Hyperspectral and multispectral skin imaging

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Towards better skin assessment

- Skin cancer, other diseases → clinicians need **non-invasive**, **patient-friendly** and **informative** devices for skin diagnostics;
- Commercial skin imaging devices – still with drawbacks:
  - Low sensitivity/specificity;
  - Insufficient reliability;
  - Bulky design, cable/PC;
  - Able to collect spectral information, but too slowly – motion artifacts create problems; image conversion undeveloped;
  - Expensive, ~20-40 kEUR.

Siascope

DermaLite

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Biophotonics laboratory: our profile

(5...40 co-workers, strongly depending on projects)

Aim – to develop handy and **affordable for end-users** methods, devices and technologies for clinical diagnostics and monitoring by exploiting **optical** features of ***in-vivo*** **skin**.

Non-invasive → non-contact imaging technologies:

- **Multi-spectral reflectance imaging** → skin chromophore mapping for diagnostics, follow-up and self-monitoring (today's topic)
- **Autofluorescence intensity, lifetime and photobleaching rate imaging** → skin cancer diagnostics (Emily's poster on Thursday)
- **Photoplethysmography imaging** → distant cardiovascular monitoring - e.g. heart rate and arrythmia, anaesthesia control (NBC-17, Tampere, in 2 weeks)

Recent review paper

sensors

MDPI

Review

Multispectral, Fluorescent and Photoplethysmographic Imaging for Remote Skin Assessment

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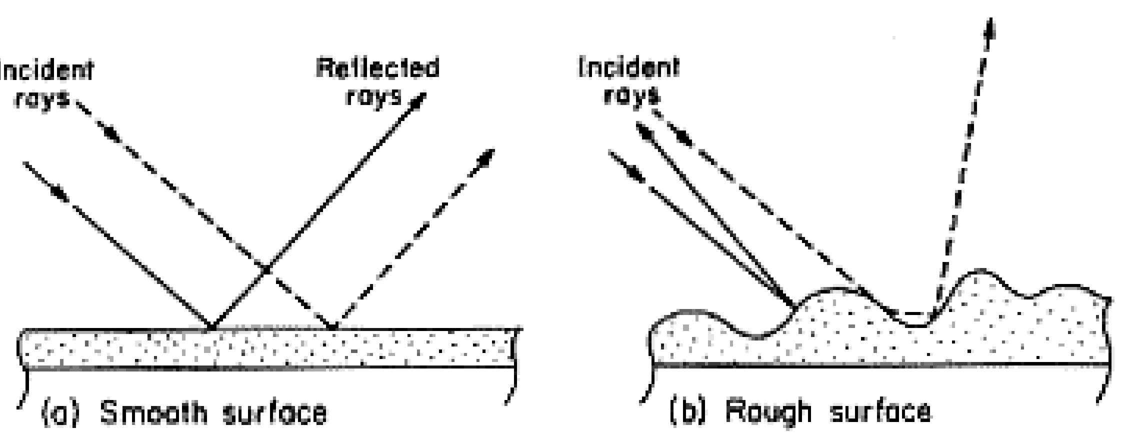
Sensors **2017**, *17*, 1165; (open access)

Outline

- Basics: spectral imaging and skin optics
- Hyperspectral imaging for skin cancer detection
- Smartphones for multispectral skin assessment
- Multi-monochomatic spectral imaging – a novel approach under development (skin + forensics)

Spectral imaging

- **Spectral reflectance** (single point): **$R(\lambda) = I_r(\lambda)/I_o(\lambda)$,**
  where $I_o(\lambda)$ – intensity of **incident** light at the wavelength λ; $I_r(\lambda)$ – intensity of **reflected** light at the same wavelength
- If reflected from a surface and detected at each point of it (e.g. by camera), we get x-y distribution of $R(\lambda)$**: spectral image** ($R_i(\lambda)$, i – number of pixels)
- λ – a specific single wavelength, e.g. 532nm



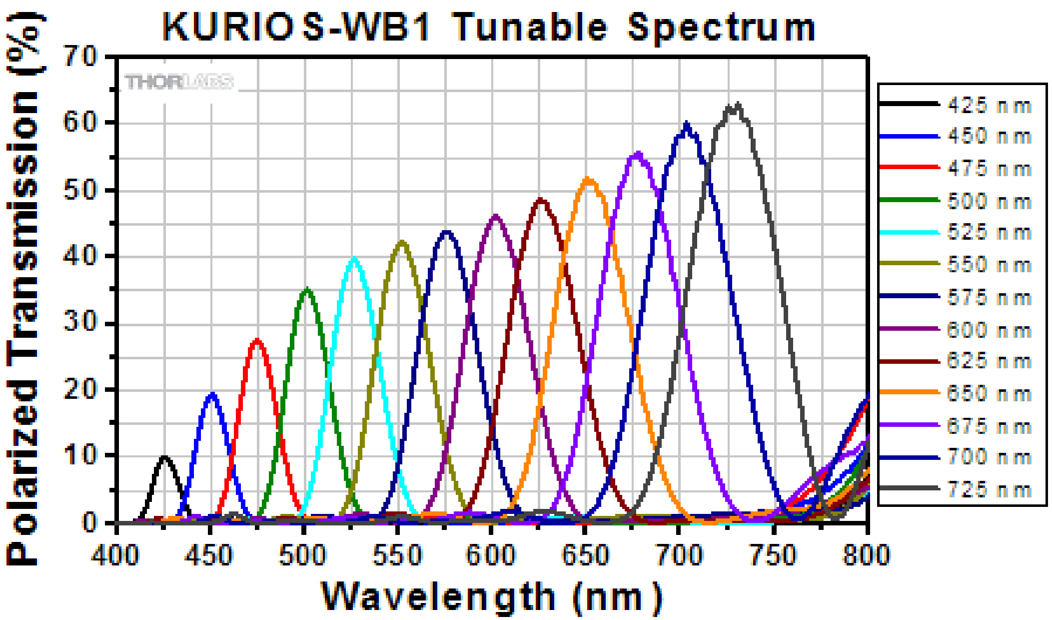
Two ways to obtain spectral images

1. By **narrowband filtering** of the photo-detector at broadband (e.g. white) illumination - for example, satelite spectral imaging of Earth (yesterday, Katya Lefevre on HSI)
2. By spectrally **narrowband illumination** of the object – only this particular spectral band can be reflected and detected (not always possible)

Hyperspectral & **multi**spectral imaging (single → multiple wavelengths)

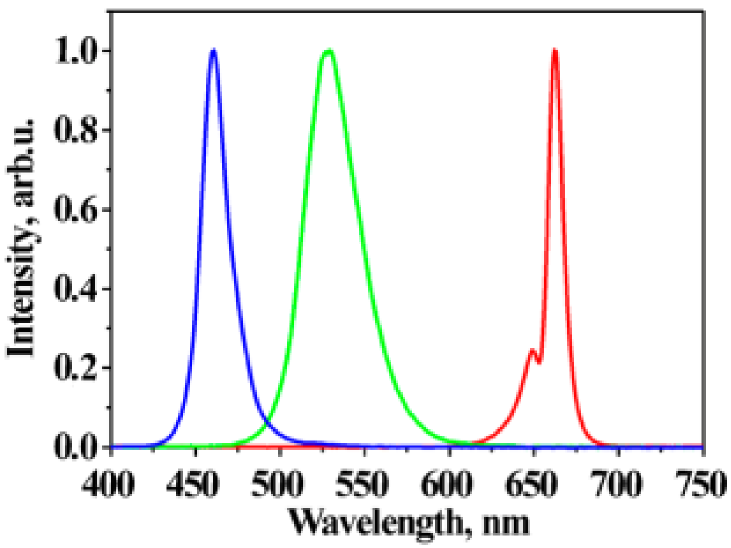
<u>Hyperspectral</u>:

adjacent overlapping spectral bands



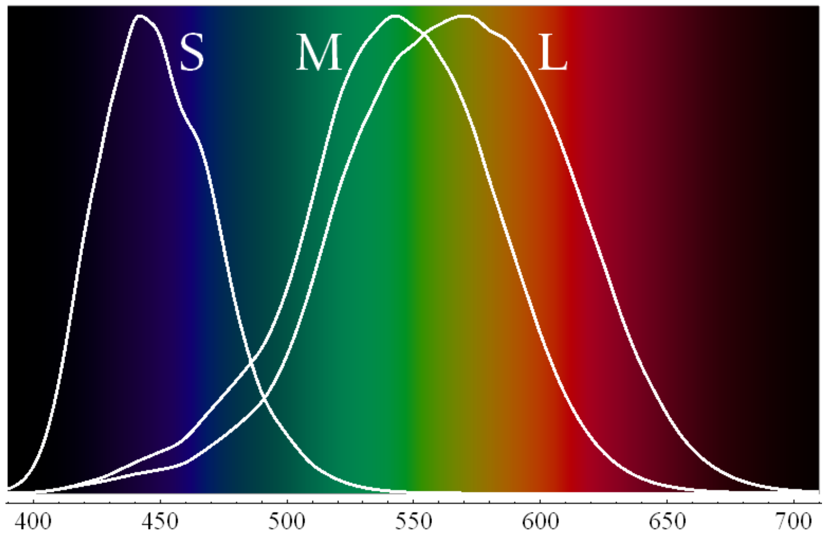
<u>Multispectral</u>:

selected non-overlapping spectral bands

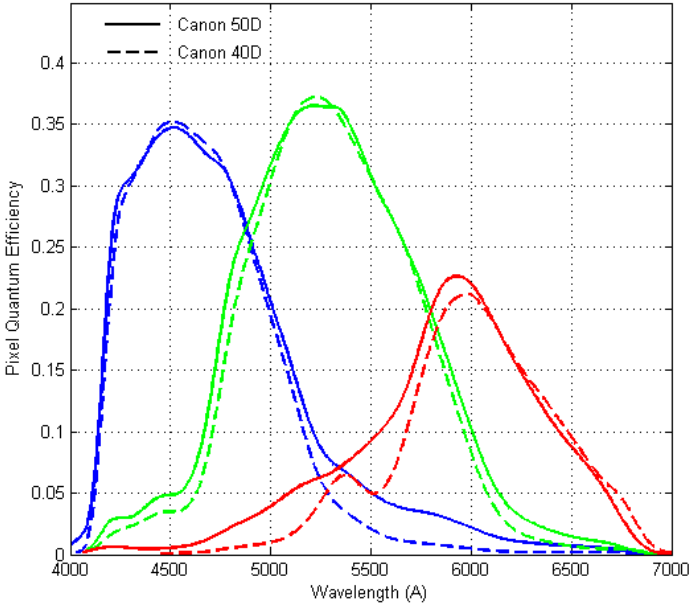


Human eyes and RGB image sensors are **hyper**spectral image detectors

Human eye



CMOS sensor



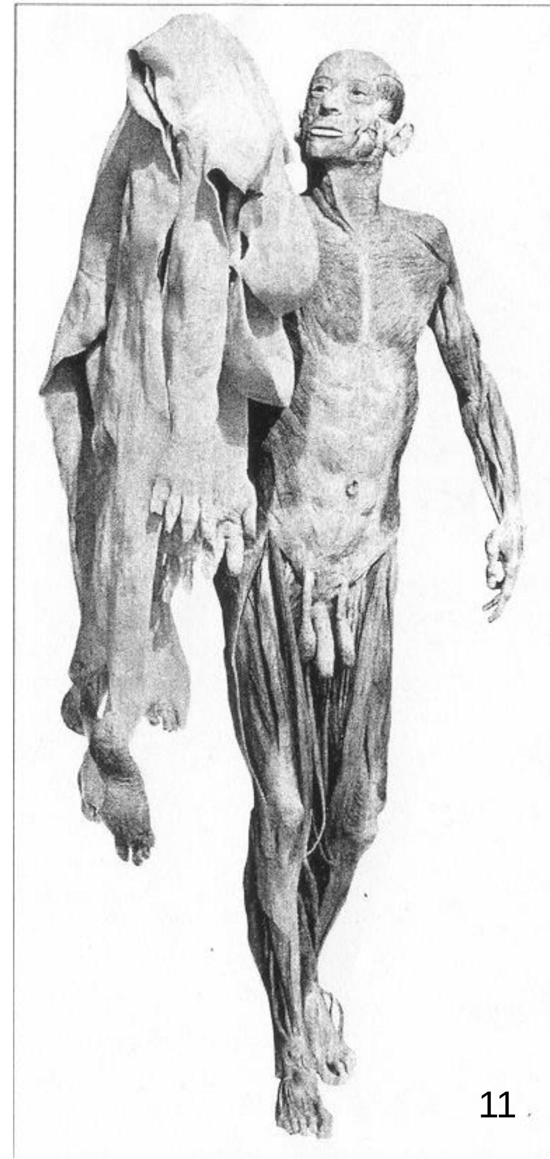
Human vision: brain processes in parallel the outputs of all 3 **retinal cones**, ΣRGB. Always merged (integrated) signal, **never a pure spectral image** (e.g. only R).

Image sensor first measures and reports **separated R, G, B values** from each pixel, and then calculates the corresponding color coordinates for the particular pixels

RGB image → R-image, G-image, B-image; **3 SEPARATED SPECTRAL IMAGES**!

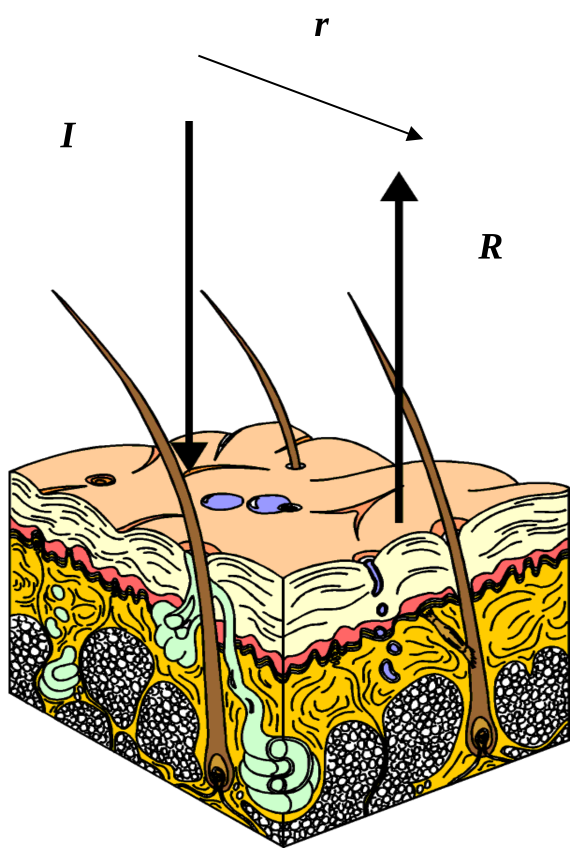
Skin: important for everybody

- total area ~ 1,5-2 m^2
- contains ~ 1 liter blood (15-20% of total blood in human body)
- protects internal organs and tissues mechanically and biochemically
- thermoregulates the body (sweating, blood perfusion, ...)
- exchanges water (~ 1% / 24h) and salts
- ensures senses by skin receptors
- “soil” for hairs
- ...



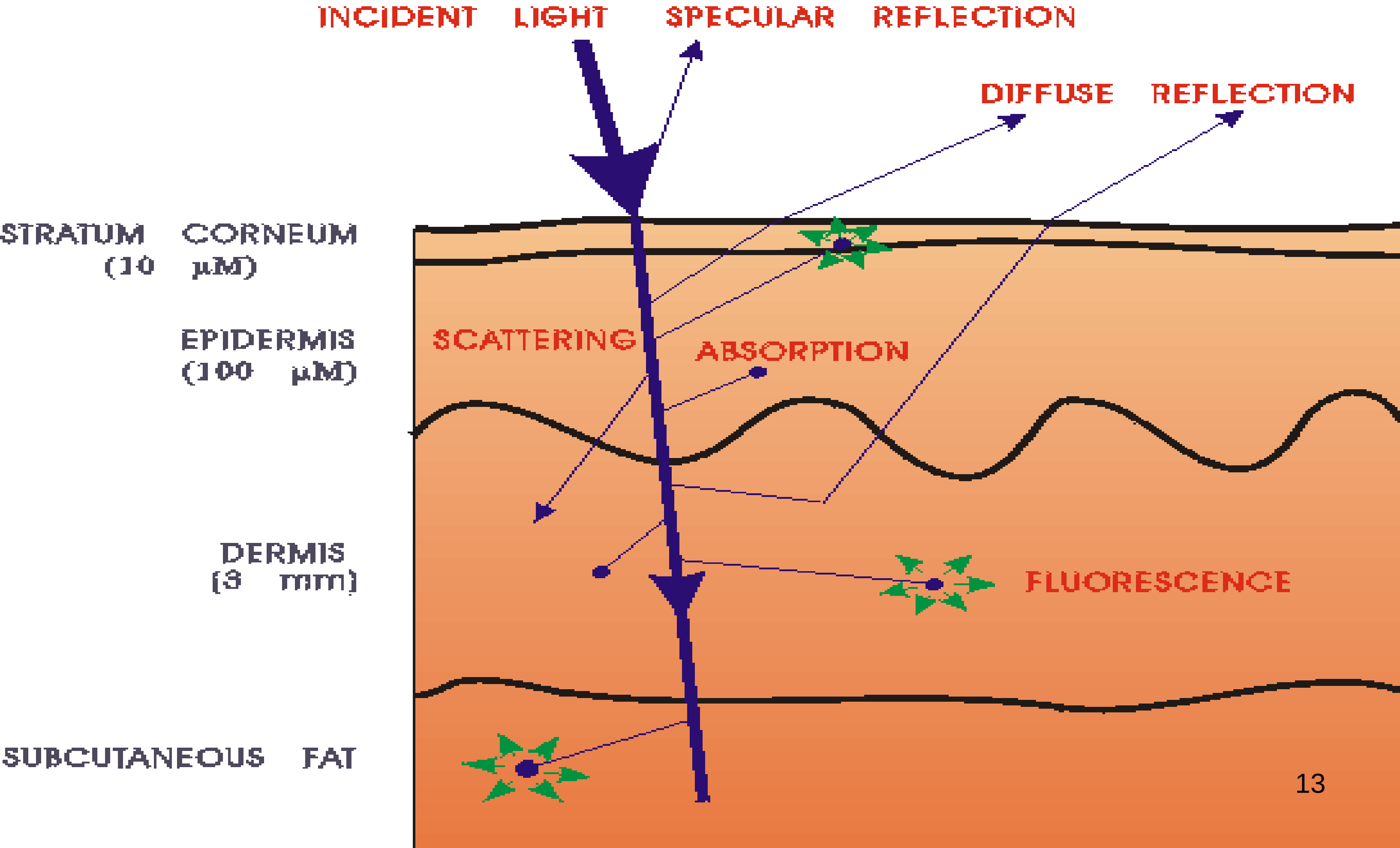
Skin structure

- Skin has a multi-layer (anisotropic) structure
- Each layer (stratum corneum, epidermis, dermis, hypodermis) has different optical parameters
- Absorption and scattering coefficients at each layer have different wavelength dependencies (spectra)
- Very complicated skin **chromophore** (pigment) and **fluorophore** composition

