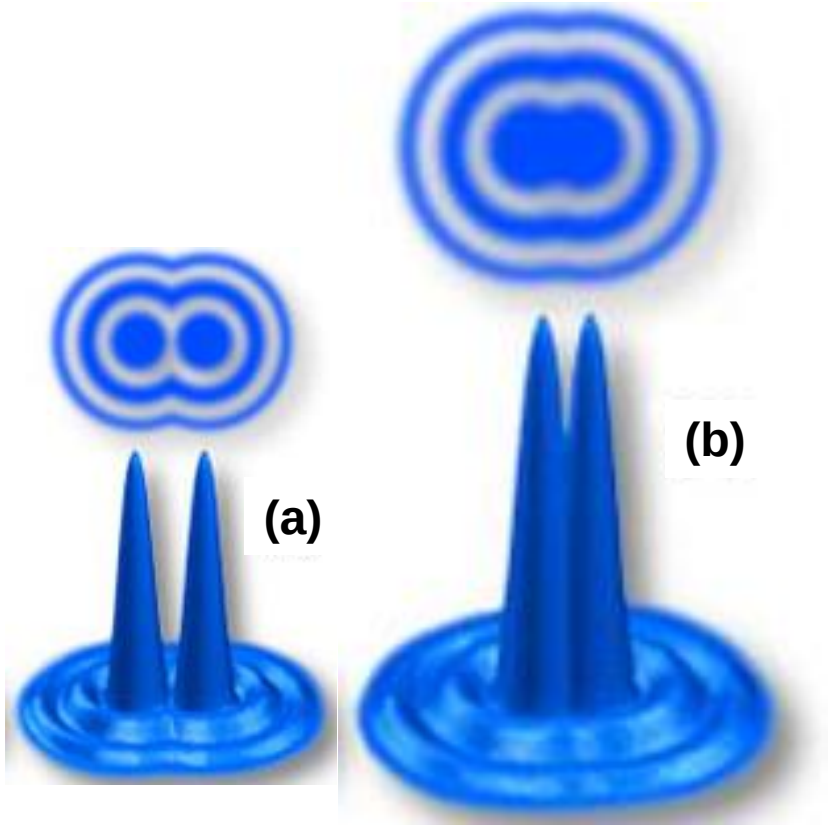


→ (a) exhibits the larger aperture since it diffracts the transmitted light to a lesser degree. In contrast, b yields larger and overlapping Airy patterns.

the resolution limit….

Quiz 4:

Which objective a or b yields higher resolution?



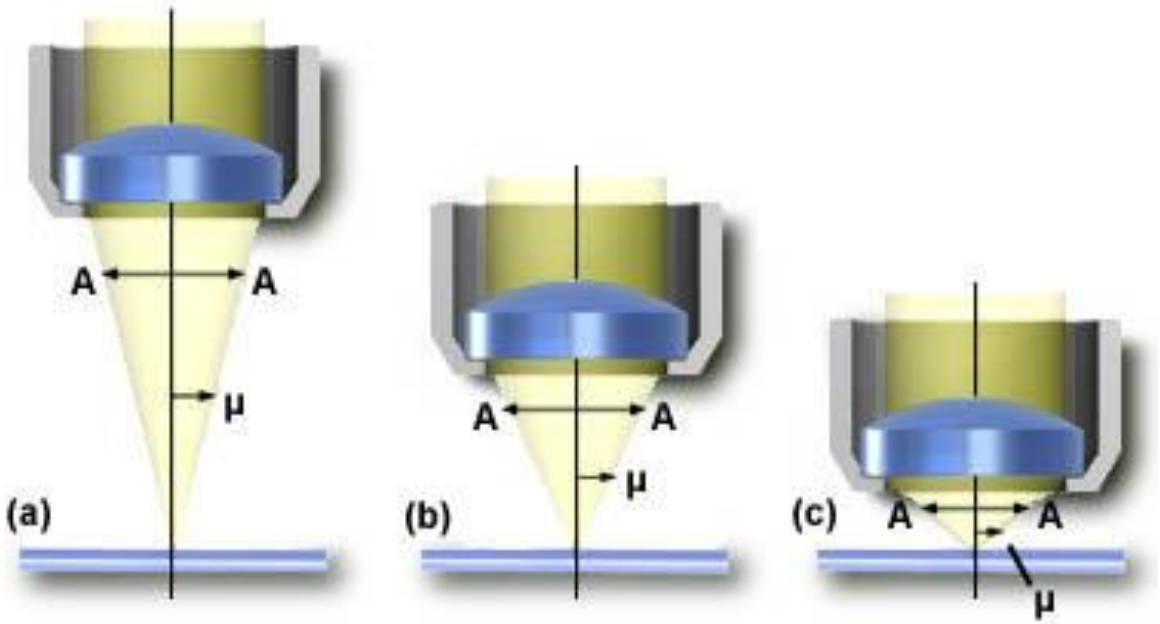
→ (a), the larger aperture one.

the resolution limit….

Rayleigh's criterion

Two neighboring points of an object are distinguishable if the main intensity peak from one point is located on the first dark fringe of the second point's Airy pattern. This is satisfied for distances 'd' equal or greater than:

$$d = \frac{0.61 \cdot \lambda}{n \cdot \sin(\mu)}$$

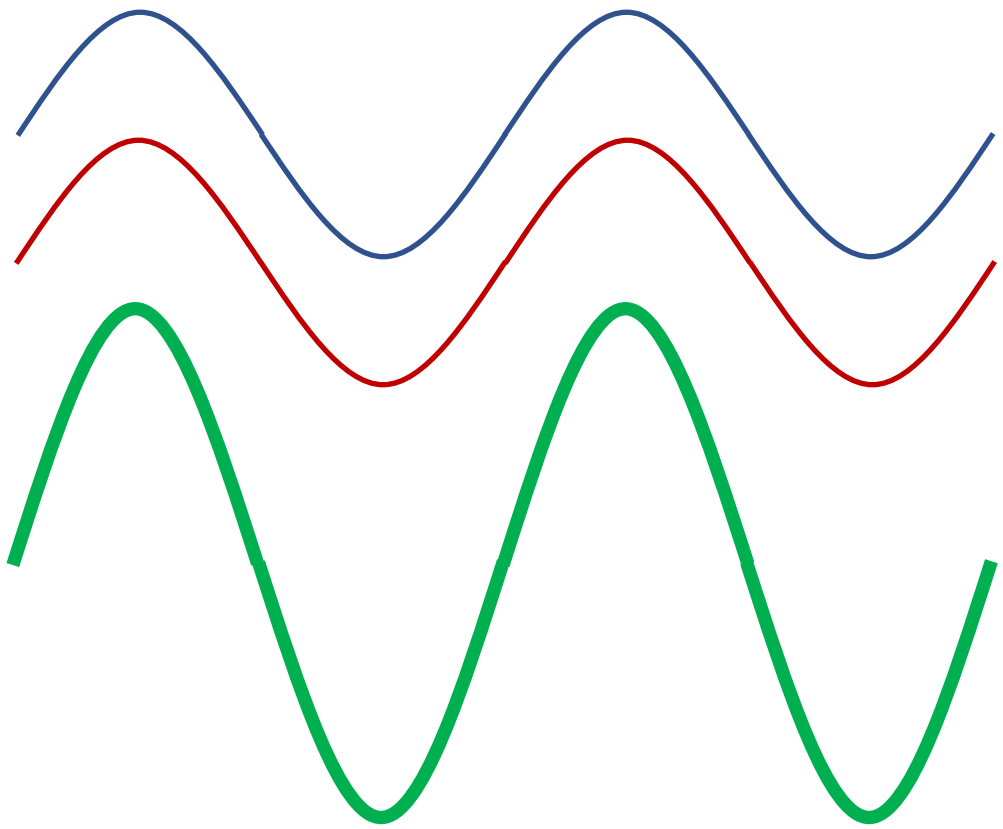


https://micro.magnet.fsu.edu/primer/anatomy/numaperture.html

d can never be smaller than ~200nm unless we 'trick' light

interferometry

interferometry

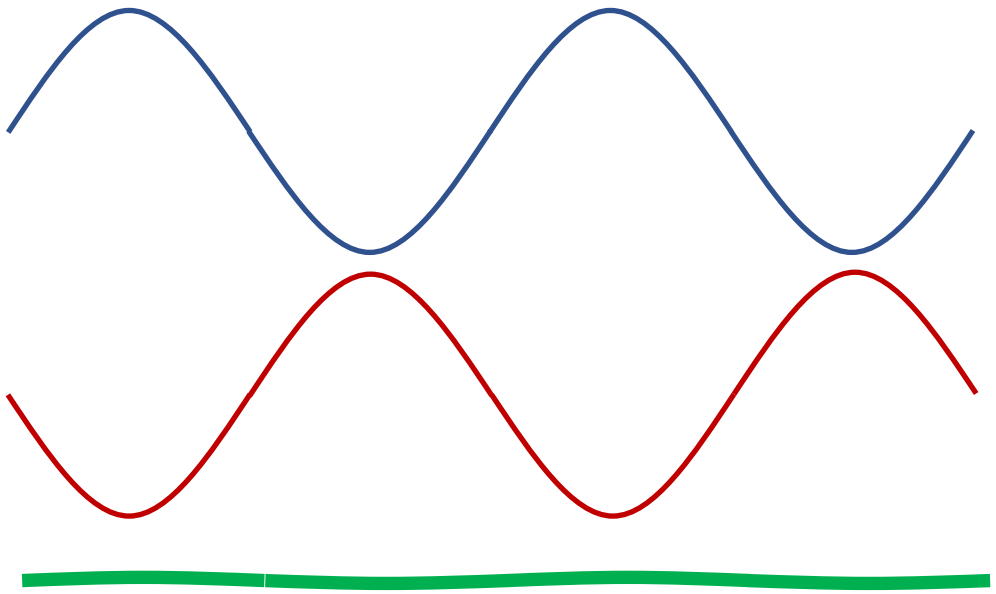


<u>wave 1</u>: $E_1 = E_o \cdot e^{i\cdot(\varphi_1 - \omega\cdot t)}$

<u>wave 2</u>: $E_2 = E_o \cdot e^{i\cdot(\varphi_2 - \omega\cdot t)}$

constructive interference
for $\varphi_1 - \varphi_2 = 2\cdot\pi \cdot n$, with $n = \{0,1,2,\ldots\}$

interferometry

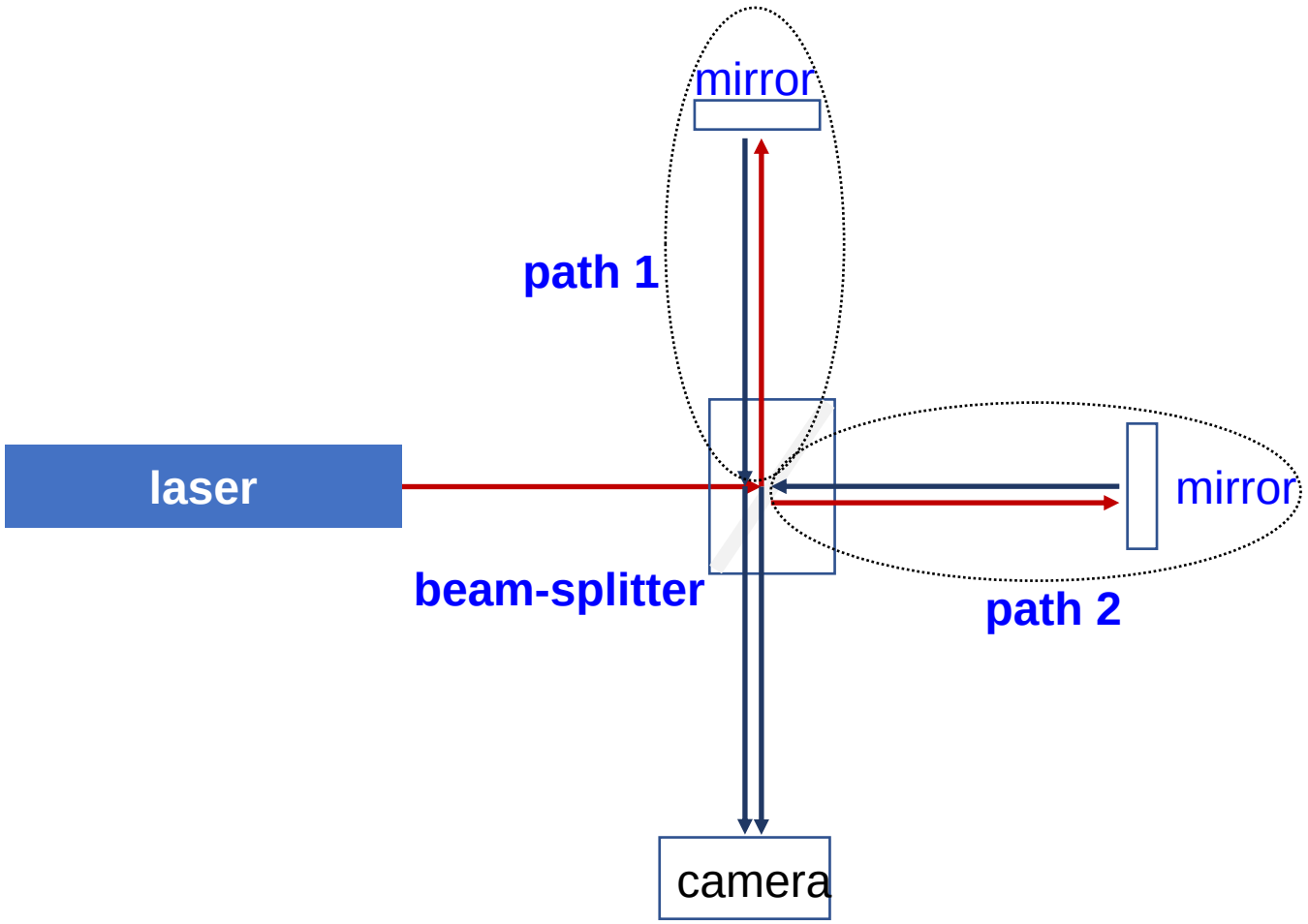


<u>wave</u> 1: $E_1 = E_o \cdot e^{i\cdot(\varphi_1 - \omega\cdot t)}$

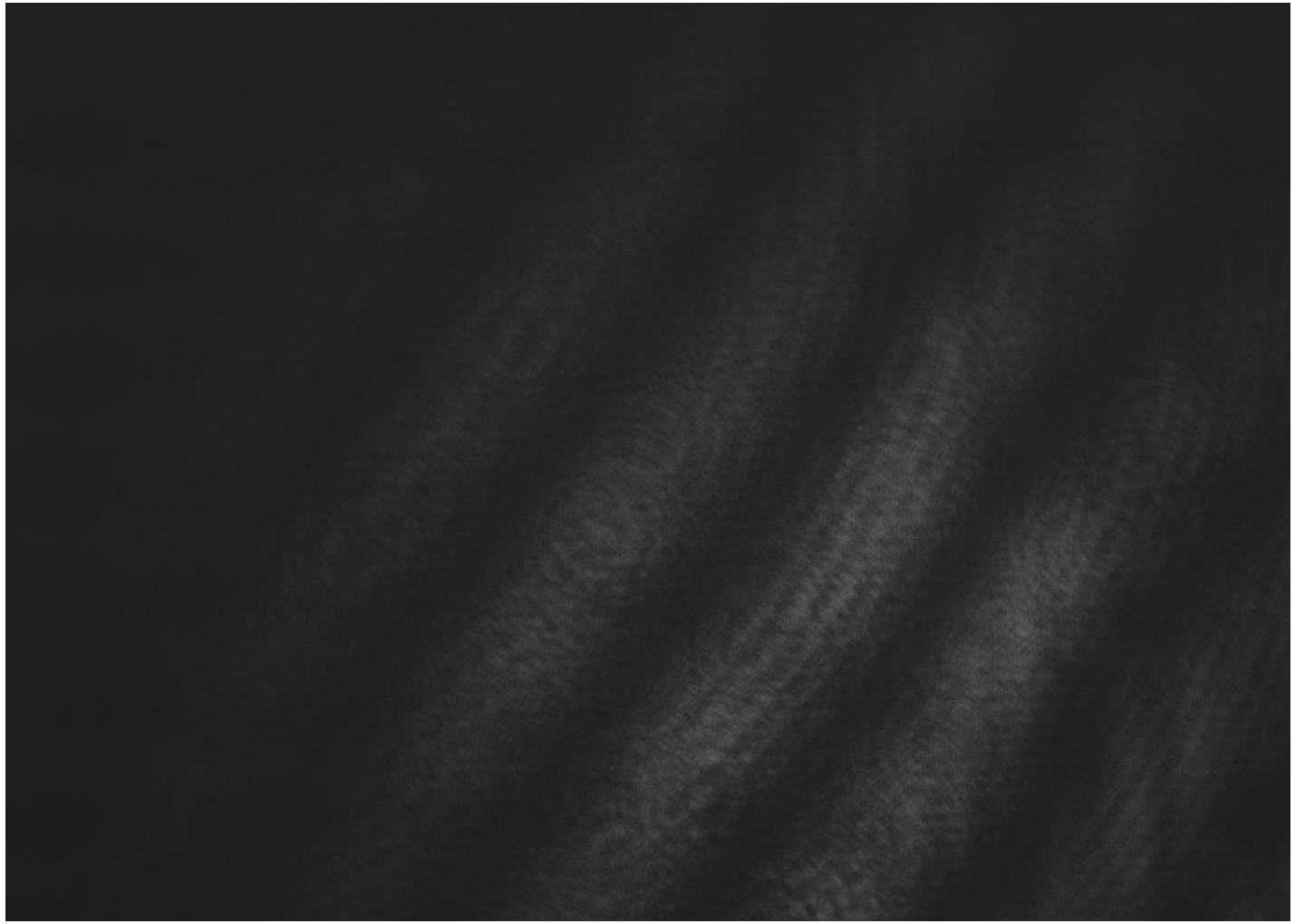
<u>wave</u> 2: $E_2 = E_o \cdot e^{i\cdot(\varphi_2 - \omega\cdot t)}$

