XIV CONGRESSO SOCIETÀ OFTALMOLOGICA CALABRESE

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Corso teorico pratico di Semeiotica Strumentale

Responsabile Scientifico: Amedeo Lucente

Nuovi OCT: Prospettive Future

dott. A. Lucente
Studio Oculistico
in oculis salus

The author declares no competing financial interests

- ***Imaging***
- ***Principi di fisica degli OCT***
- ***SS-OCT***
- ***AO-OCT & Imaging***

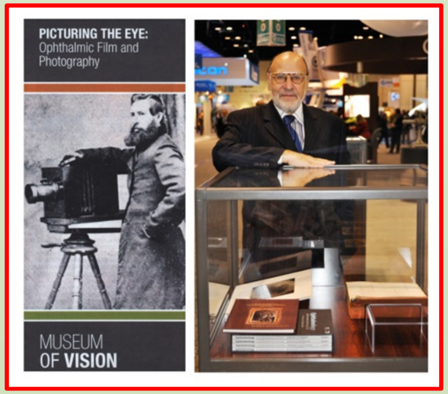
Imaging

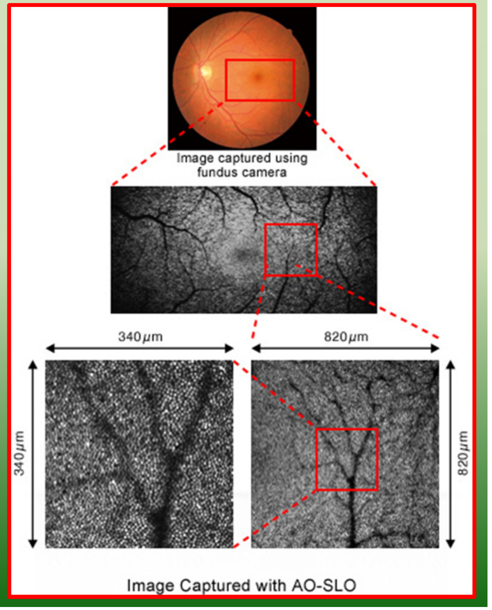
What is Imaging

- Il termine imaging è stato inventato qualche anno fa negli Stati Uniti, per definire al meglio l’evoluzione dei processi di produzione e riproduzione dell’immagine

- Identifica l’integrazione tra tutti gli elementi, prodotti, tecnologie e servizi che portano alla realizzazione di una comunicazione visiva

- Integra insieme fotografia, informatica, grafica, sviluppo, stampa





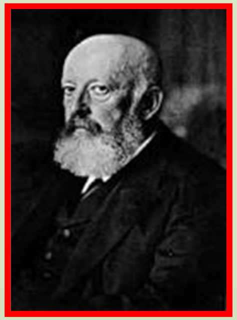
History of Imaging: a flood of innovation

- ***1851*** Hermann von Helmholtz

  direct ophthalmoscope

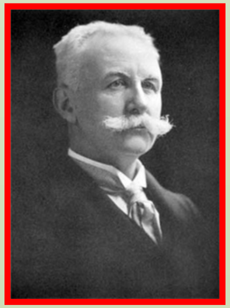
- ***1871*** Adolf von Bäyer

  Nobel Prize in chemistry 1905, synthesized fluorescein dye



- ***1887*** L. Howe "Photographs of the interior of the eye"

  Trans. Amer. Ophth. Soc. 1887



- ***1915*** Francis A. Welch and William Noah Allyn

  world's first hand-held direct illuminating ophthalmoscope

- **1925/1932** ***Carl Zeiss* by J.W. Nordenson**
  modern ophthalmoscopy and photography
- **1930** ***Stroboscopic flash* by Harold Edgerton**
  “the man who stopped time”
- **1957** ***Confocal microscopy* by Marvin Minsk**
  father of artificial intelligence
- **1961** ***Fluorescein angiography (FA)* by Harold Novotny and David Alvis**
- **1975** ***The digital camera Kodak Laboratories* by Steven Sasson**
- **1979** ***Scanning Laser Ophthalmoscopy SLO* by Robert H. Webb**
- **1987** ***Digital photography integrated into a fundus camera* by Topcon**
- **1991** ***Optical Coherence Tomography OCT* by D. Huang, J. G. Fujimoto et al**
- **1992** ***First angiographer using cSLO (HRA Classic)* by Heidelberg Engineering**

Optical Coherence Tomography

DAVID HUANG, ERIC A. SWANSON, CHARLES P. LIN,
JOEL S. SCHUMAN, WILLIAM G. STINSON, WARREN CHANG,
MICHAEL R. HEE, THOMAS FLOTTE, KENTON GREGORY,
CARMEN A. PULIAFITO, JAMES G. FUJIMOTO*

Science, New Series, Vol. 254, No. 5035 (Nov. 22, 1991), 1178-1181.

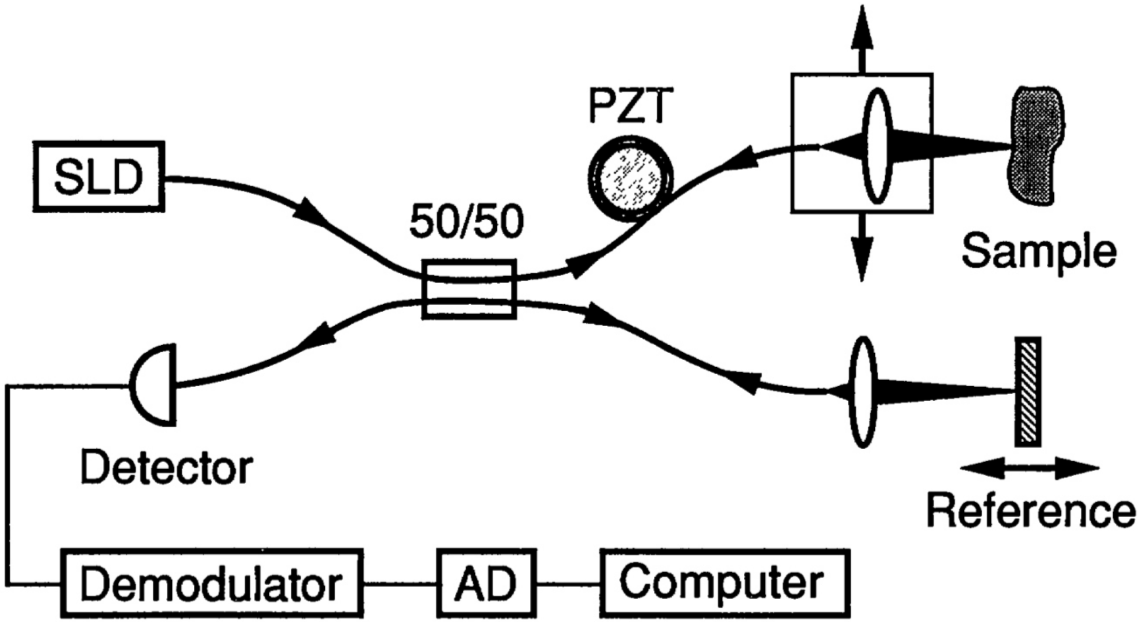
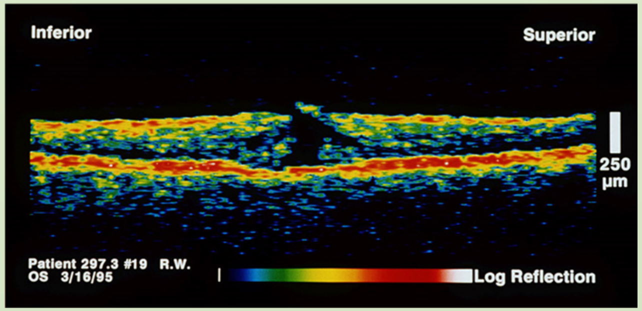
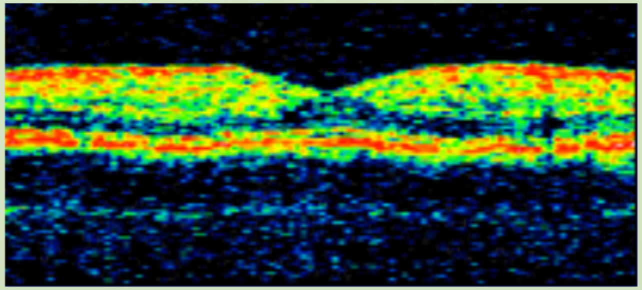
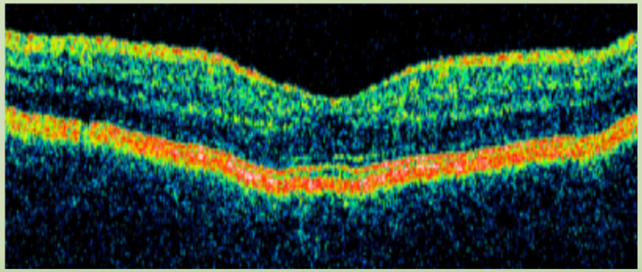
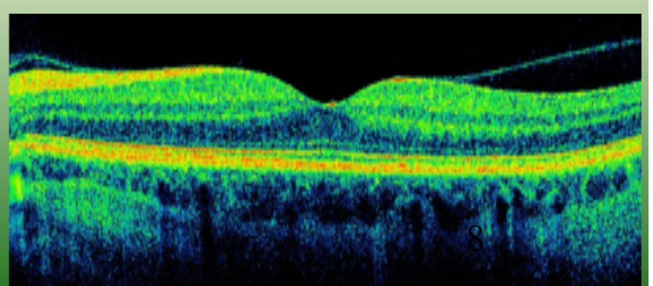
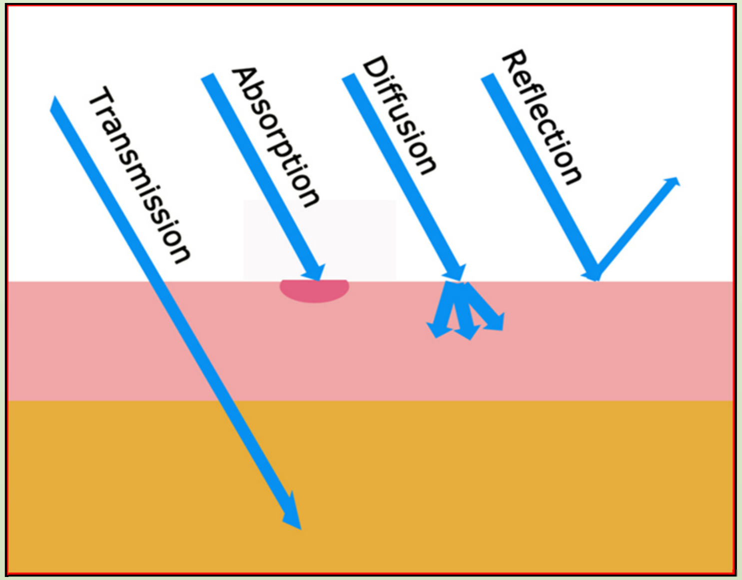


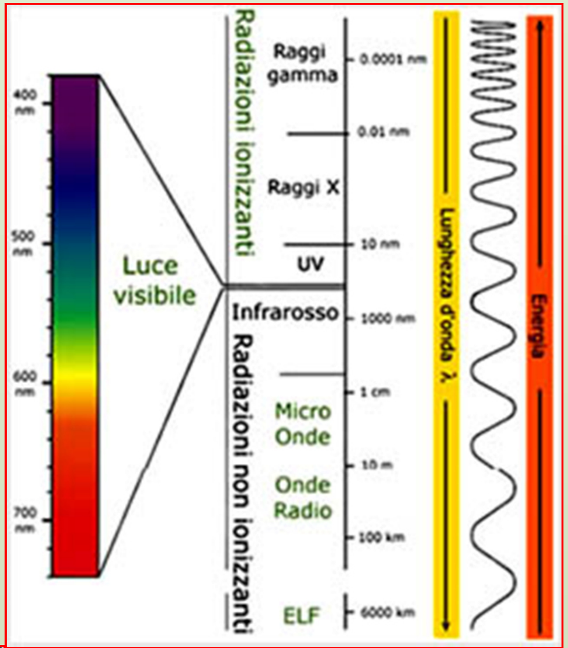
Fig. 1. Schematic of the OCT scanner. The SLD output is coupled into a single mode fiber and split at the 50/50 coupler into sample and reference arms. Reflections from the two arms are combined at the coupler and detected by the photodiode. Longitudinal scanning is performed by translating the reference mirror with a stepper motor stage at 1.6 mm s^{-1}, generating a 3.8-kHz Doppler shift. The piezoelectric transducer (PZT) in the sample arm further provides 21.2-kHz phase modulation to the interferometric signal. Interferometric modulation of the output intensity is detected by the photodetector when the reference and sample arm delays are nearly matched. The detector output is demodulated at the sum modulation frequency of 25 kHz to produce the envelope of the interferometric signal, which is then digitized (AD) and stored on computer. A series of longitudinal scans are performed. The lateral beam position is translated after each longitudinal scan.