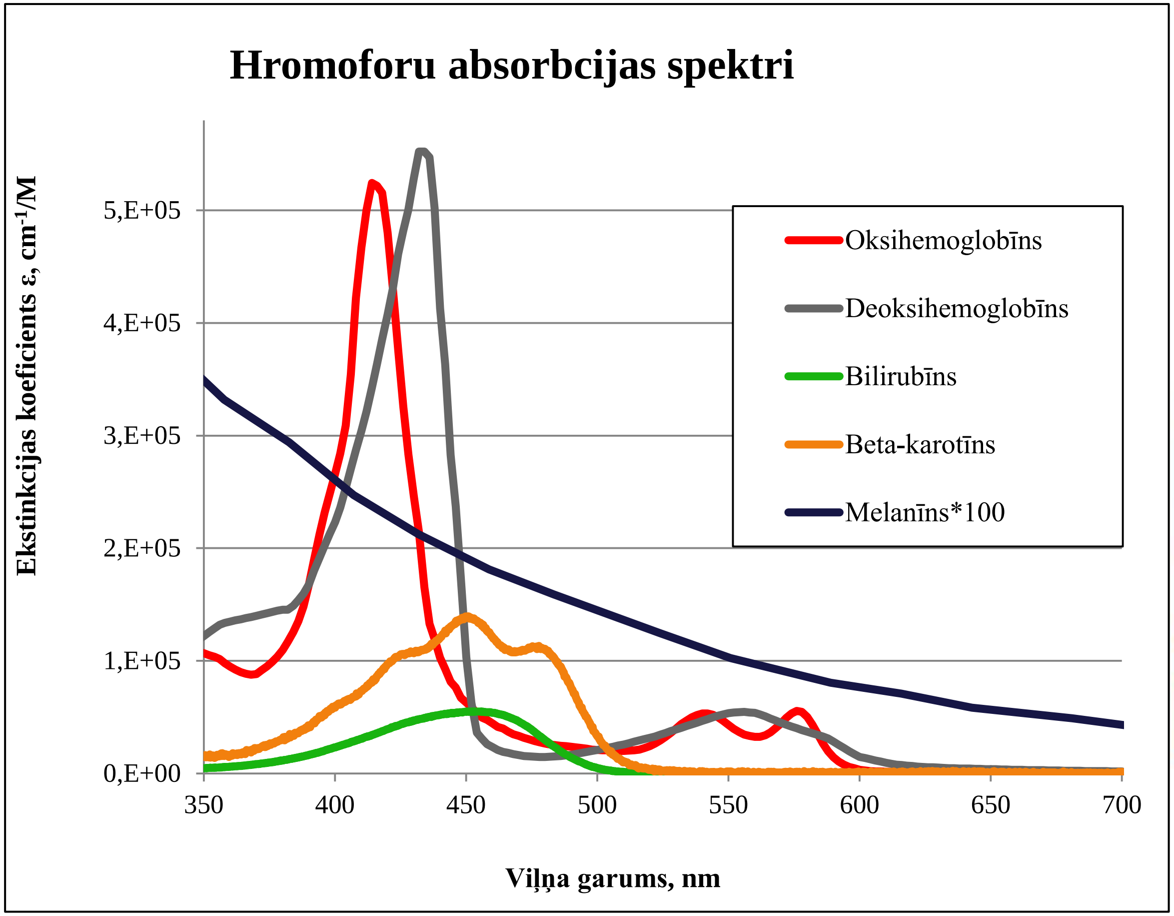


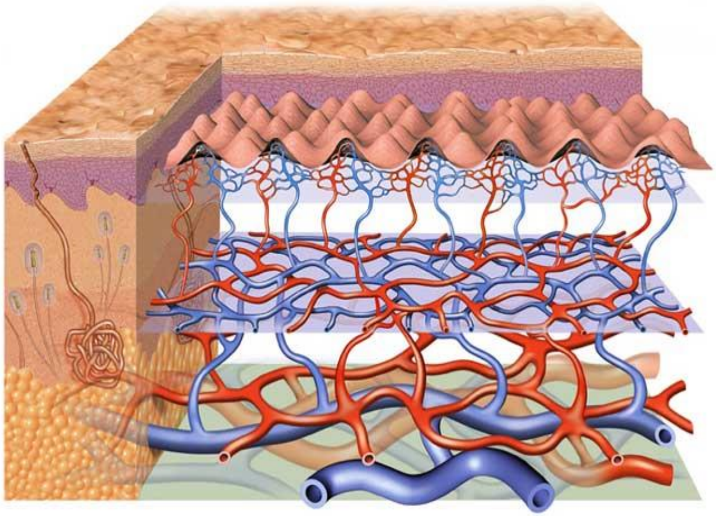
Skin tissue

Shining light to skin: the basic options



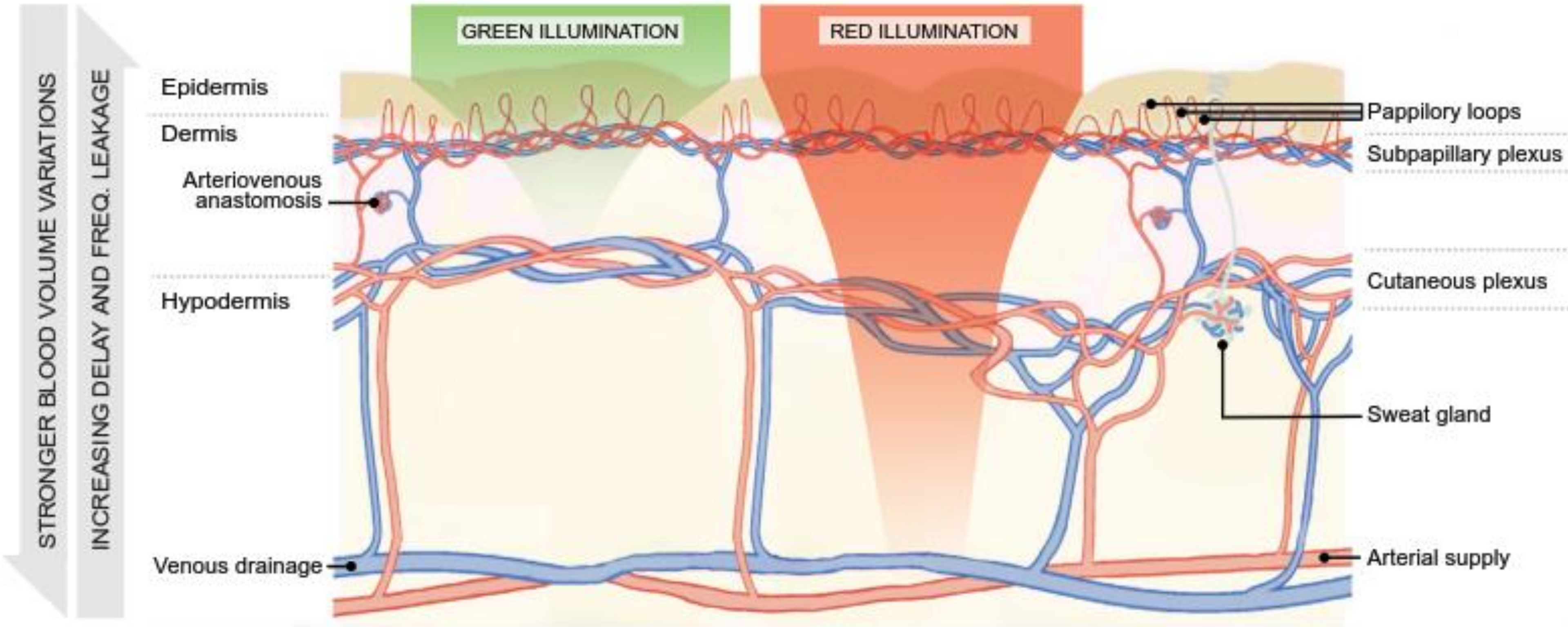
The main absorbers (chomophores) in skin





Skin color (400-700nm) is mainly determined by 3 chromophores – **melanin** (in epidermis) and **oxy- and deoxy-hemoglobin** (blood in dermis). **Bilirubin** content increases in bruises and if liver is not funcioning properly (yellowish skin).

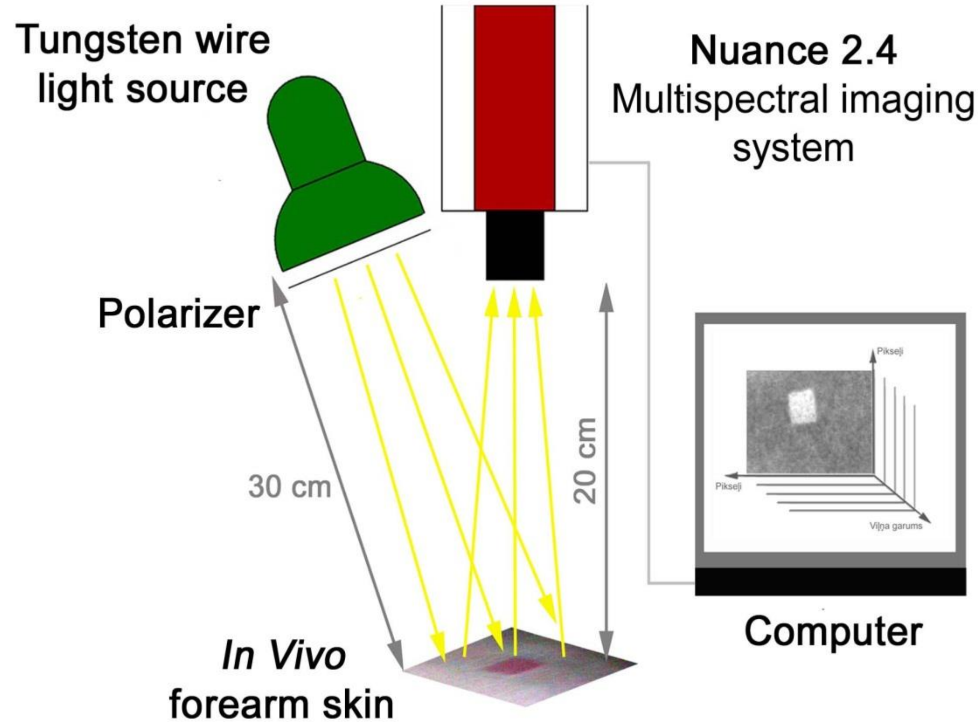
Light penetration in skin: depends on wavelength

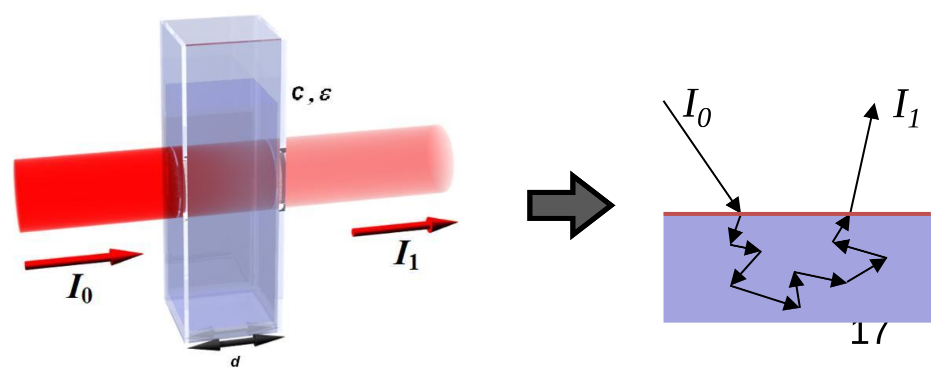


So, can we somehow measure the skin hromophore content and distribution?

