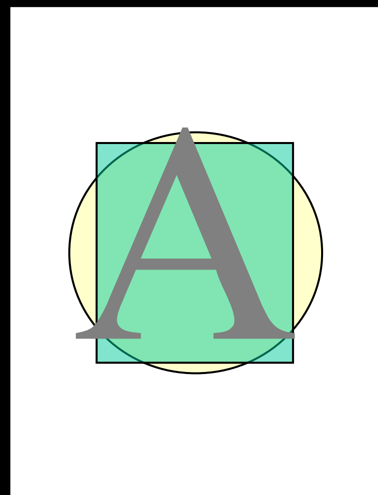
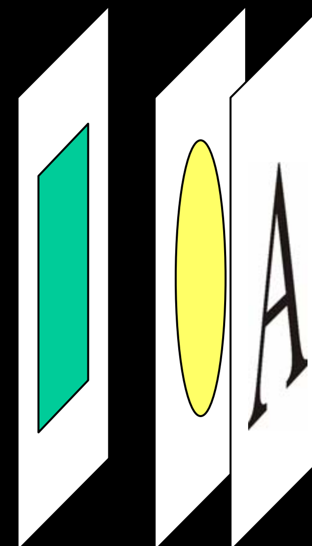
Andrzej Kowalczyk

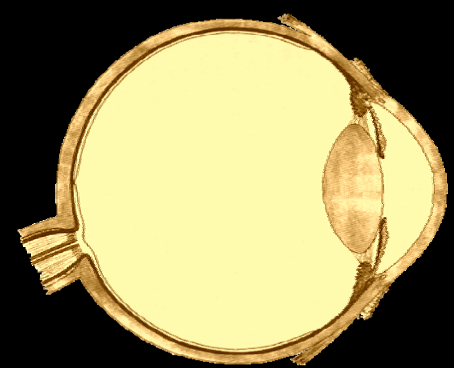
Optical Coherence Tomography
(19th century physics as a diagnostic tool for ophthalmology and art conservation)

Nicolaus Copernicus University, Toruń, Poland

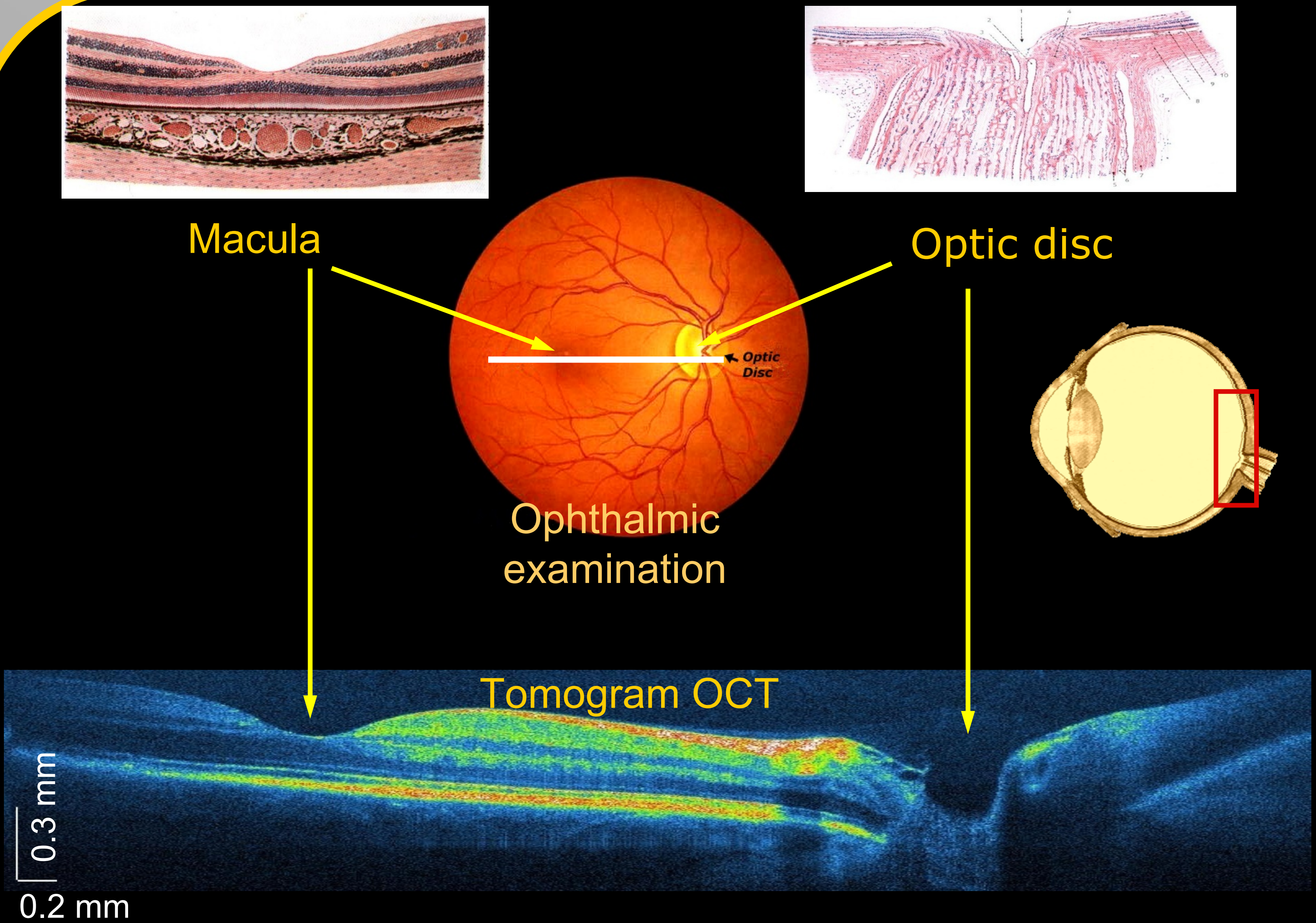
OCT: from *en face* illumination & observation to cross sectional image