Device		Single line scan	Scans/ second	Resolution (microns)	Imaging
	OCT1 1995	100 A-scans x 500 points	100	20	
	OCT2 2000	100 A-scans x 500 points	100	20	
	OCT3 Stratus OCT 2002	512 A-scans x1024 points	500	10	
	Cirrus HD-OCT 2007	4096 A-scans x 1024 points	27,000	5	

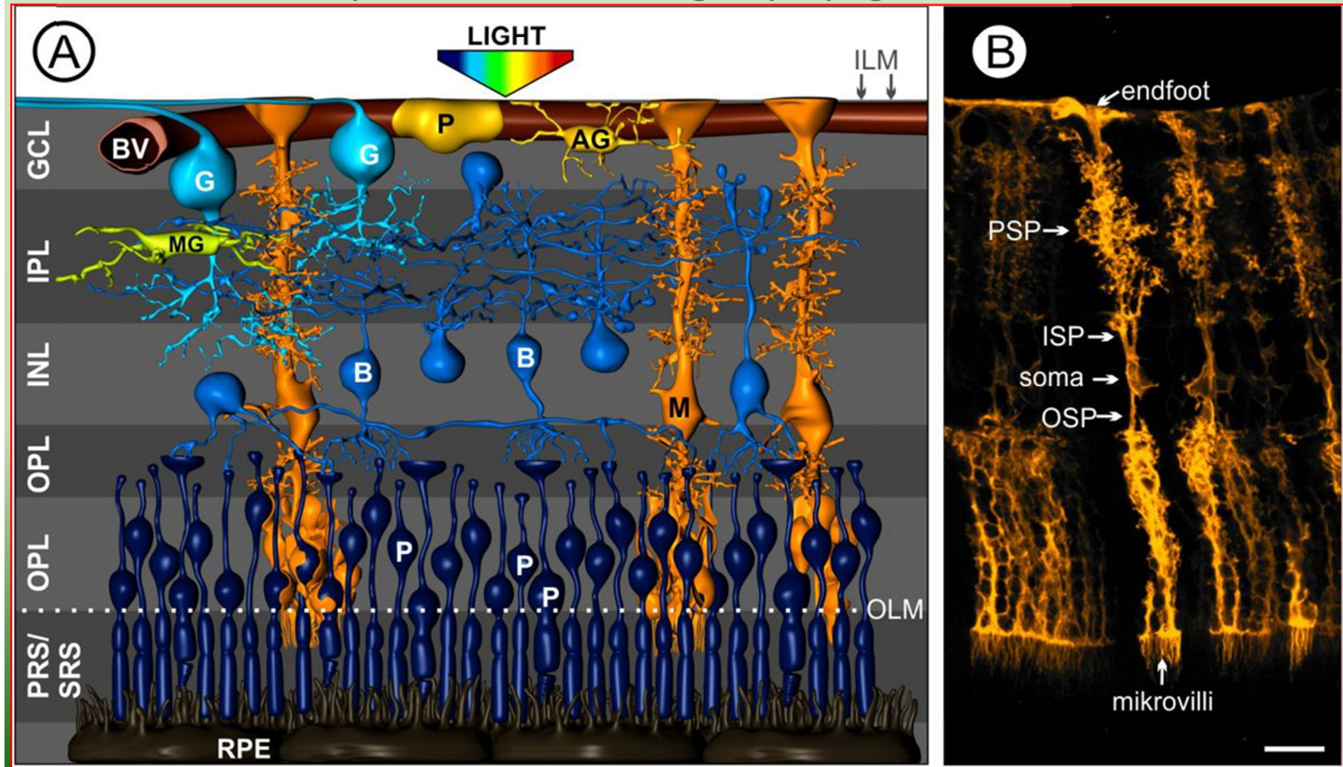
Principi di Fisica

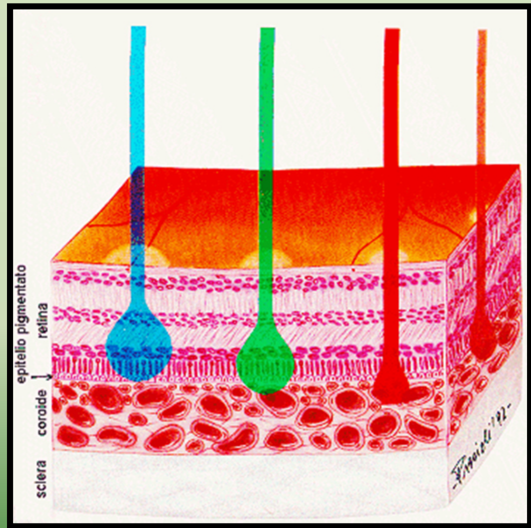


Luce
Retina



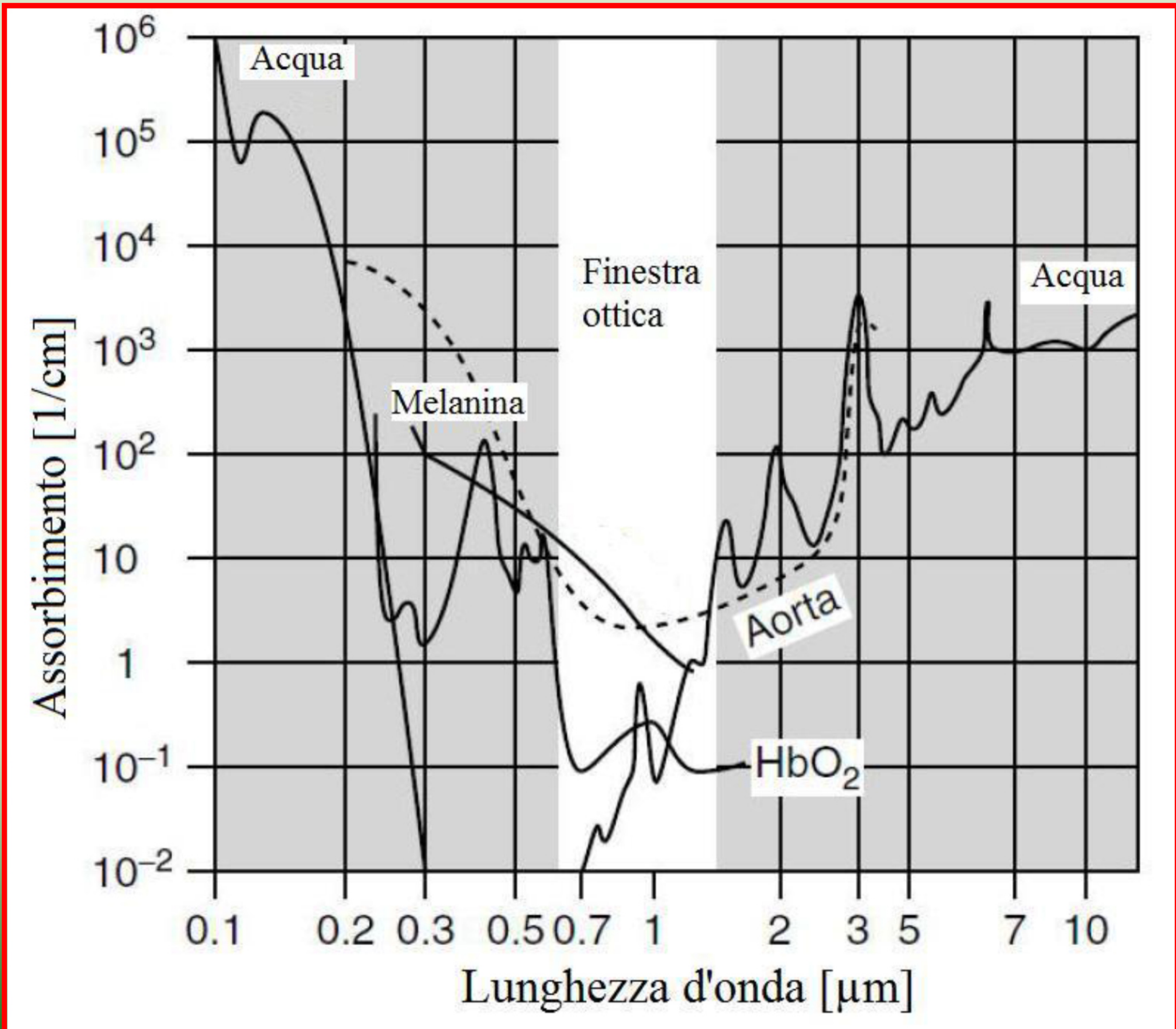
Diffusione = Dispersione = Scattering = Sparpagliamento

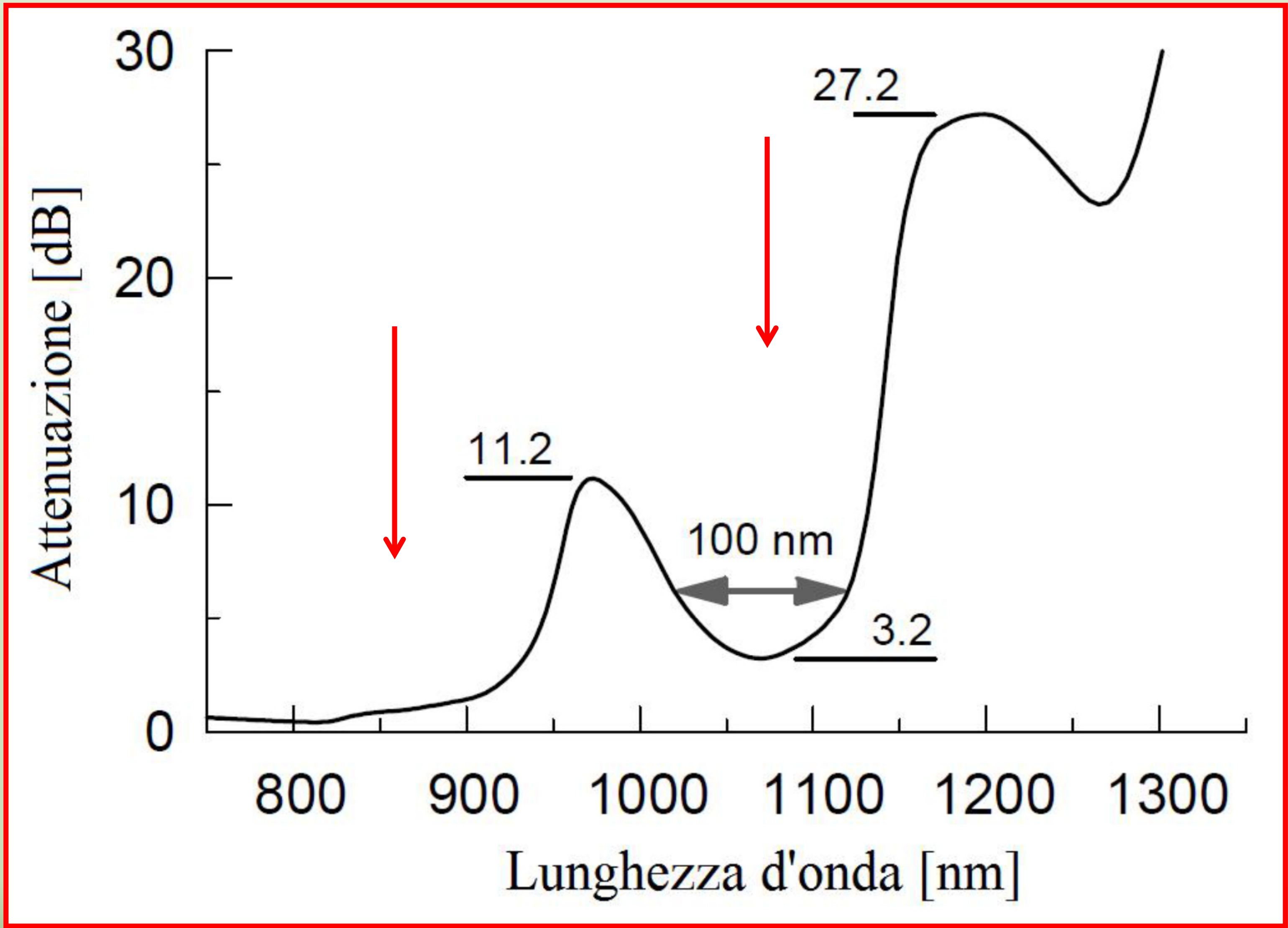




Assorbimento luce/tessuti

Finestra ottica d'utilizzo 600nm/1500nm



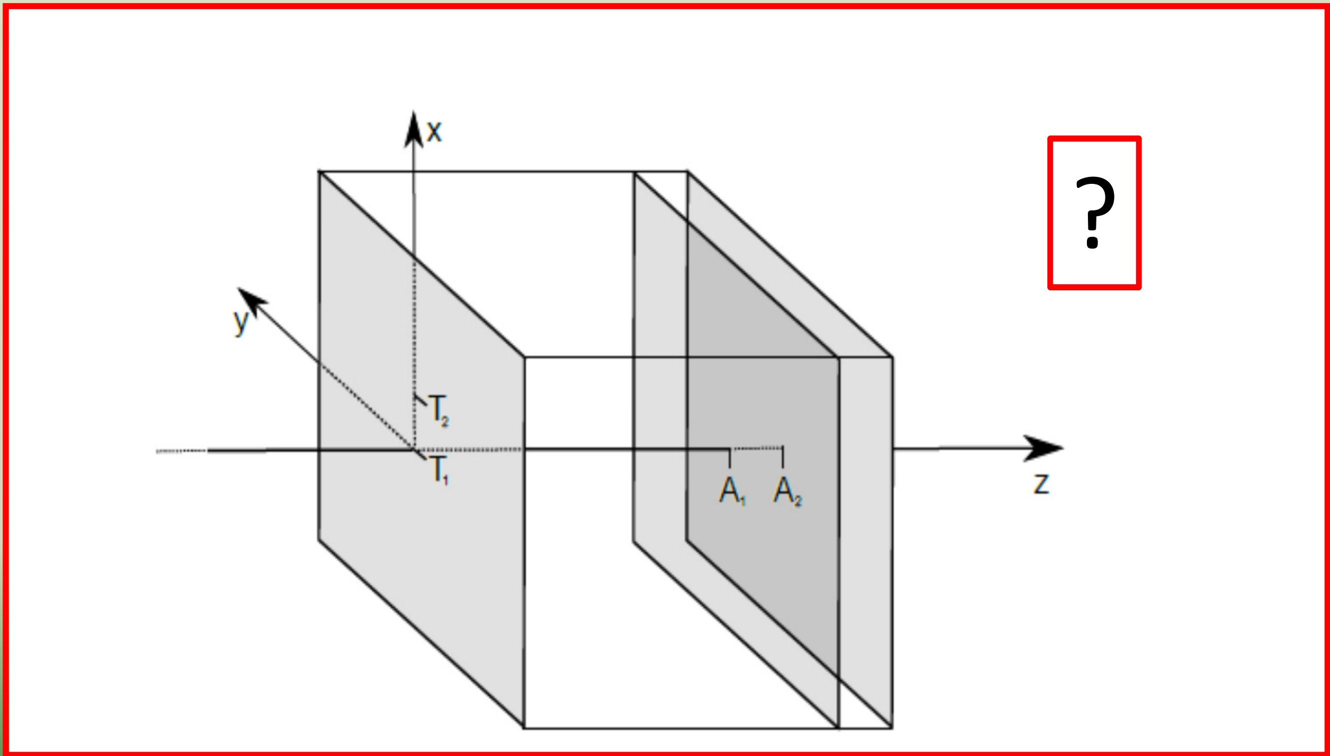


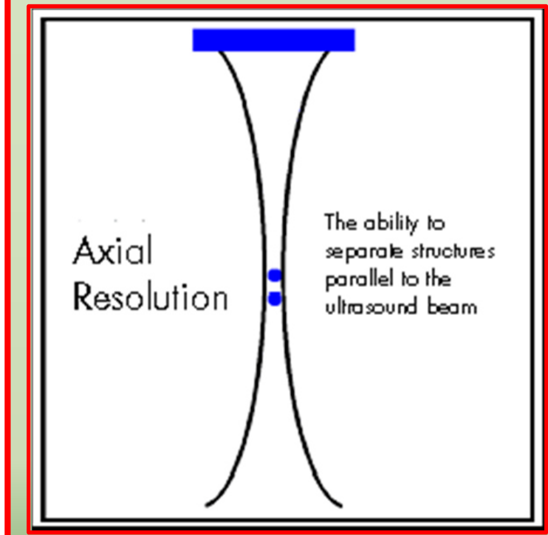
Andamento dell'attenuazione dovuta a 50 mm di acqua, in funzione della lunghezza d'onda; 50 mm di acqua corrispondono circa al percorso di andata e ritorno attraverso l'occhio umano