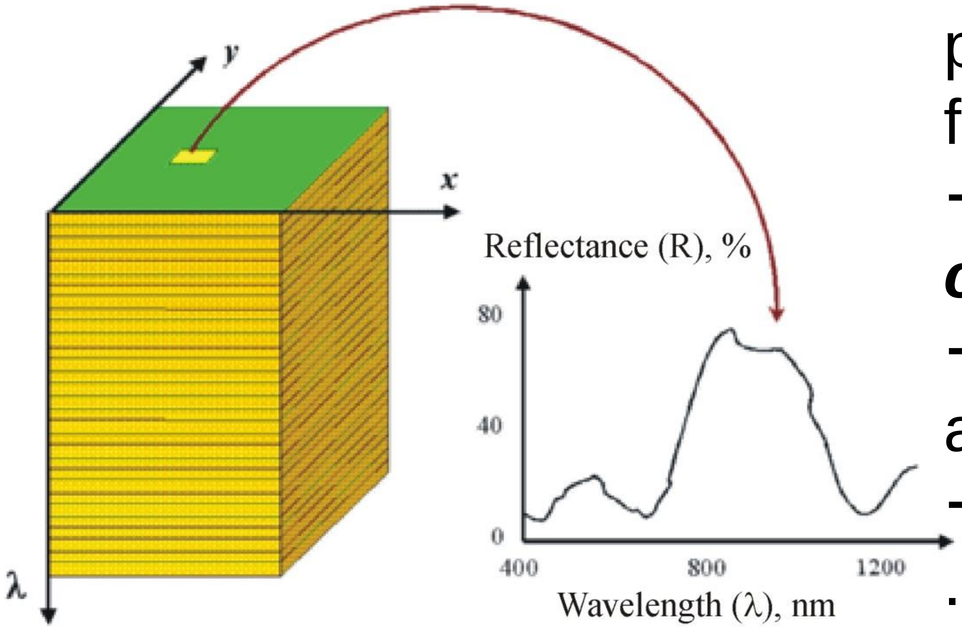
Reflectance imaging spectroscopy

- Hyperspectral imaging cameras allow remote measuring of DR spectra at each image pixel (skin spot <1mm^2)
- New challenge: distant mapping of skin chomophore distribution
- Surface reflection is not informative, should be avoided (e.g. by crossed polarizers)





Skin chromophore mapping



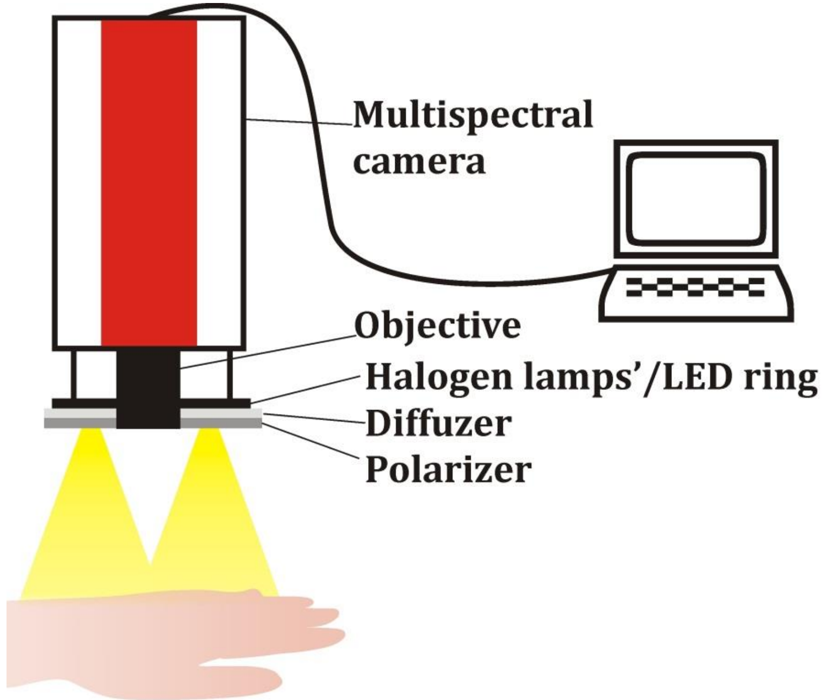
Principle: spectral **image cube** provides reflection spectrum from each image pixel
→ ***Fit the measured and calculated spectra***
→ find chromophore composition at each pixel
→ draw skin chromophore maps
.... white reference needed (***I***)

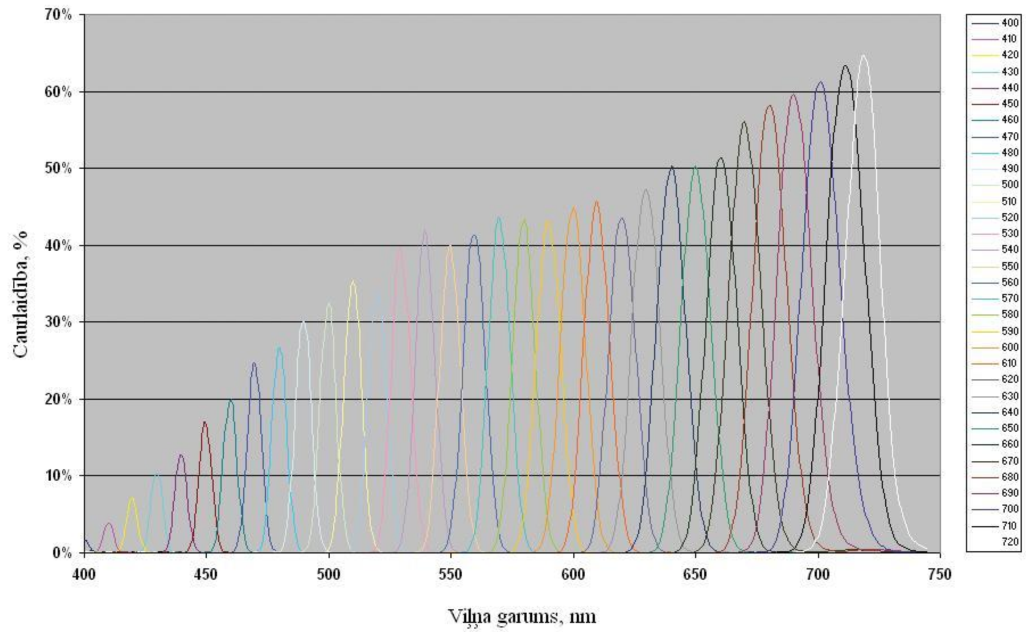
3-chromophore approximation:

$$\mathbf{OD(\lambda) = a_{HbO2}\varepsilon_{HbO2}(\lambda) + a_{Hb}\varepsilon_{Hb}(\lambda) + a_m\varepsilon_{Mel}(\lambda) + a_{back}\ \ [= 10\ lg(\mathit{I_o}/\mathit{I})]}$$

D. Jakovels and J. Spigulis, 2-D mapping of skin chromophores in the spectral range 500-700 nm. ***J. Biophoton.***. v.3, No. 3, pp. 125–129 (2010).

HSI clinical measurement set-up





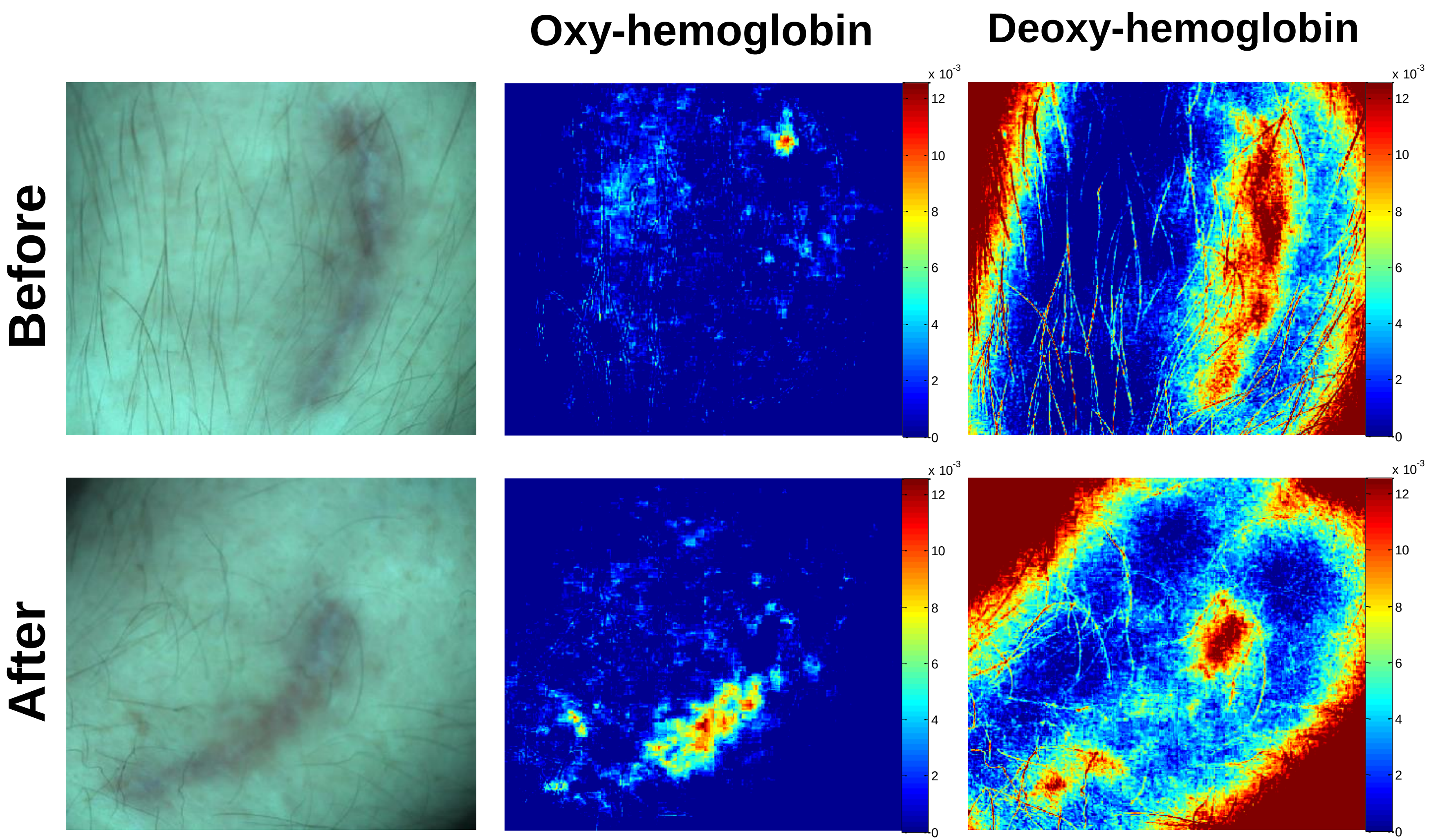
Hyperspectral imaging camera *Nuance EX*, adapted for skin in vivo measurements:

- CCD 1392x1040 pixels
- Tunable liquid-crystal filter, selects 51 spectral band 450-950nm, Δ ~ 15nm