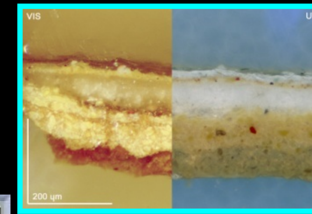


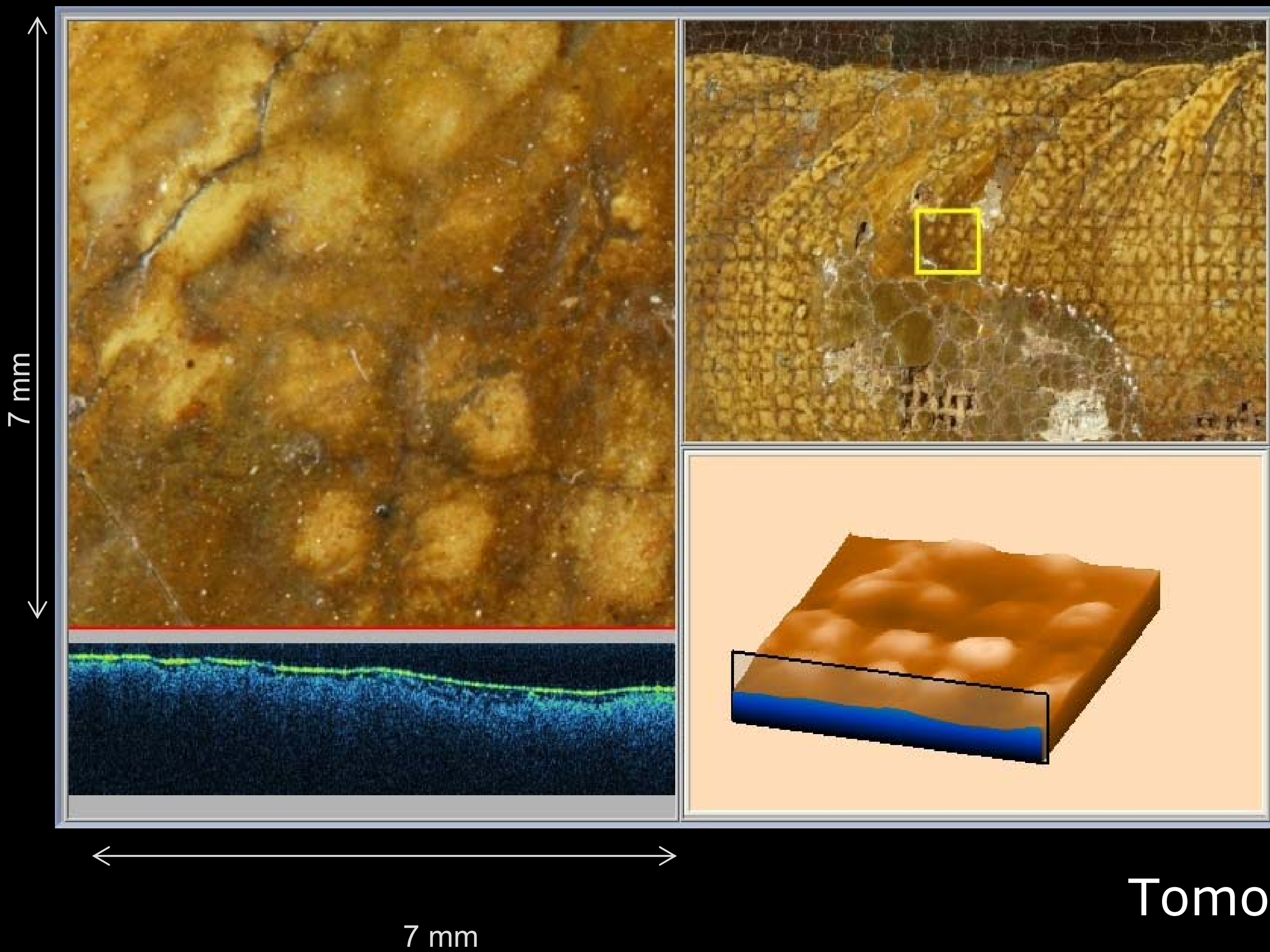
Ophthalmology: retina



Art conservation - varnish

Sample taken by traditional way





Tomogram OCT

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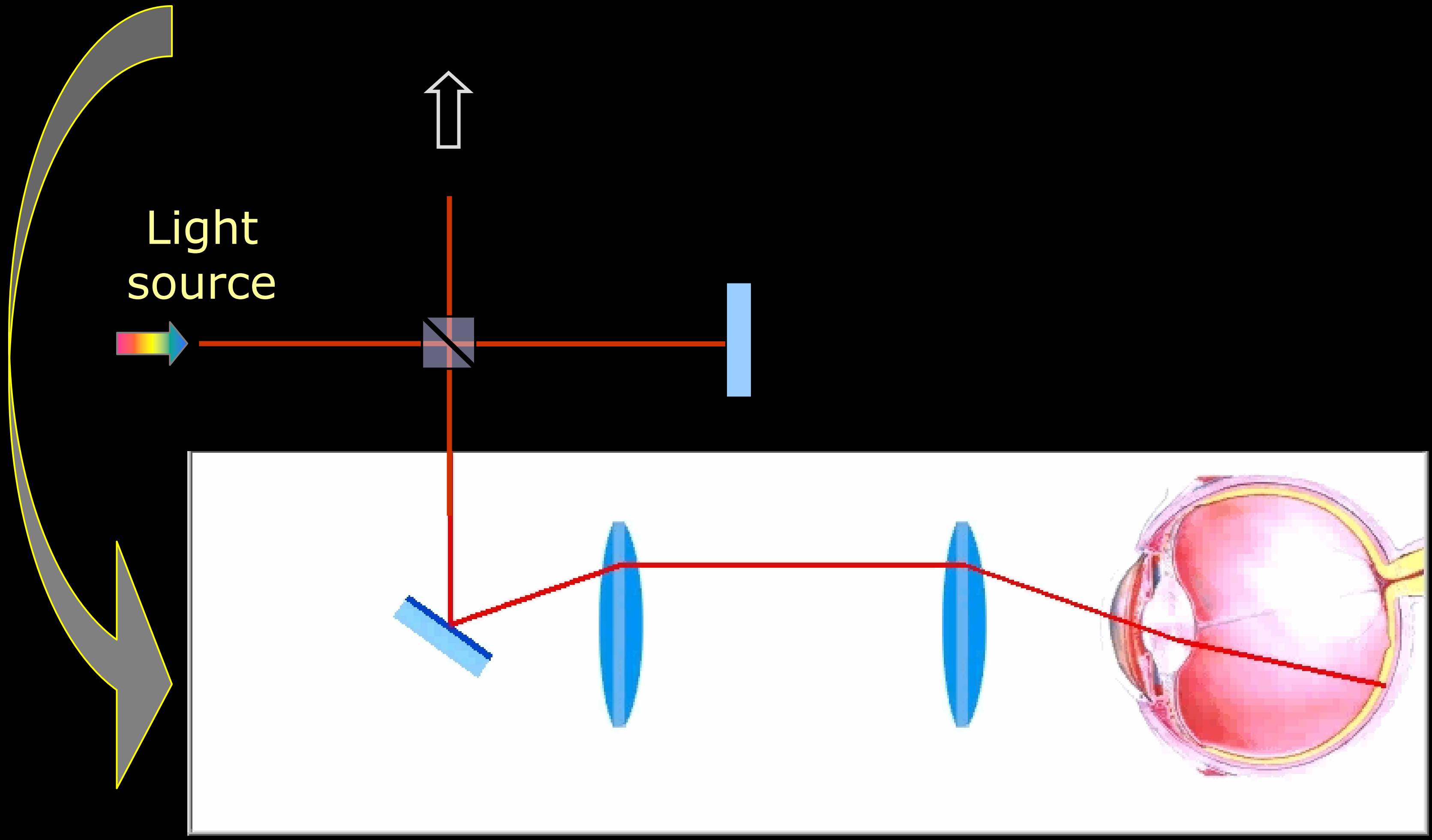
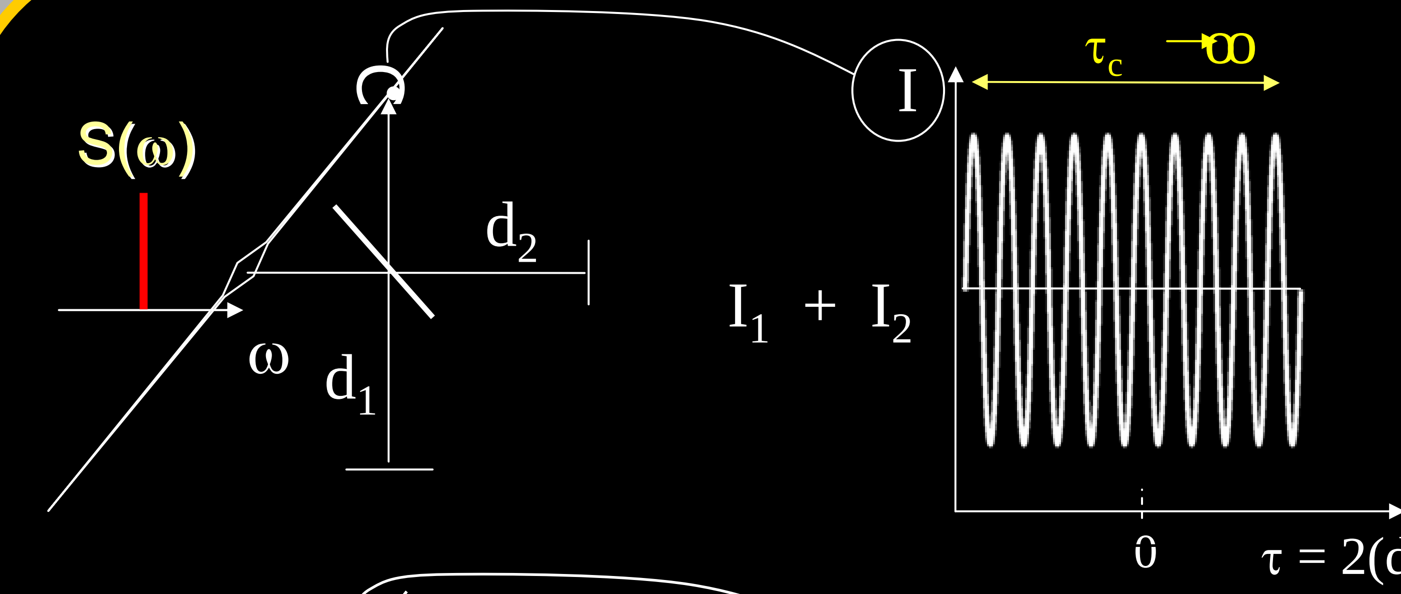
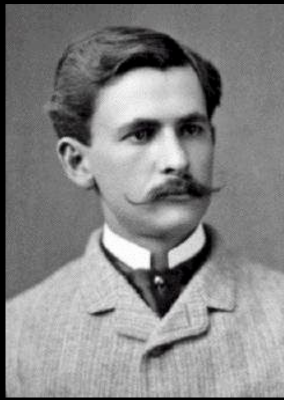
Tomogram consists of lines



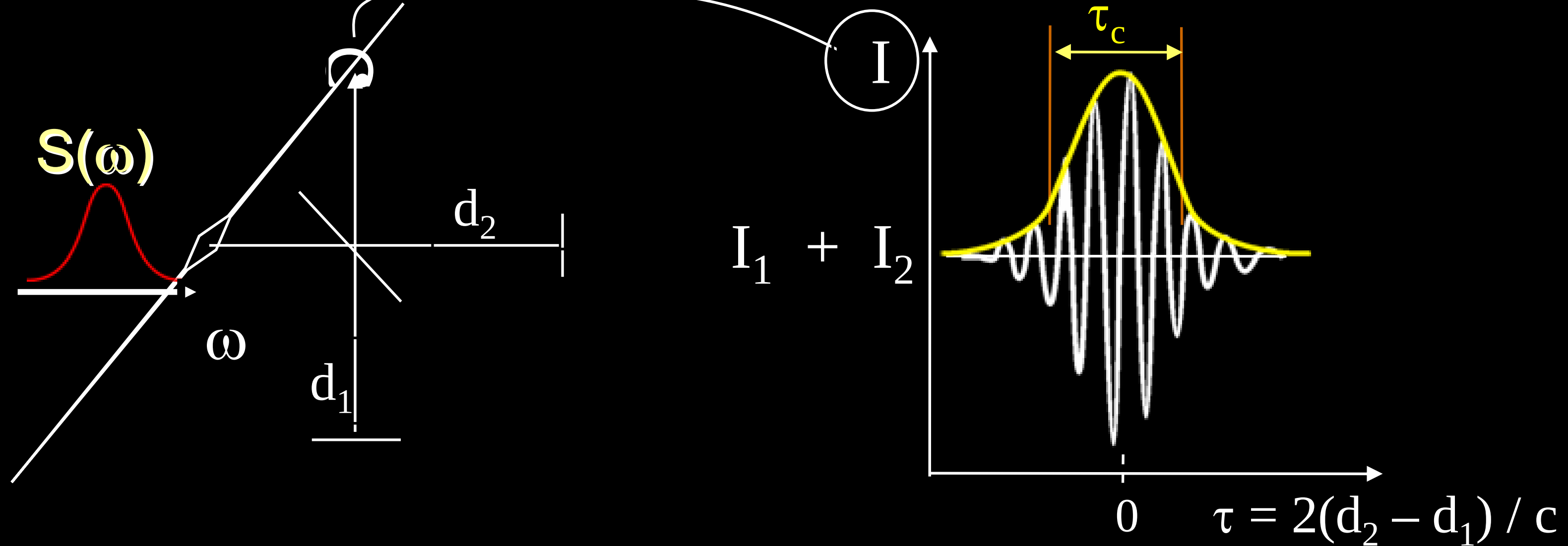
But how to get an individual line?

Basic tricks – same as in Michelson's definition of the meter





A.A. Michelson
1852-1931



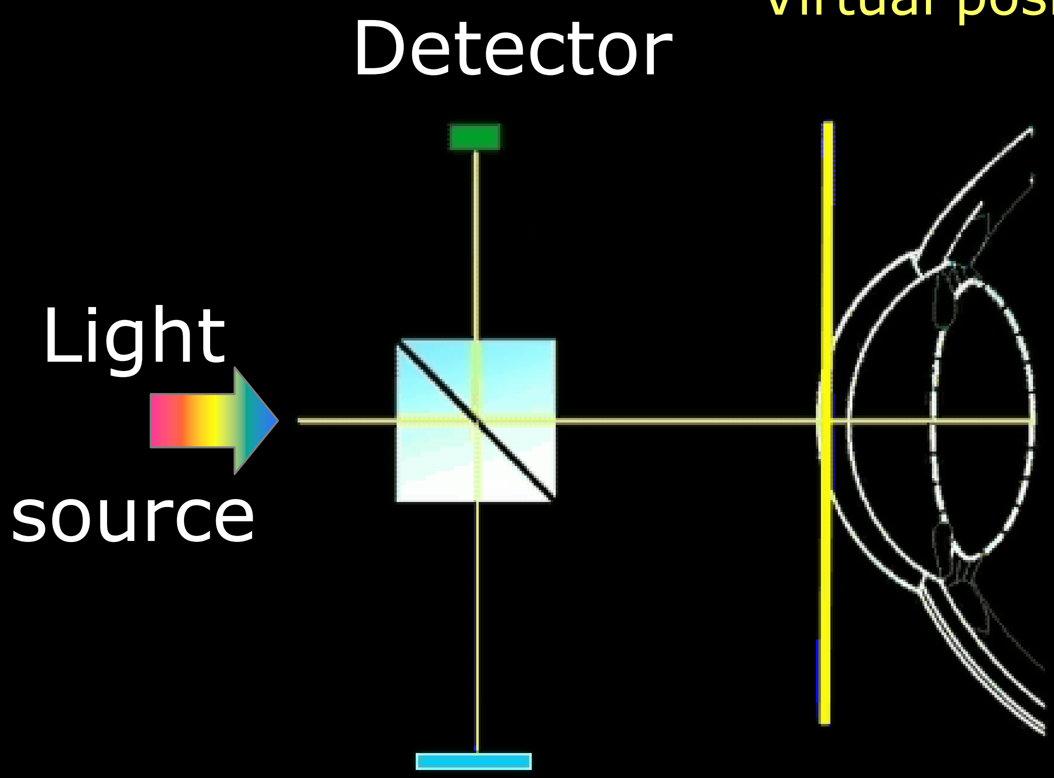
Precision of arms length match & axial resolution

Wider spectrum of the source S(ω) → narrower coherence envelope Γ(τ):