Risoluzione Assiale e Trasversale

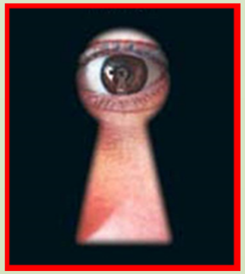
Risoluzione Assiale = A1 / A2

Risoluzione Trasversale = T1 / T2





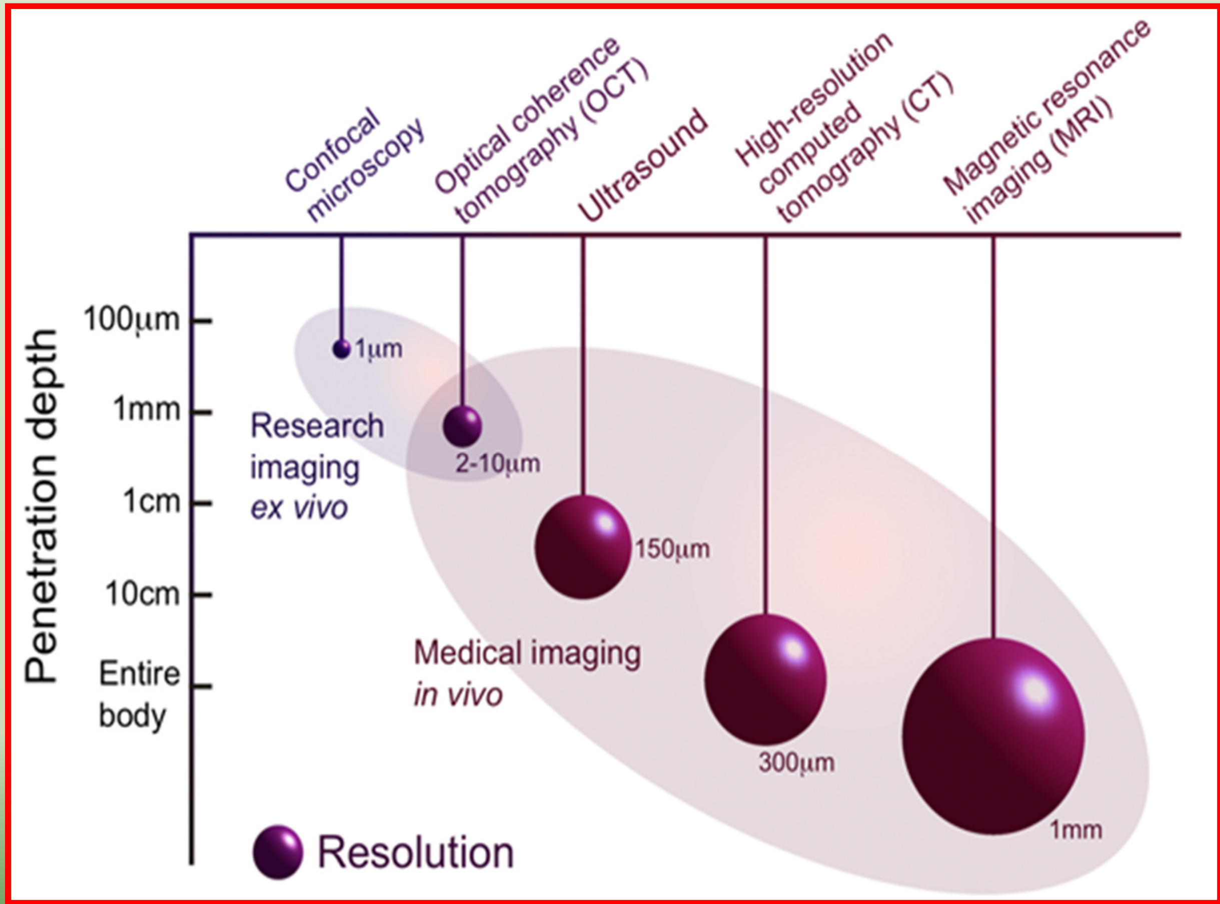
Comparison of OCT resolution and imaging depths to those of alternative techniques; the ***"pendulum" length*** represents imaging depth, and the ***"sphere" size*** represents resolution



Occhio umano
0,1mm = 100 µm

Microscopio Ottico
0,2 µm
1 µm = 0,001mm

Microscopio Elettronico
0,1nm
1nm = 0,001 µm

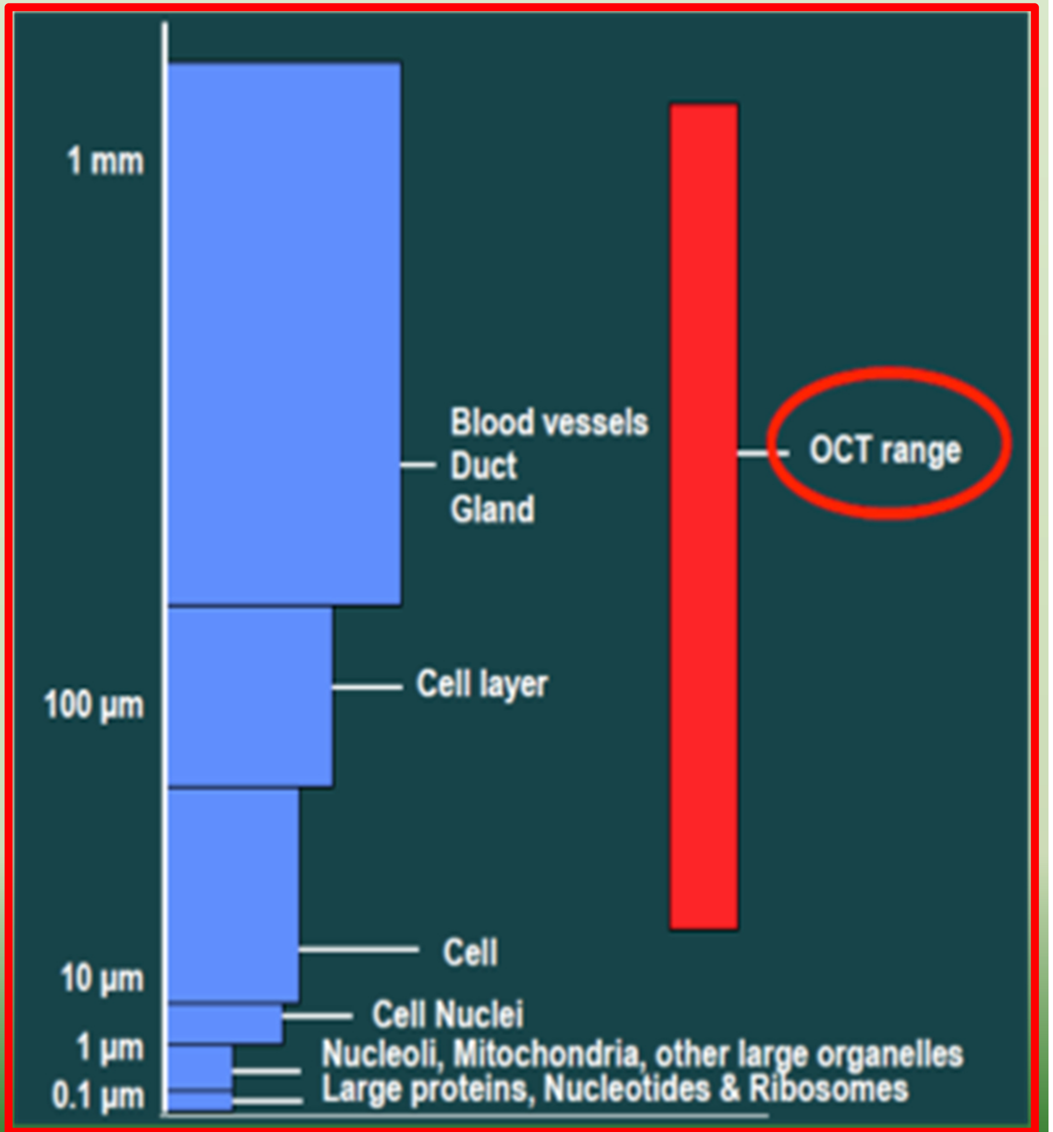


Field of view in OCT: viewing at the micrometer scale is possible cells such as macrophages can be identified in the plaque

Occhio umano
0,1mm = 100 µm

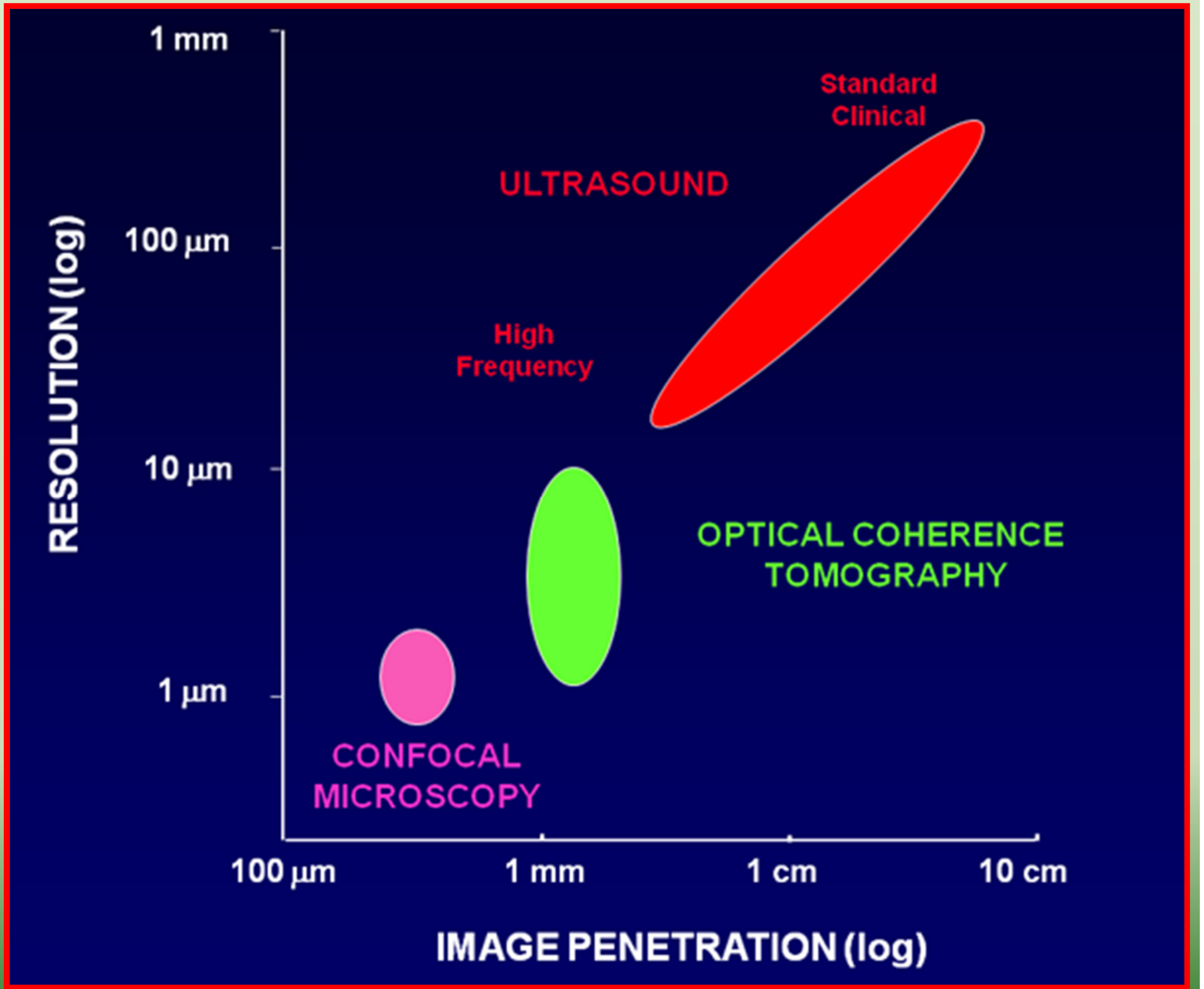
Microscopio Ottico
0,2 µm
1 µm = 0,001mm