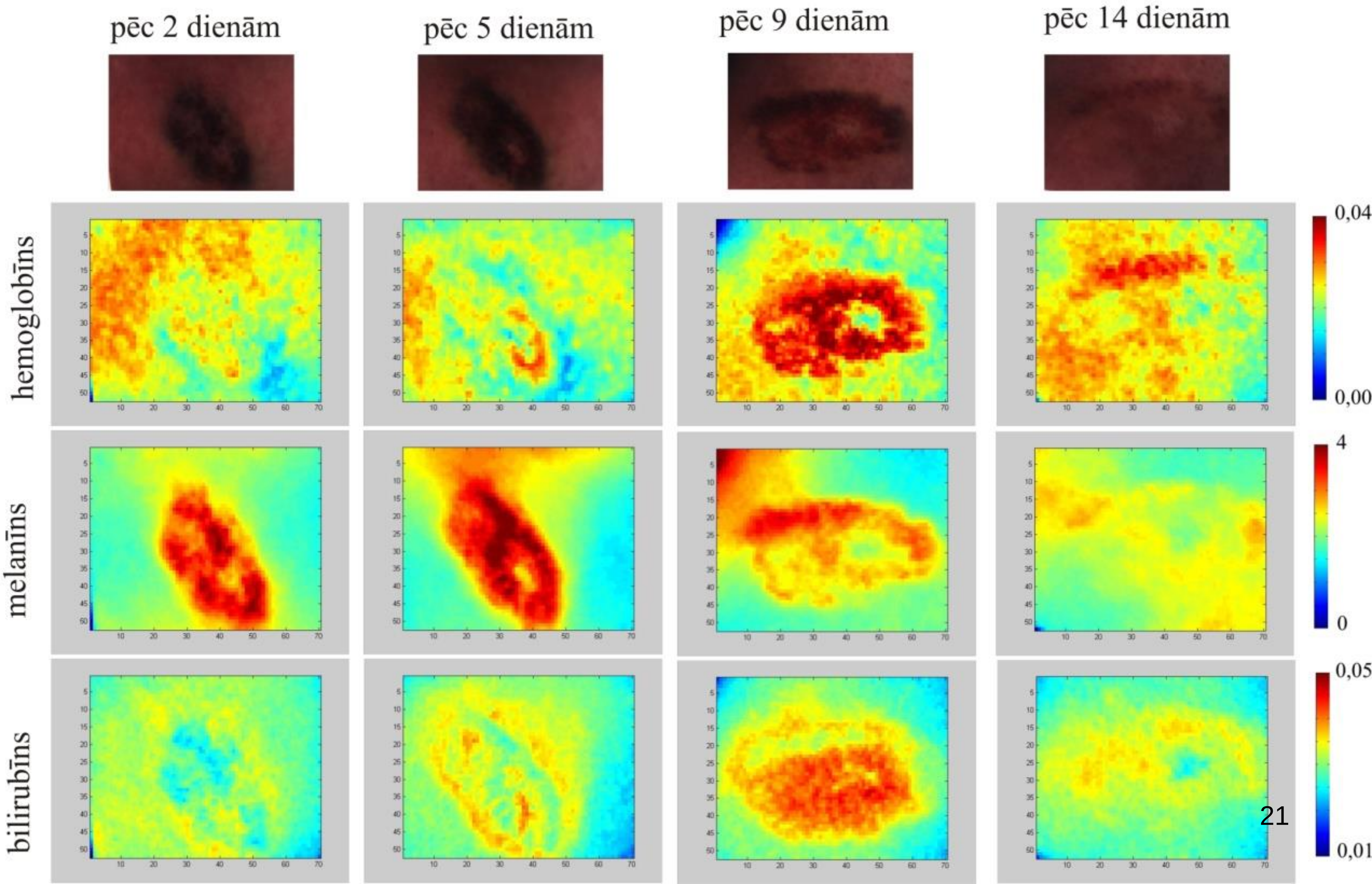
+ white polarized light source
+ white reflector (reference) on skin

Chromophore maps: Scar phototherapy

Treatment performed with 810 nm diode laser



Development of a skin bruise



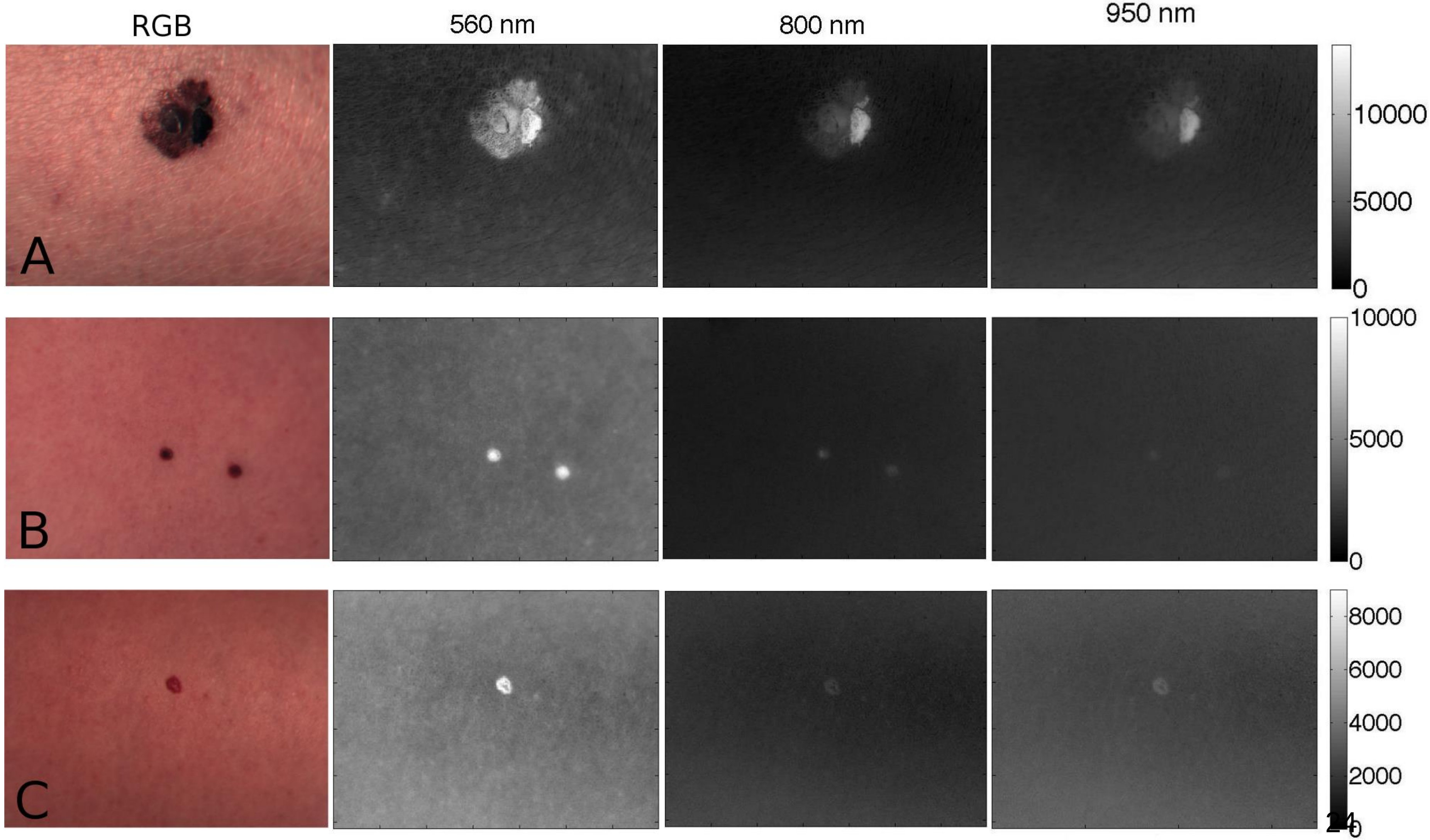
Dermatology: **skin melanoma**

- Melanoma is a leading fatal illness responsible for 80% of deaths from skin cancer
- Only biopsy (invasive sampling) can determine exact malformation diagnose: painful, long waiting time, can rise metastasizing
- Non-invasive / non-contact early assessment would be helpful to select melanomas from other pigmented lesions

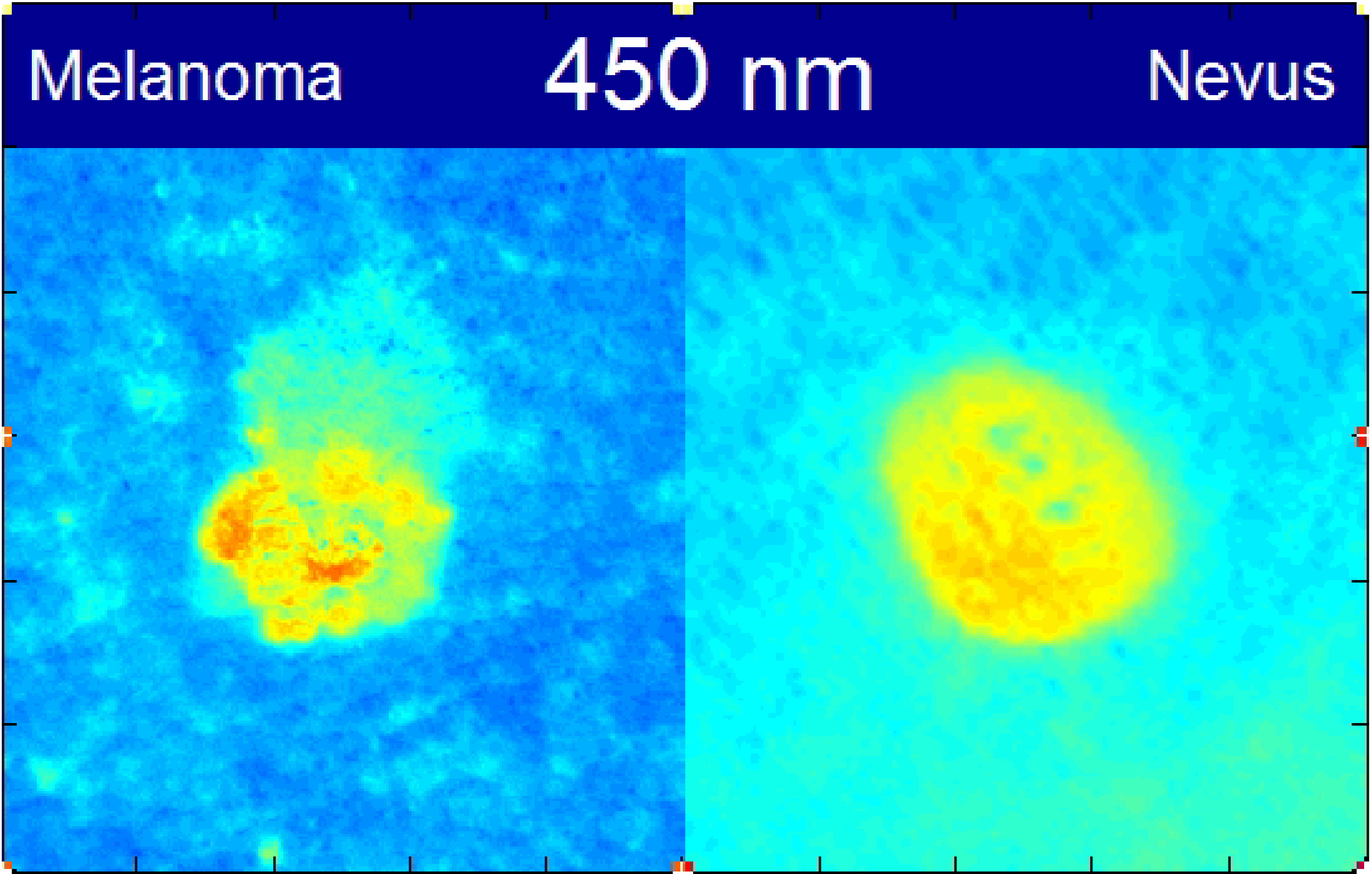
Clinical trial

- 266 pigmented lesions and 49 vascular lesions have been studied by hyper-spectral imaging analysis in three Riga clinics:
  - **malignant pigmented lesions** (***16 cutaneous melanomas***, 6 dysplastic nevi and 1 lentigo maligna) - 23 cases,
  - **non-malignant pigmented lesions** (different kind of nevi and superficial pigmentation) – 243 cases,
  - **non-malignant vascular lesions** (port-wine stain, hemangioma, telangiectasia) – 49 cases,
  - **others** – 19 cases
- The hyperspectral imaging system *Nuance 2.4 (CRI)* and self-developed algorithms for mapping of the three main skin chromophores (melanin, Hb and HbO) were used.
- Pathology grouping: by correlation graphs of chromophores