destructive interference
for $\varphi_1 - \varphi_2 = \pi\,(2 \cdot n+1)$

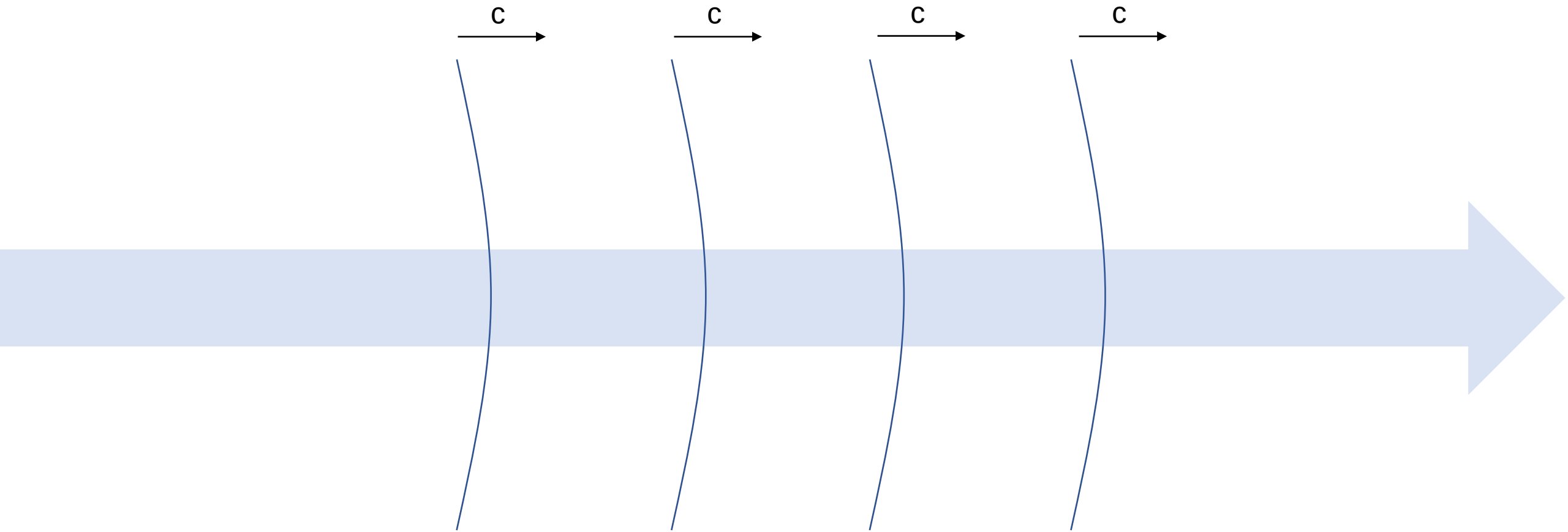
interferometry



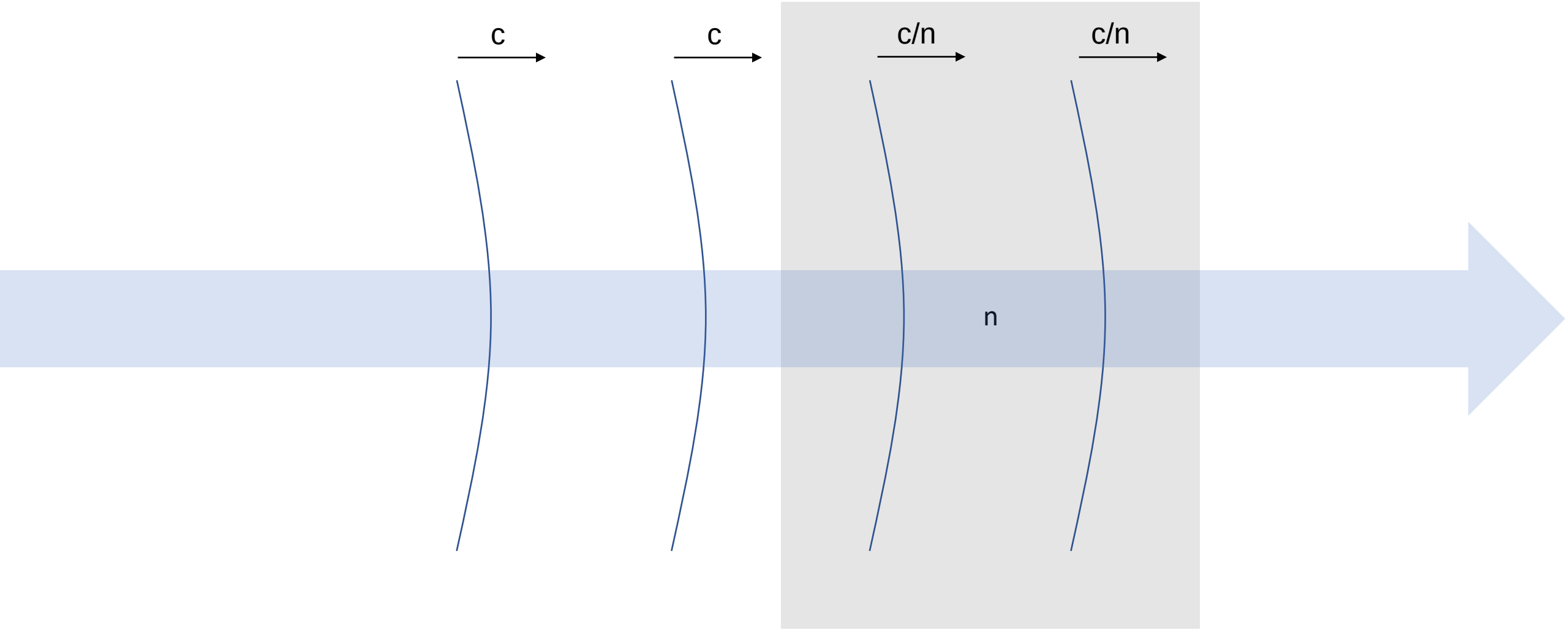
interferometry



tricking light – *transmission*

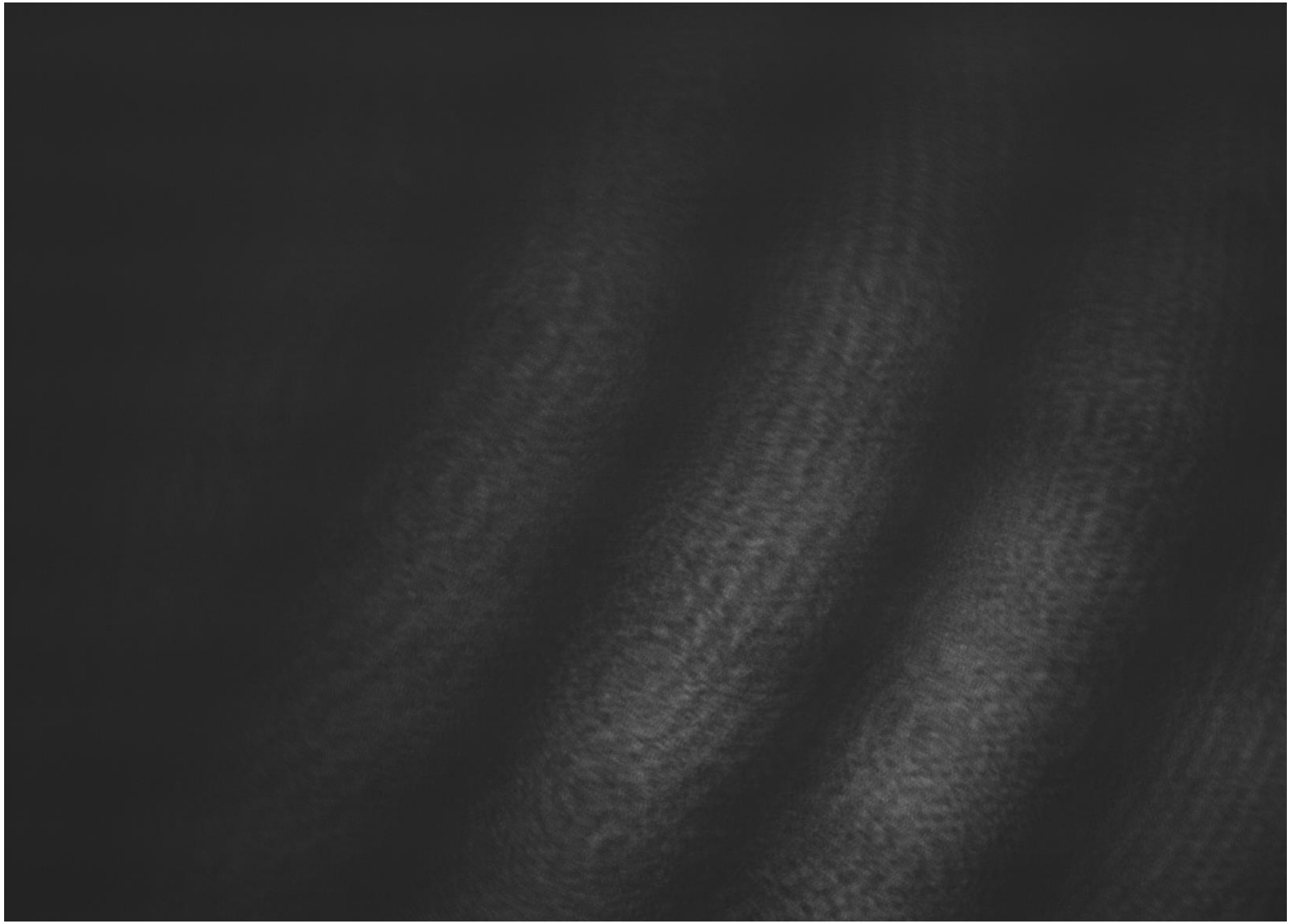