Microscopio Elettronico
0,1nm
1nm = 0,001 µm

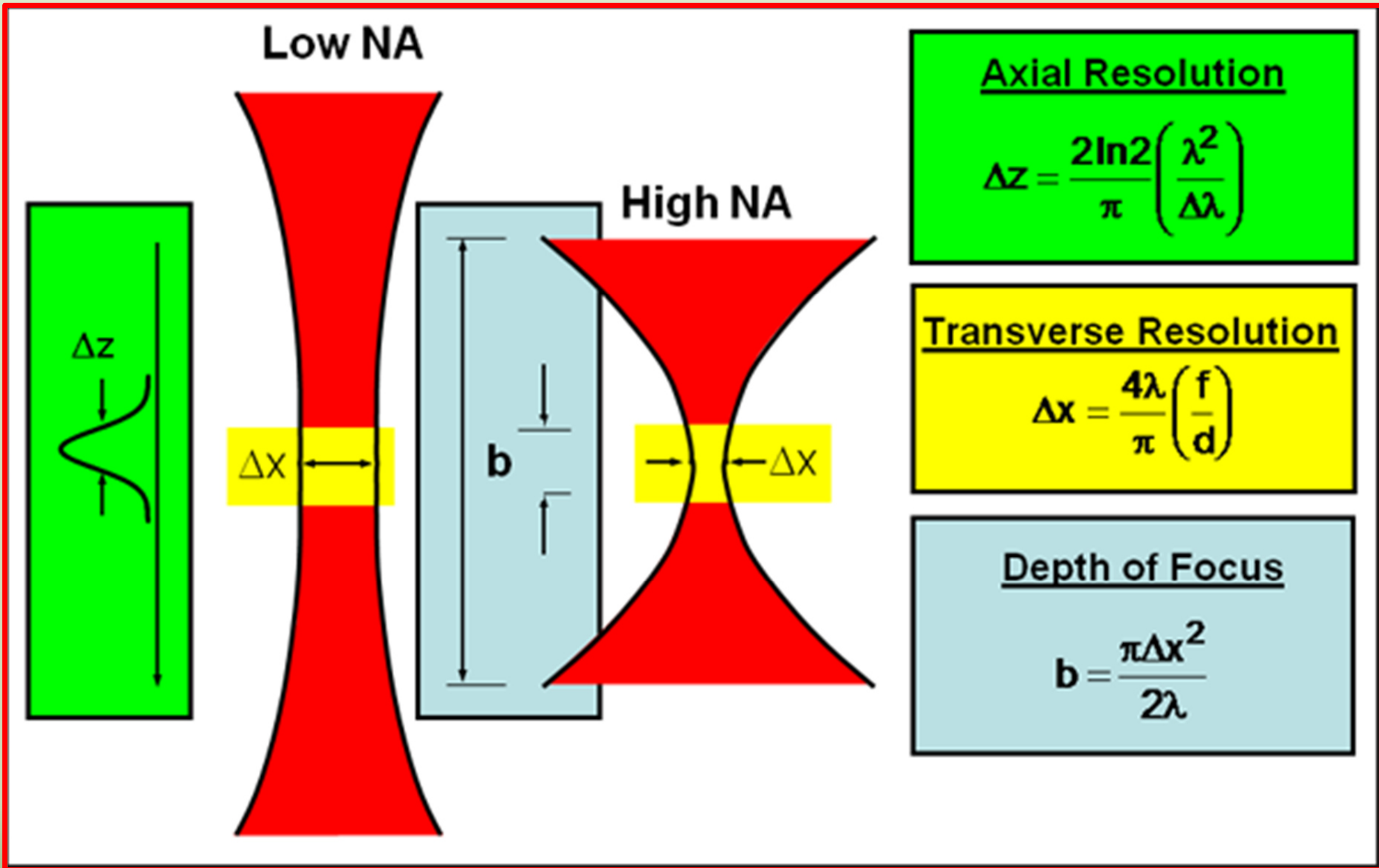


Comparison of resolution and imaging depth for ultrasound, OCT and confocal microscopy

Standard clinical ultrasound can image deep structures, but has limited resolution. Higher frequencies yield finer resolution, but ultrasonic attenuation is increased limiting image penetration. The axial image resolution in OCT ranges from 1 to 15 µm and is determined by the coherence length of the light source. In most biological tissues, the imaging depth is limited to 2 to 3 mm by attenuation from optical scattering.Confocal microscopy has submicron resolution, but optical scattering limits the imaging depth to a few hundred microns in most tissues.



Resolution: limits of OCT



OCT can achieve high axial resolutions independent of numerical aperture. Using low coherence interferometry, the axial resolution is inversely proportional to the bandwidth of the light source. The transverse resolution is given by the focus spot size. The depth of field is determined by the confocal parameter of the focused beam

Performance of OCT

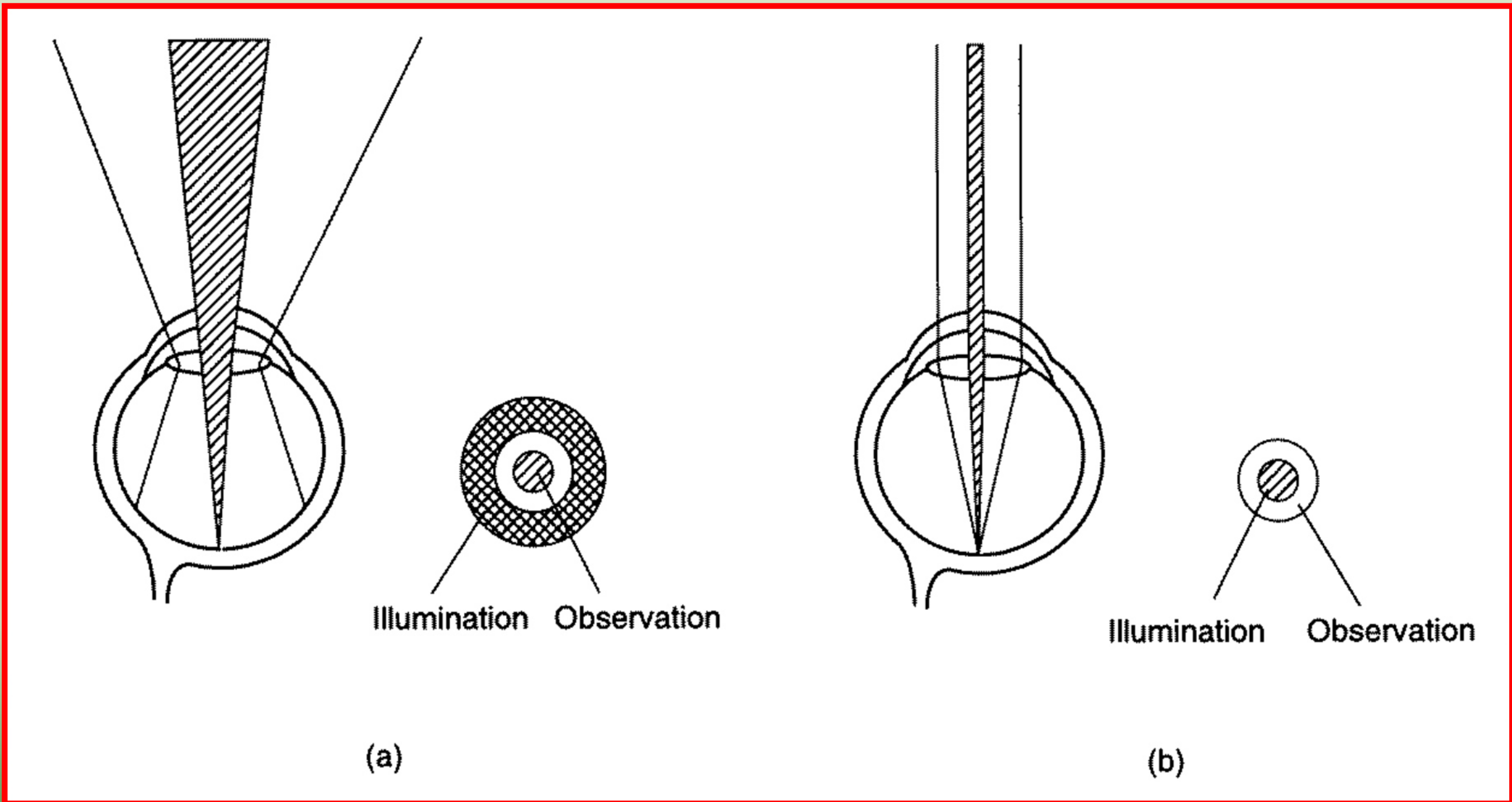
- **Roll-off di performance** riduzione della potenza del segnale OCT con l'aumentare della profondità (~ 20dB/profondità di 2 mm)

- **Sensibilità** rapporto segnale/rumore SNR; intensità riflessa o retrodiffusa fino a ~ 95dB

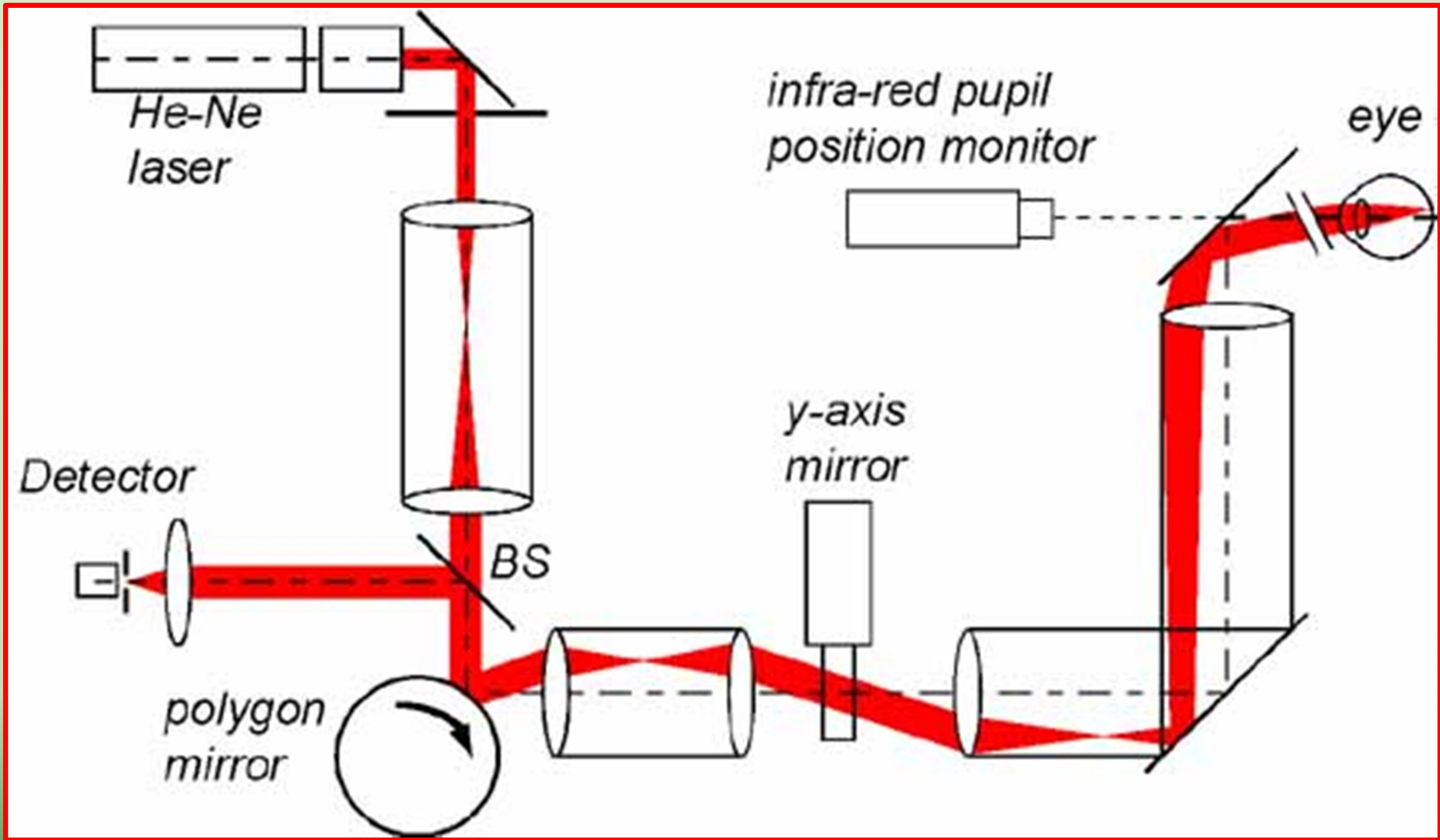
- **Velocità d'acquisizione o d'imaging** A-scan rate

- **Range dinamico** rapporto di potenza del segnale, tra la più forte e la più debole riflessione A-scan che può essere misurata (~ 40-50dB)

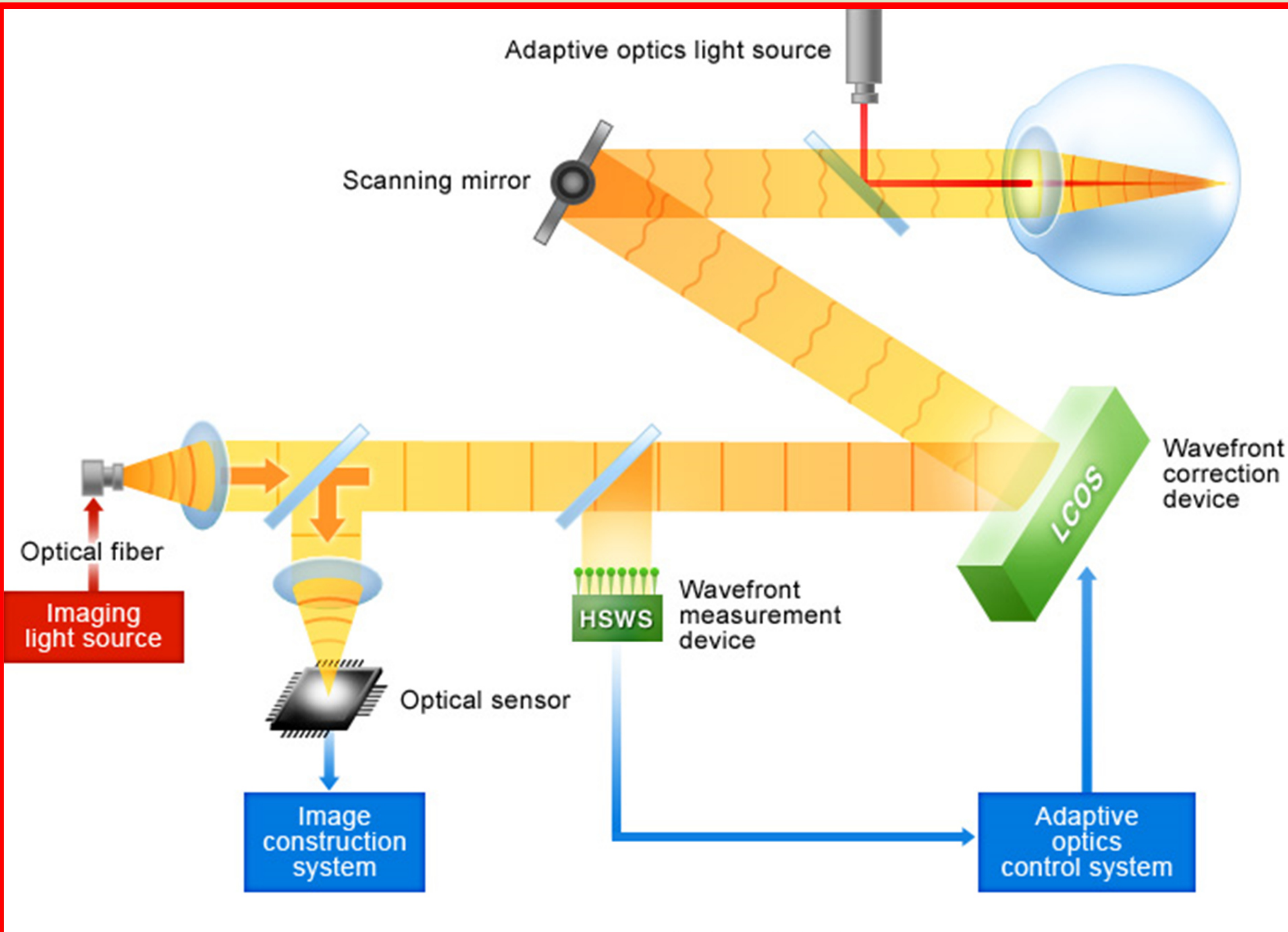
Illumination and observation of the retina by (a) the fundus camera and (b) the SLO