$$\Gamma(\tau) = FT\{S(\omega)\}$$

Axial resolution with: Sodium lamp: 0.6 mm,
Superluminescent diode: 5 - 15 μm

Individual line in Time domain OCT

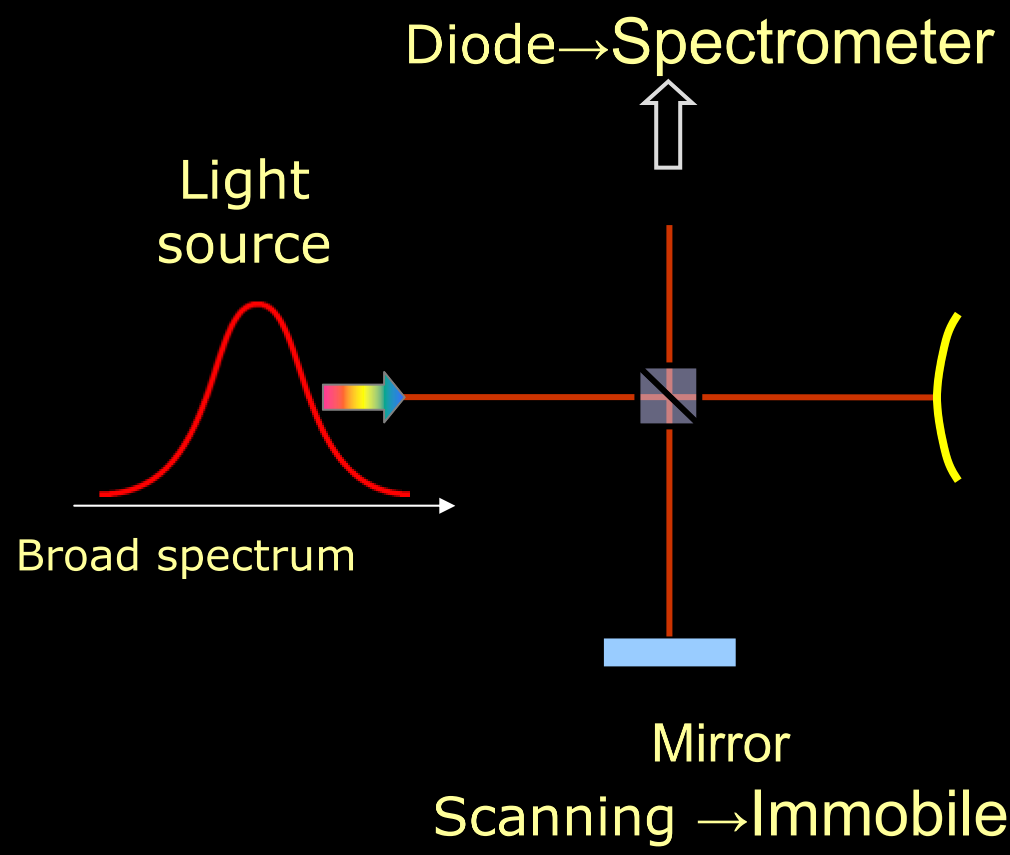


J. Fujimoto, MIT

J. Fujimoto, MIT, 1991; Humphrey Zeiss, 1996, Zeiss Meditec 2003

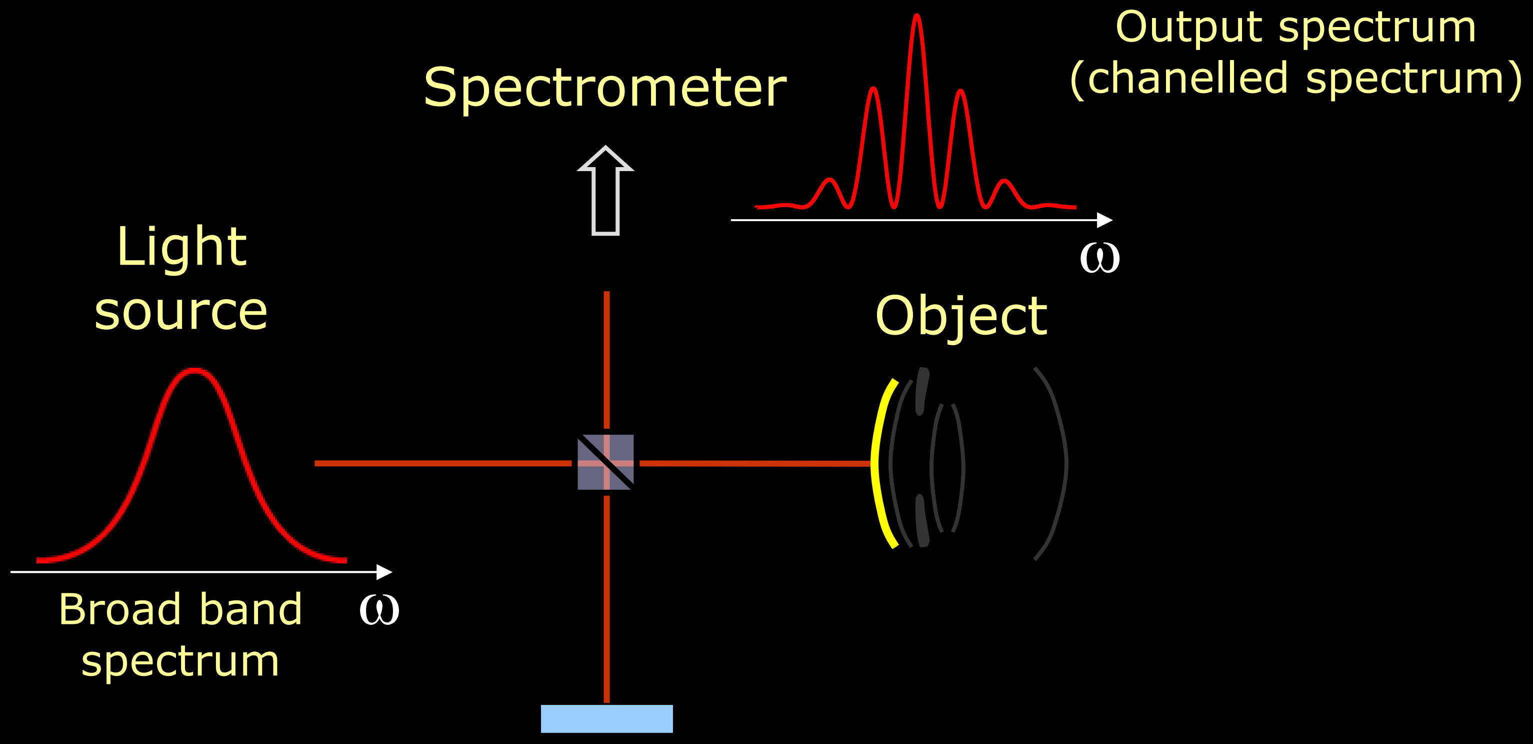
Is it possible to use light more effectively?

In Time domain OCT light penetrates the object during mirror movement (about 10 ms) but only the fraction reflected at sequential interfaces contributes to the signal



A.F.Fercher, MedUni, Vienna

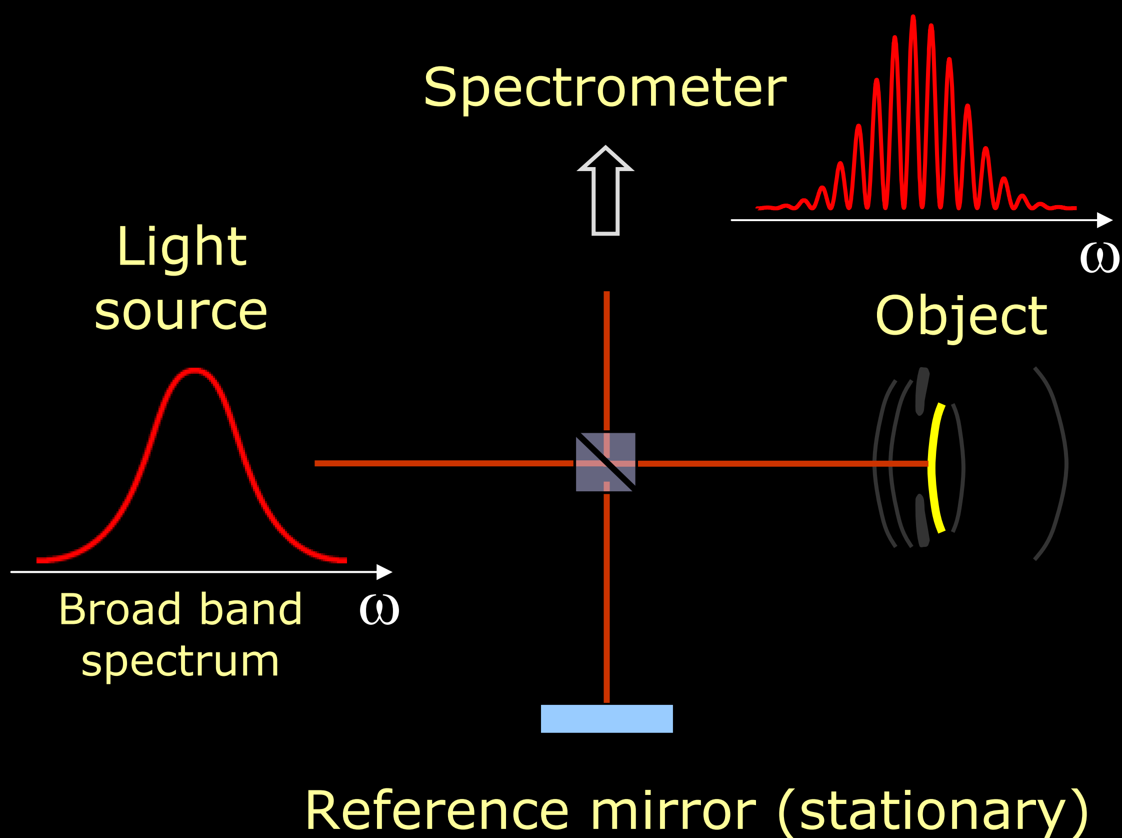
Individual line in Spectral OCT



Reference mirror (stationary)

$$I(\omega) = I_1(\omega) + I_2(\omega) + 2\sqrt{I_1(\omega) I_2(\omega)} \cos\left[\frac{2(d_2 - d_1)}{c}\omega\right]$$

Spectral OCT – spectrum modulation ∞ Δd



$$I(\omega)=I_1(\omega)+I_2(\omega)+2\sqrt{I_1(\omega)I_2(\omega)}\cos\left[\frac{2(d_2-d_1)}{c}\omega\right]$$

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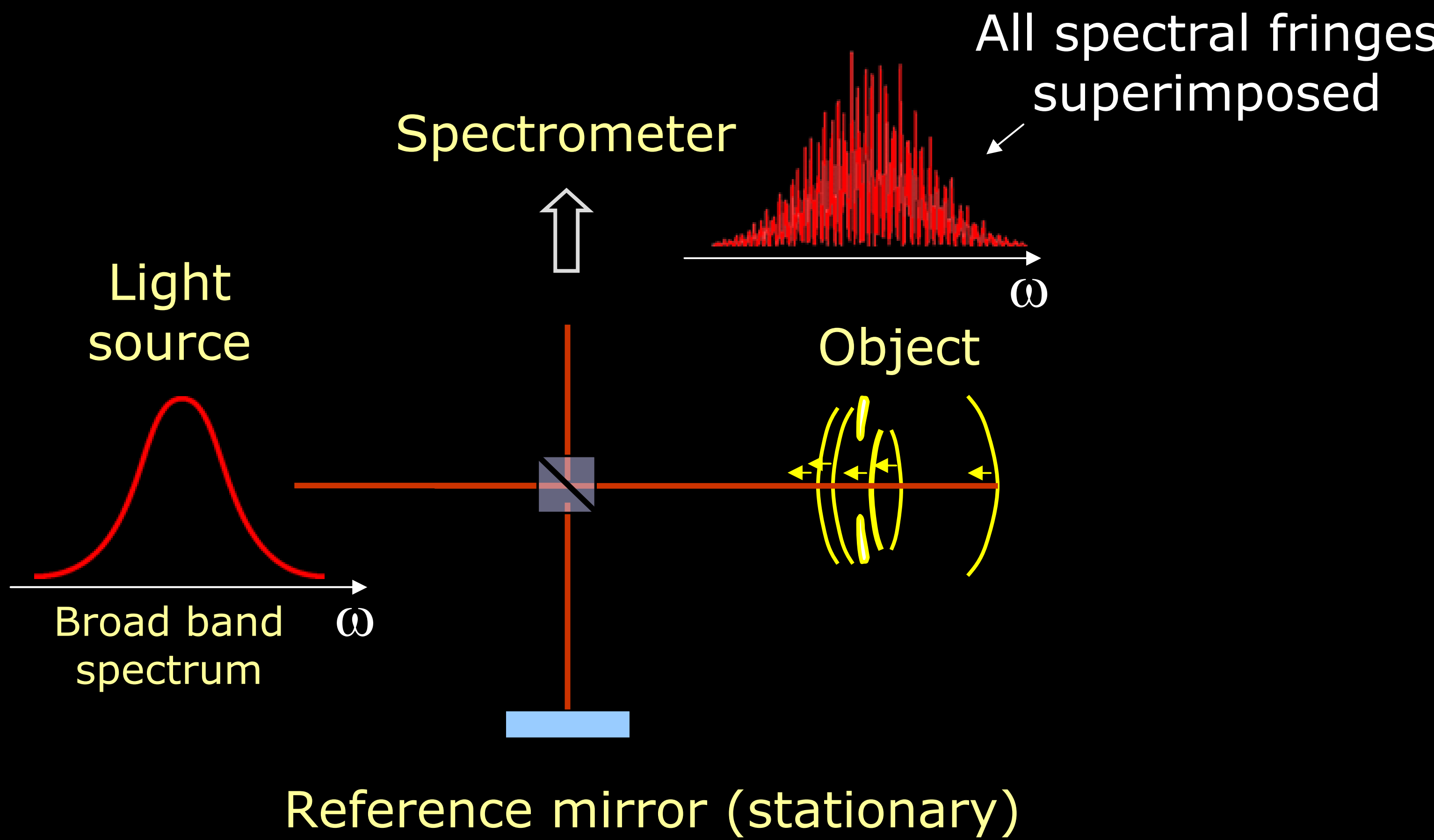
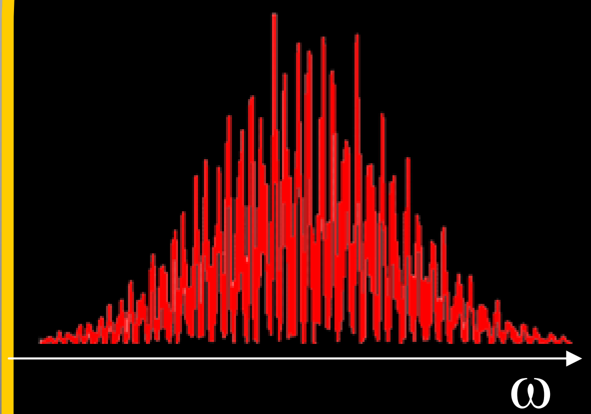
Information along one line collected in 20μs