tricking light – *transmission*

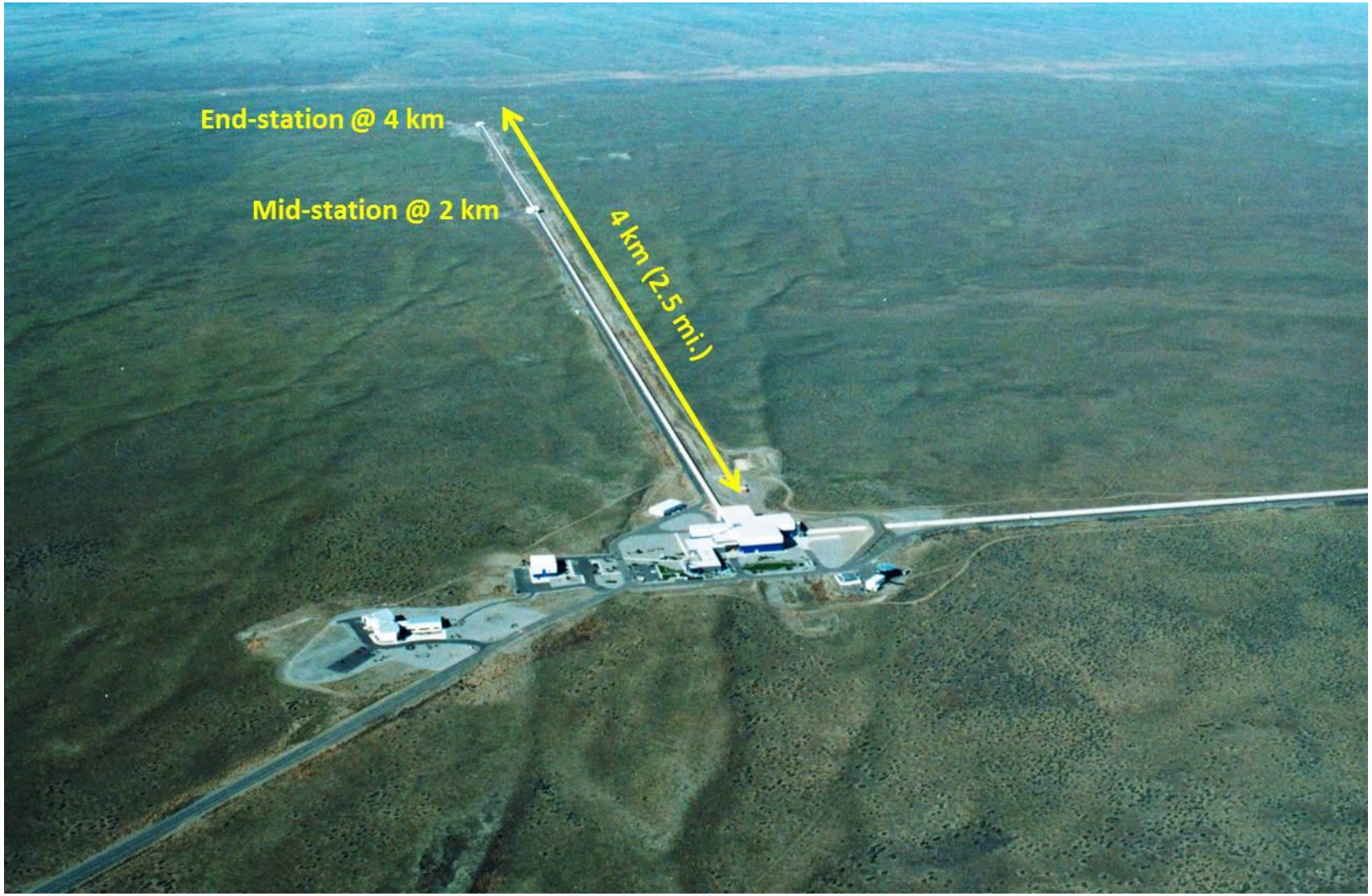


$$\phi_o = \frac{2 \cdot \pi}{\lambda} \longrightarrow \phi_1 = \frac{2 \cdot \pi \cdot n}{\lambda} \longrightarrow \Delta\phi = \frac{2 \cdot \pi \cdot \Delta n}{\lambda}$$