Confocal Scannig Laser Ophthalmoscopy

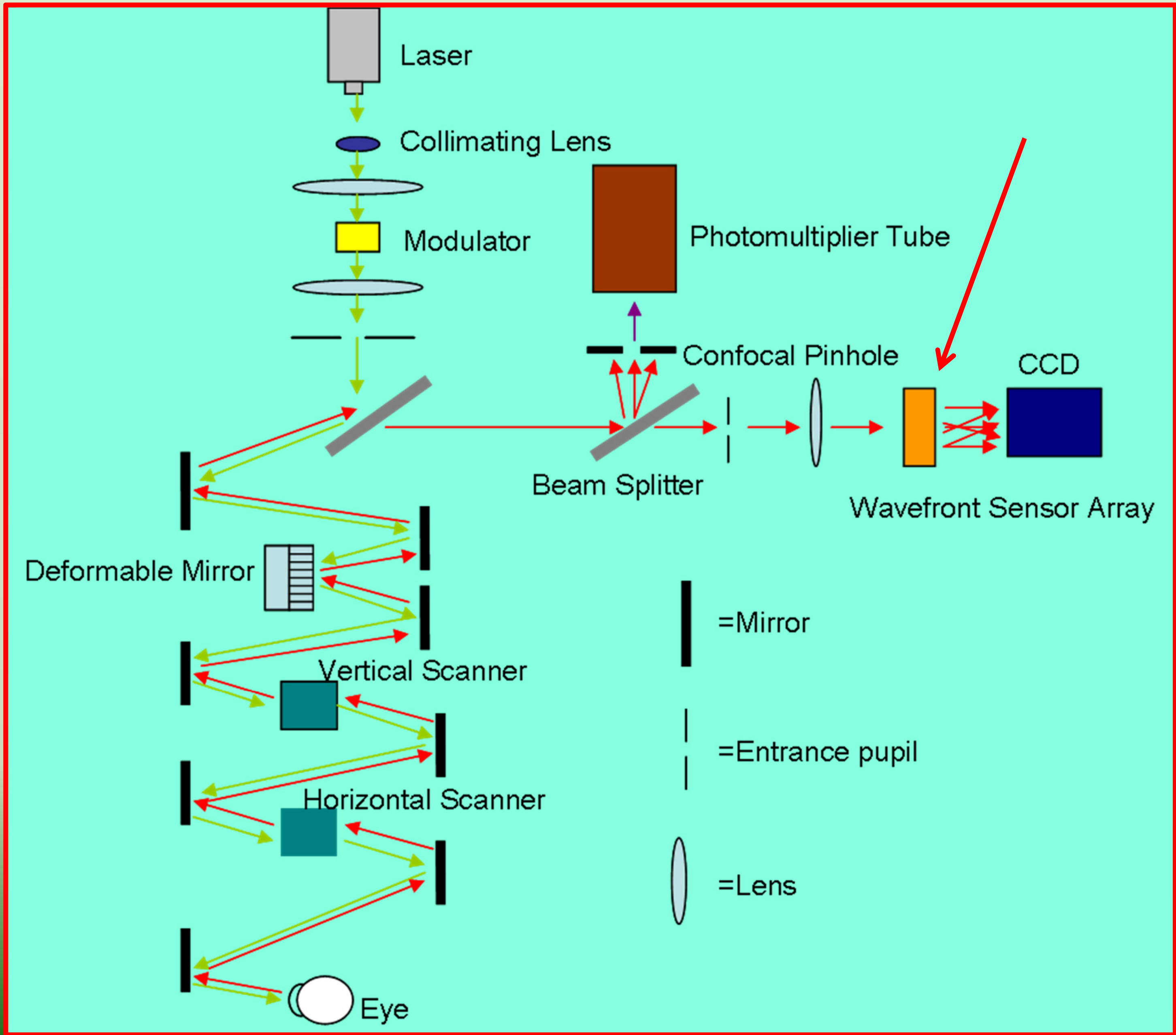


Schematic Overwiev of AO-SLO

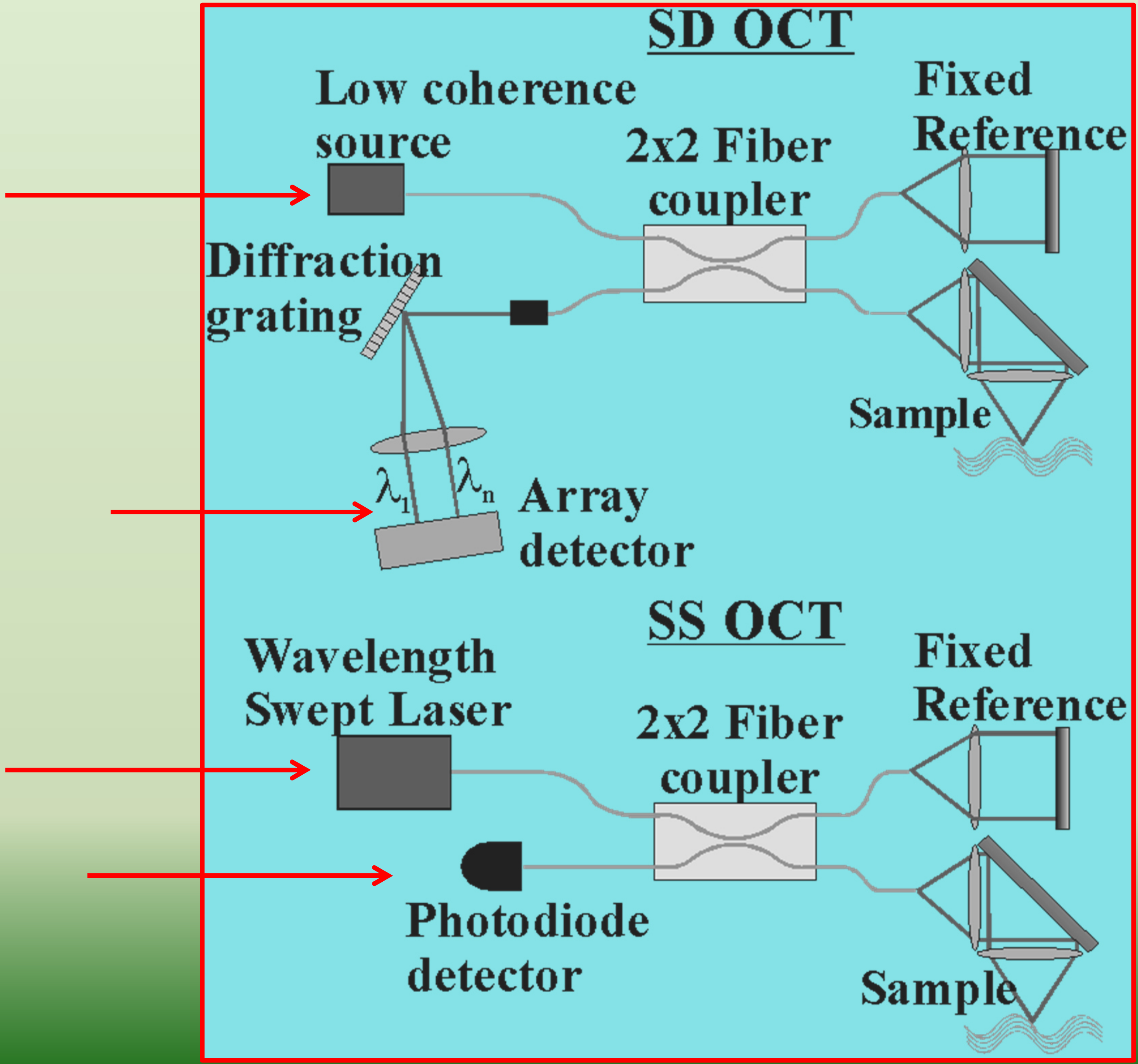


Schematic Overview of AO-SLO

Adaptive Optics Scanning Laser Ophthalmoscopy



Swept Source OCT



SD OCT
Low coherence source
2x2 Fiber coupler
Fixed Reference
Diffraction grating
Sample
λ_1
λ_n
Array detector
SS OCT
Wavelength Swept Laser
2x2 Fiber coupler
Fixed Reference
Photodiode detector
Sample

Swept Source v/s Sepctral Domine OCT

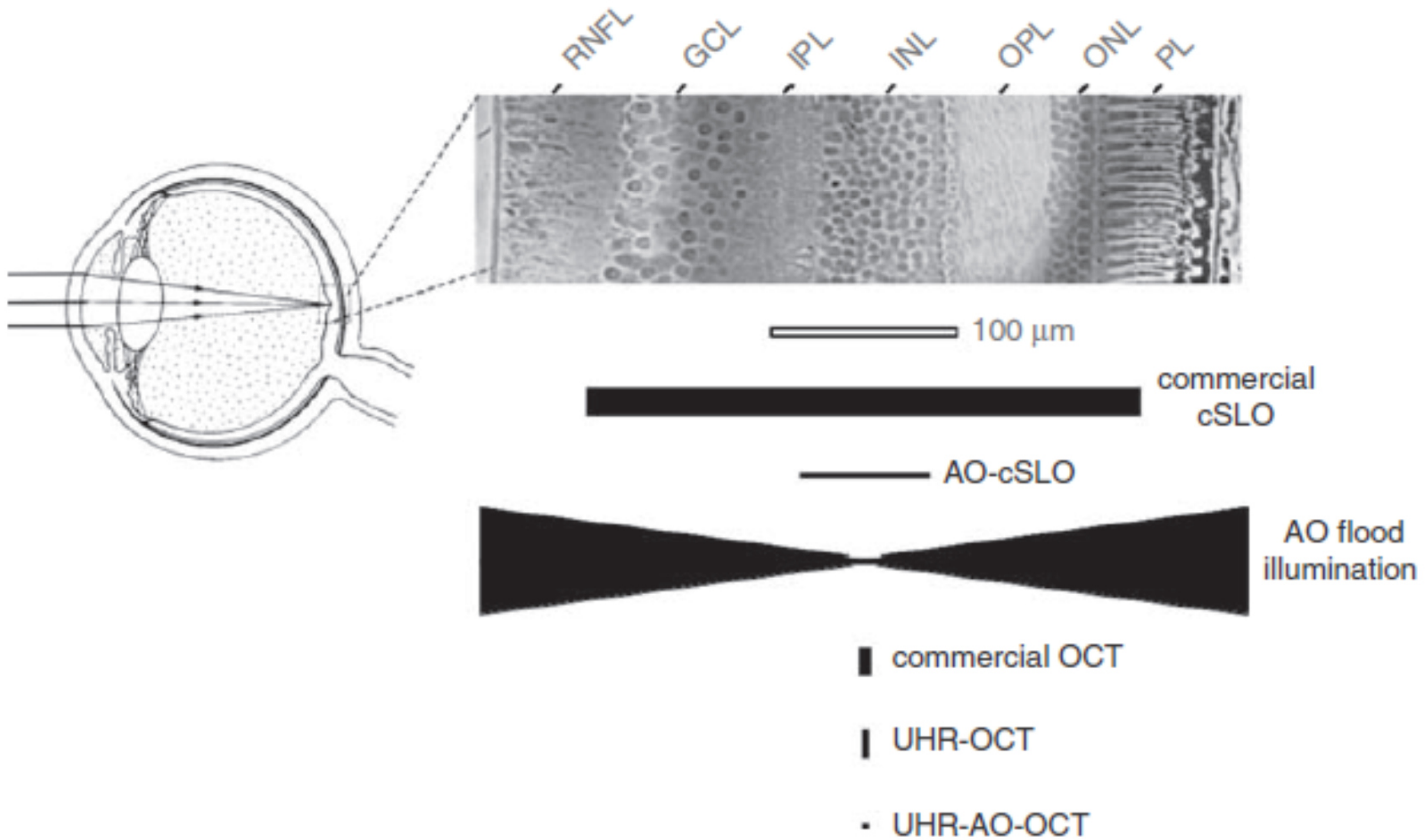
	SS-OCT	SD-OCT
Light source	Swept laser	SLD
Center wavelength	**1,050 nm**	840 nm
A-scan rate	**100,000 Hz**	50,000 Hz
Resolution (x)	20 um	20 um
Resolution (z)	8 um	6 um
B-scan measurement time	1.0 sec (96x)	1.0 sec (50x)
Imaging depth	**2.6 mm**	2.3 mm