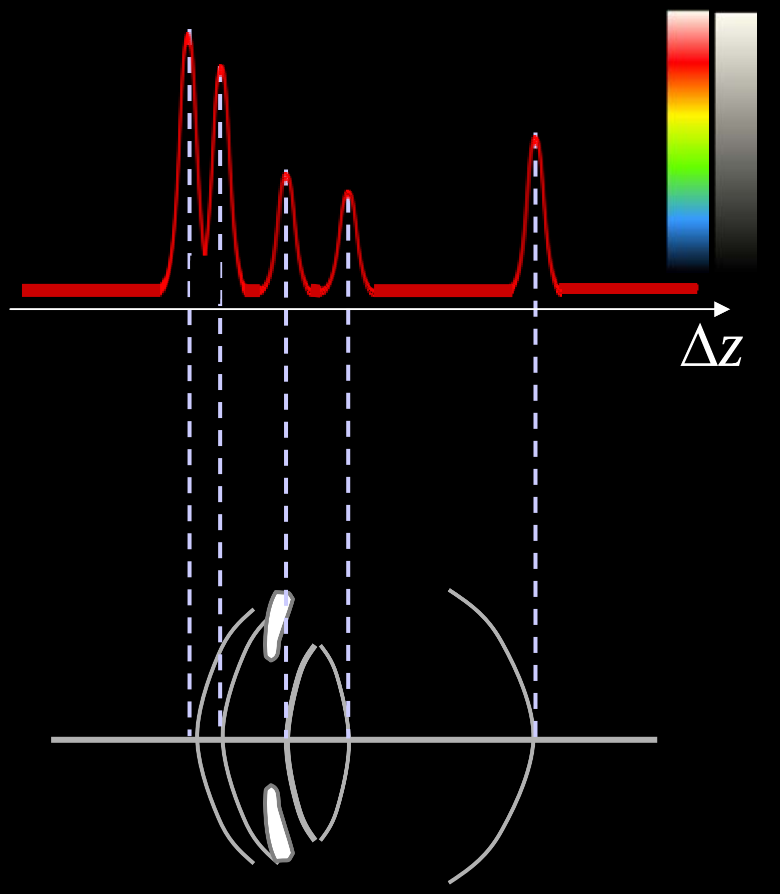
Additional effort is required

Spectral Fringes



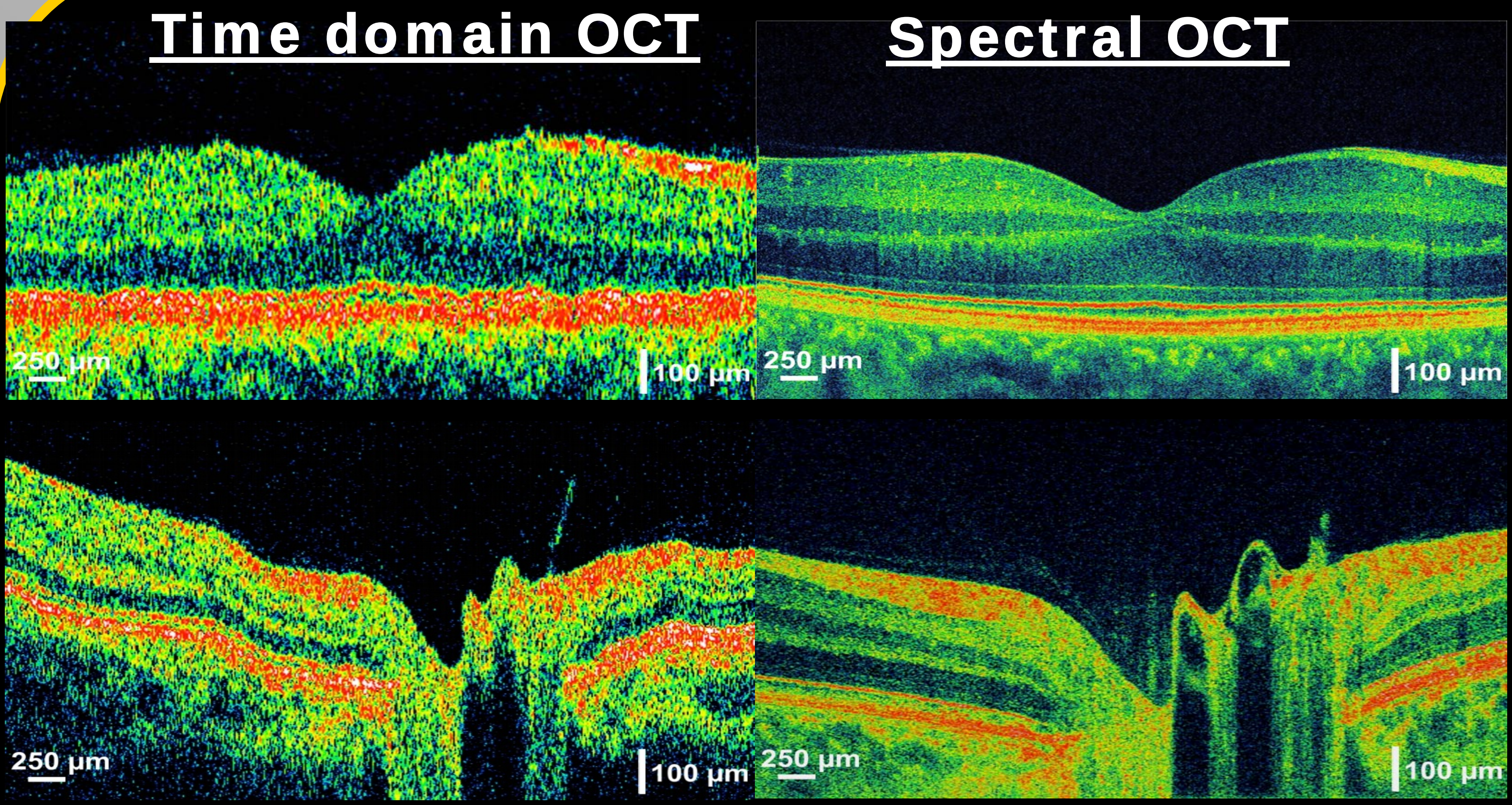
$|FT|^2$

One tomogram line
(axial structure of the object)



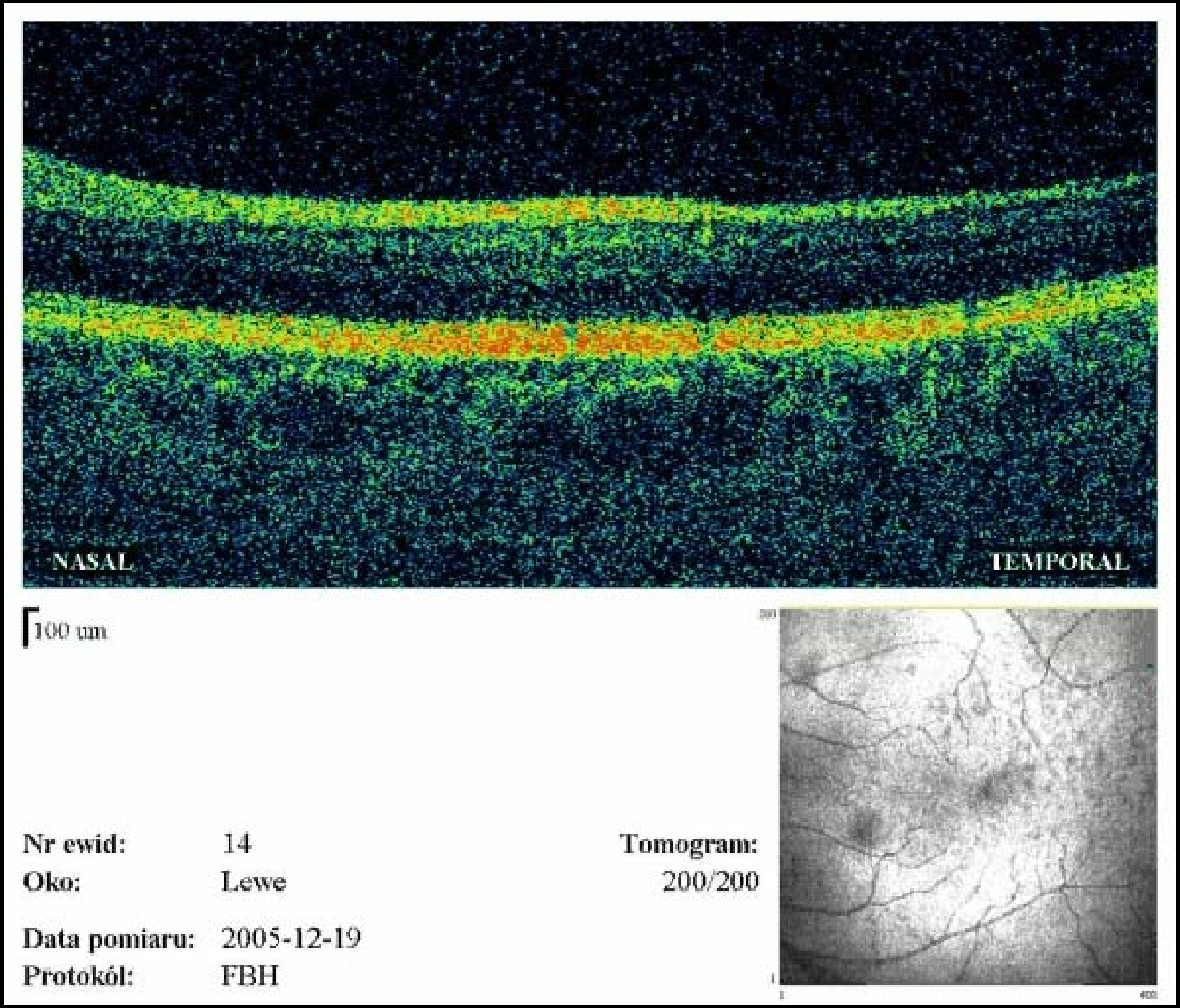
Jean Baptiste Joseph Fourier
1768-1830

Advantages: more lines in shorter time



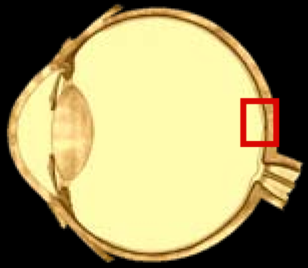
1. Time domain OCT– 500 lines in 1.4 sec
2. Spectral OCT – 9000 lines in 0.4 sec

Tradeoff: low density of lines ⇔many cross sections at different locations (3D rendering)

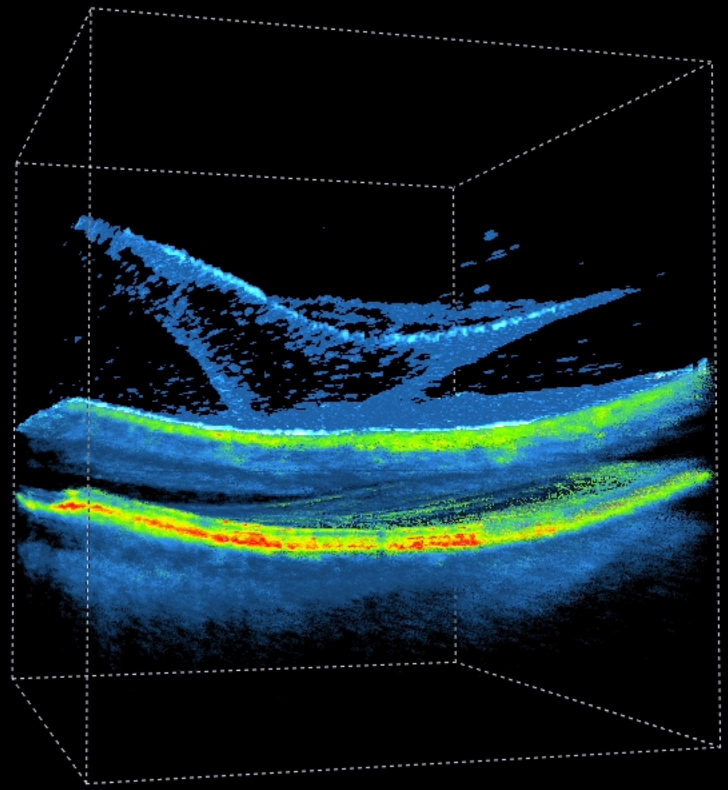


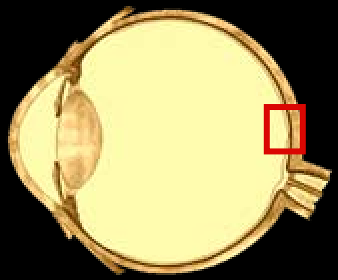
Age-related Macular Degeneration

Meas. time 2 s



Tradeoff: low density of lines ⇔many cross sections at different locations (3D-cube)





Tractions →macular hole

Tradeoff: low density of lines ⇔ many cross sections at the same location (movie)

