Optical coherence tomography for noninvasive imaging of structures and functions in biomedicine

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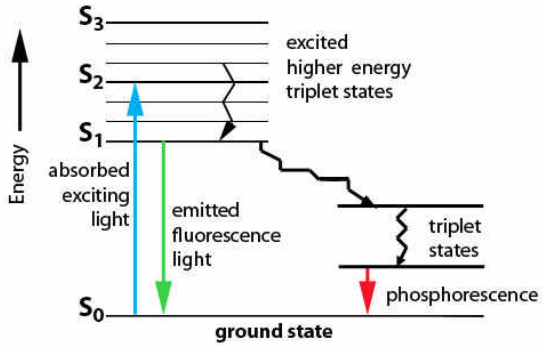
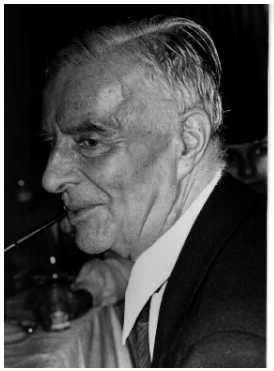
- Alexander Jablonski





National Laboratory of Atomic, Molecular and Optical Physics (FAMO)

National Laboratory of Quantum Technologies

Center of Quantum Optics

Center for Modern Interdisciplinary Technologies

Optical Biomedical Imaging Group (OBIG)

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Ewa Kwiatkowska

Collegium Medicum

Bartłomiej Kałużny
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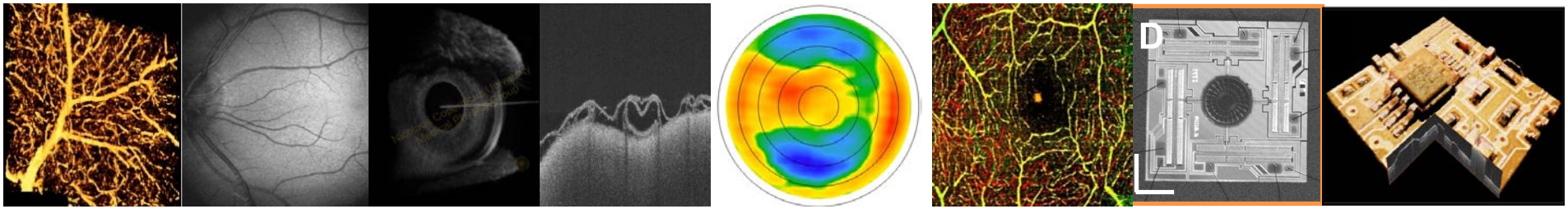
Cooperation

Research activity of the group

To integrate high-quality fundamental and applied science with transfer of technologies

- structural and functional imaging of the eye
- development of novel approaches in microscopy
- optical studies of neuronal functions
- light propagation in scattering media
- new methods of data analysis



Optical Coherence Tomography

- **measures echo time delays of light backreflected / backscattered from internal structures of the object**

c = 300000 km/s

v_s = 1.5 km/s

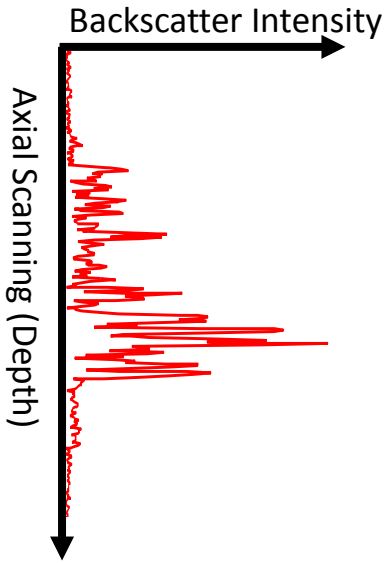
$c = 200000 \cdot v_s$

Interferometric technique is necessary

Optical Coherence Tomography

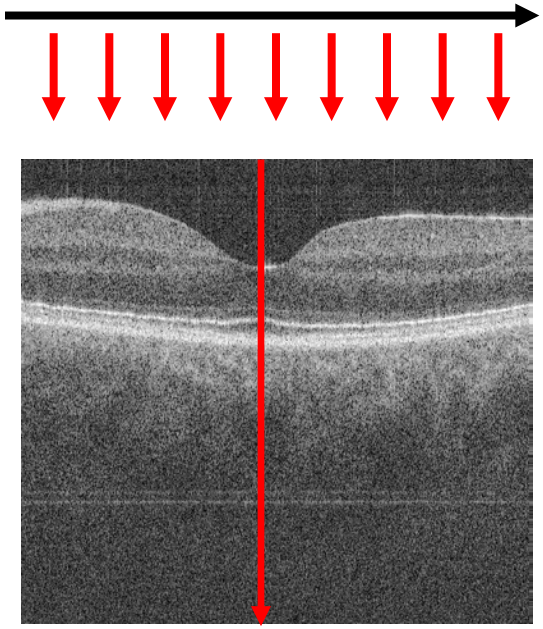
1D: A-Scan

Axial (Z) Scanning
No scanning with
Fourier Domain OCT



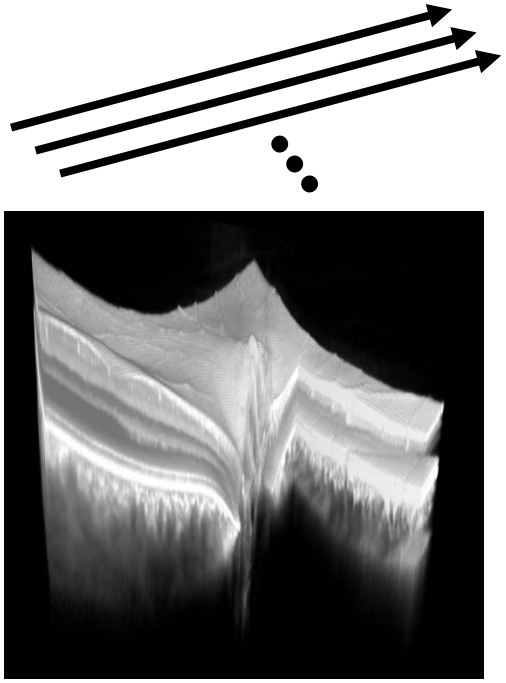
2D: B-Scan

Axial (Z) Scanning
Transverse (X) Scanning



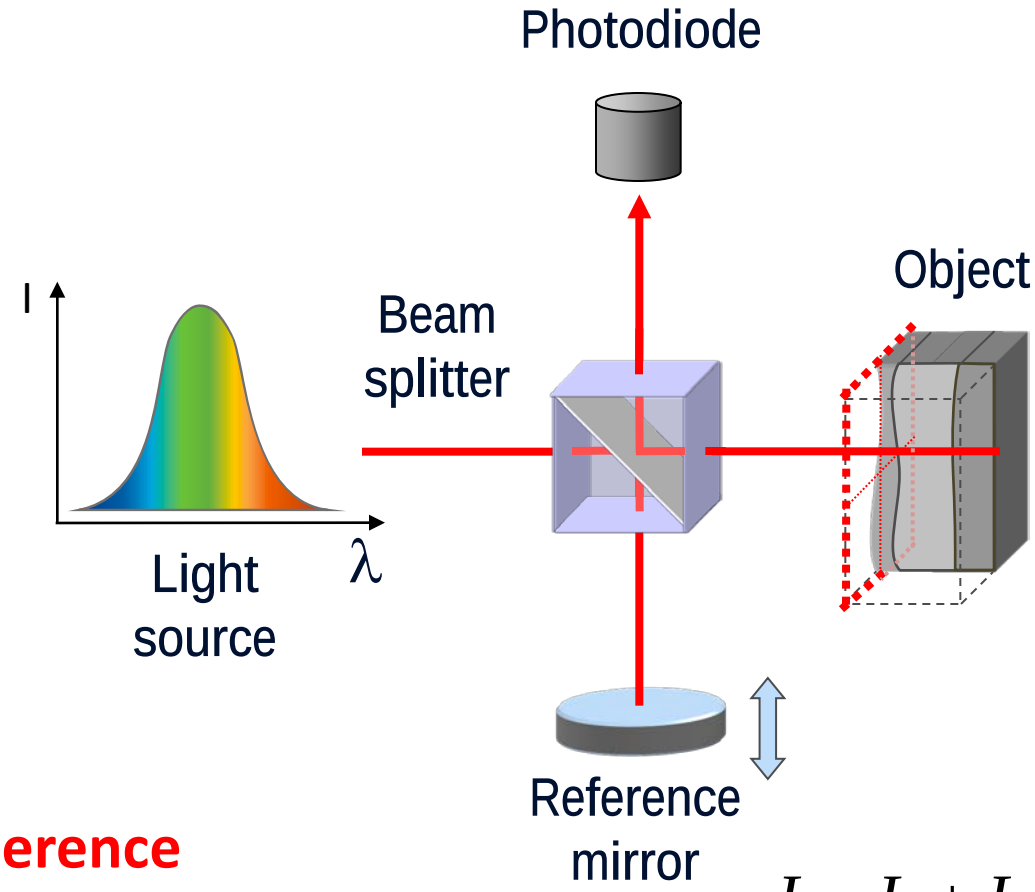
3D: Volumetric

Axial (Z) Scanning
XY Scanning



Huang *et al., Science,* 254, 1178-1181, (1991).

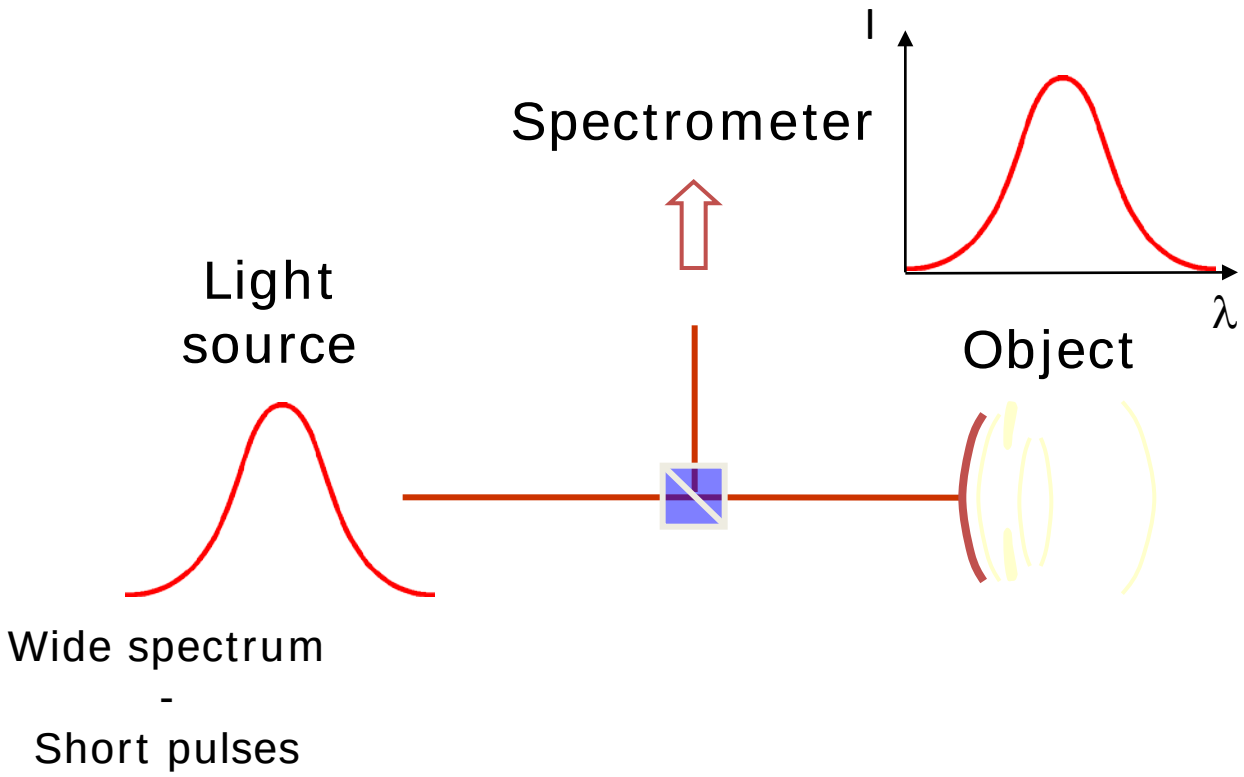
Time-domain Optical Coherence Tomography