Advantage of SS-OCT

- Velocità 5-10 volte maggiore
- Assenza di Roll-off di performance
- Miglior rapporto segnale/rumore SNR
- Larga area di scansione in retina
- Alta qualità in megapixel
- Maggiore Depth Resolution

Super Resolution OCT

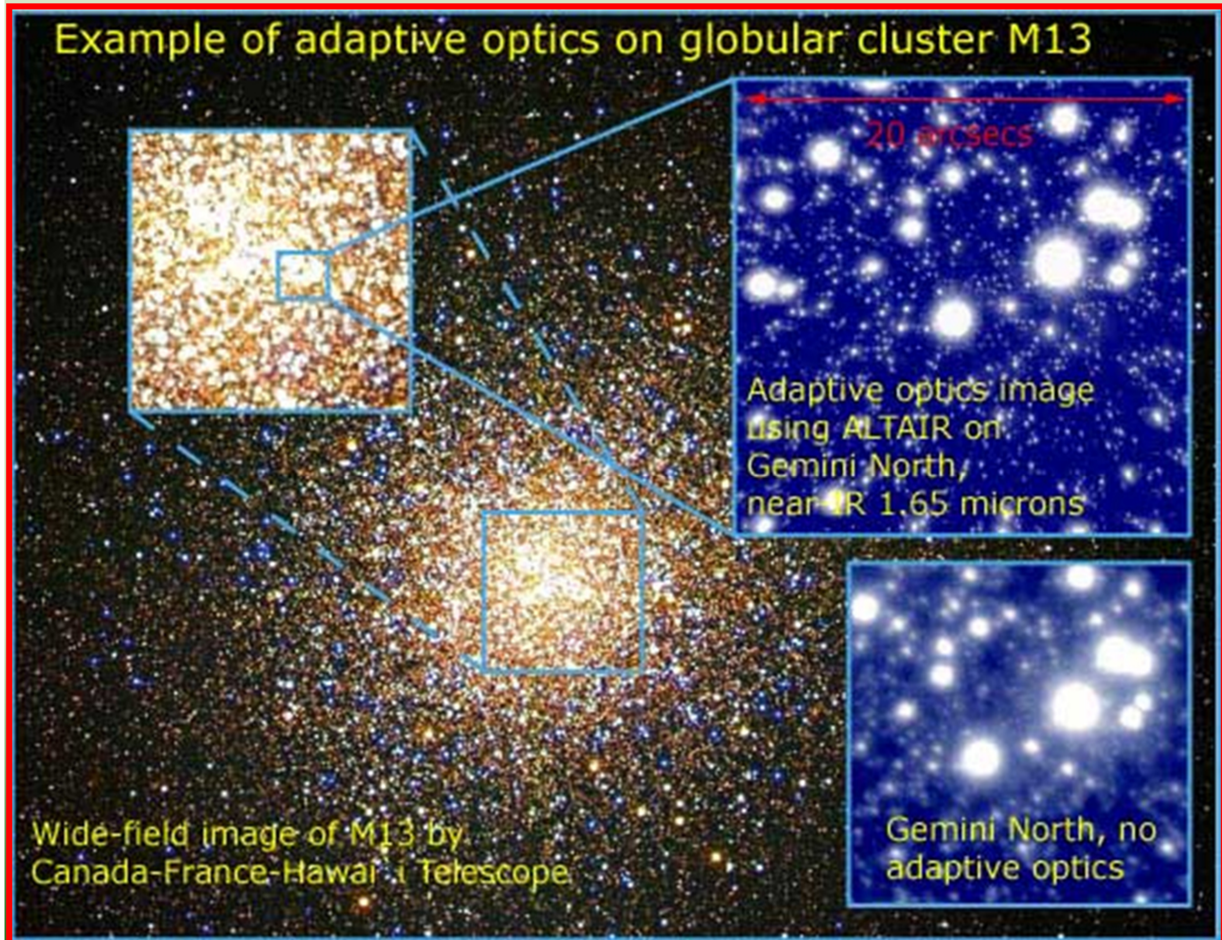
Eye (2011) 25, 321–330



Adaptive Optics OCT

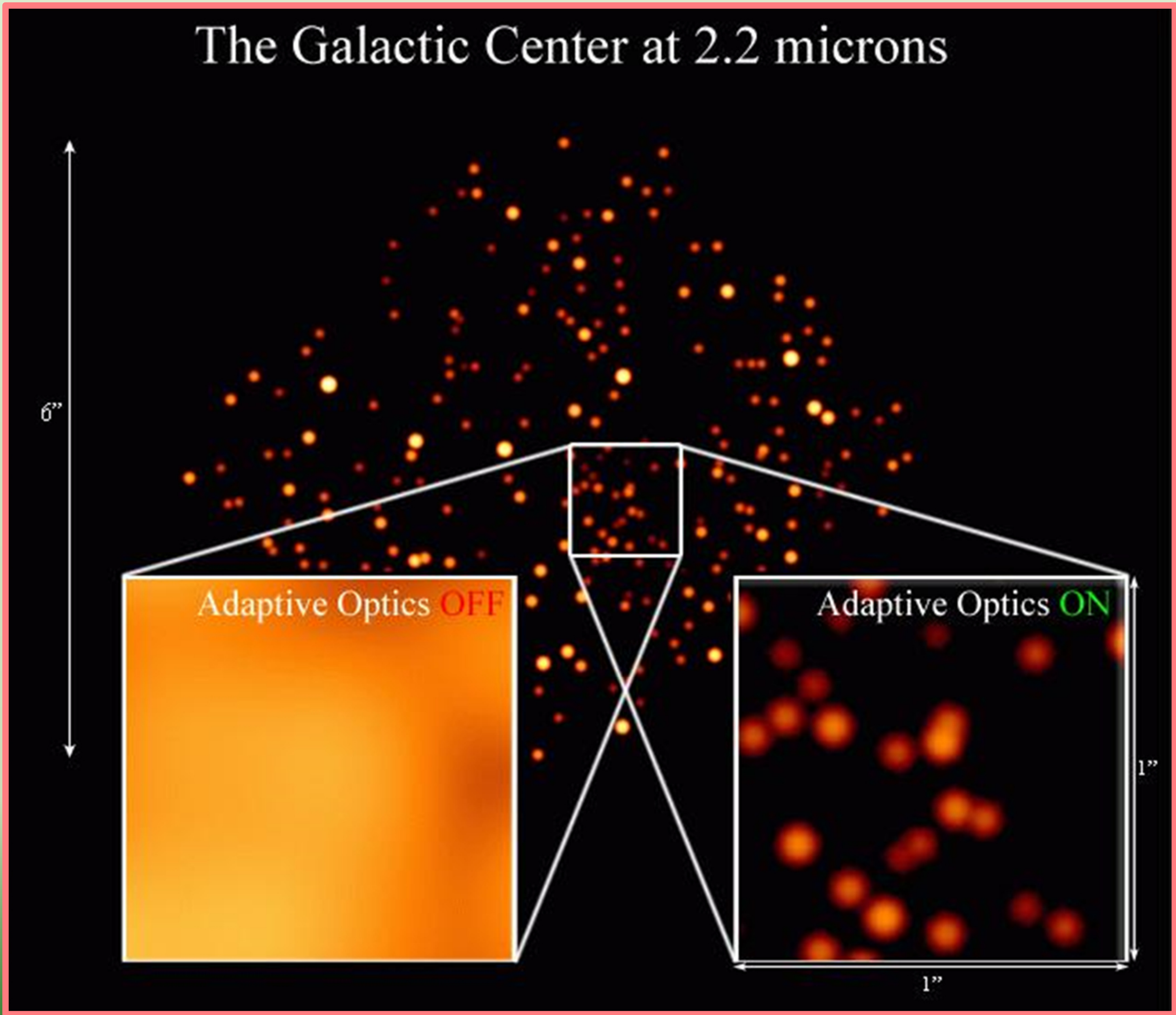
AO & *Gemini Observatory*

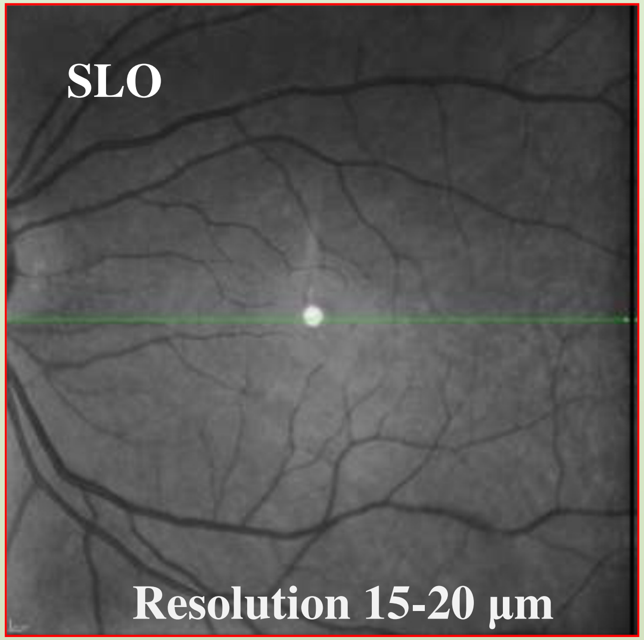
184 milioni di dollari
40 000 dollari/die per ognuno dei Telescopi.

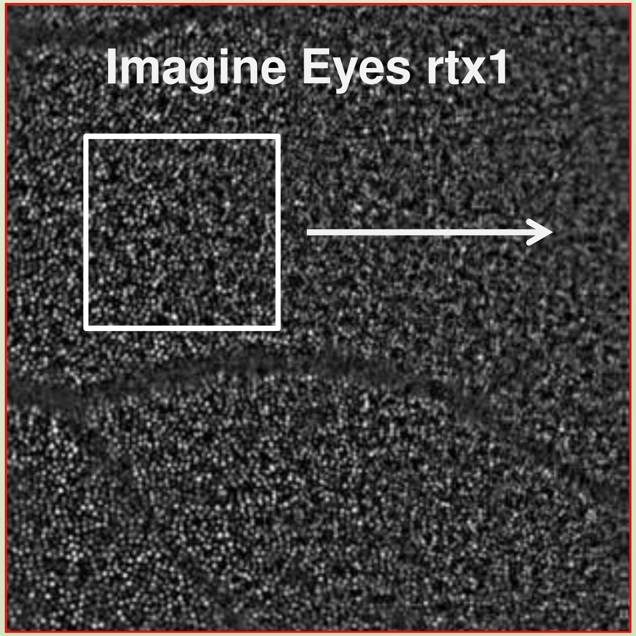


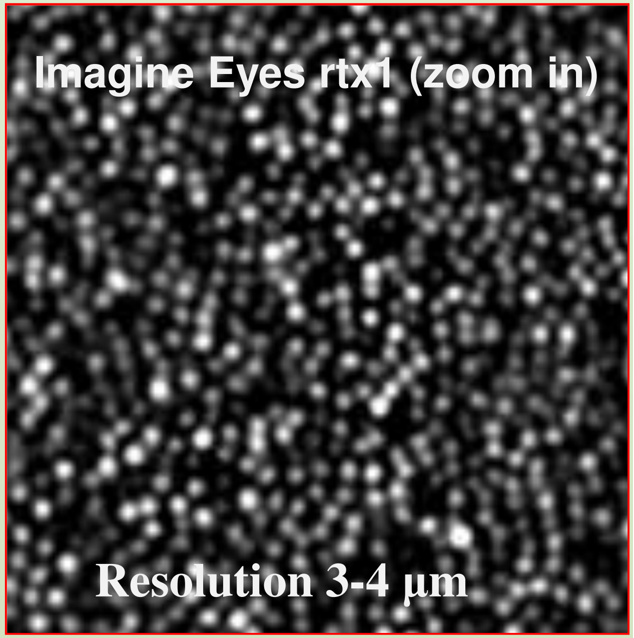
Télescope Gemini North
sur le Mauna Kea (**Hawaii**)

Télescope Gemini South
sur le Cerro Pachon (**Chili**)

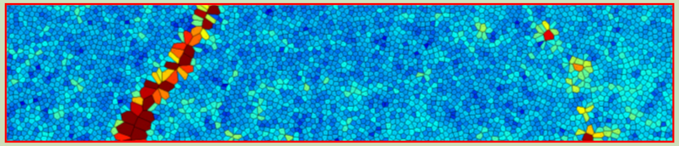

The Galactic Center at 2.2 microns
6”
Adaptive Optics OFF
Adaptive Optics ON
1”
1”



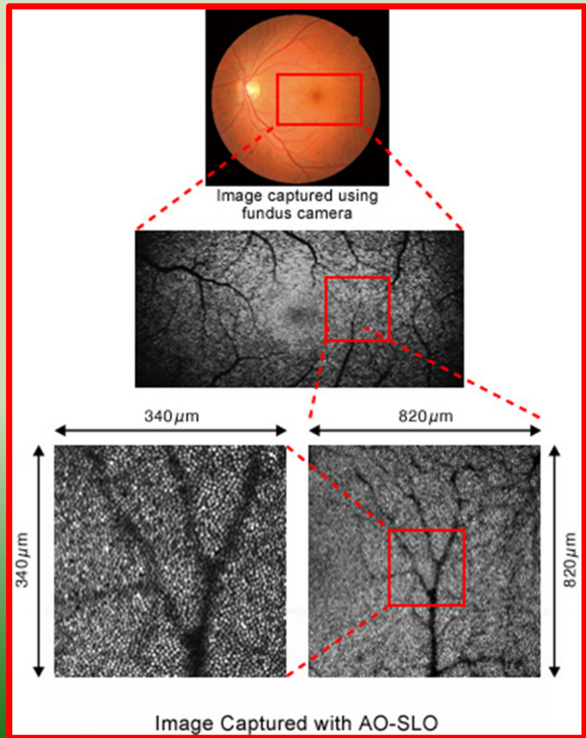




50 μm



AOimage™



AOdetect™-mosaic

AOdetect™-artery

i2k Retina Stitching

Adaptive Optics Retinal Camera rtx1

En face reflectance imaging

Flashed non-coherent near-infrared illumination

Low-noise CCD camera

1.6 µm [2]