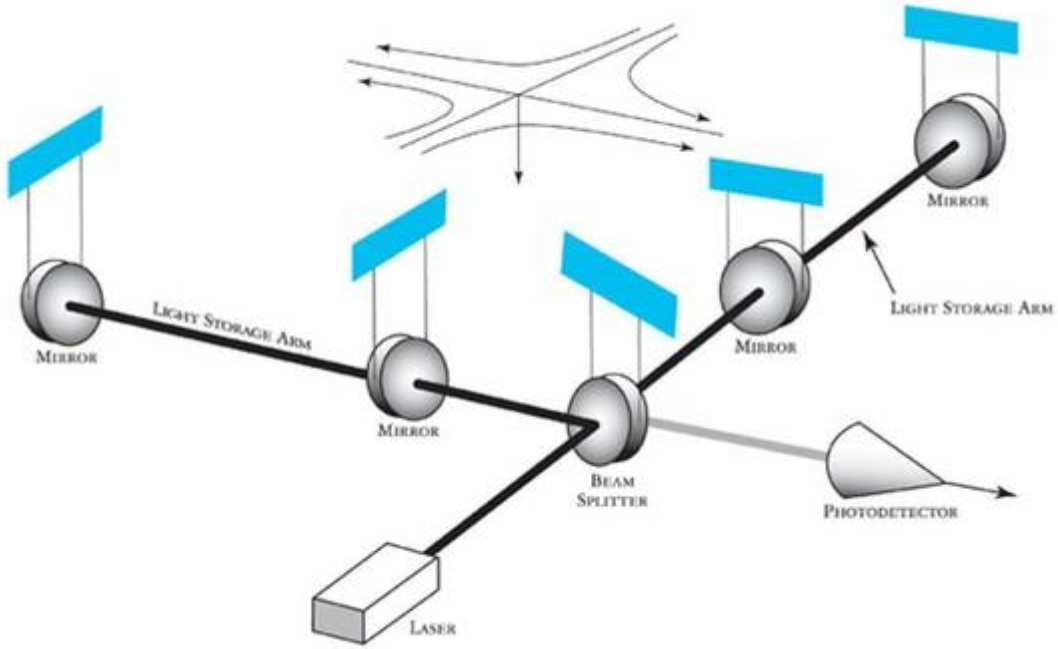
interferometry



interferometry



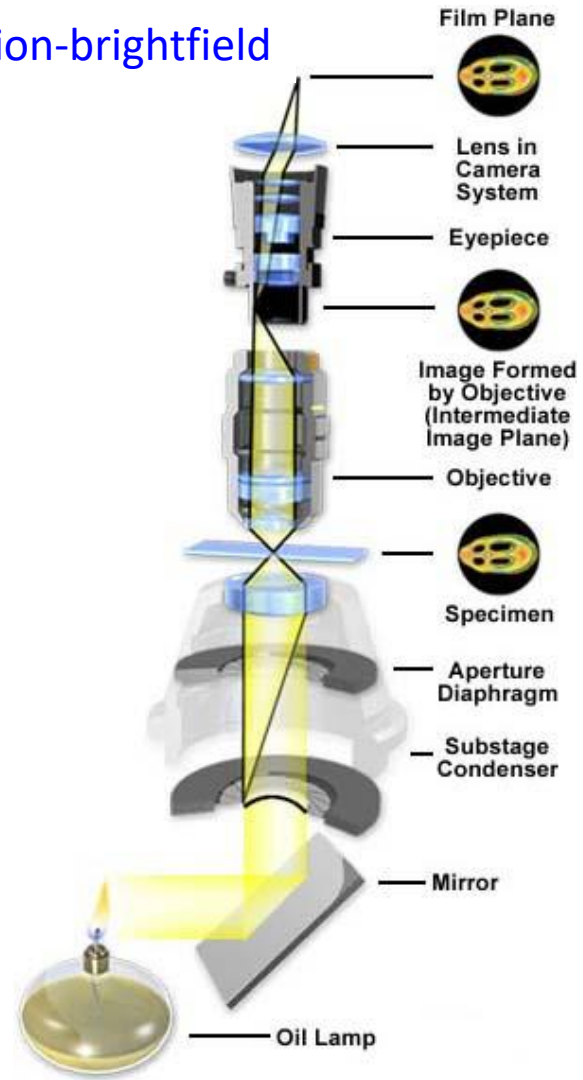
interferometry

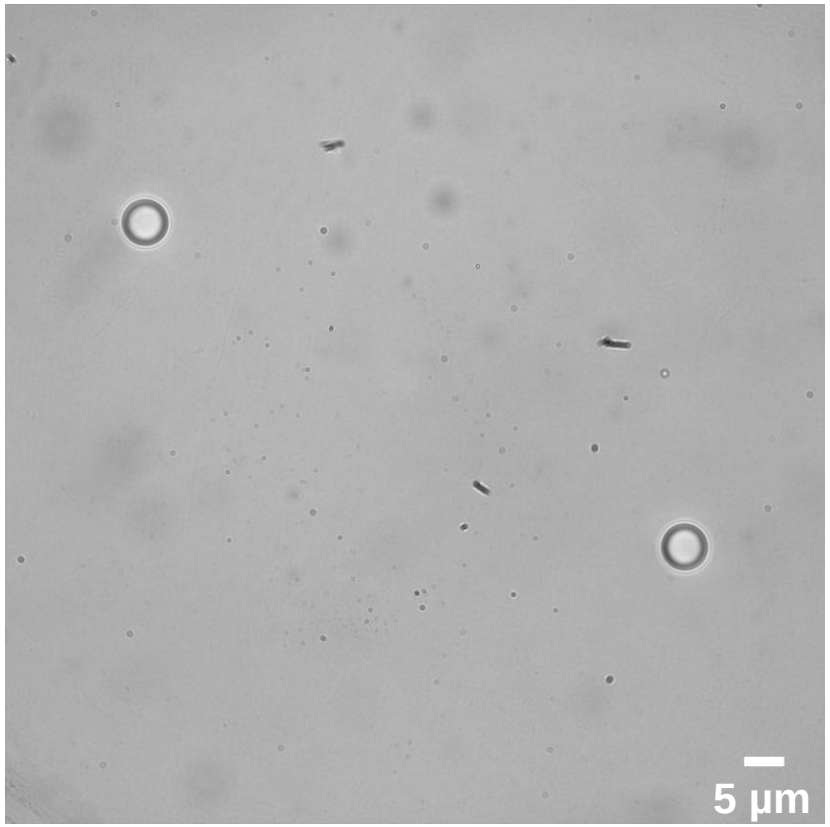


interferometric imaging

interferometry – imaging by *transmission*

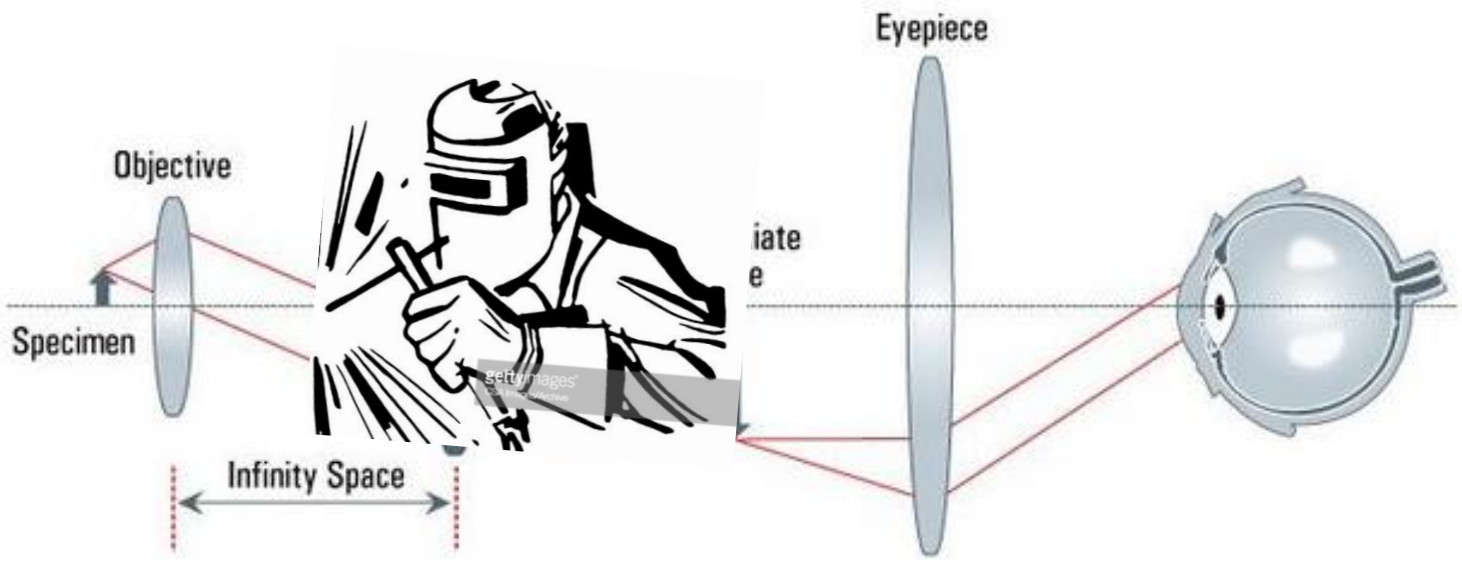
transmission-brightfield





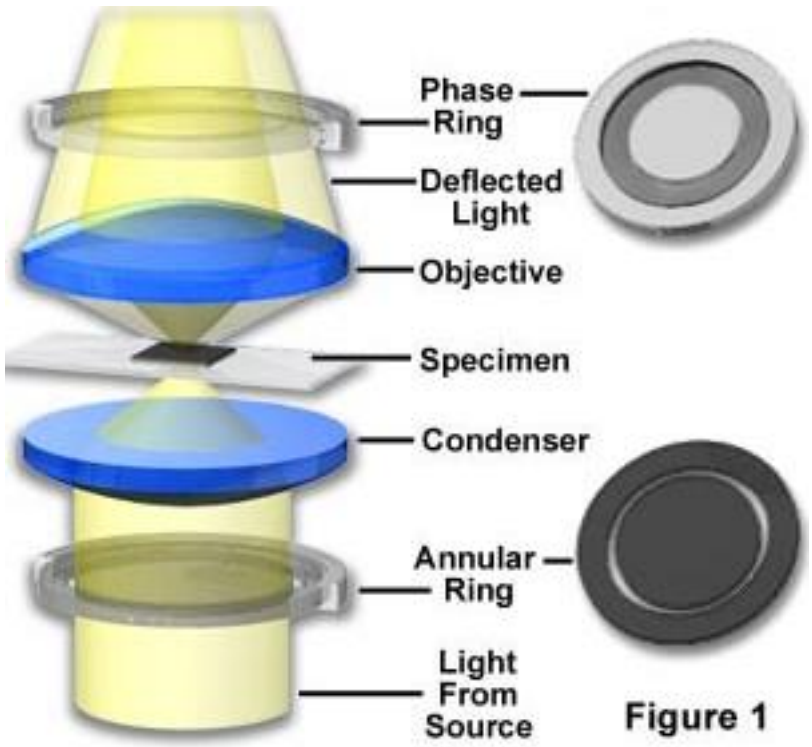