Low coherence interferometry

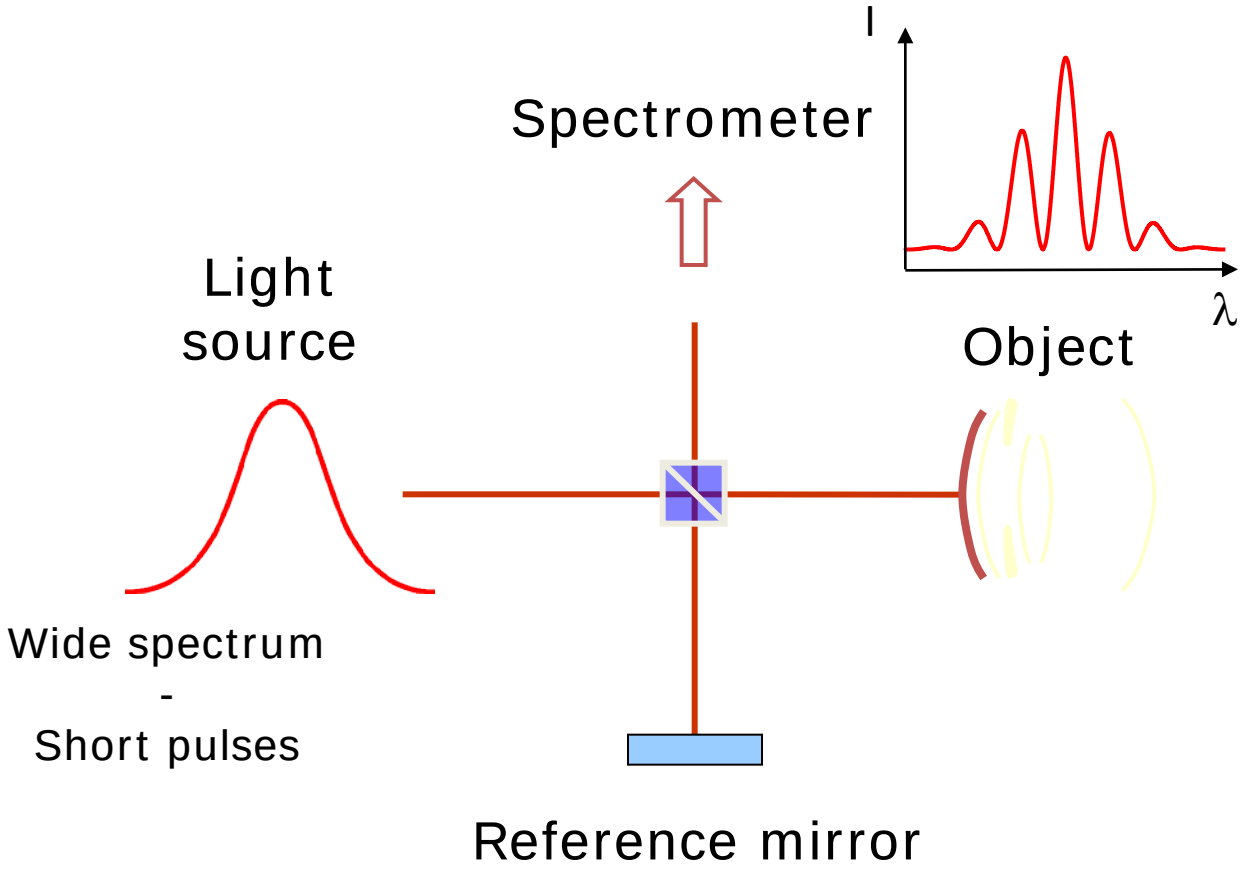
$$I = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos(\omega\tau)$$

Fourier-domain Optical Coherence Tomography



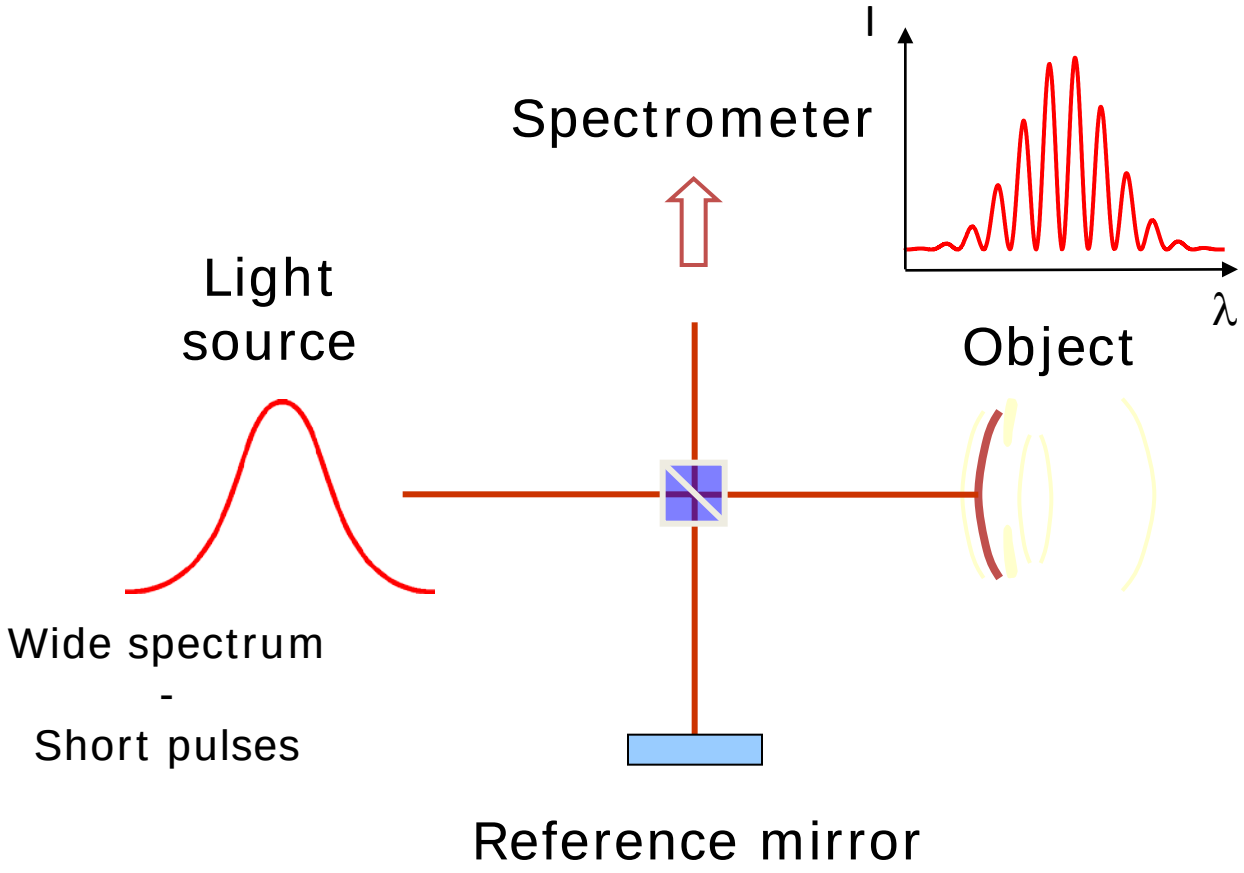
Spectral OCT

Fourier-domain Optical Coherence Tomography



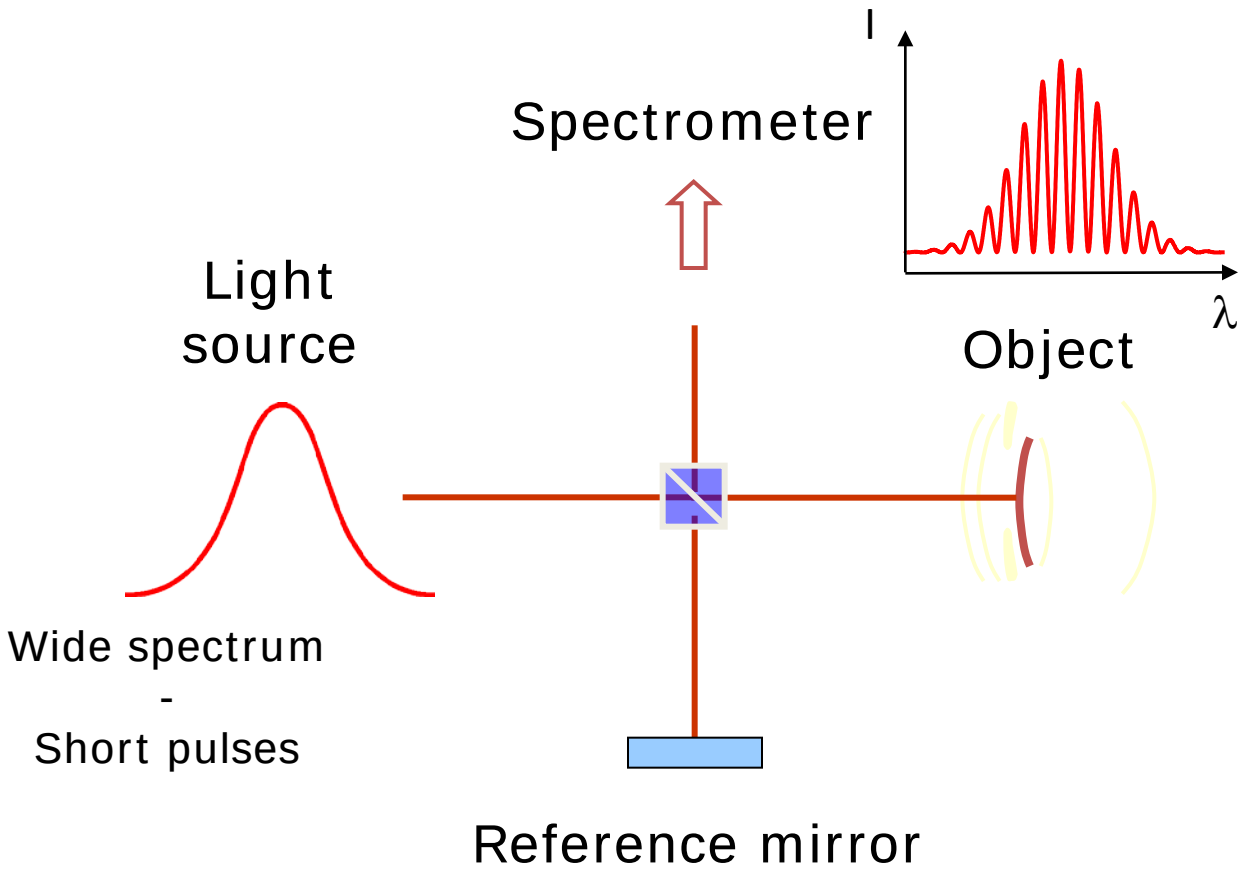
$$I = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos(k \cdot \Delta z)$$