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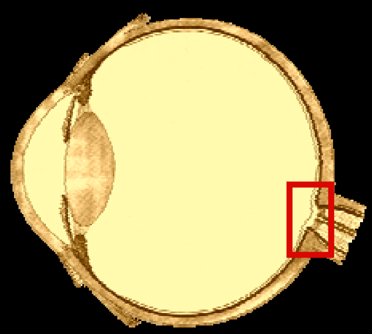
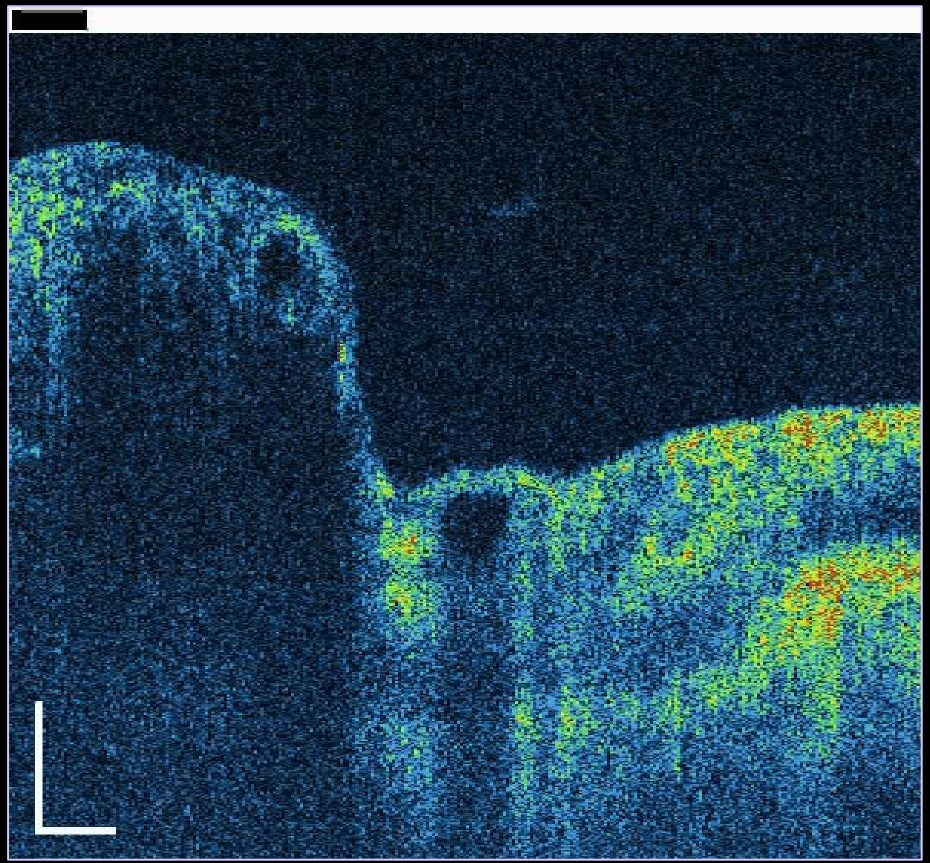
The human nerve head
in vivo
Size: 600 A-scans
Registration: 33 fr/s
Play-back: 33 fr/s





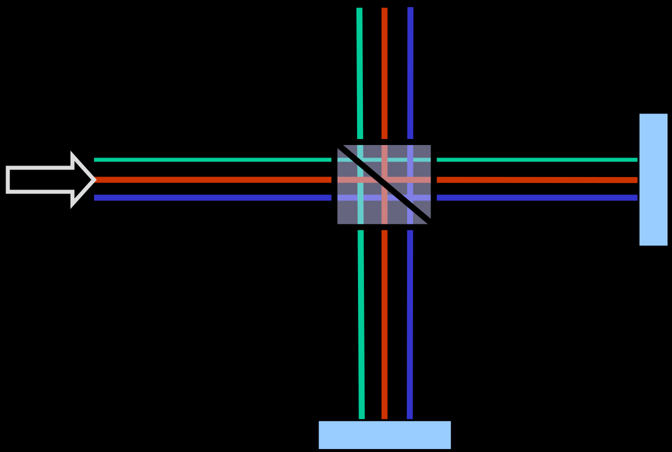
0.2 mm

Question #1:

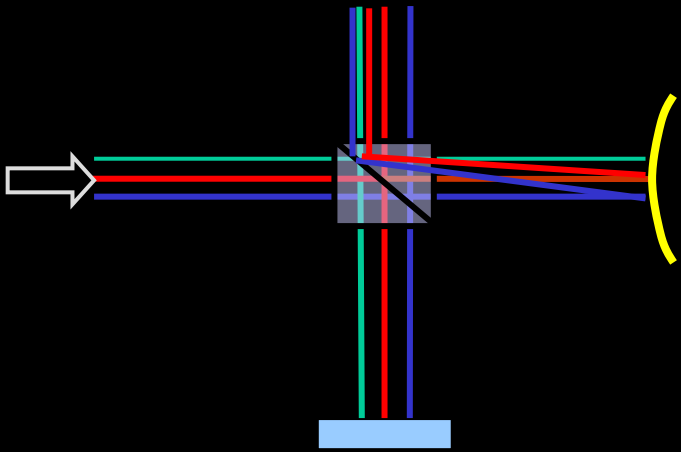
Why Michelson has not invented OCT despite he used the same idea to define the meter in terms of λ_{Kr}?

Technology:

- computers were not available
- there were no efficient light sources of high transversal coherence (small hole=no light)