https://www.olympus-lifescience.com

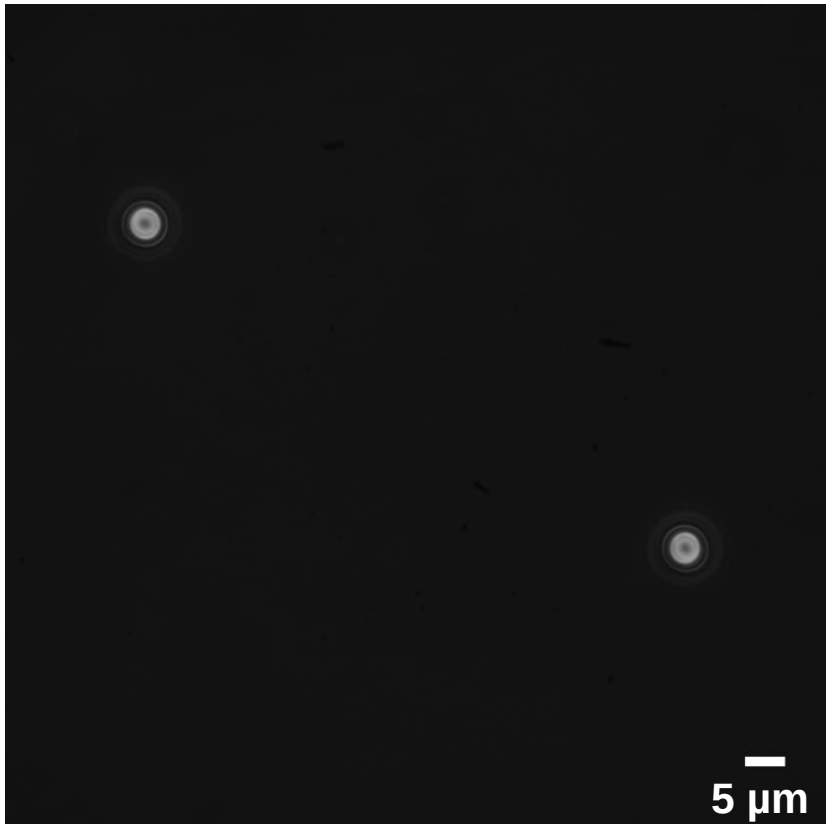
tricking light – *transmission*



interferometry – imaging by *transmission*

interferometric imaging

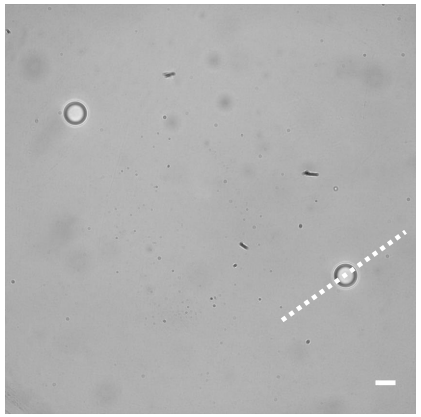


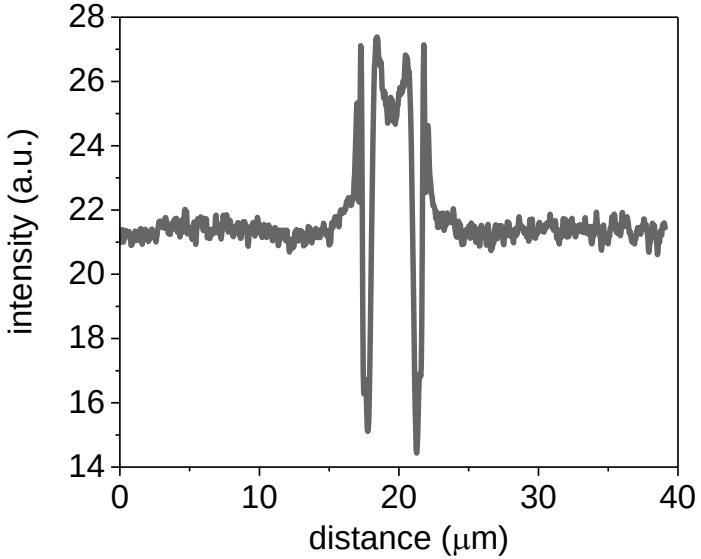


https://www.olympus-lifescience.com

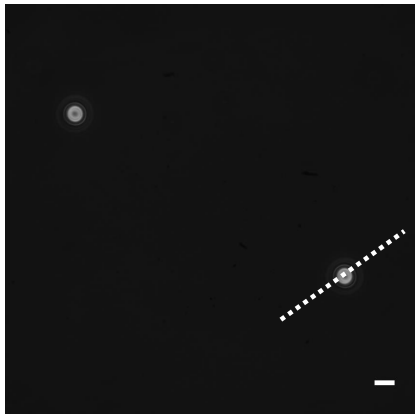
interferometry – imaging by *transmission*