Fourierowska detekcja w OCT w praktyce



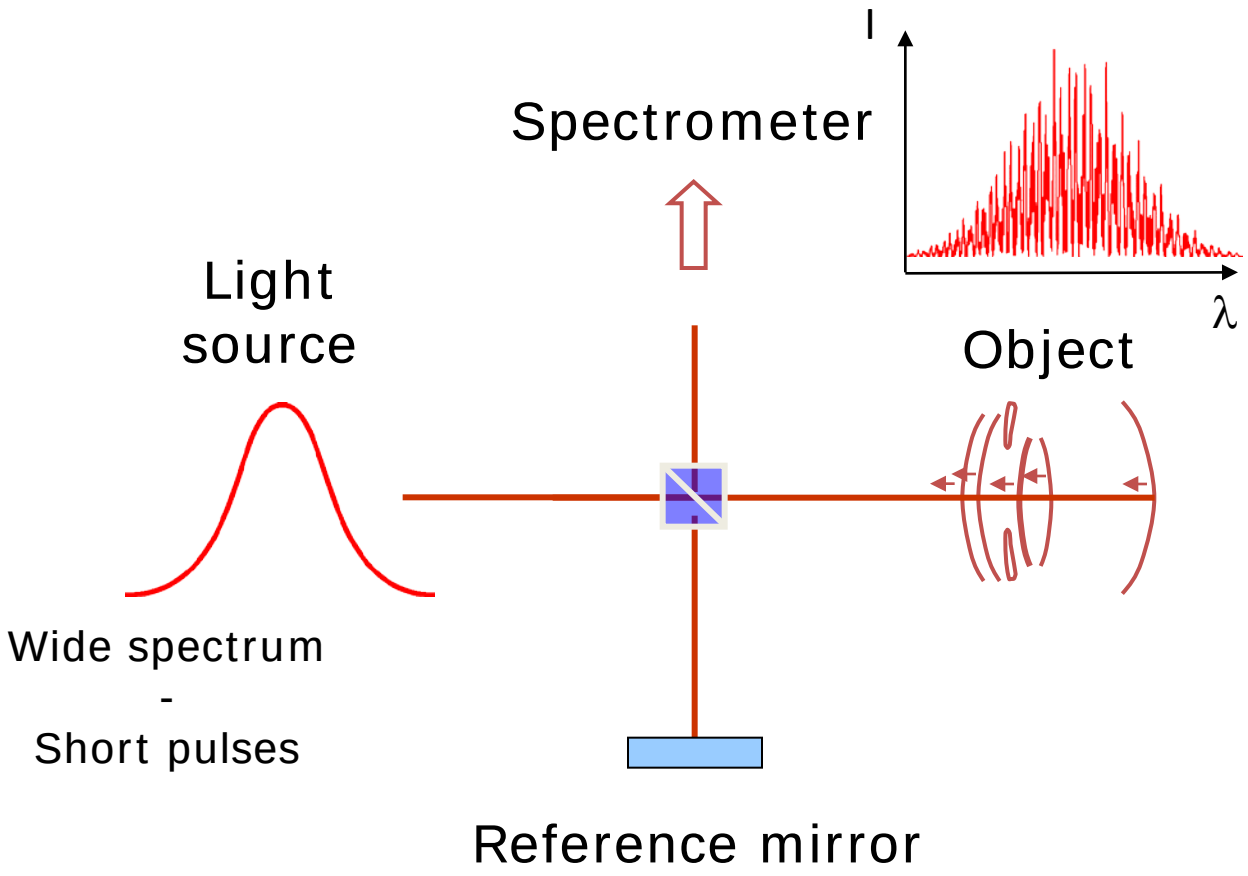
Spectral OCT

Fourier-domain Optical Coherence Tomography



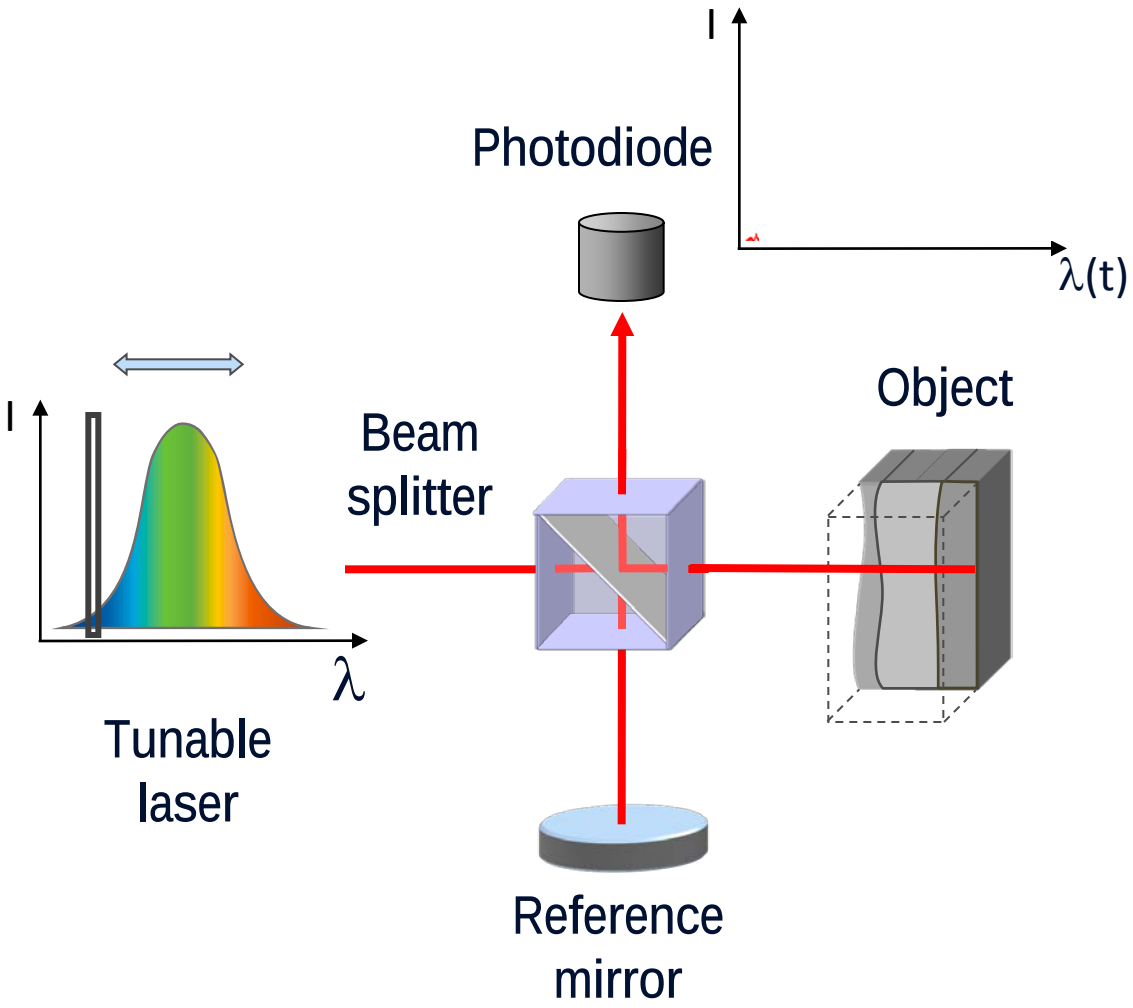
Spectral OCT

Fourier-domain Optical Coherence Tomography



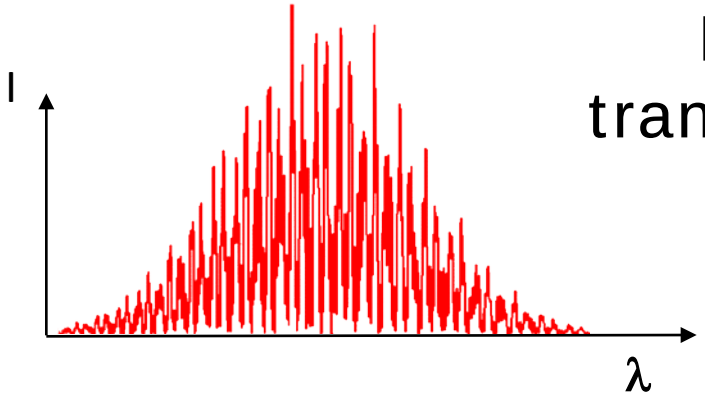
Spectral OCT

Fourier-domain OCT with swept laser source



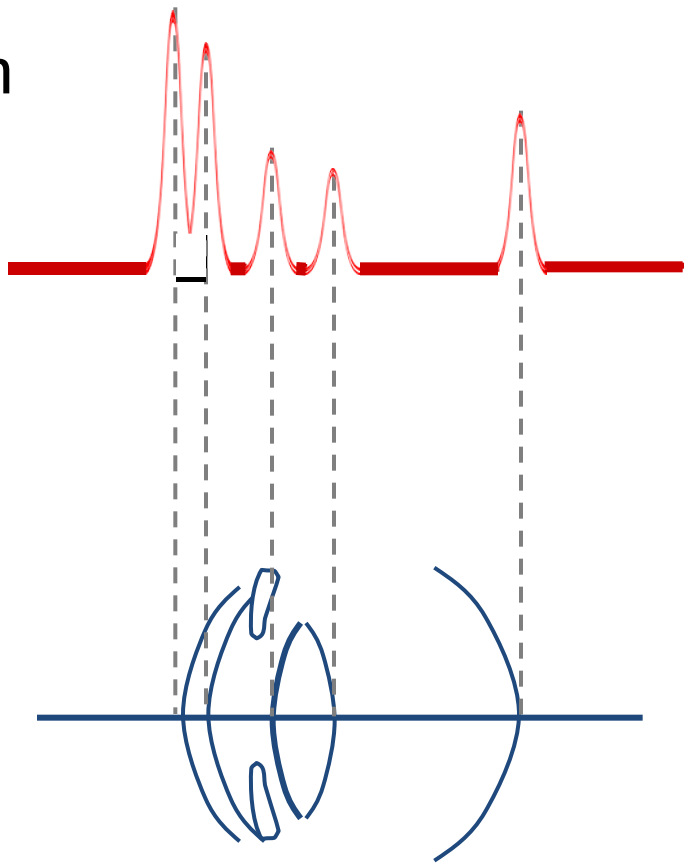
Fourier domain OCT

Spectral fringes



Fourier transformation

Axial scan

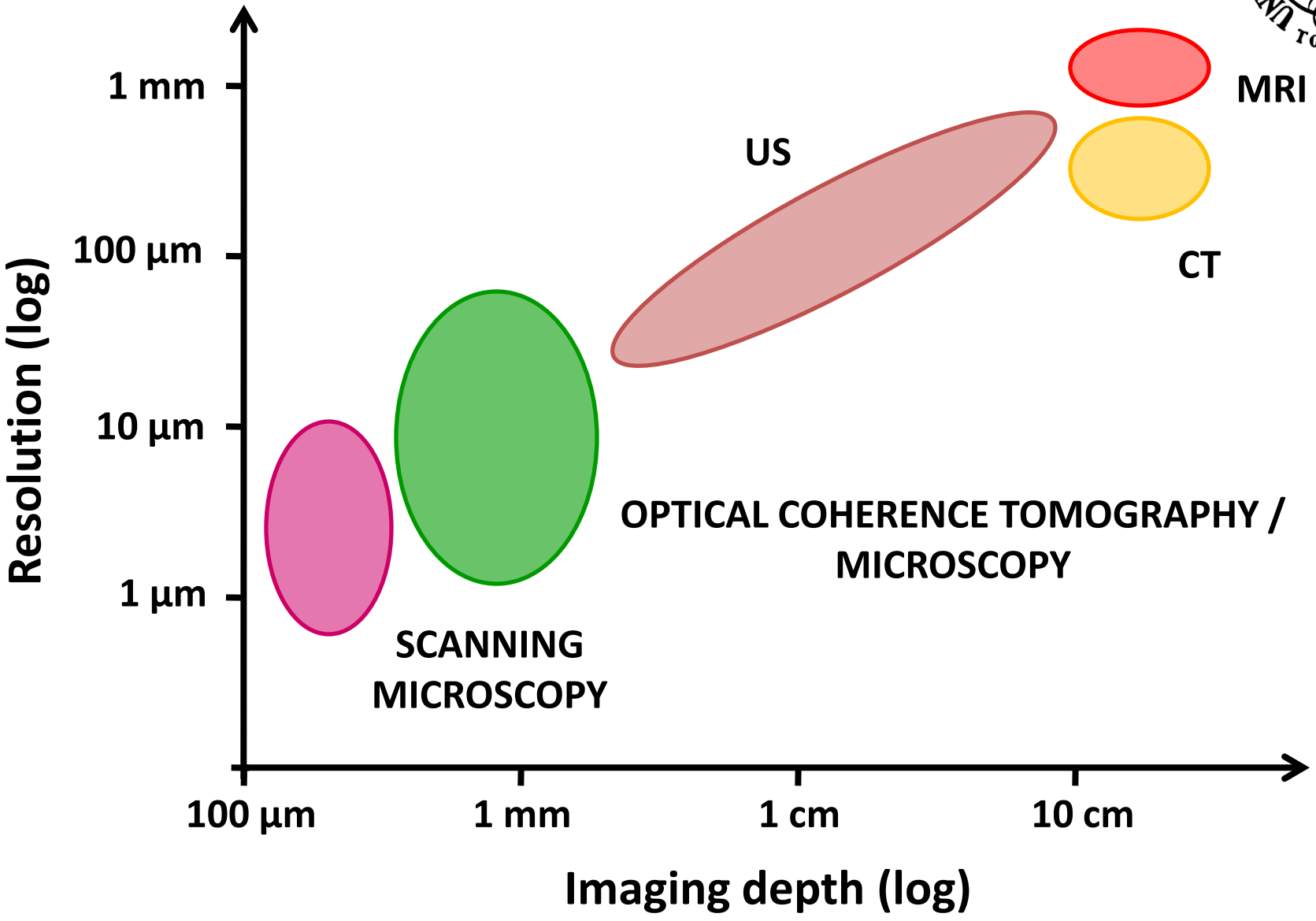


Interdisciplinary approach

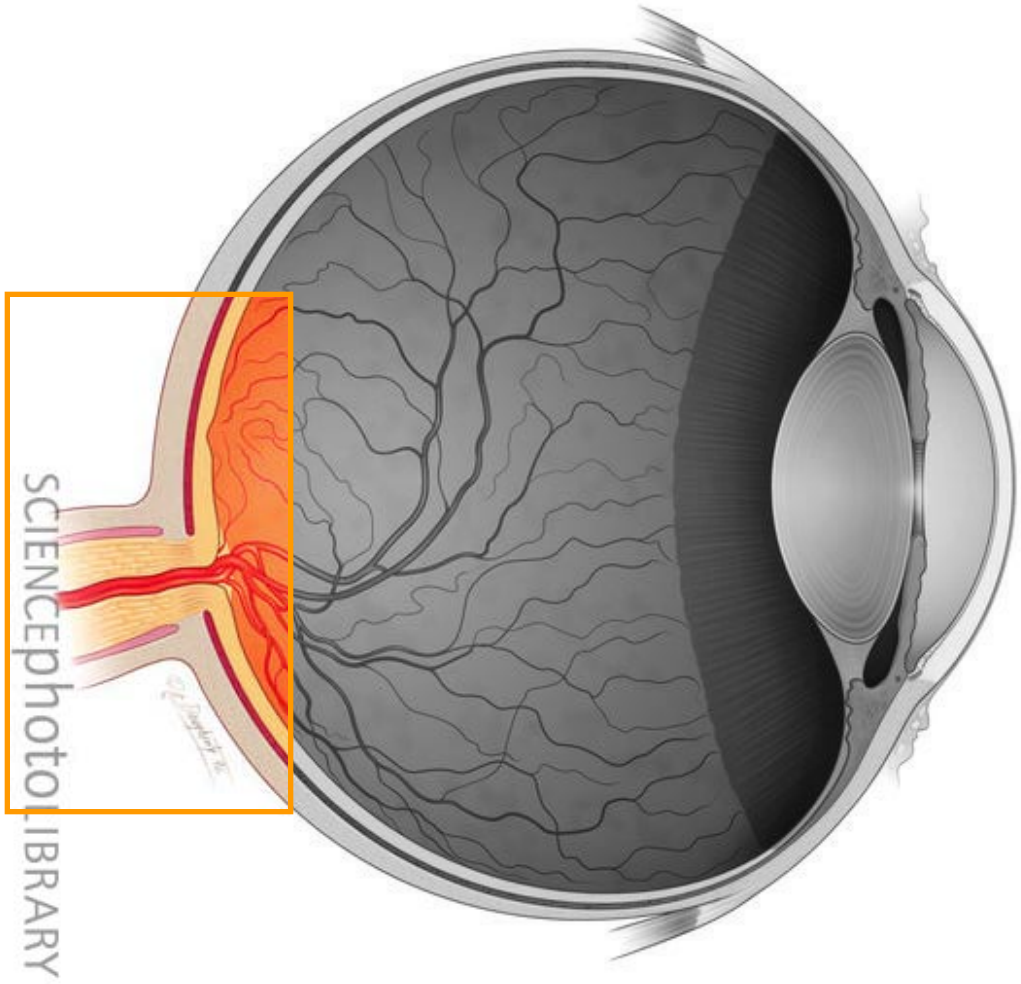
Development of OCT technology requires integration of different fields including:

- laser physics
- optical system design
- biophysics
- high-speed electronics
- data processing and signal analysis
- clinical studies

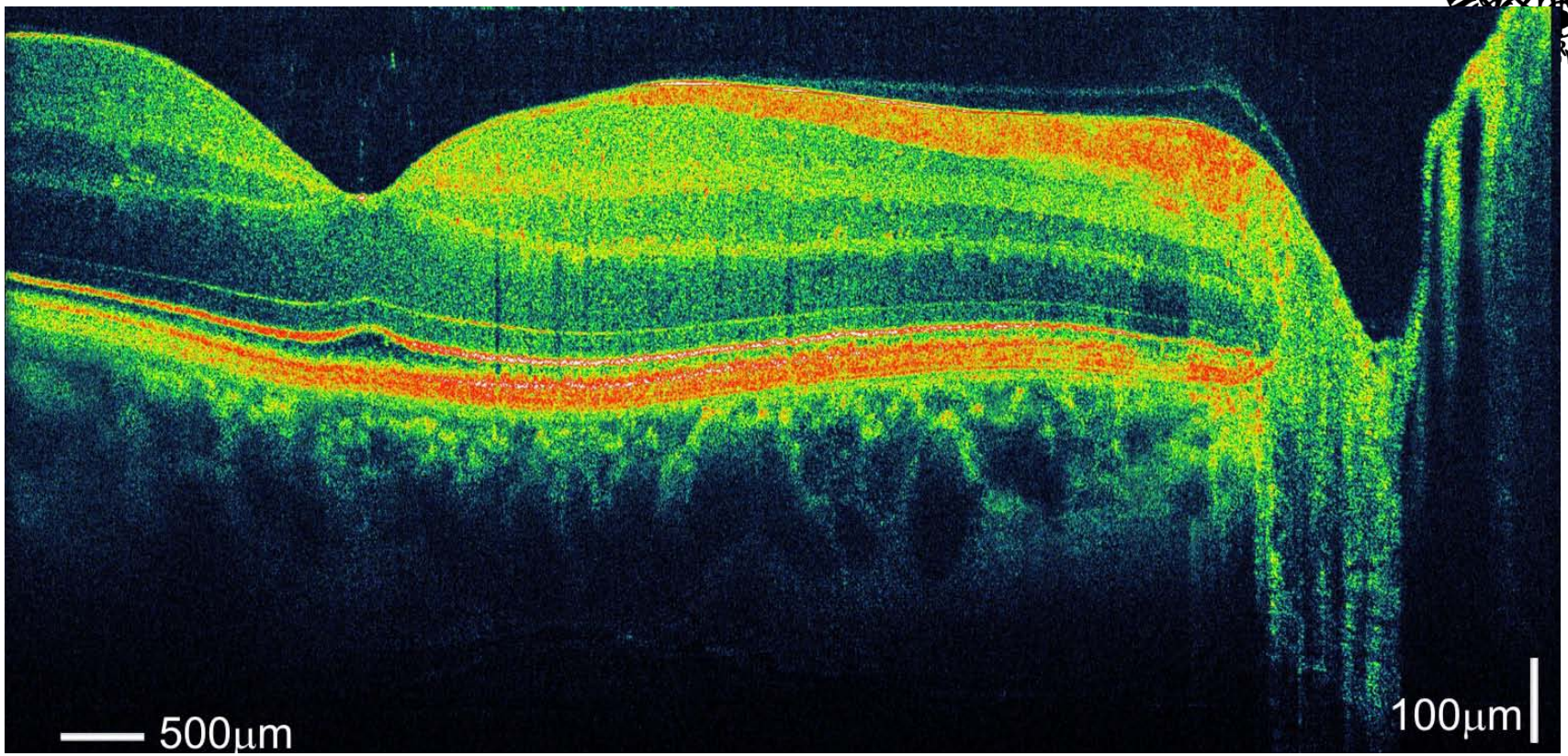
Biomedical imaging techniques



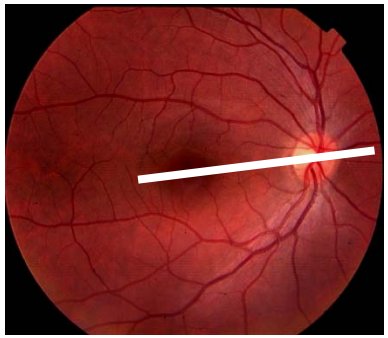
Retinal and Choroidal Imaging



Retinal imaging

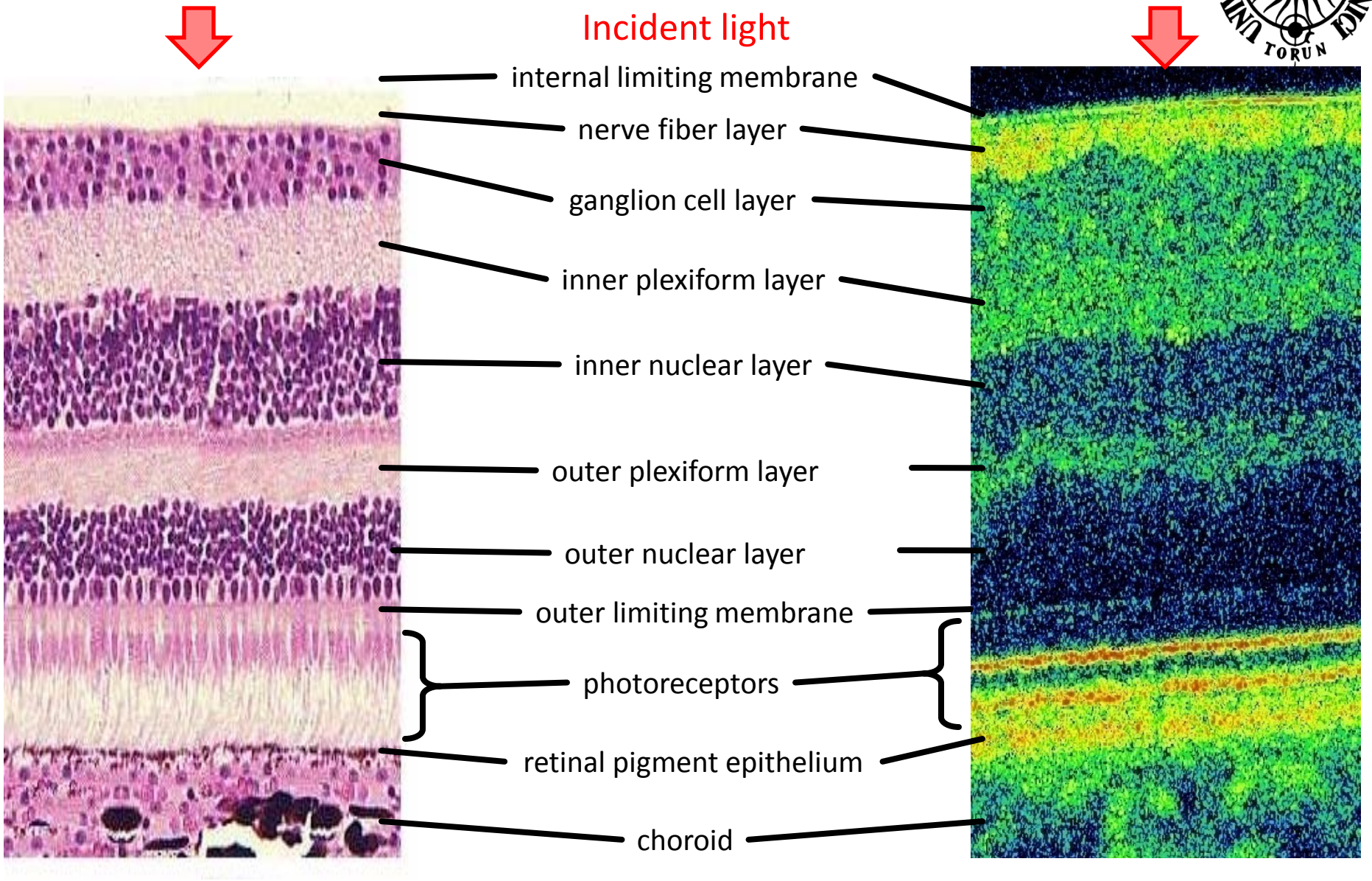


t_{rep} = 60 µs
16,7 kA-scans/s
10000 A-scans
0,6 s

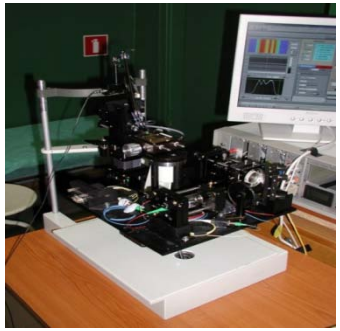


M. Wojtkowski et al., Ophthalmology 112 (10), 1734-1746, 2005

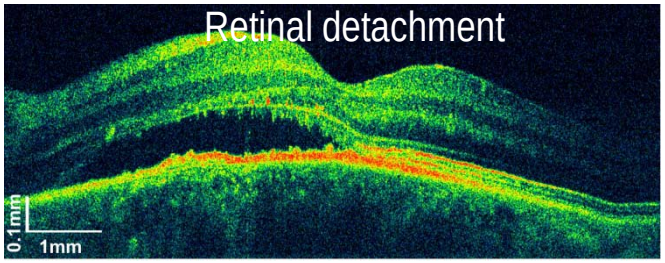
OCT as optical biopsy

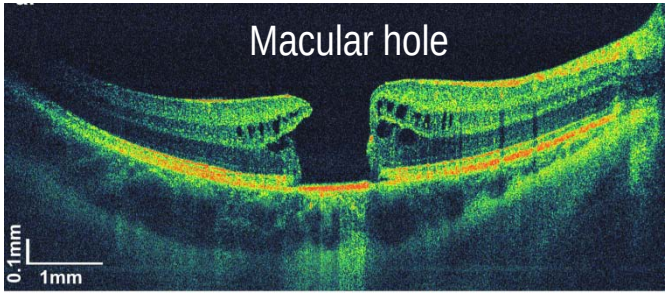


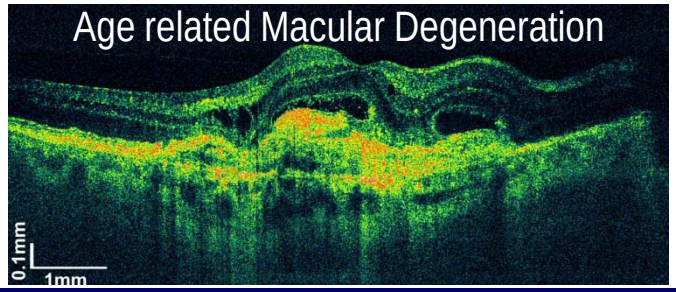
Imaging in clinical practise

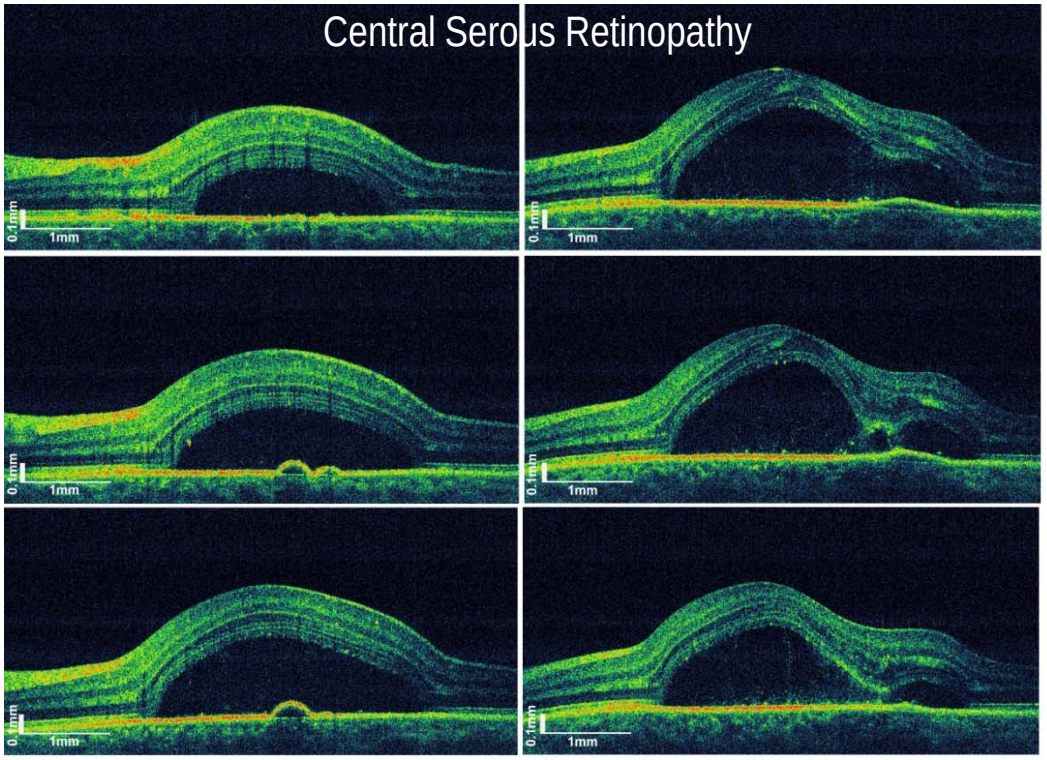


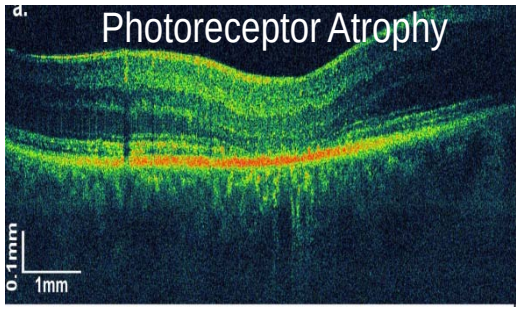
System performance:
Axial resolution:
3.5um
Transverse resolution:
15um;
Line rate: 23kHz