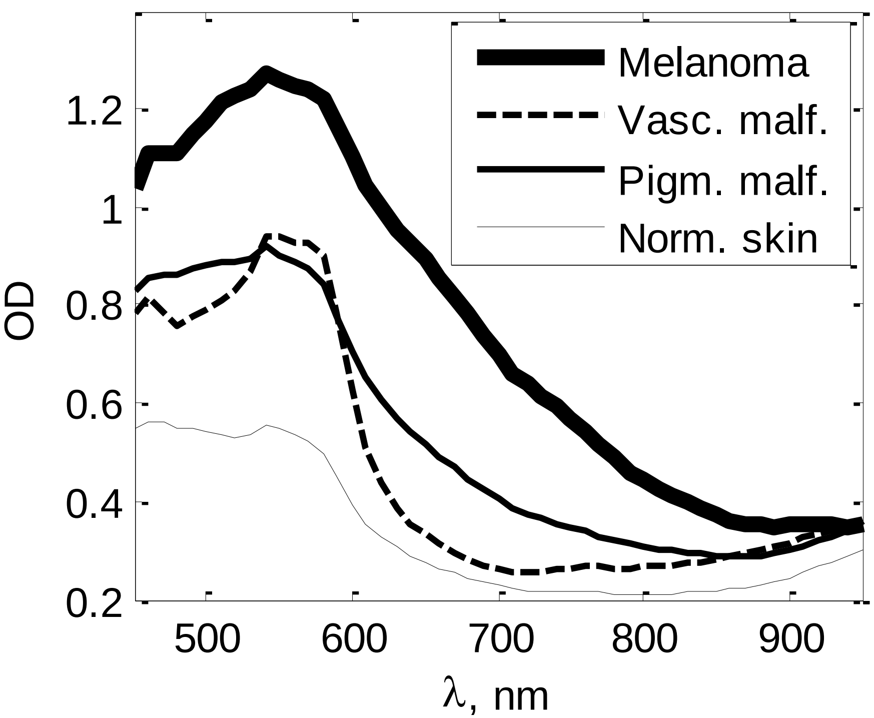
RGB and spectral images of skin malformations (A- melanoma, B- nevus, C- angioma) at three wavelength bands

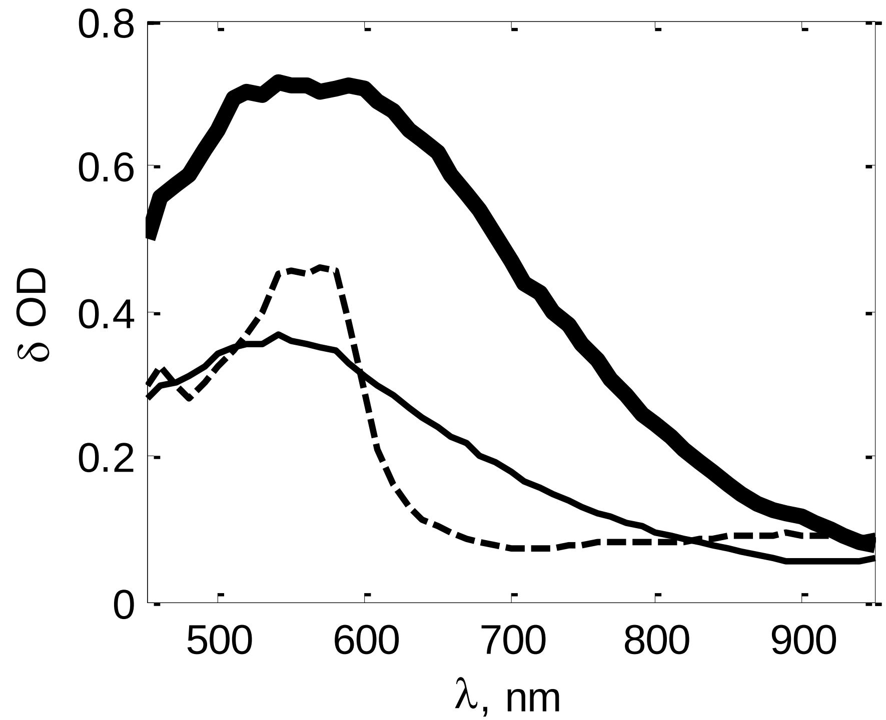


Skin reflectance (OD) at white illumination

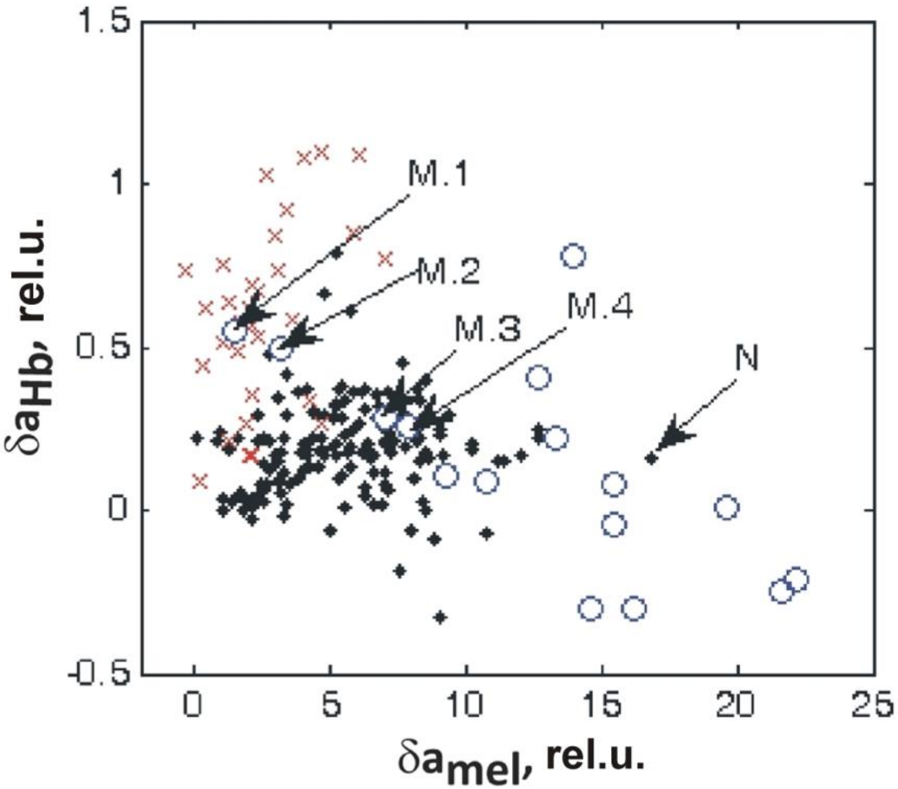


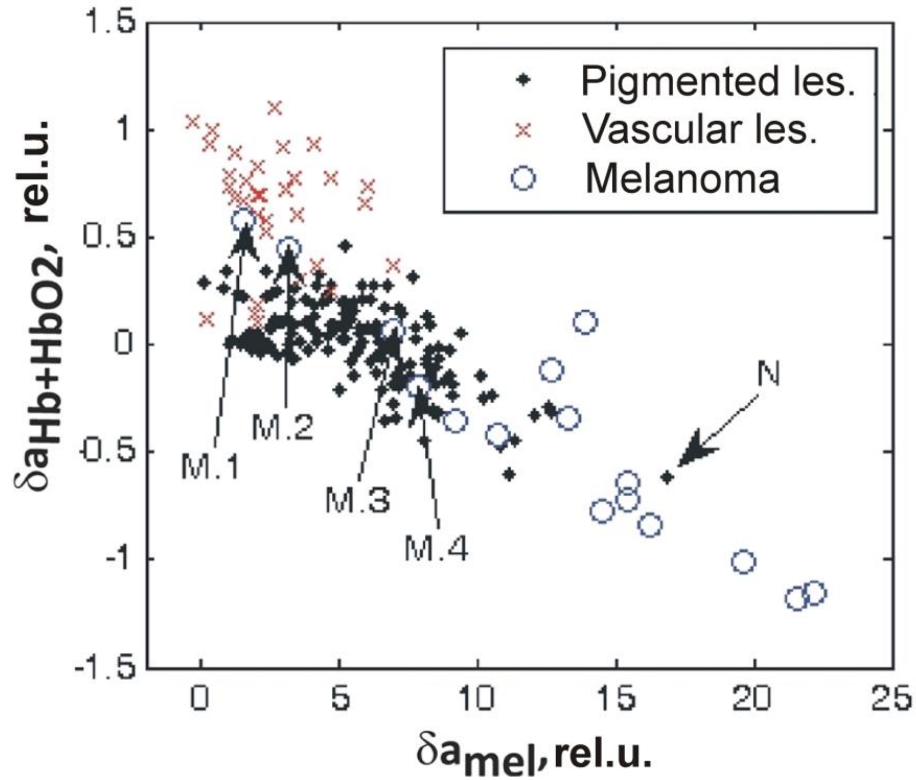
The patient-averaged OD spectra (left) and **OD difference spectra** (right) for melanomas, other pigmented malformations, vascular malformations and normal skin behind the pathology border.