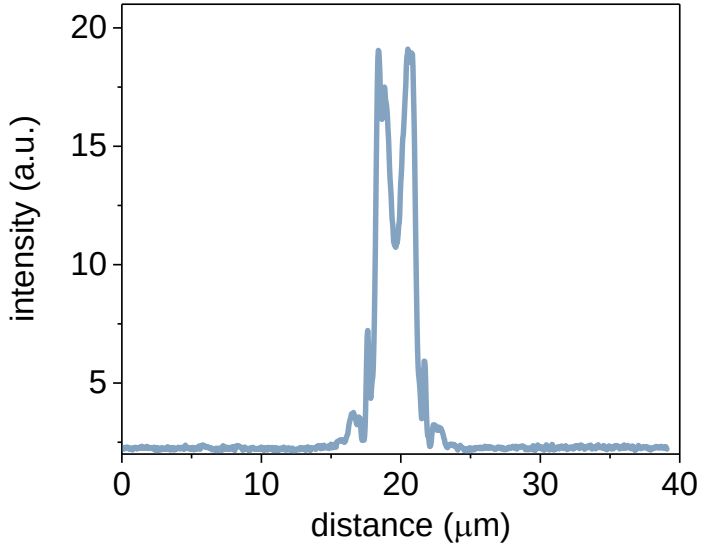
transmission



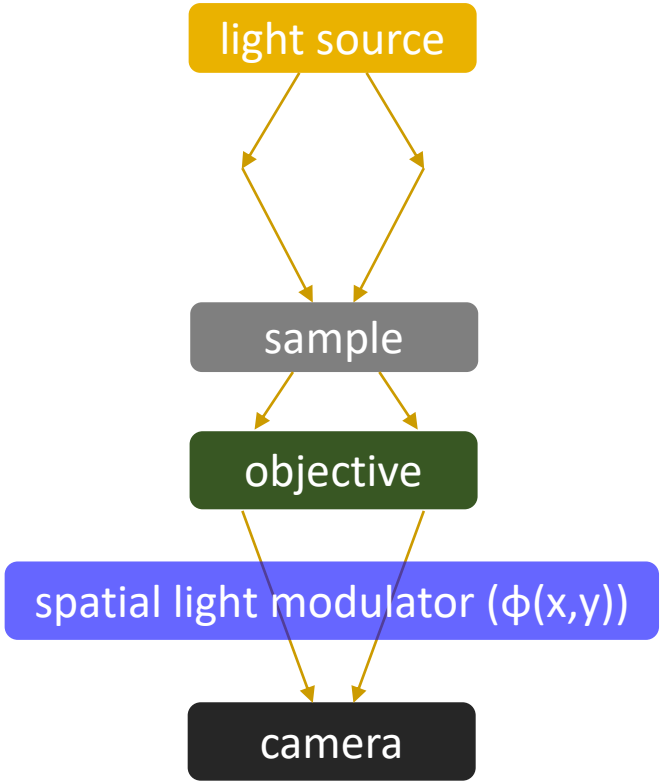


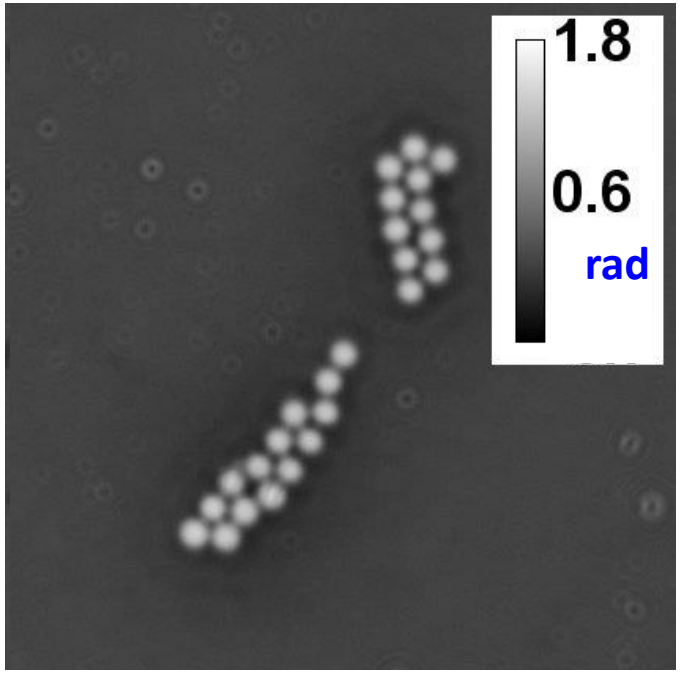
interferometric

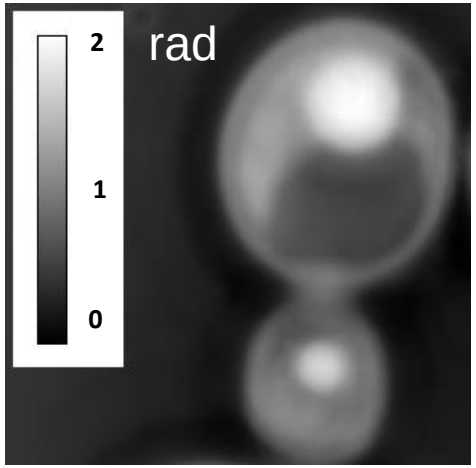




tricking light – *transmission*

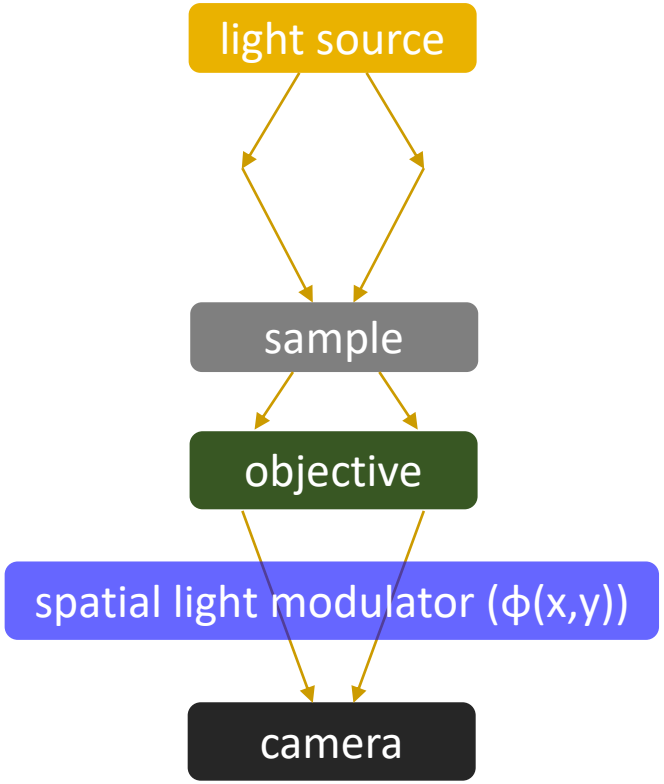


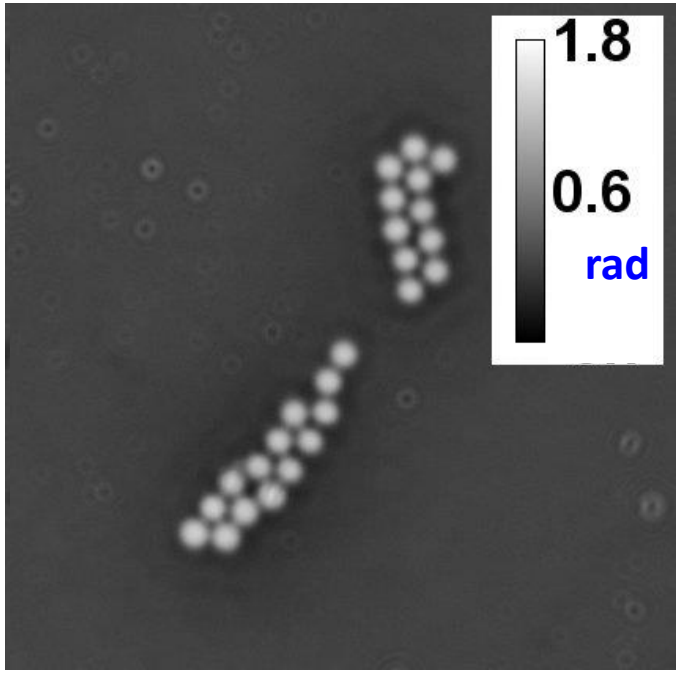


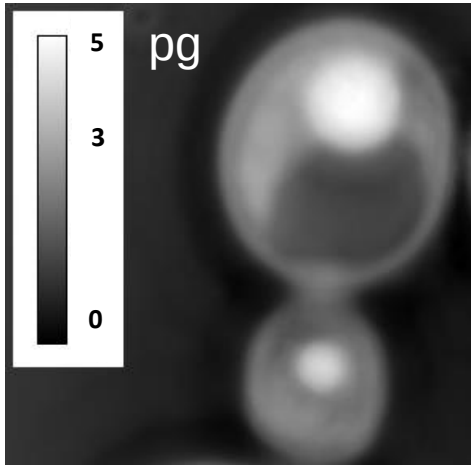


$$I(x,y;\varphi) = |U_0|^2 + |U_1(x,y)|^2 + 2|U_0||U_1(x,y)|\cos[\Delta\phi(x,y)] + \varphi]$$