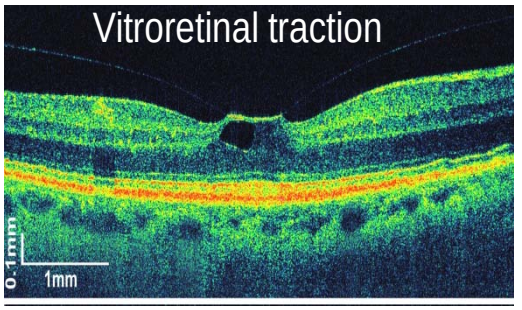




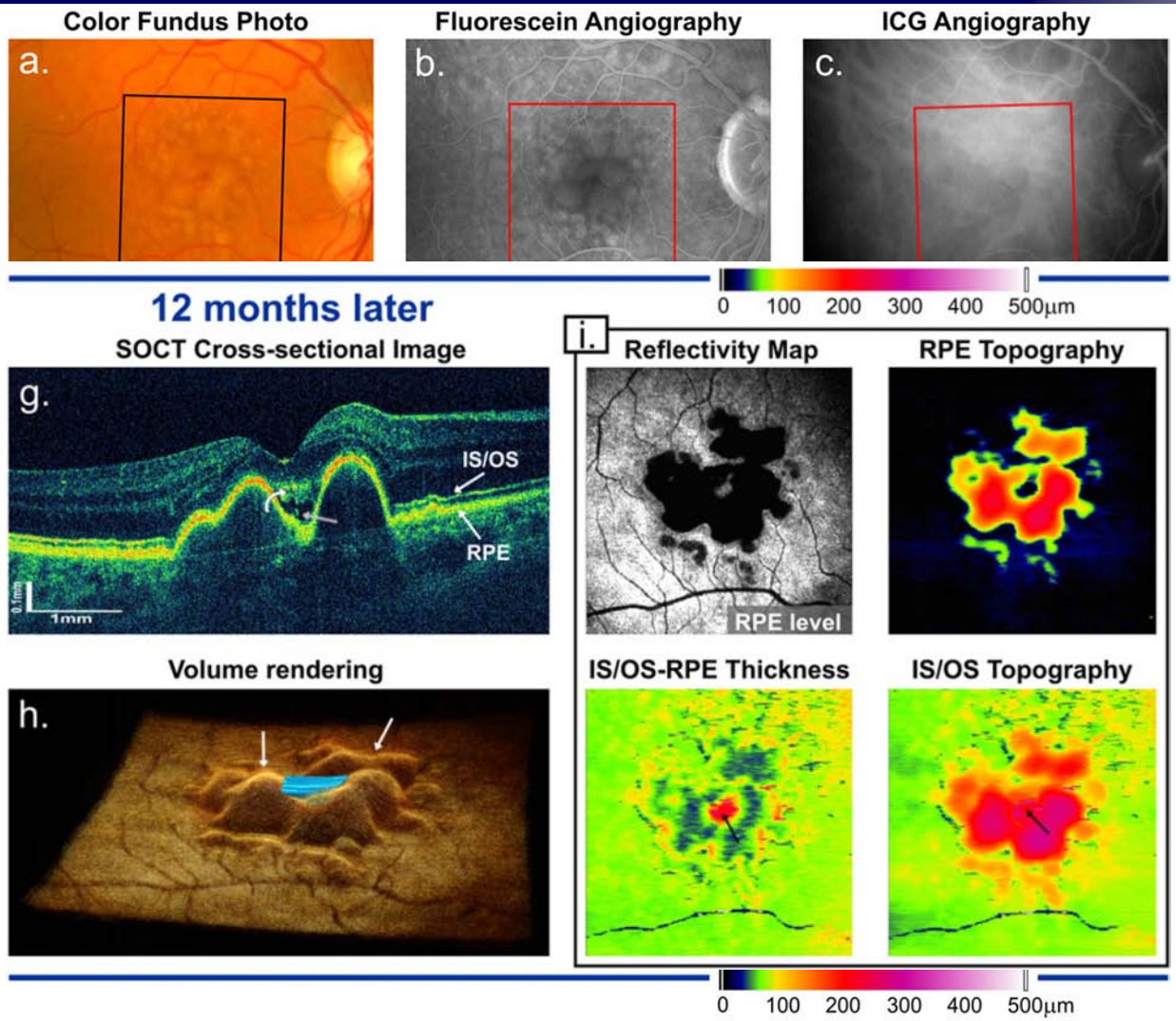






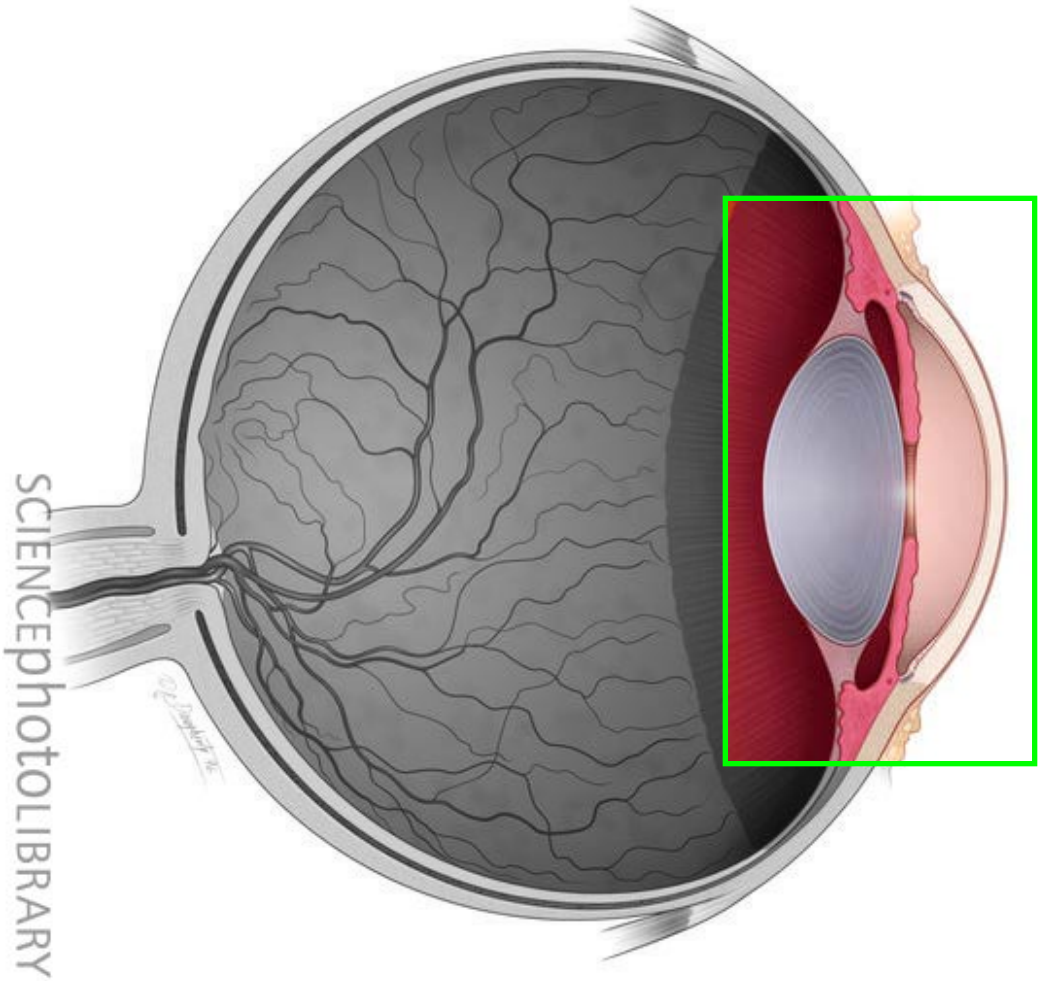


Drusen / AMD

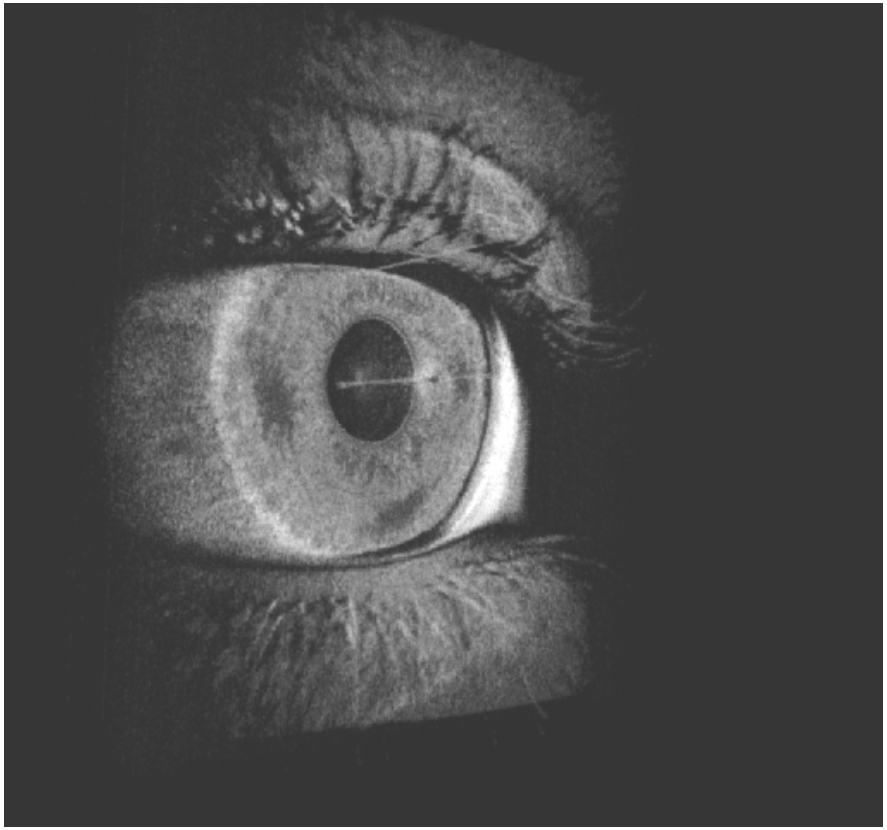


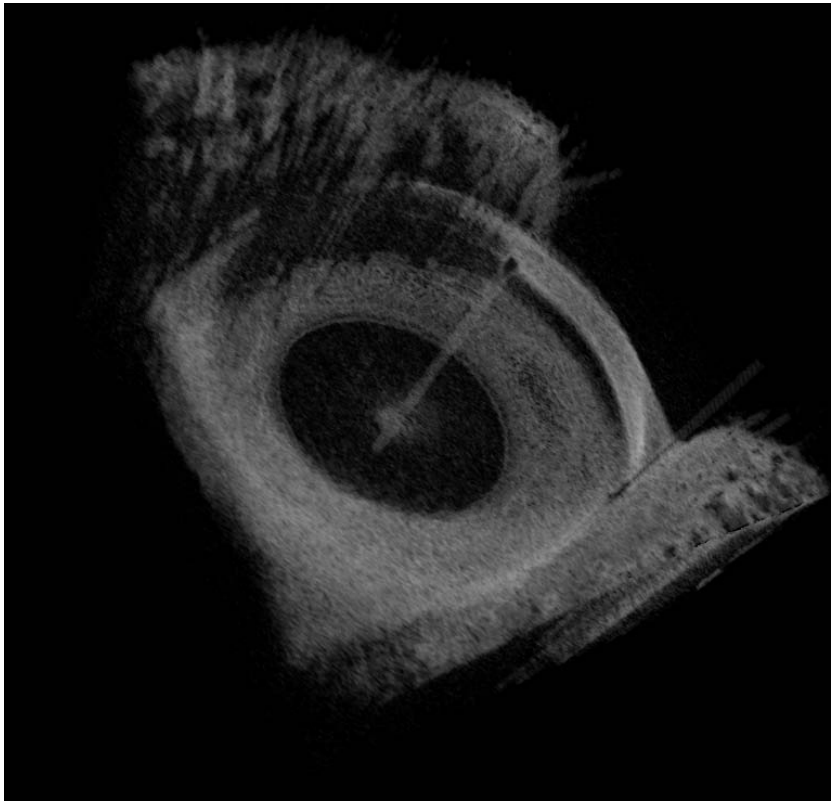
B. L. Sikorski, et al., Ophthalmology, 2011