Correlations between the relative concentrations of skin chromophores

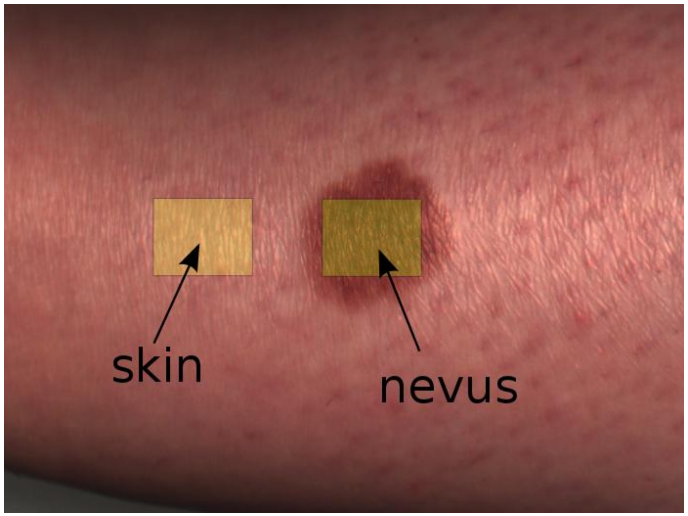




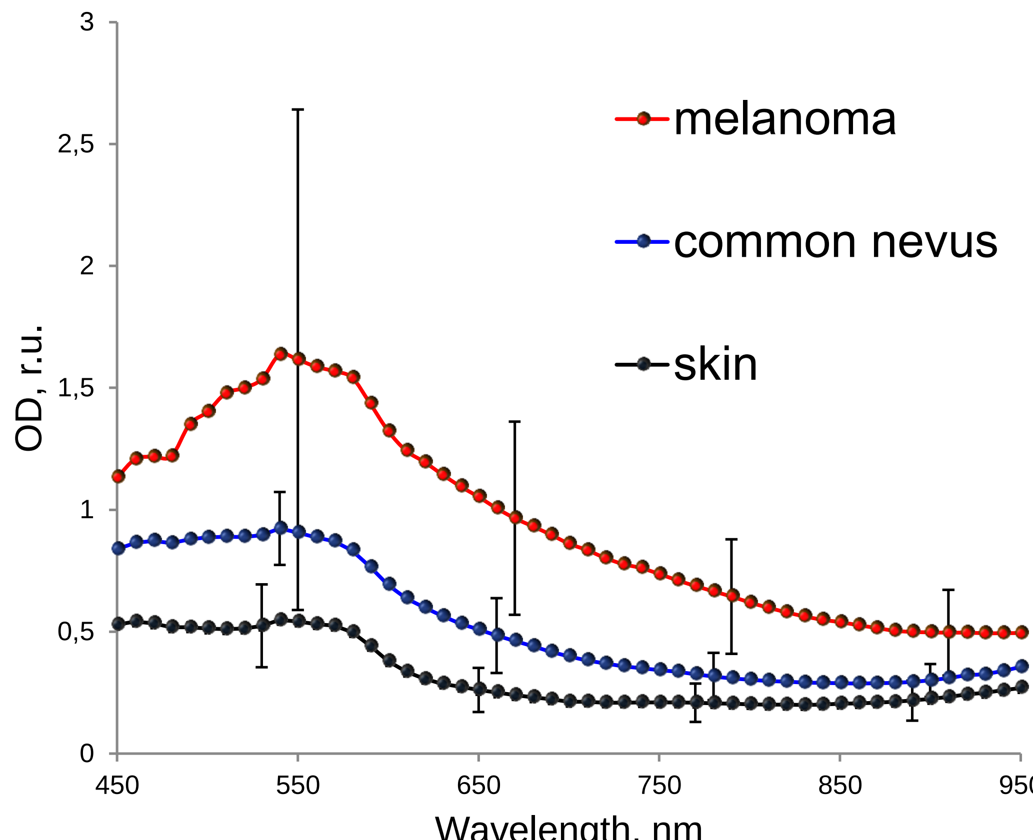
M1, M2 – melanomas in advanced stage (ulcerated) on back and foot.
M3 – melanoma on foot. **M4** – a melanoma on back.
N – an intadermal nevus with hair follicles

I.Kuzmina, I.Diebele, D.Jakovels, J.Spigulis, L.Valeine, J.Kapostinsh, A.Berzina. Towards noncontact skin melanoma selection by multispectral imaging analysis, ***J Biomed. Opt***., 16(6), 060502-1 (2011).

Reduced number of spectral bands: parametric melanoma imaging

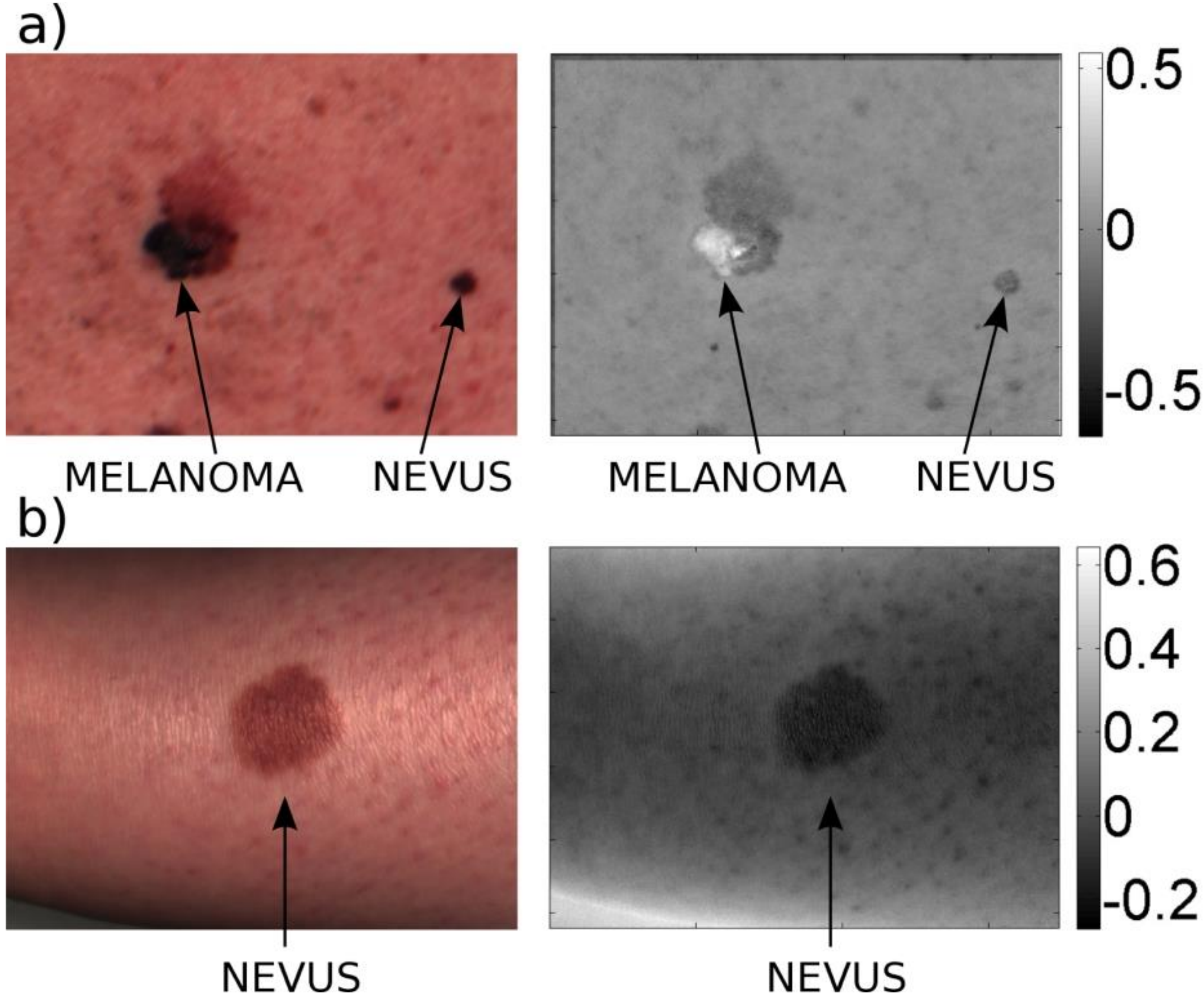


$$p = OD_{650} + OD_{950} - OD_{540}$$

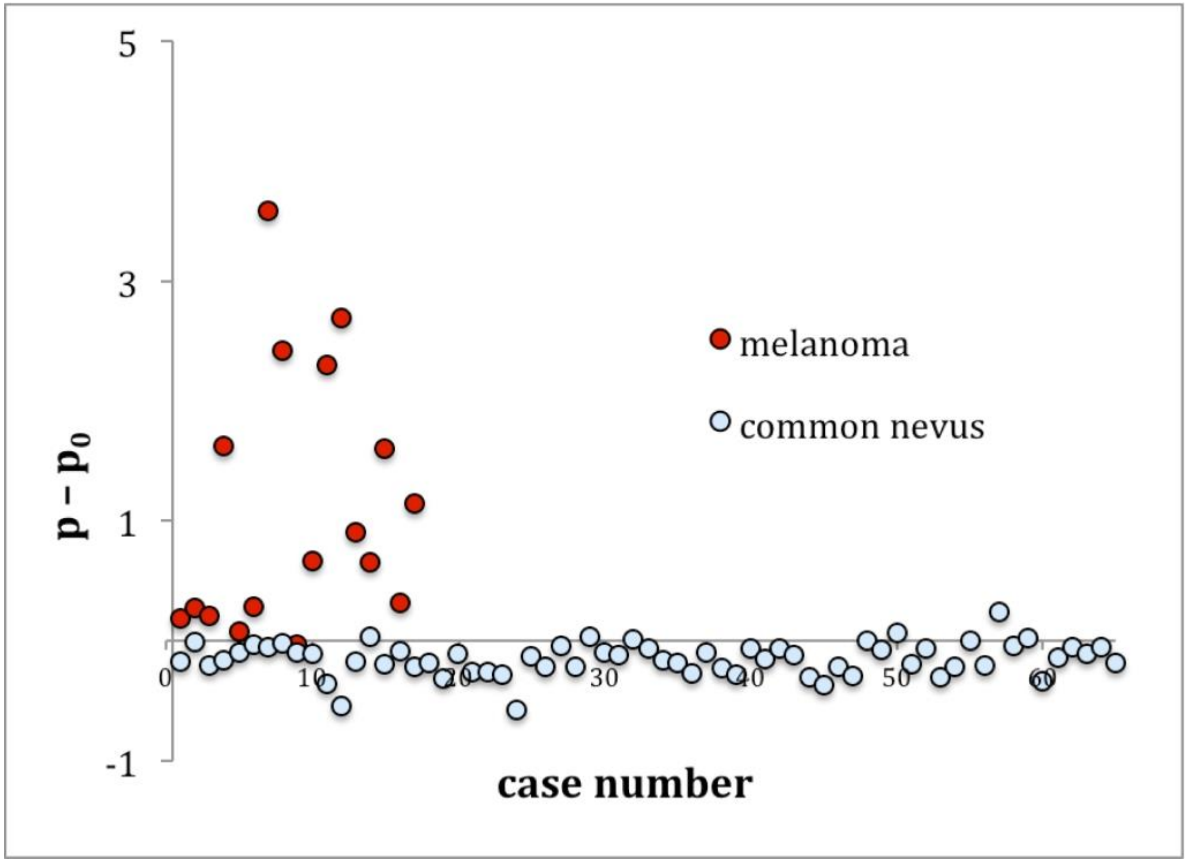


17 melanomas
65 nevi
82 healthy skin

Melanoma-nevus differentiation by parametric imaging (right)



Melanoma-nevus differentiation: sensitivity and specificity



sensitivity = 94 %
specificity = 89 %

TP(true positive) = 16
FP(false positive) = 1
TN(true negative) = 58
FN(false negative) = 7