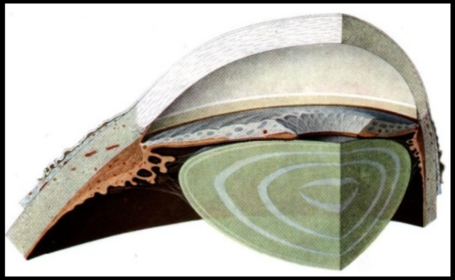
Specular reflection



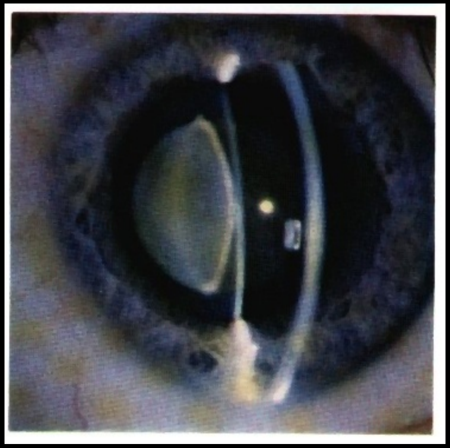
Diffuse reflection

Examples: Cornea & contact lens

Schematic diagram

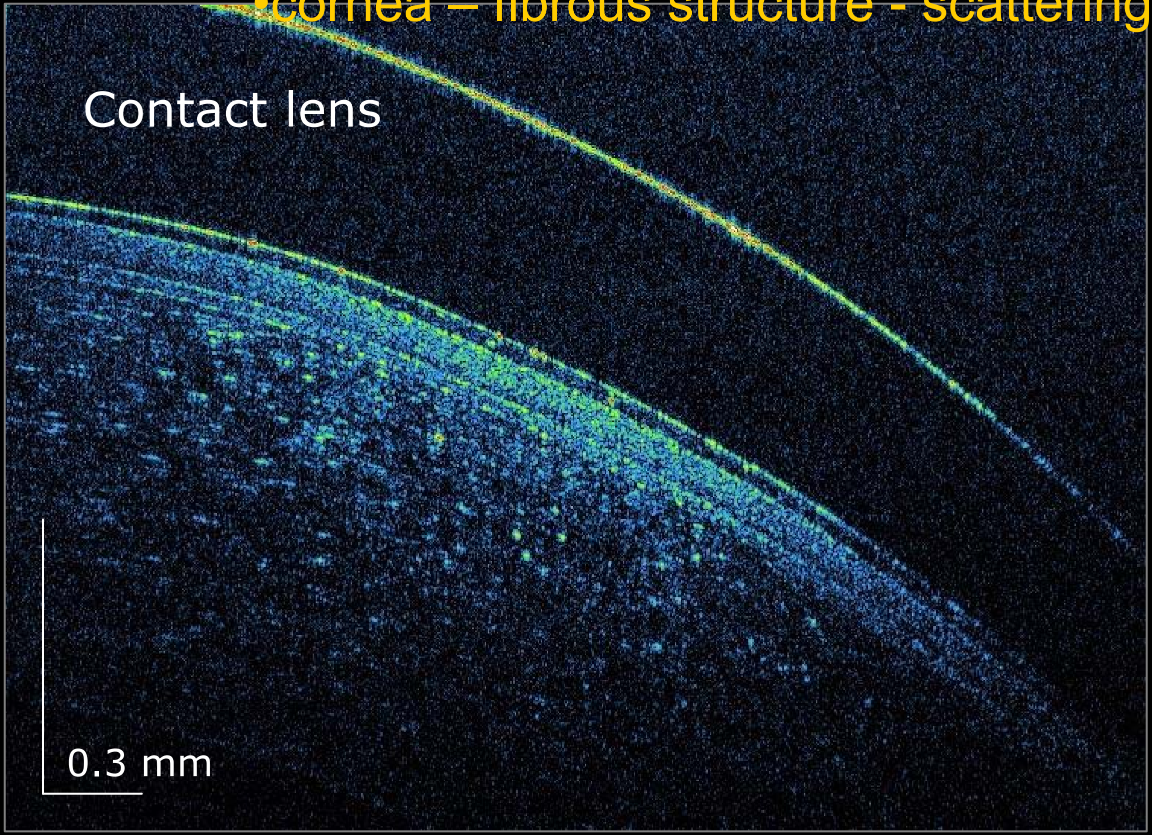


Classical examination



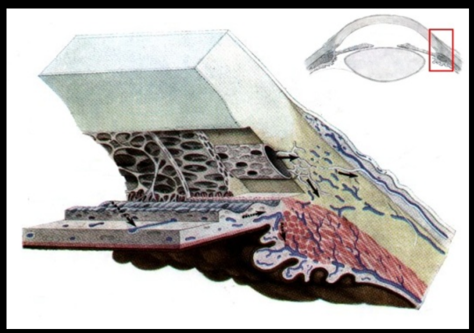
Cornea & contact lens, both transparent

- lens - homogenous – no scattering
- cornea – fibrous structure - scattering

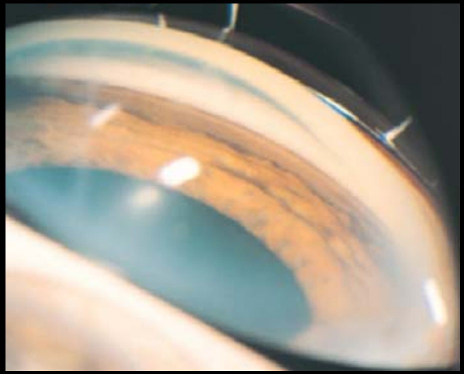


Examples: corneo-scleral angle & iris

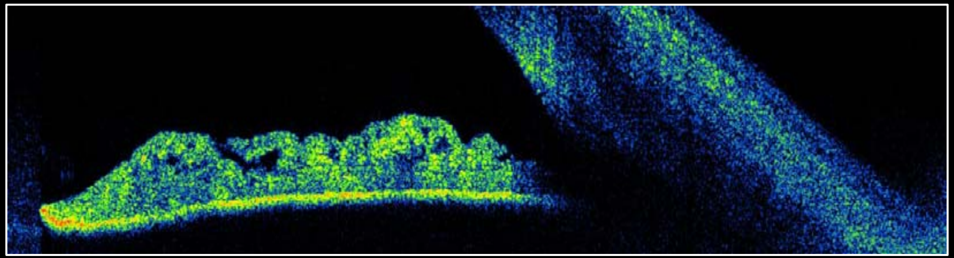
Schematic diagram



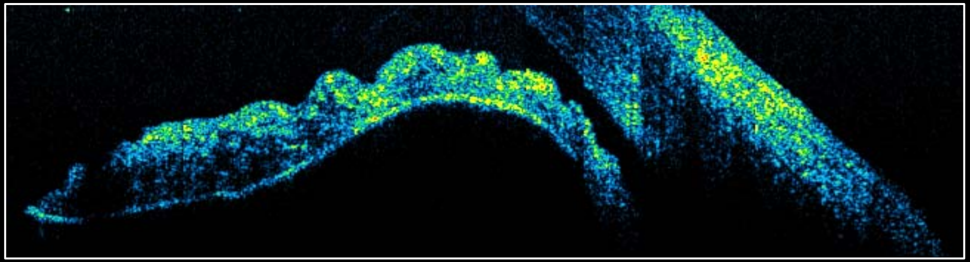
Classical examination

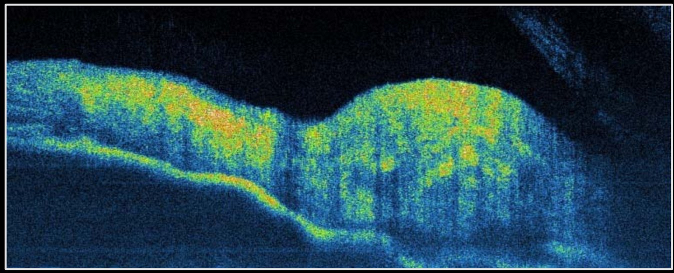


Normal eye



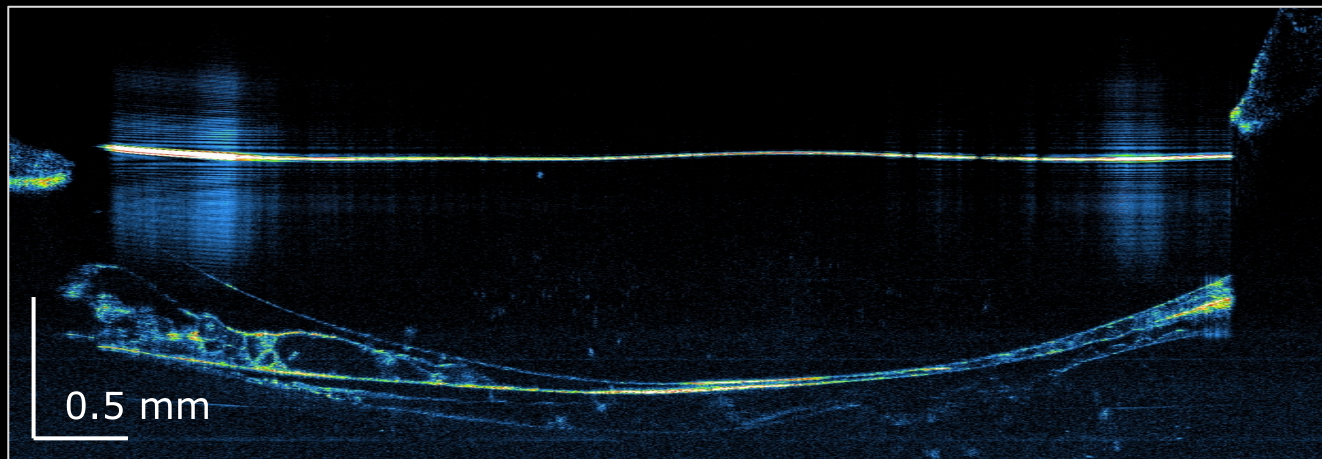
Pathologies

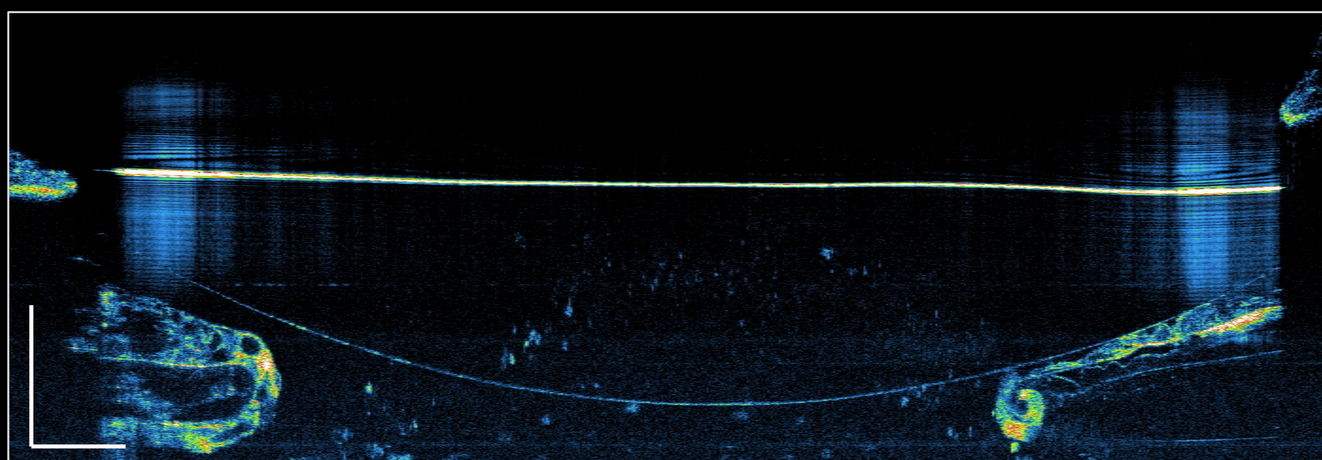




0.4 mm

Examples: Intra ocular lenses



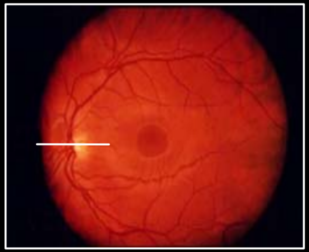


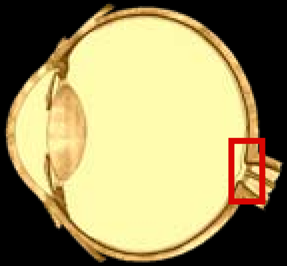
0.5 mm

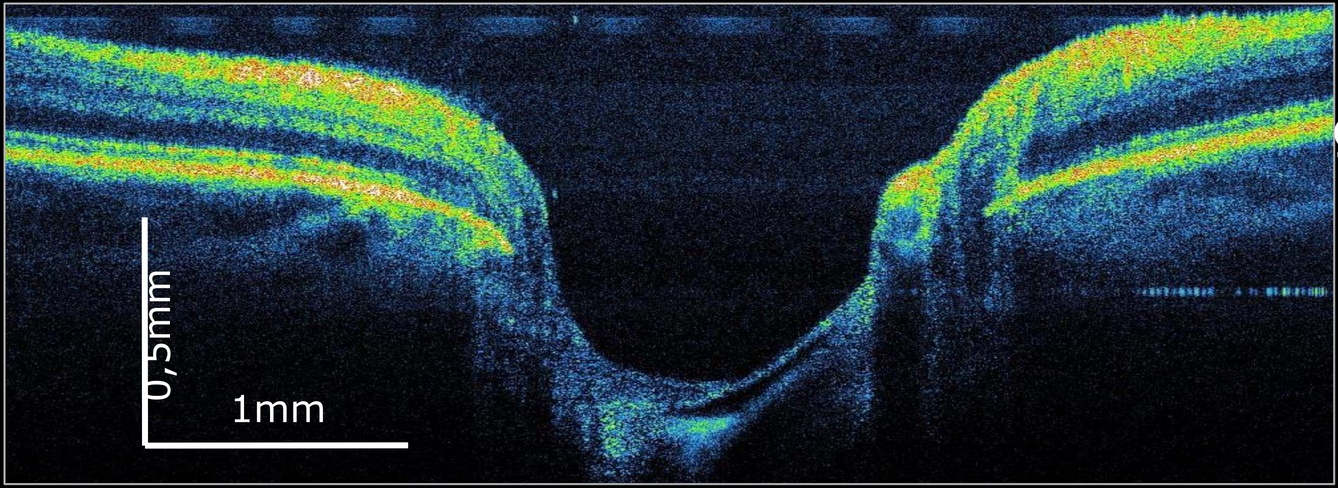
Secondary cataract
before and after capsulotomy