Anterior Segment Imaging



Anterior segment imaging



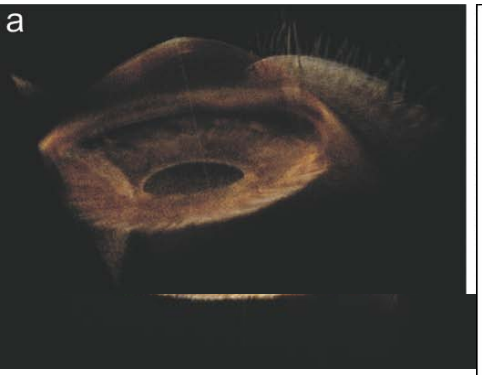


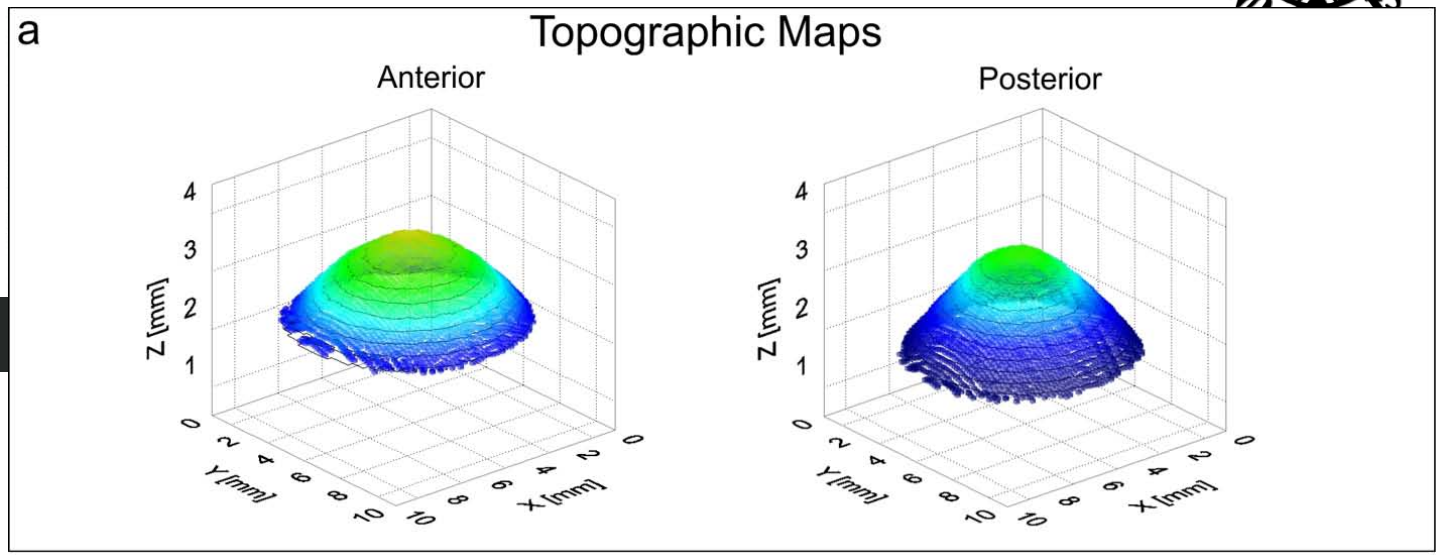
M. Gora et al. Optics Express 17(17), 14880-14894, 2009, I. Grulkowski et al..Opt Express, 17 (6), 4842-4858, 2009.

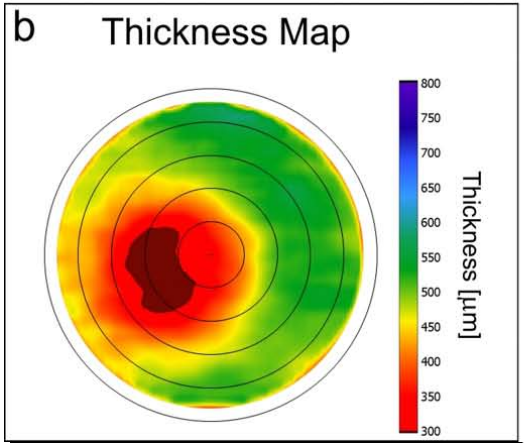
S. Ortiz et al. Biomed. Opt. Express 2, 3232-3247 (2011) , S. Ortiz et al., Opt Express, 18 (3), 2782-2796, 2010.

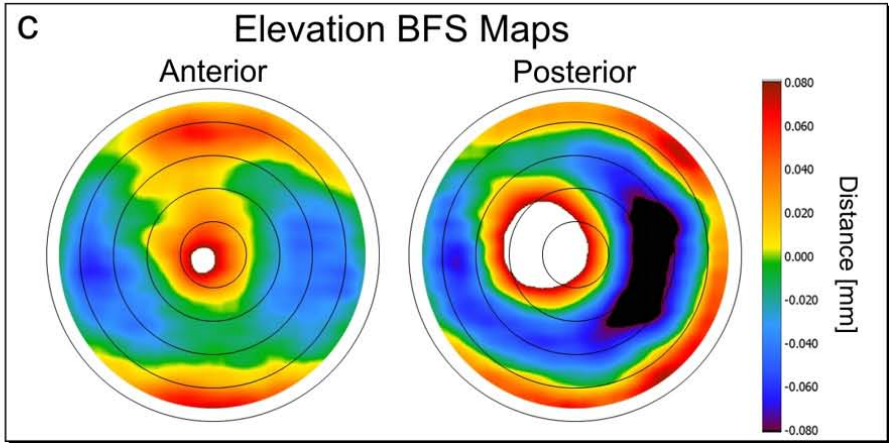
K. Karnowski et al., Biomedical Opt Express, 2 (9), 2709-2720, 2011

Ocular morphometry



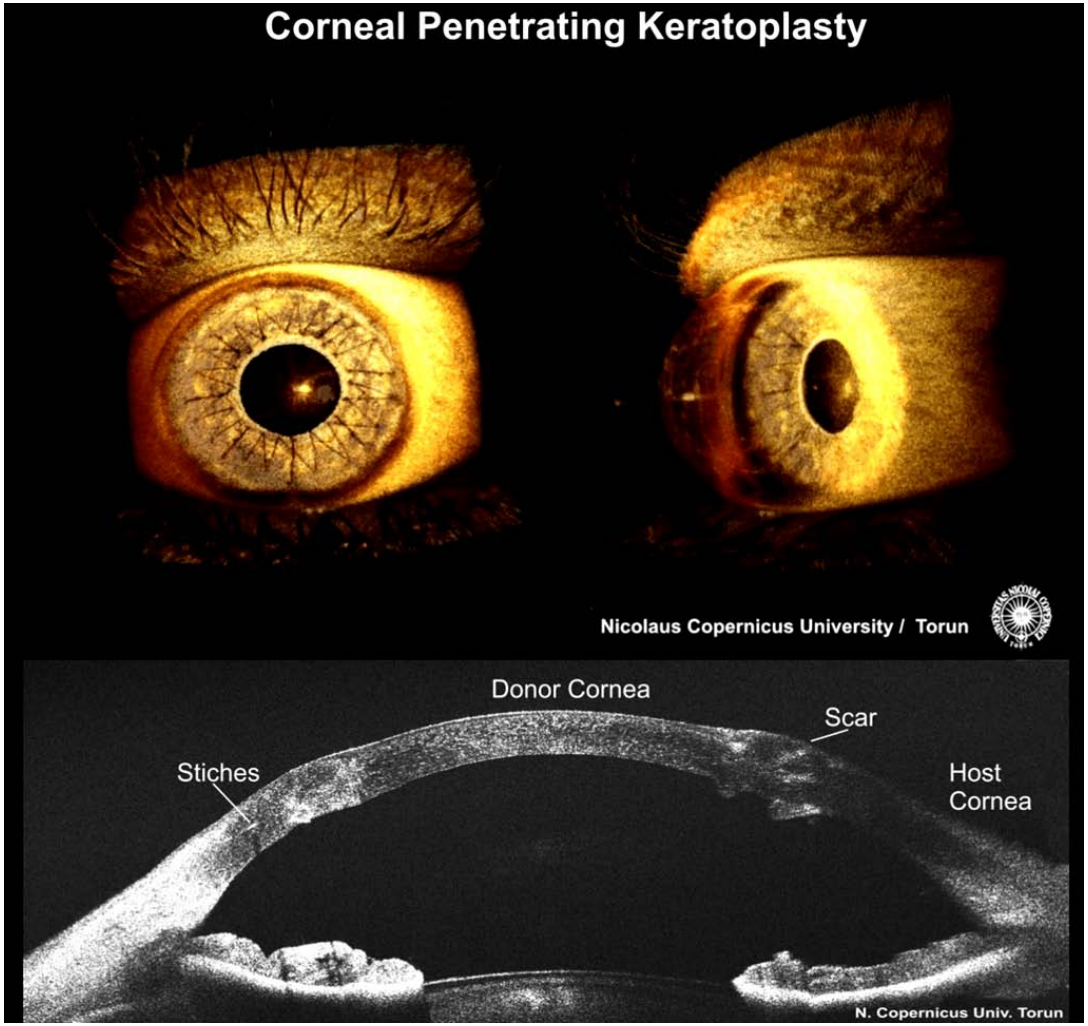


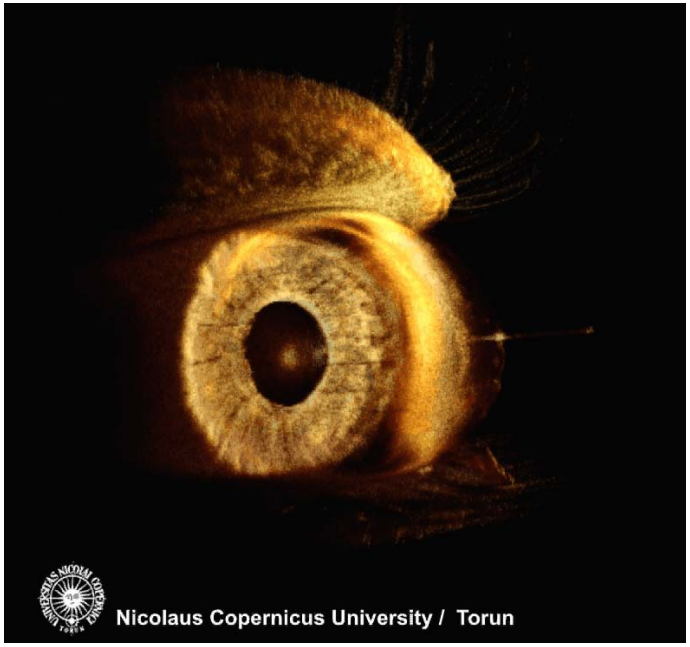




M. Gora et al., Optics Express 17(17), 14880-14894, 2009

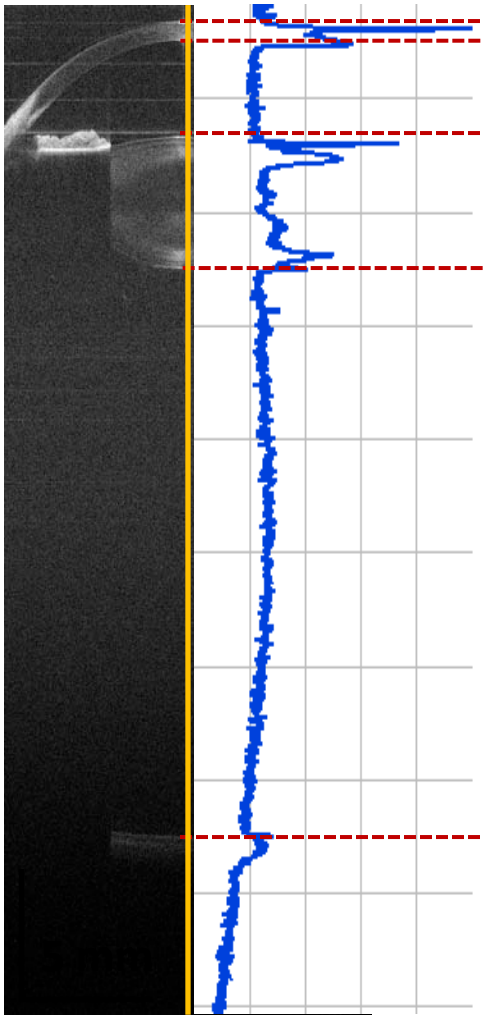
Corneal transplant





K. Karnowski et al., Biomedical Opt Express, 2 (9), 2709-2720, 2011

Full Eye Imaging and Non-Contact Ocular Biometry



Intraocular Distances	
Central Corneal Thickness	0.527±0.003mm
Aqueous Depth	3.305±0.030mm
Anterior Chamber Depth	3.831±0.029mm
Lens Thickness	3.880±0.030mm
Vitreous Depth	18.674±0.018mm
Axial Eye Length	26.384±0.016mm

and more ….