tricking light – *transmission*

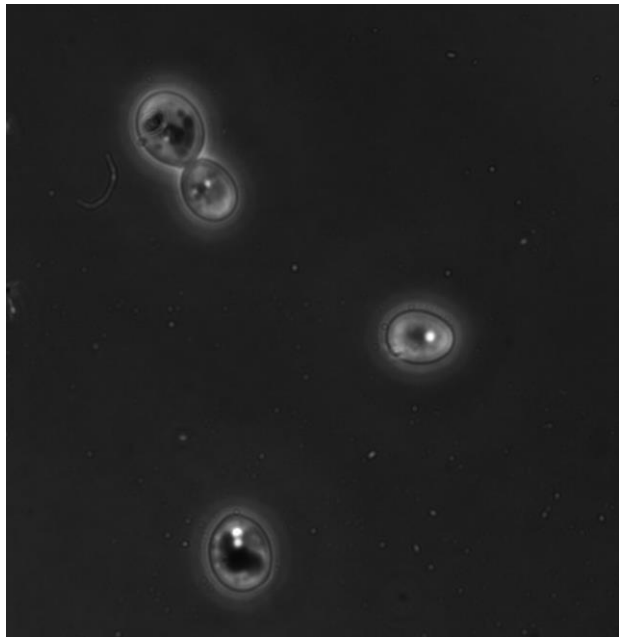


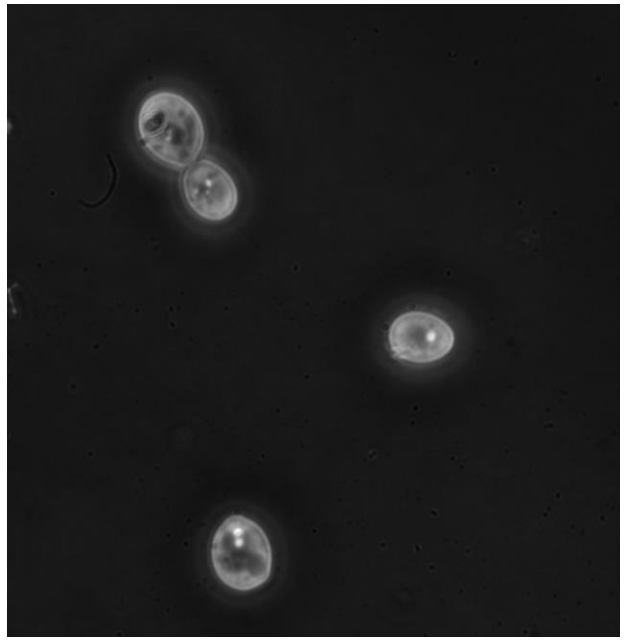


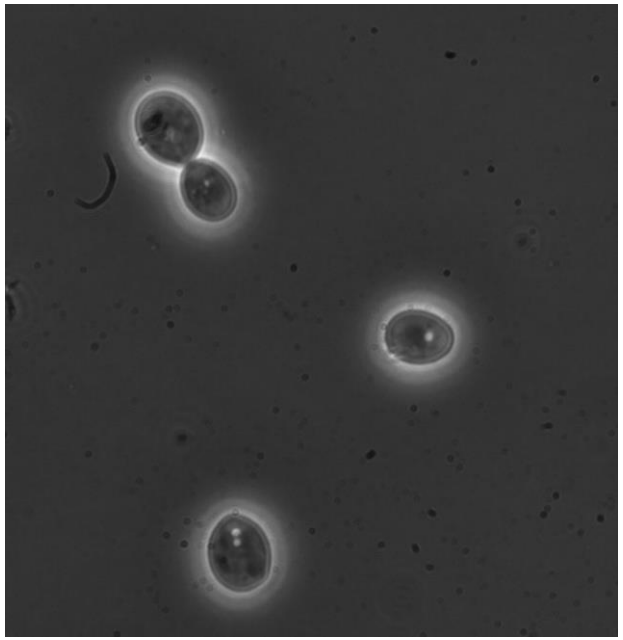


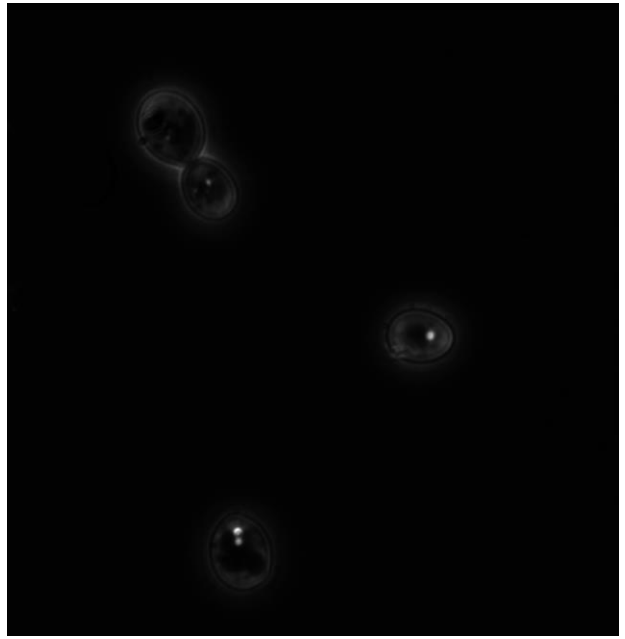
$$I(x,y;\varphi) = |U_0|^2 + |U_1(x,y)|^2 + 2|U_0||U_1(x,y)|\cos[\Delta\phi(x,y)] + \varphi]$$

tricking light – *transmission*





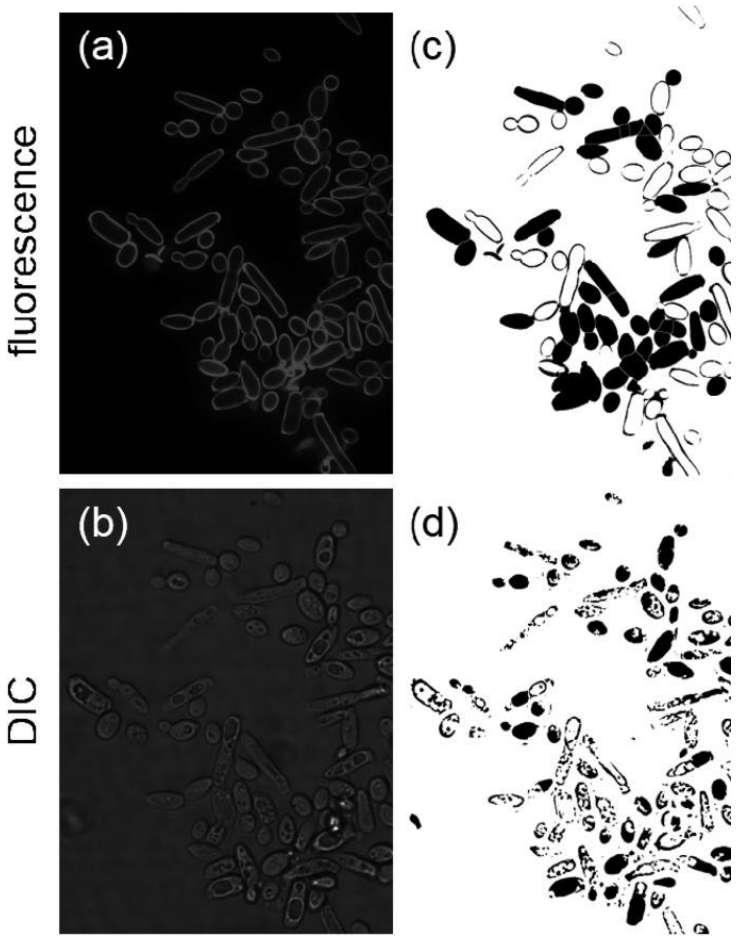


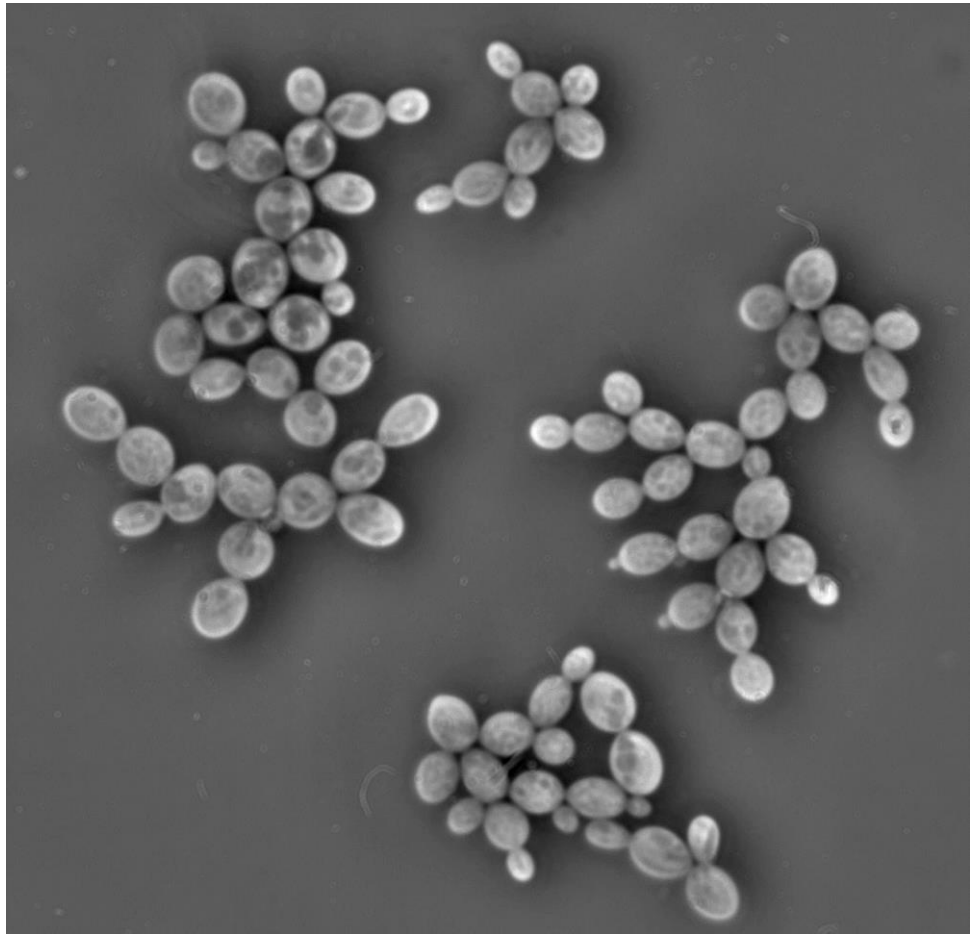


label-free organelle detection (PLoS ONE 2021)

tricking light – *transmission*

label-free cell detection, *H. Alanazi* Cytometry A (2017)





THURSDAY → 4 groups of 2

EP305: 1:30 pm – 2:30 pm

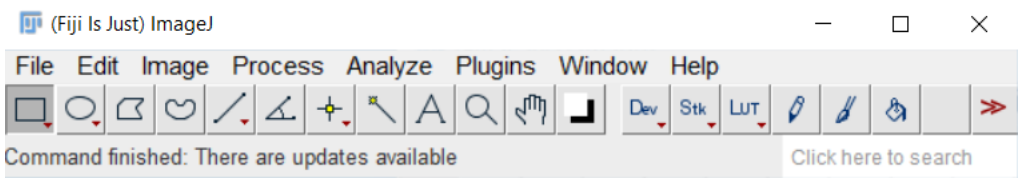
Questions to answer in your report:

[1] Which one, “image1_a” or “image1_b” is an intensity image and which one is a phase image?

[2] Using image2, determine the diameter of the particle and its refractive index (camera pixel size is 3.65 μm and we used a 63x objective at λ = 550 nm)?

[3] Can you determine if the two particles are made of the same material in image3?

[4] Can you determine if the four particles are made of the same material in image4?



download: https://imagej.nih.gov/ij/download.html

how to use: https://imagej.nih.gov/ij/docs/index.html

how to use: https://www.youtube.com/watch?v=xXE7MBiWJIc