Examples: pathology of the optic disc

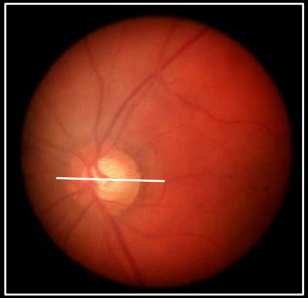
normal



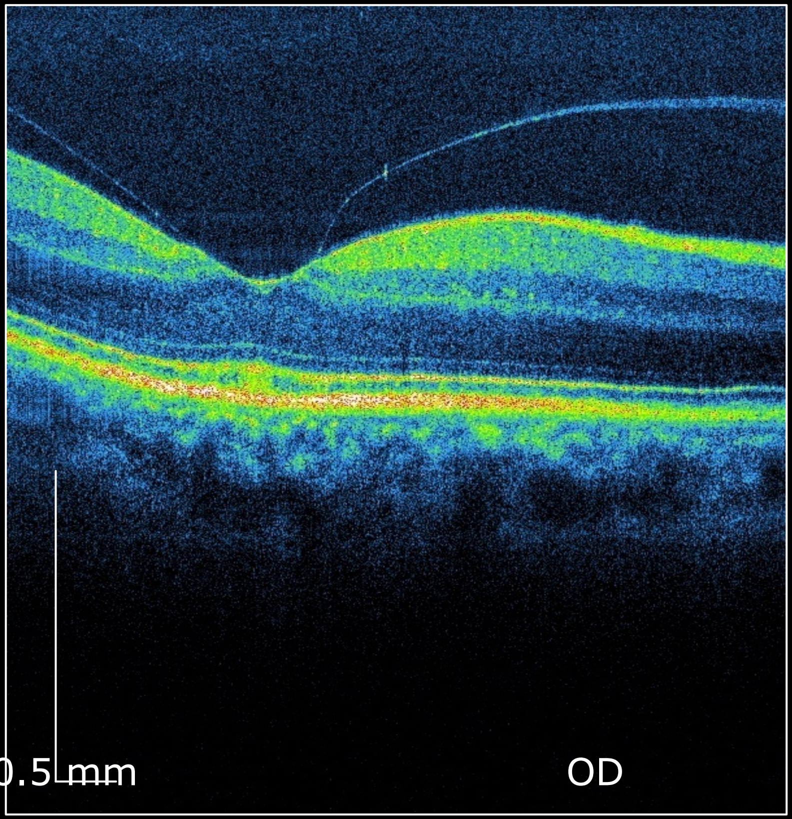


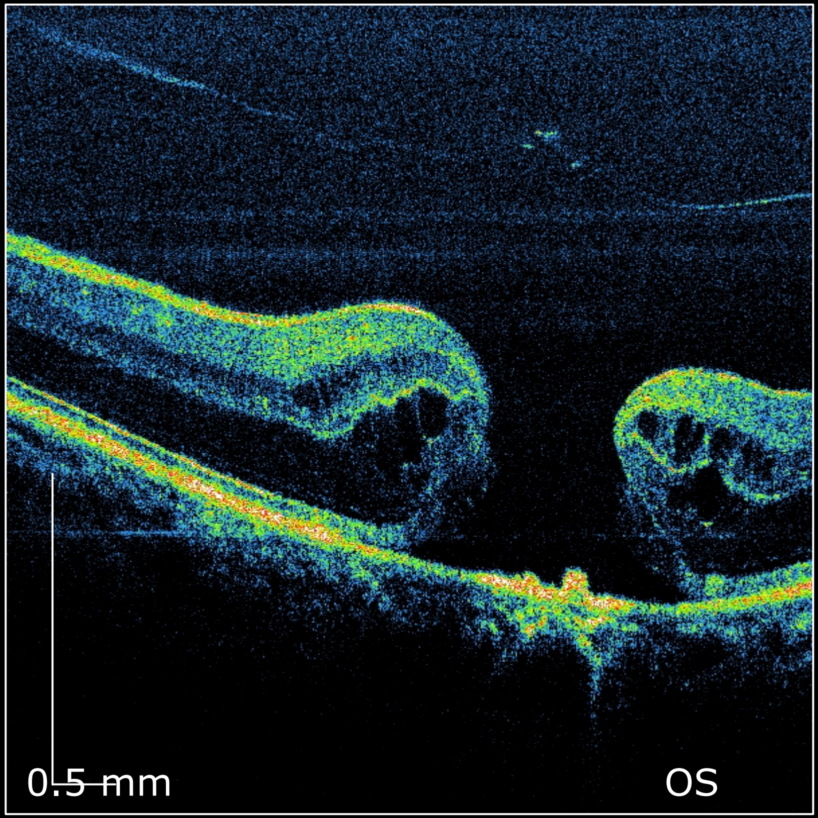


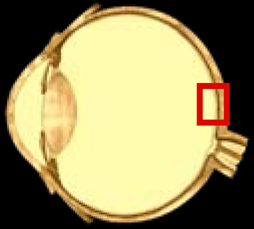
glaucomatic



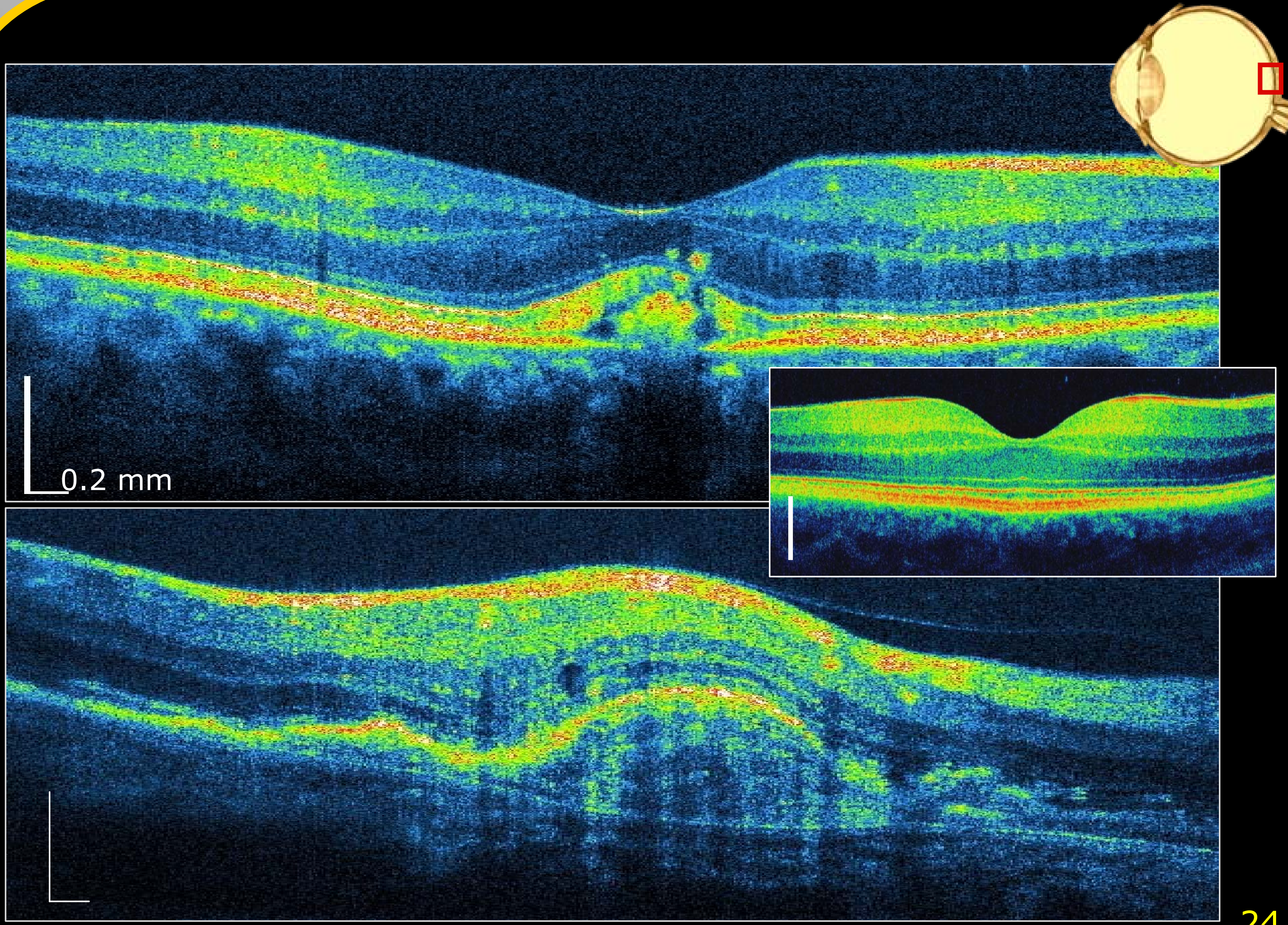
Examples: Macular hole



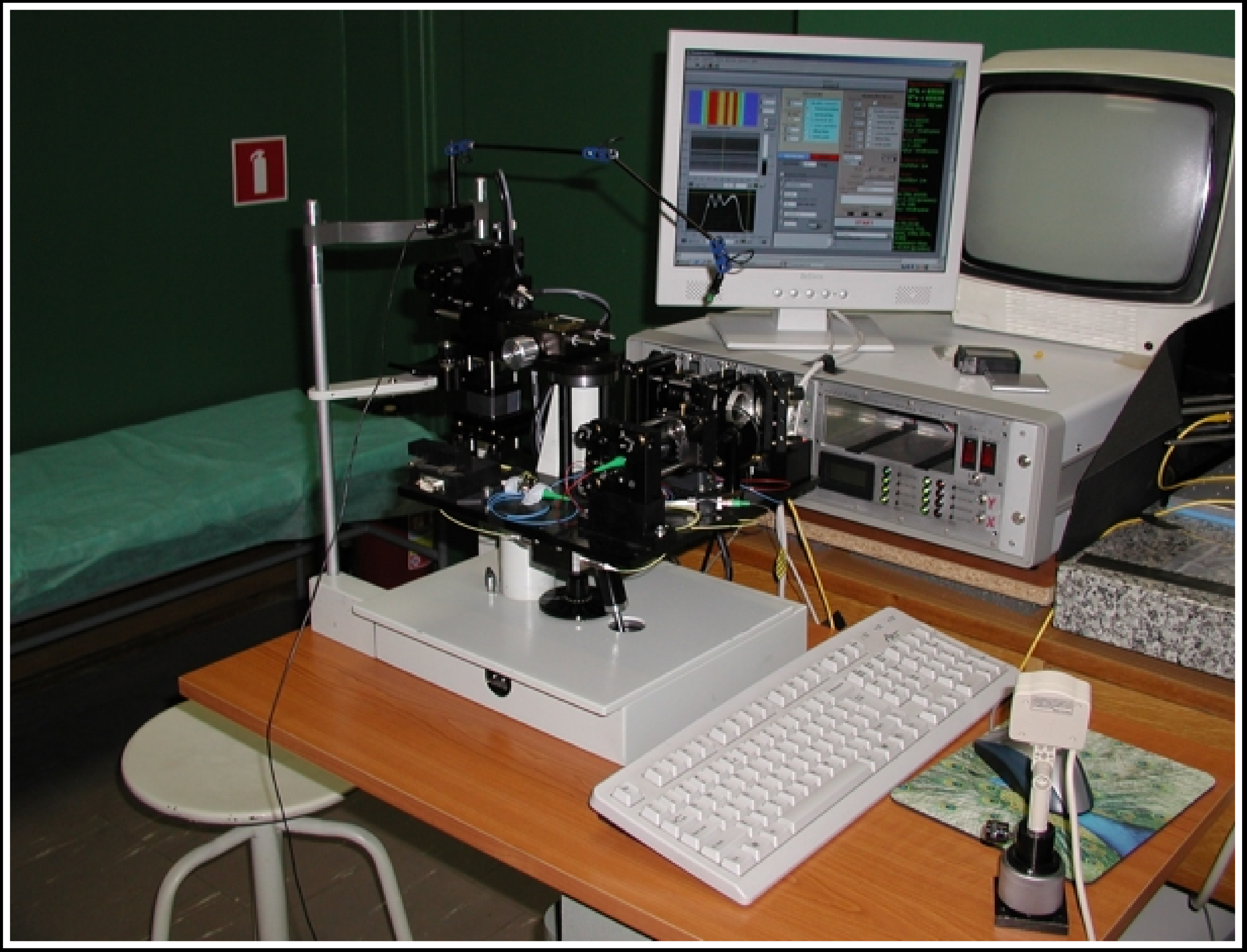




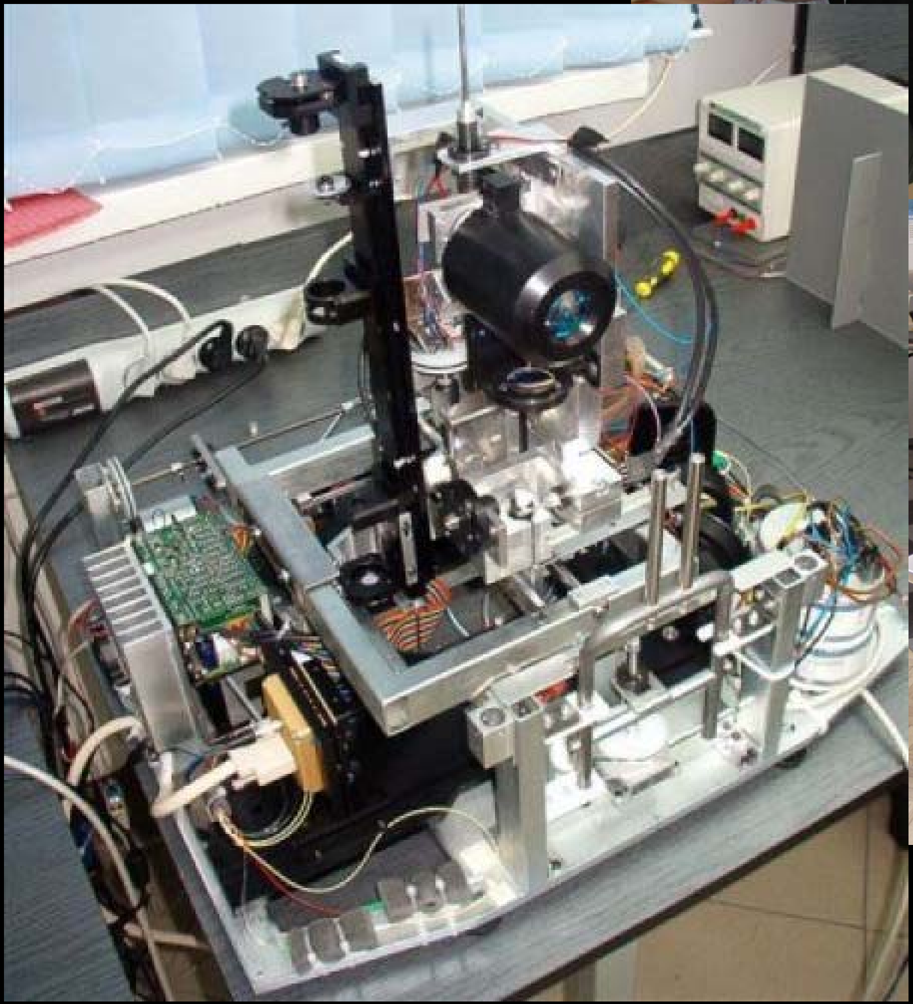
Example: Age related macular degeneration –pathology of the macula



Laboratory prototype in clinic…



…and commercialized version: SOCT Copernicus



Question #2:

Why newcomers pioneered in fast ophthalmic OCT measurements?

Technology:

•CCD were too slow to be used in ophthalmology →CCD matrix used as a fast memory.

•since 2003 fast line scan CCD made Spectral OCT available to all.

A. Jabłoński & A.K. 1979

Psychology:

•positive attitiude to applied research

•patience

Methodology:

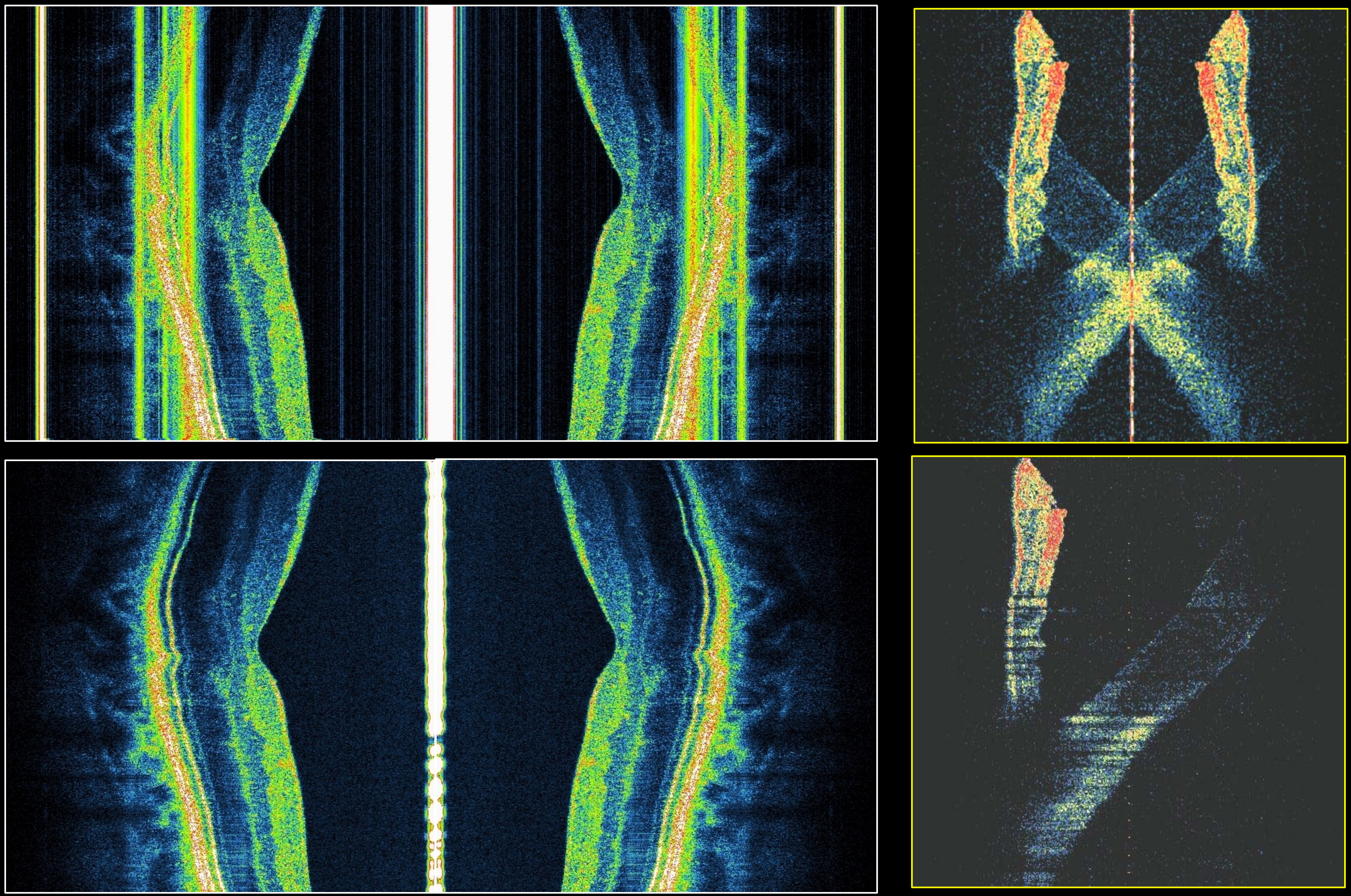
How to deal with overlap of:

•twin images

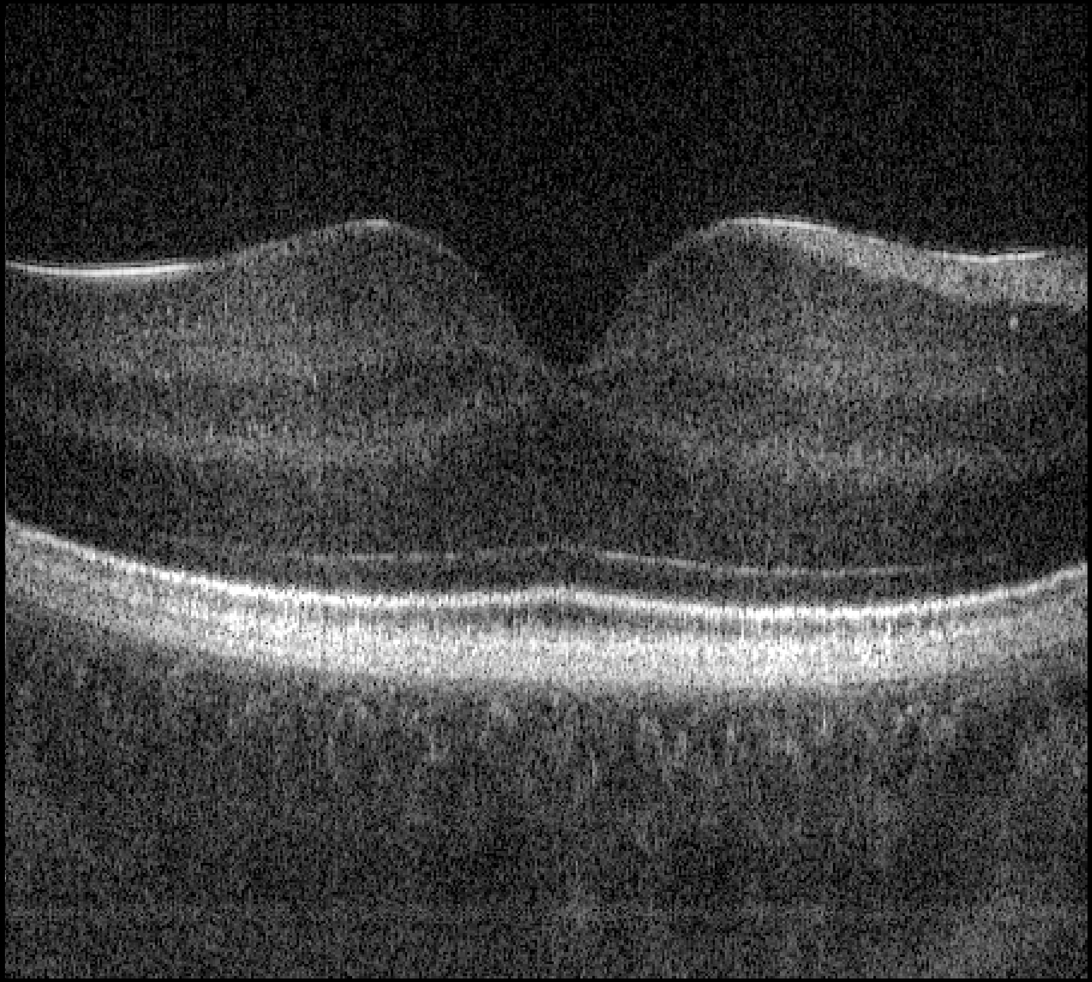
•useful and useless information

see next 2 slides

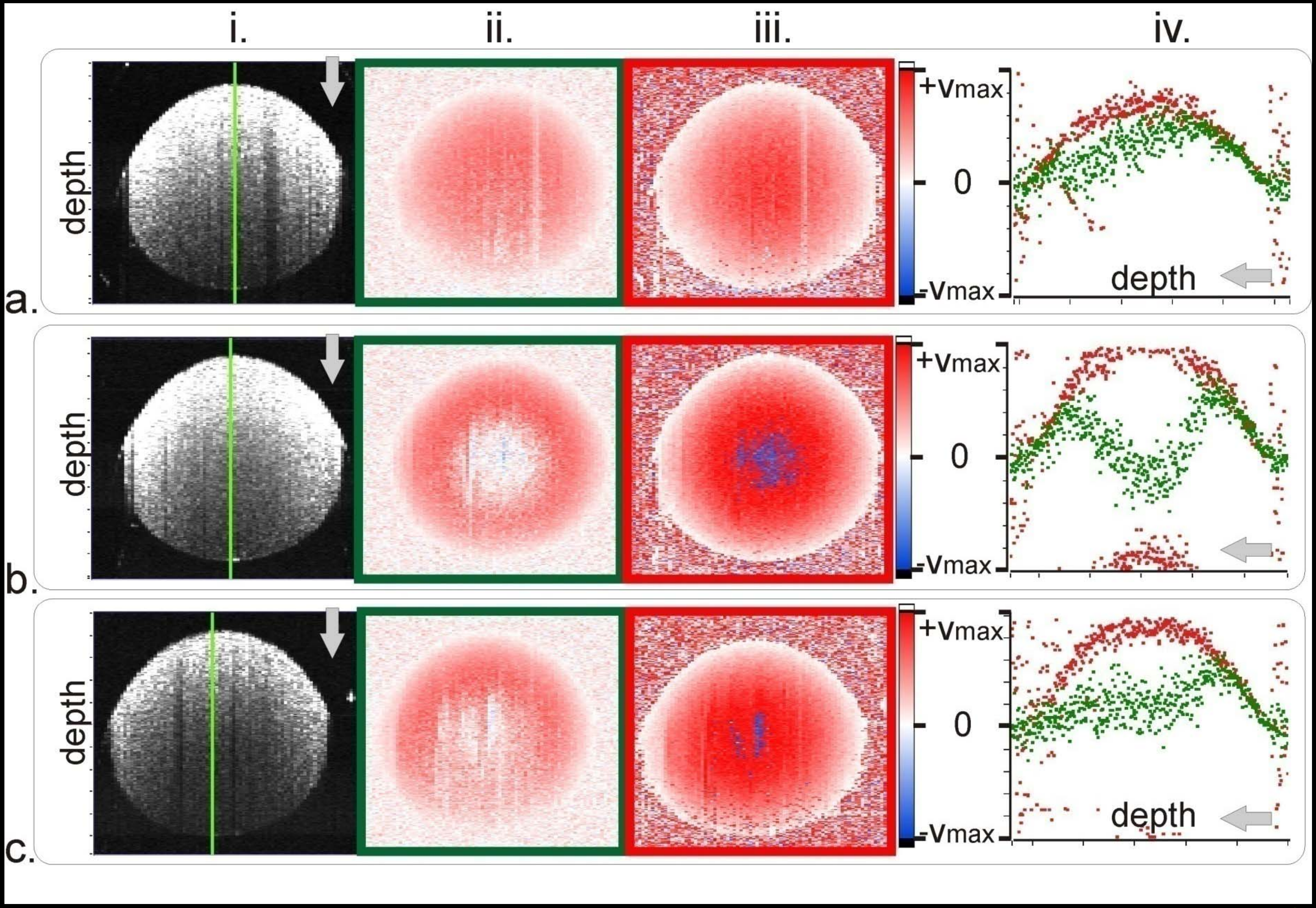
|FT{real valued function}|→twin images



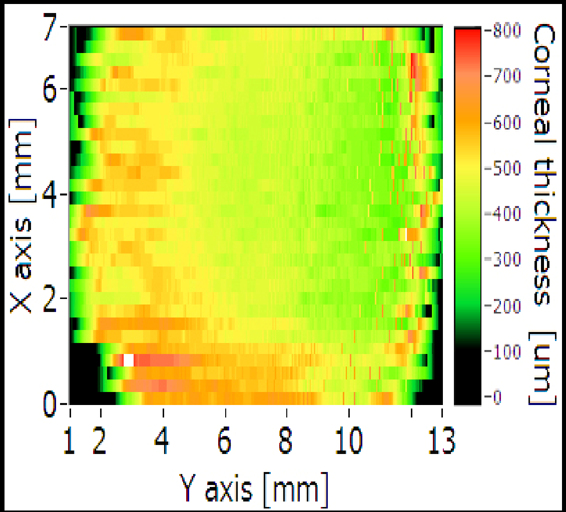
Useful & useless information together

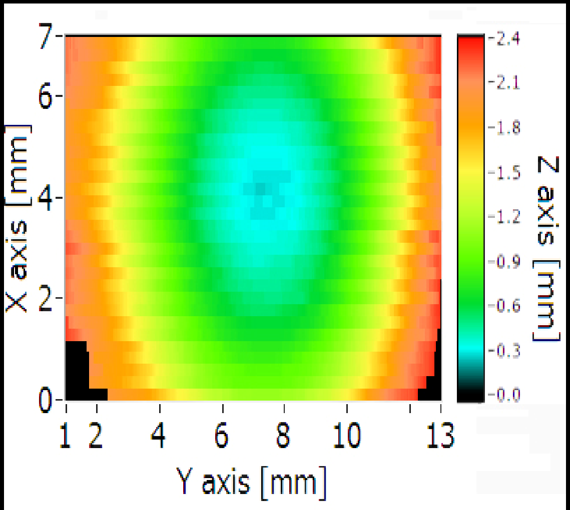


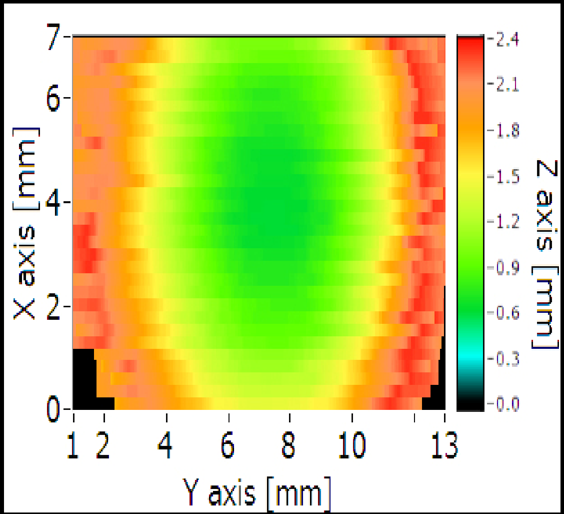
What next: proper imaging of flows



What next: topography of cornea in 25 ms!







thickness map

topography of anterior surface

topography of posterior surface

Medical Physics Group

Prof. Andrzej Kowalczyk

Dr hab. Piotr Targowski

Dr Maciej Wojtkowski

Dr Iwona Gorczyńska

Dr Ireneusz Grulkowski

Mgr Anna Szkulmowska

Mgr Michalina Góra

Mgr Karol Karnowski

Mgr Danuta Bukowska

Mgr Szymon Tamborski

Mgr inż. Daniel Szlag

- Thank you