IOL Master – 20 um
Immersion Ultrasound – 100 um

OCT can provide a lot of information

structure

- intensity of light back-scattered / back-reflected
- refractive index gradient

motion

- Doppler shift (axial velocity)
- phase variance, Doppler shift variance (transverse velocity)
- speckle analysis

contrast in OCT images

molecular contrast

- absorbance
- absorption coefficient
- concentration of the absorbing agent

phase change

- differential phase contrast

elastic properties

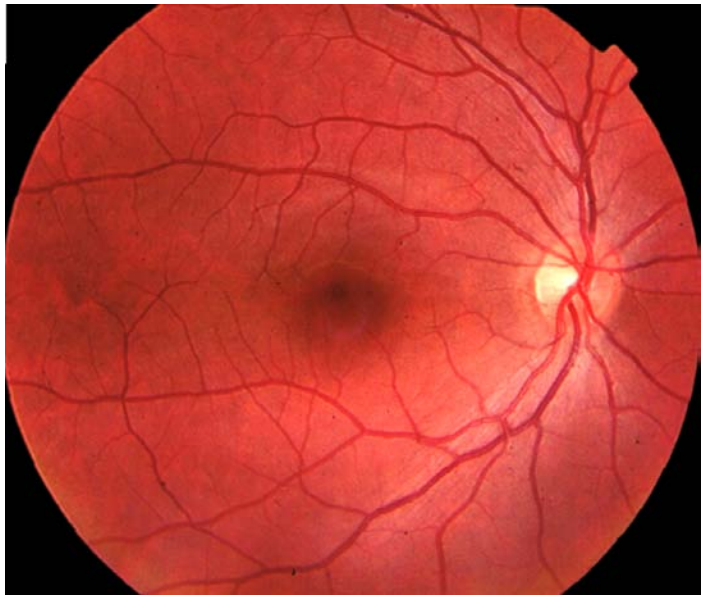
- stress
- deformation
- elastic coefficient

birefringence

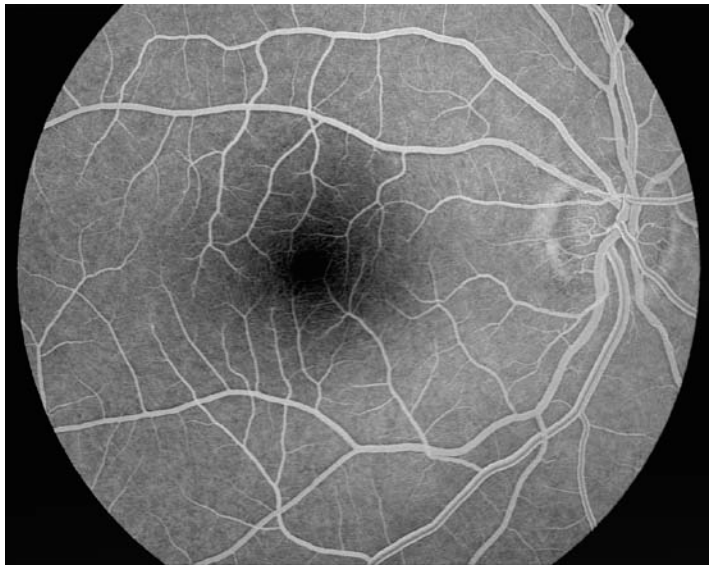
- retardation
- birefringence
- ellipticity

Visualization of retinal vasculature

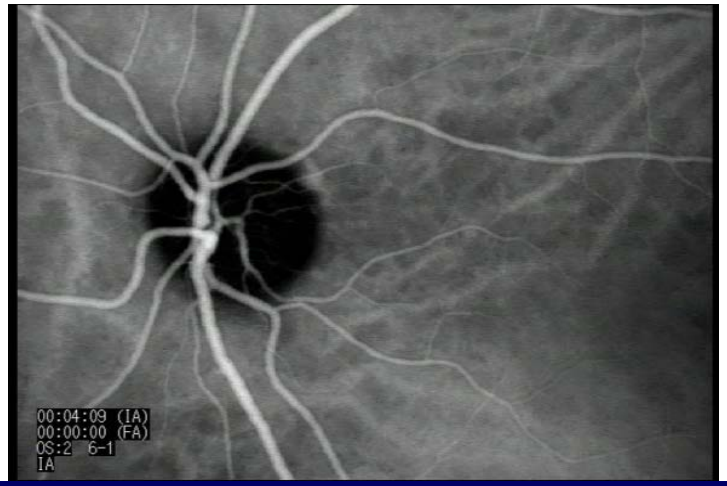
Fundus photograph



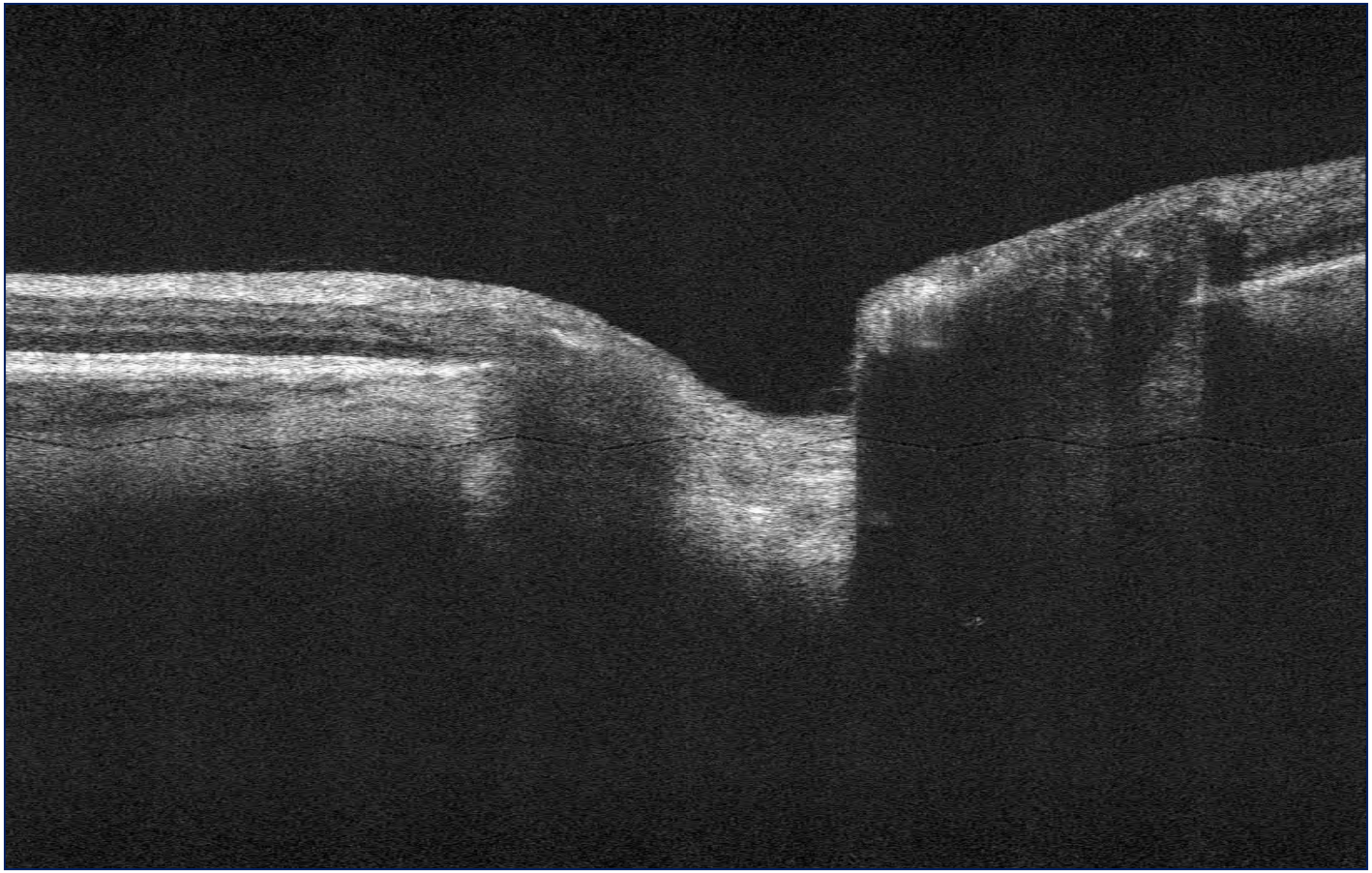
Fluorescein angiography



ICG Angiography

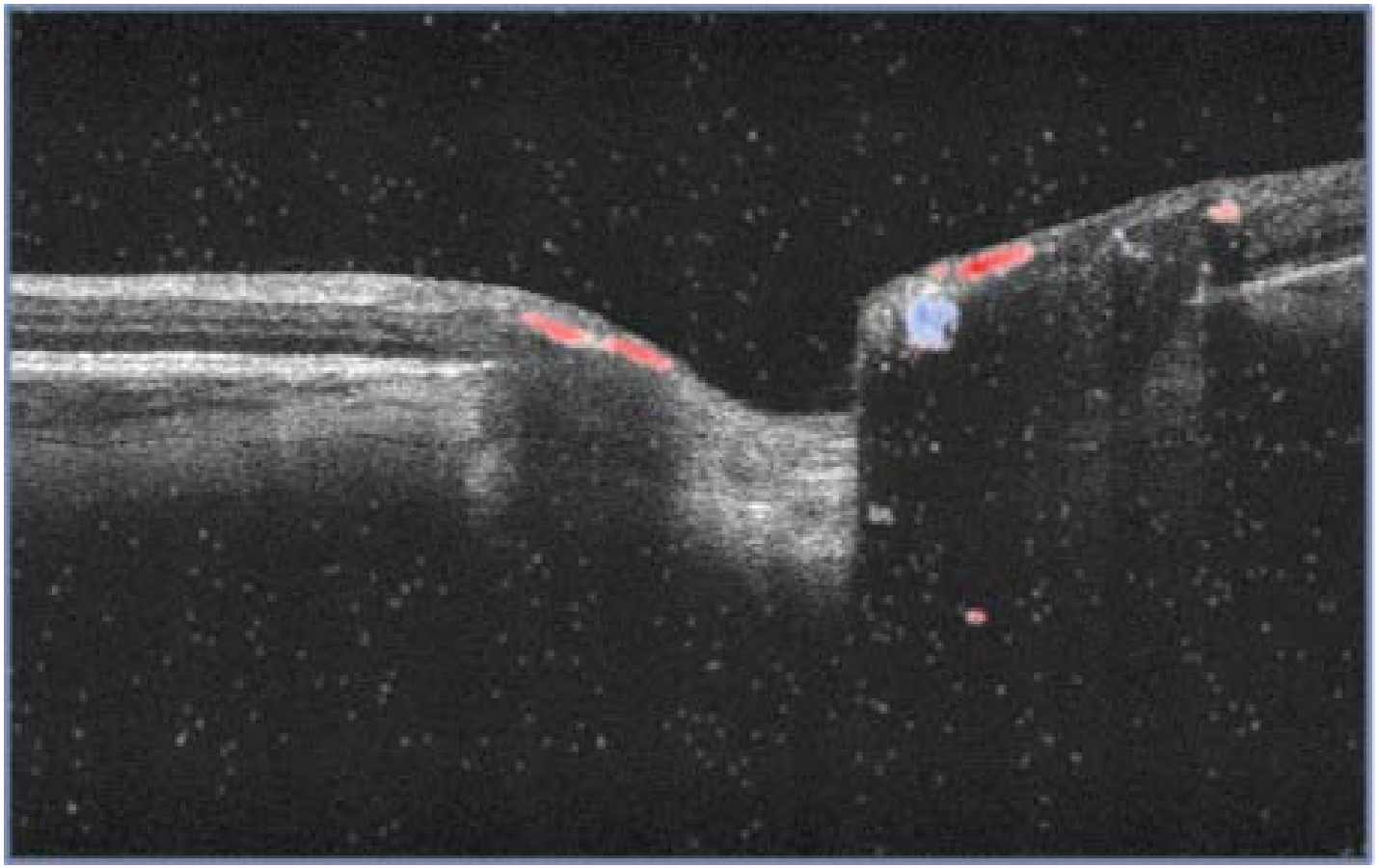


Doppler OCT



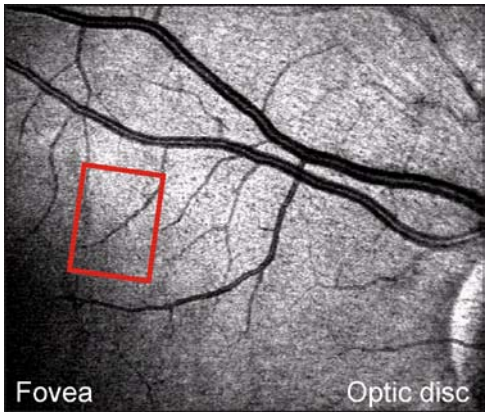
M. Szkulmowski, et al, Opt. Express, **16**(9), 6008, 08