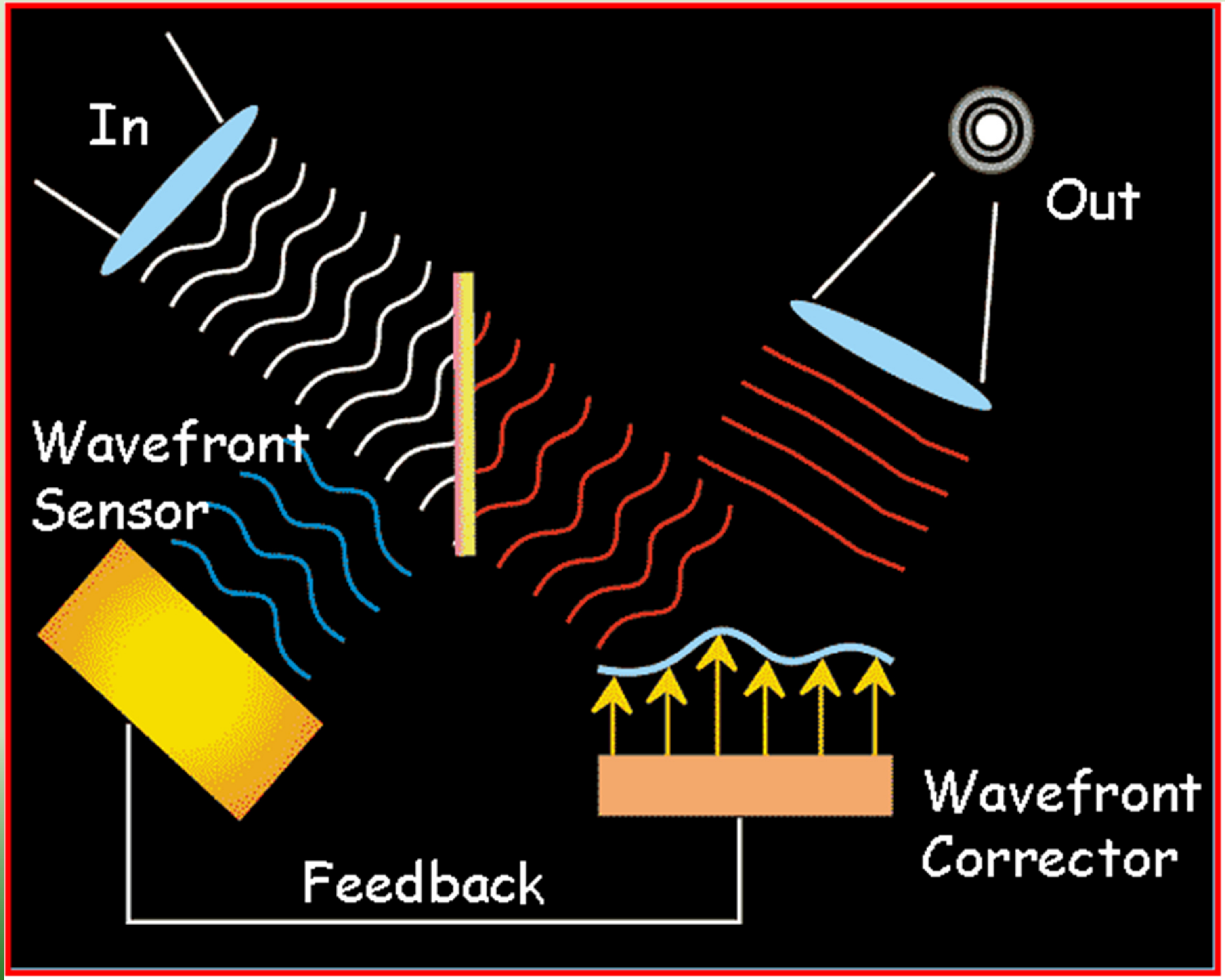
250 line pairs per millimeter (lppmm) [2, 3]

4° x 4° [2]

PNG (Portable Network Graphic) , DICOM

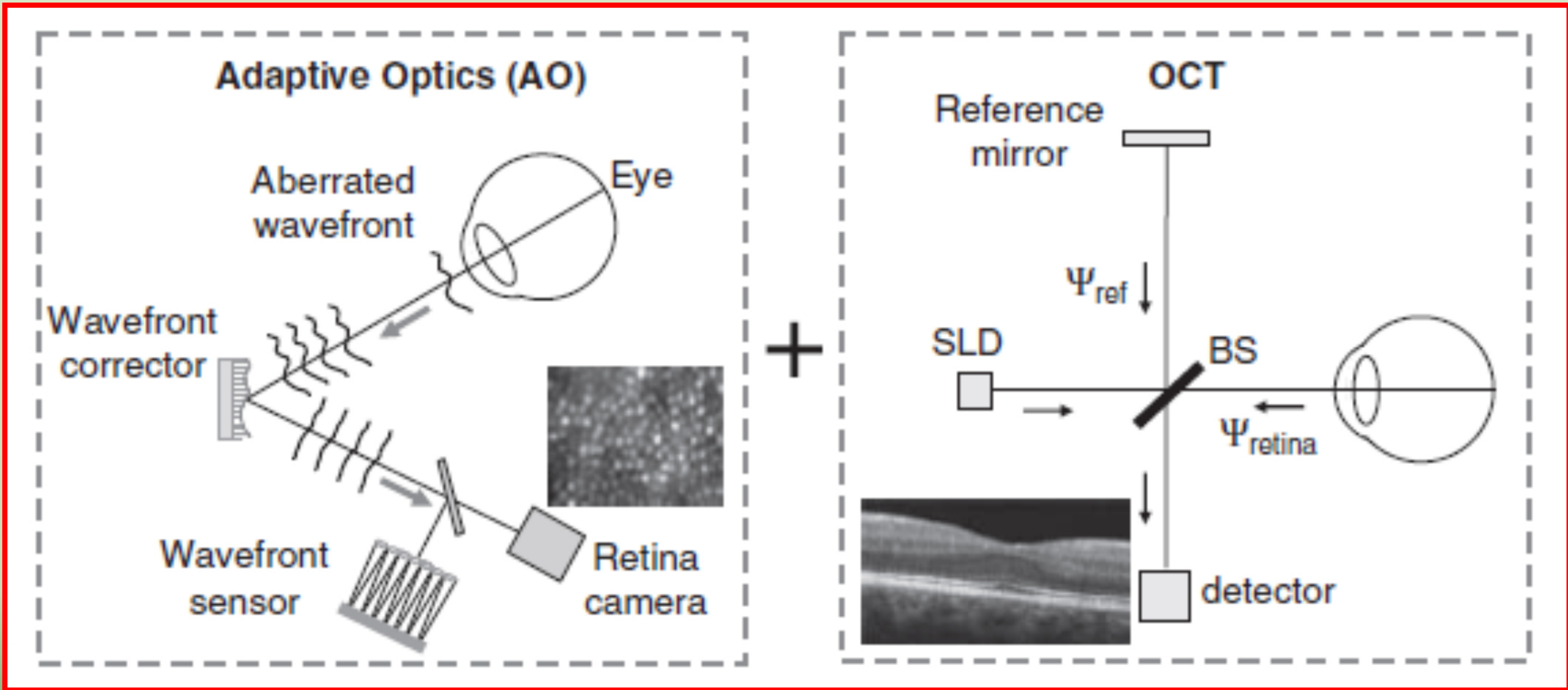
imagine eyes®

AO-OCT

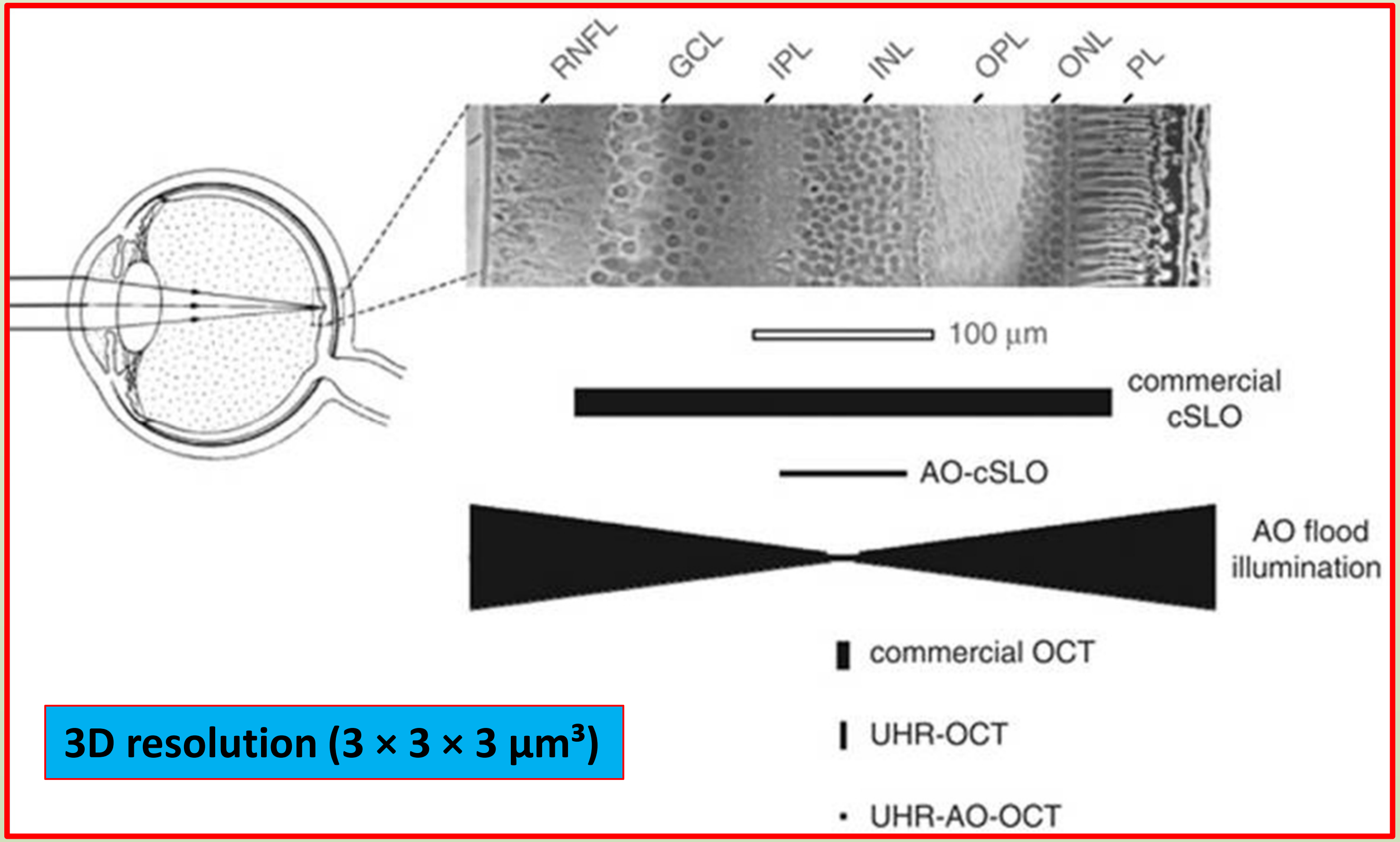


Benefit of Adaptive Optics

a) Increased lateral resolution
b) Reduced speckle size (granular artifact)
c) Increased sensitivity to weak reflections



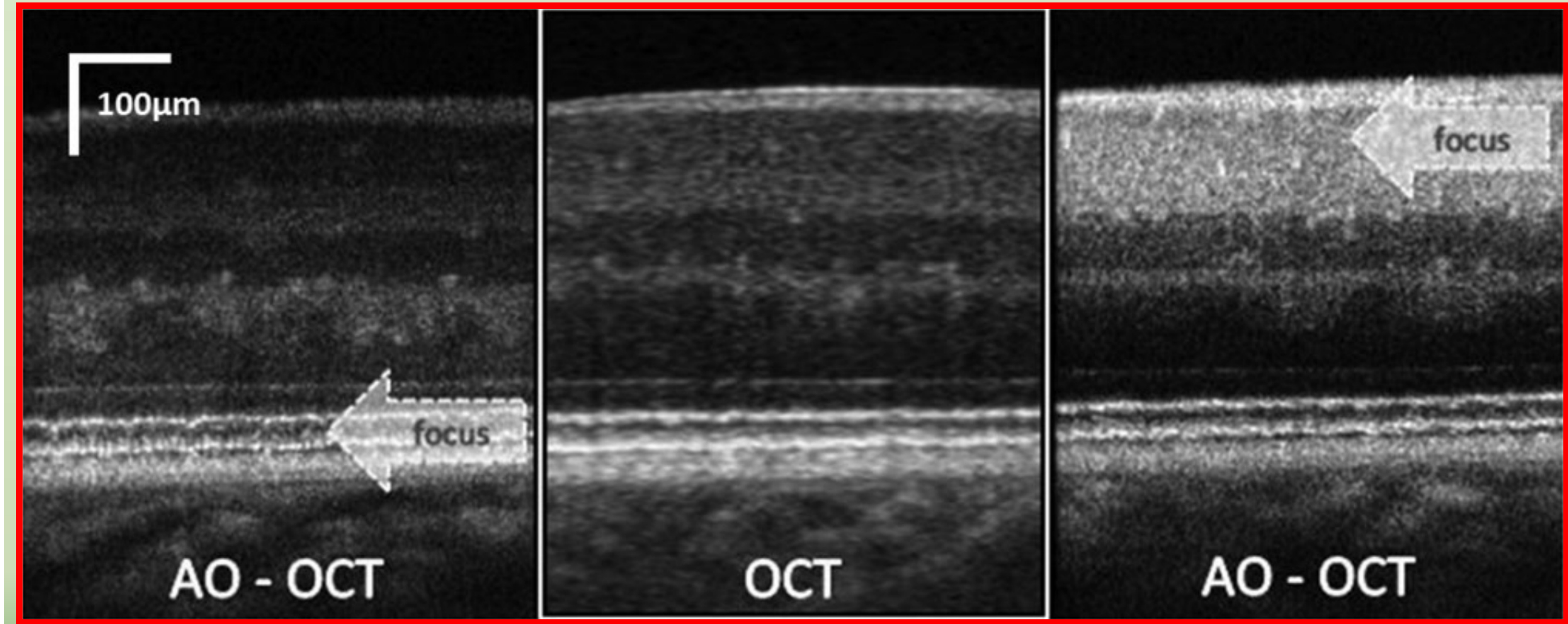
Correction of ocular imperfections across a large pupil results in unprecedented lateral resolution (2–3 mm), sufficient for resolving individual cells en face



Comparison of (top) cell size in a histological cross section of the human retina with (bottom) the resolving capability of the major types of retinal imaging modalities with and without AO. The vertical and horizontal dimensions of the solid black symbols denote, respectively, the lateral and axial resolution of the instruments. Examples shown include the commercial confocal scanning laser ophthalmoscope **(cSLO)**, confocal scanning laser ophthalmoscope with adaptive optics **(AO–cSLO)**, flood illumination with adaptive optics, **commercial OCT**, ultrahigh-resolution **OCT (UHR–OCT)**, and ultrahigh-resolution OCT with adaptive optics **(UHR–AO–OCT)**.