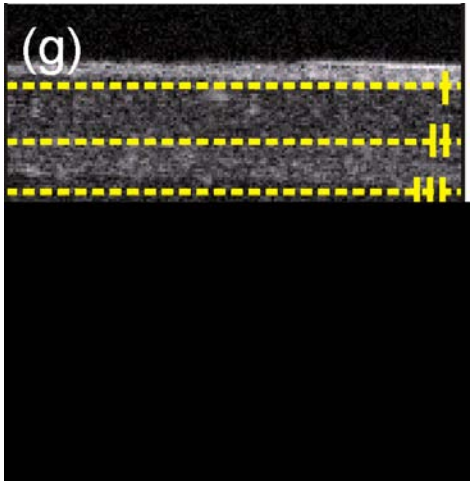
Doppler OCT

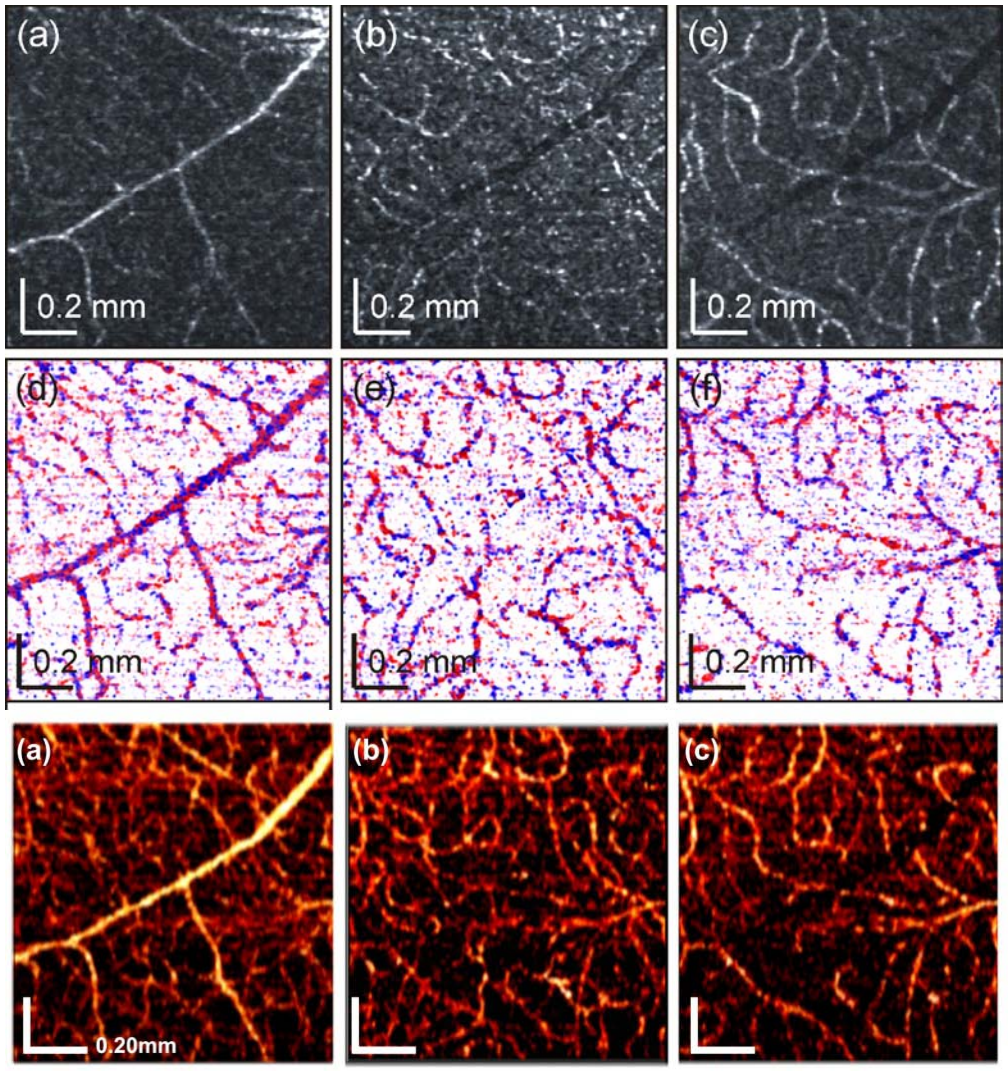


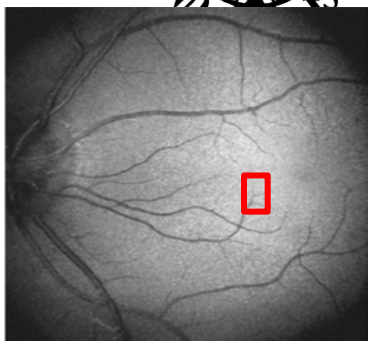
M. Szkulmowski, et al, Opt. Express, **16**(9), 6008, 08

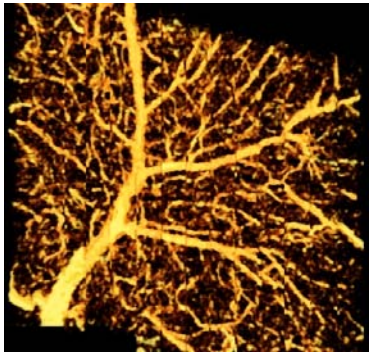
Retinal microcappilary network

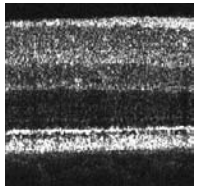


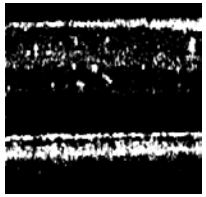








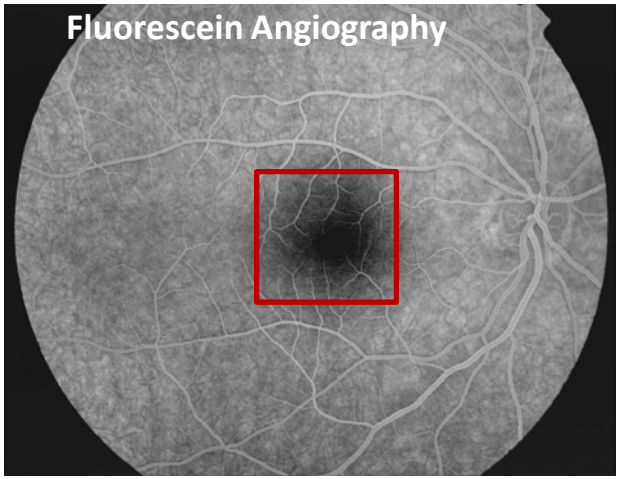




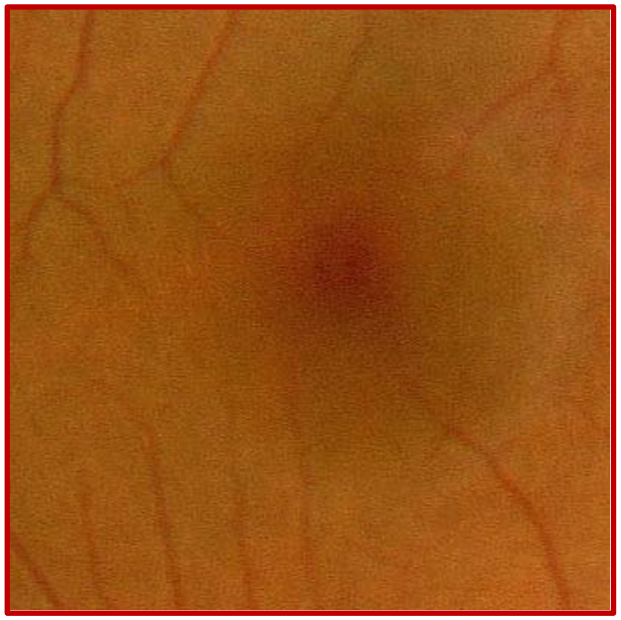
I. Grulkowski et al., Optics Express 17 (26), 23736–23754, 2009

I. Gorczyńska et al. ARVO/ISIE'12

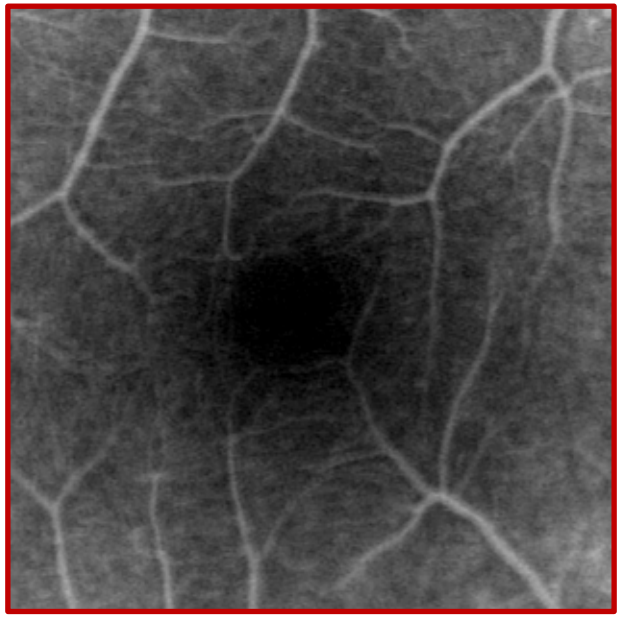
OCT angiography for flow imaging



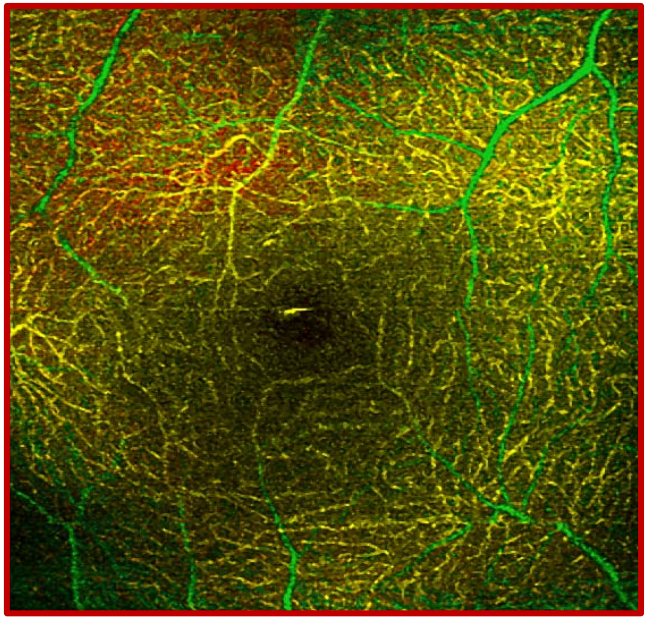
Fundus photography



Fluorescein Angiography

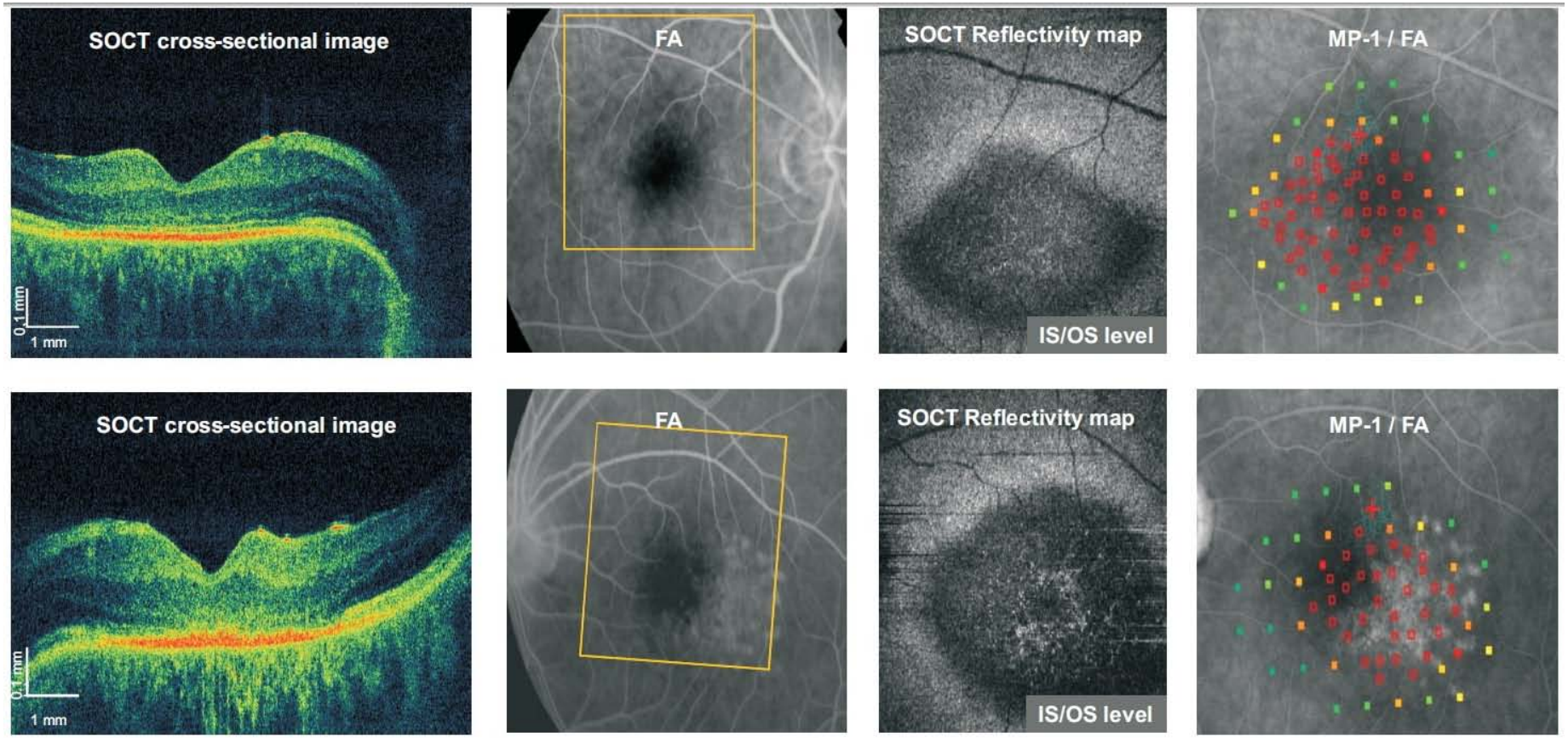


OCT depth color-coded projection



OCT-based reflectometry

Photoreceptor dystrophy



MP-1 – Microperimeter (Nidek/Japan)

B. L. Sikorski et al., Brit J Ophthalmol 92, 1552-1557, 2008

Summary

- interferometric techniques enable multi-scale imaging
- OCT as a toll for noninvasive imaging of both structure and functions of the objects
- cross-sectional images, volumetric data sets and 4-D imaging
- multiple disciplines involved

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