Miller DT1, Kocaoglu OP, Wang Q, Lee S. Eye (Lond). 2011 Mar;25(3):321-30. doi:10.1038/eye.2011.1.

AO-OCT



Robert J. Zawadzki IEEE JOURNAL OF SELECTED TOPICS IN QUANTUM ELECTRONICS, VOL. 20, NO. 2, MARCH/APRIL 2014

OCT future

SS-OCT (1050nm)

AS-OCT (1310nm)

SLO

AO Adaptive Optics

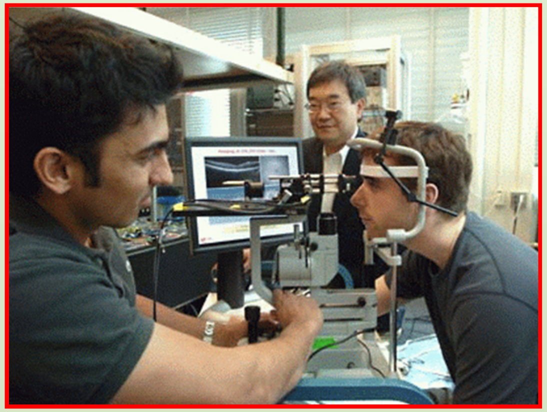
OCM Optical Coherence Microscopy

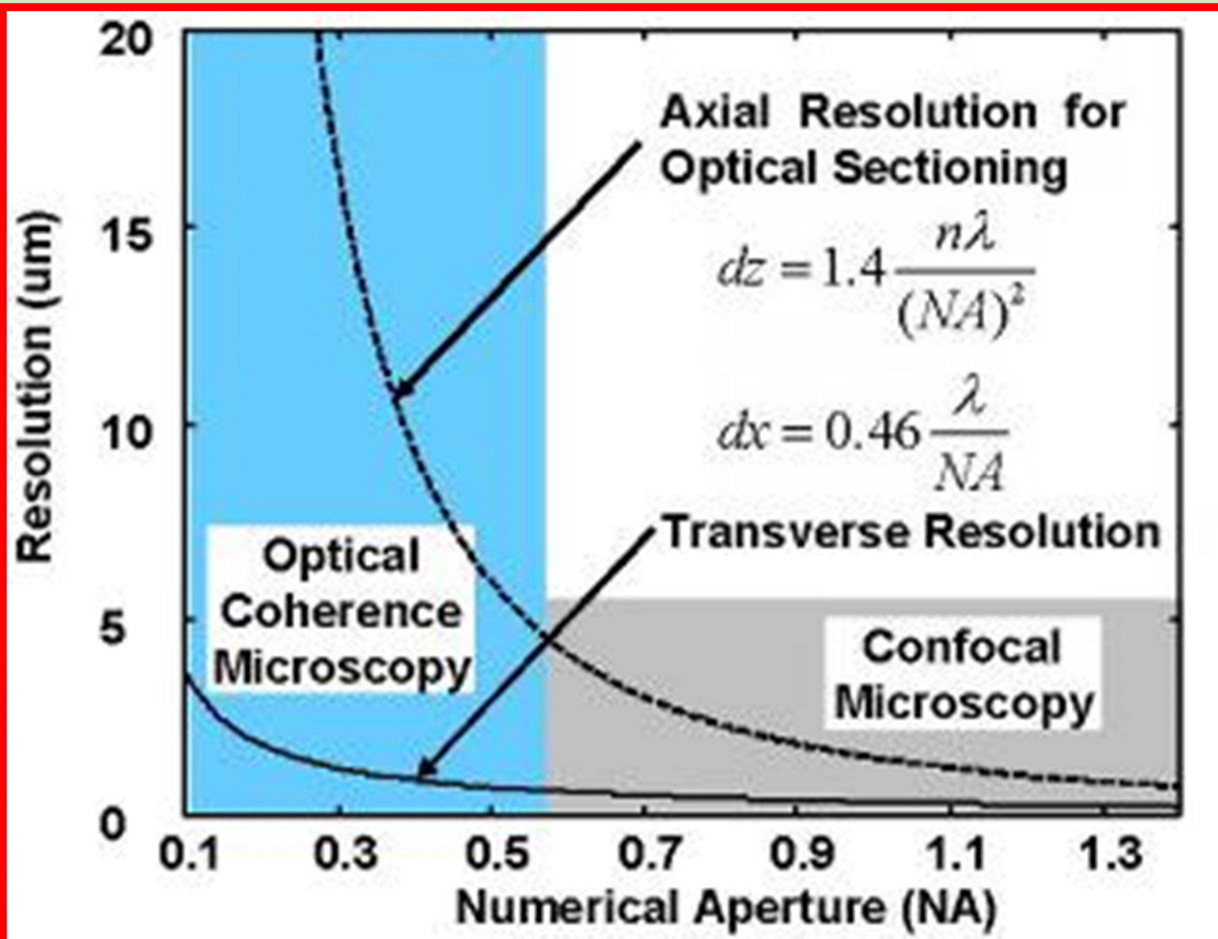
Wide Field

Agreement

Updateable Algorithms

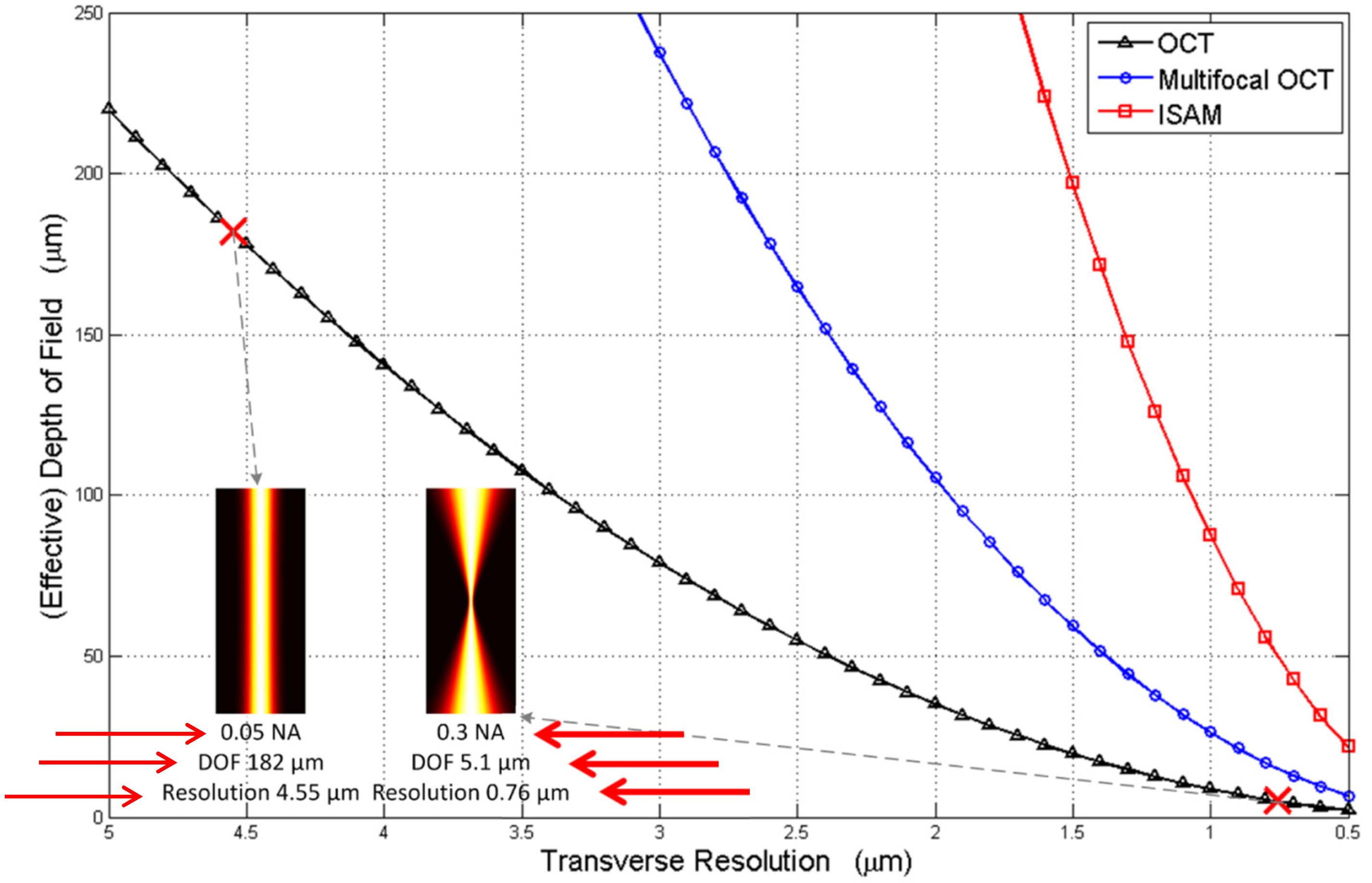
Optical Coherence Microscopy (OCM) combines the coherent detection methods of OCT with confocal microscopy. OCM provides enhanced penetration depth compared to standard confocal microscopy, while dramatically improving the resolution over cross-sectional OCT imaging by James G. Fujimoto



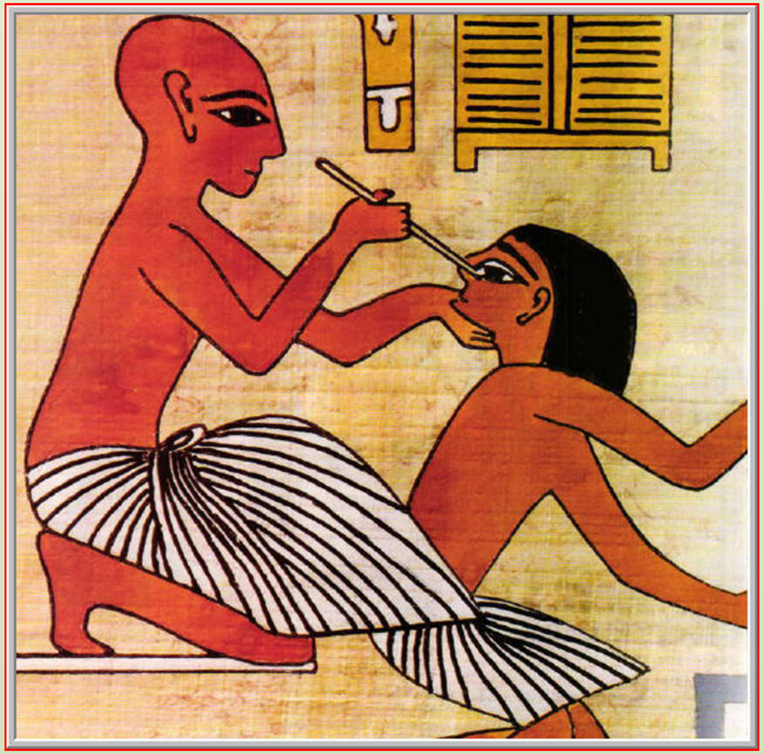


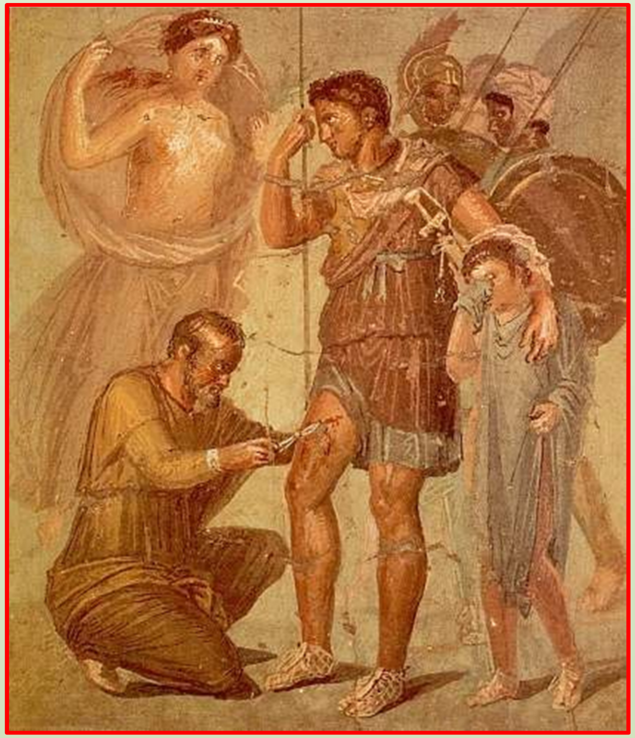
Yang Xu et al. published 27 Jun 2014 OPTICS EXPRESS

MISAM *Multifocal Interferometric Synthetic Aperture Microscopy*



Trade-off between the effective **DOF**, **Depth Of Field**, and **Transverse Resolution** in **OCT Multifocal OCT** and **ISAM**, **Interferometric Synthetic Aperture Microscopy**, at **wavelength** of **1 μm** and whth refractive index of 1.4





Il medico deve curare a volte, alleviare spesso, confortare sempre.

Edward Livingston Trudeau

Thanks for Your attention

Studio Oculistico
dott. A. Lucente
in oculis salus