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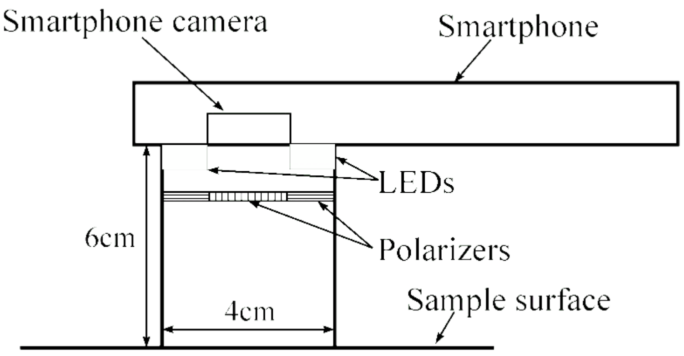
sensitivity = TP/(TP + FN)
specificity = TN/(TN + FP)

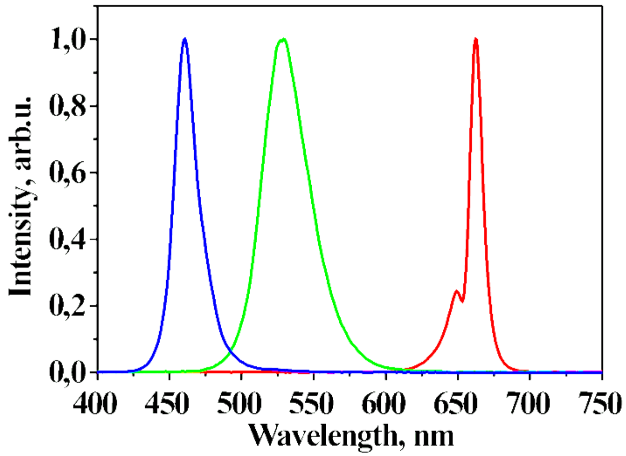
$p > p_0$
p – lesion
p_0 – surrounding healthy skin

I.Diebele, I.Kuzmina, A.Lihachev, J.Kapostinsh, A.Derjabo, L.Valeine, J.Spigulis. Clinical evaluation of melanomas and common nevi by spectral imaging, ***Biomed. Opt. Express*** 3(3), 467-472 (2012).

RGB-LED smartphone system



(a)



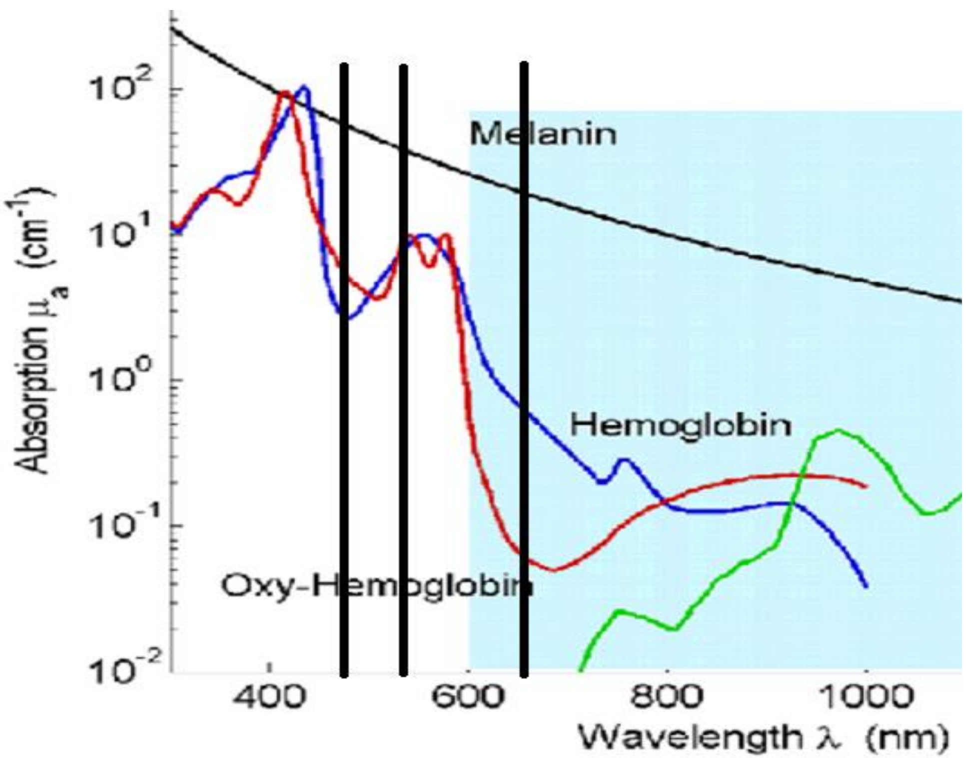
(b)

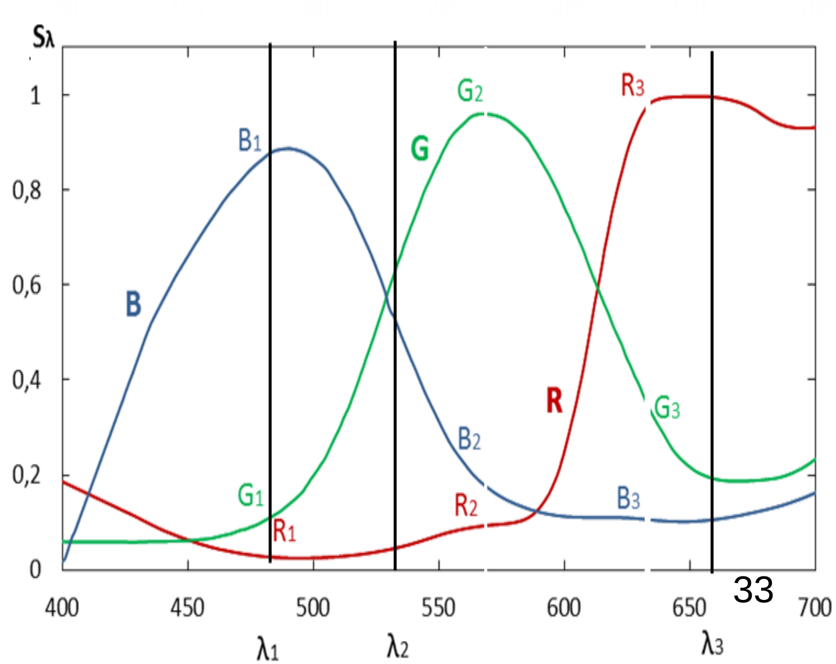
Kuzmina I., et al. Study of smartphone suitability for mapping of skin chromophores. *J.Biomed.Opt*., **2015**, 20(9): 090503

Can we do it faster and with narrower spectral bands?

Multi-monochromatic spectral imaging

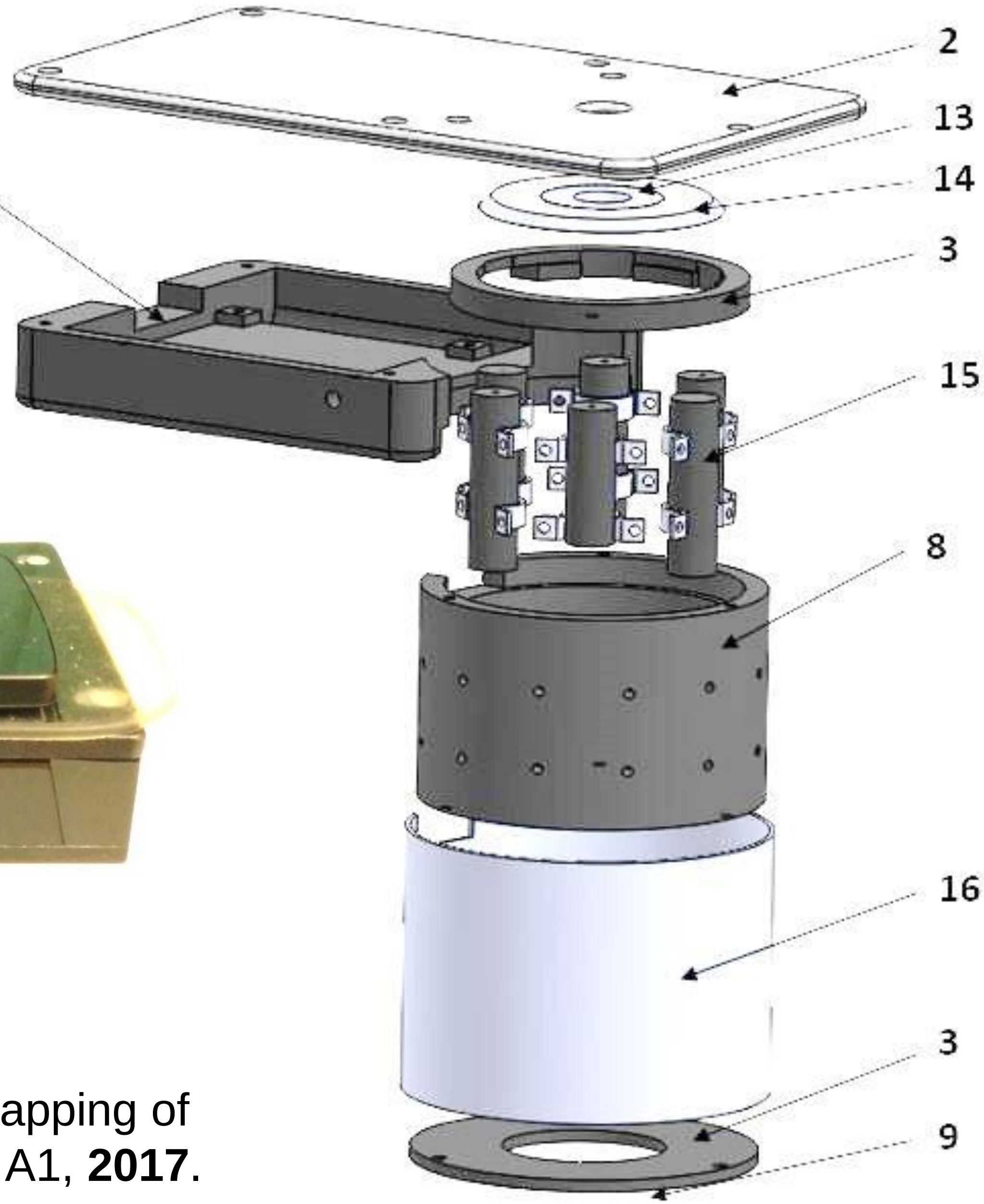
- We can extract 3 **monochromatic spectral images** from a **single-snapshot** RGB image data, if object (skin) is <u>illuminated simultaneously by 3 laser lines</u> and the RGB-band sensitivities of the image sensor are known
- Next step – conversion of 3 monochromatic spectral images into distribution maps of 3 main skin chromophores





Smartphone add-on triple wavelength laser illuminator:

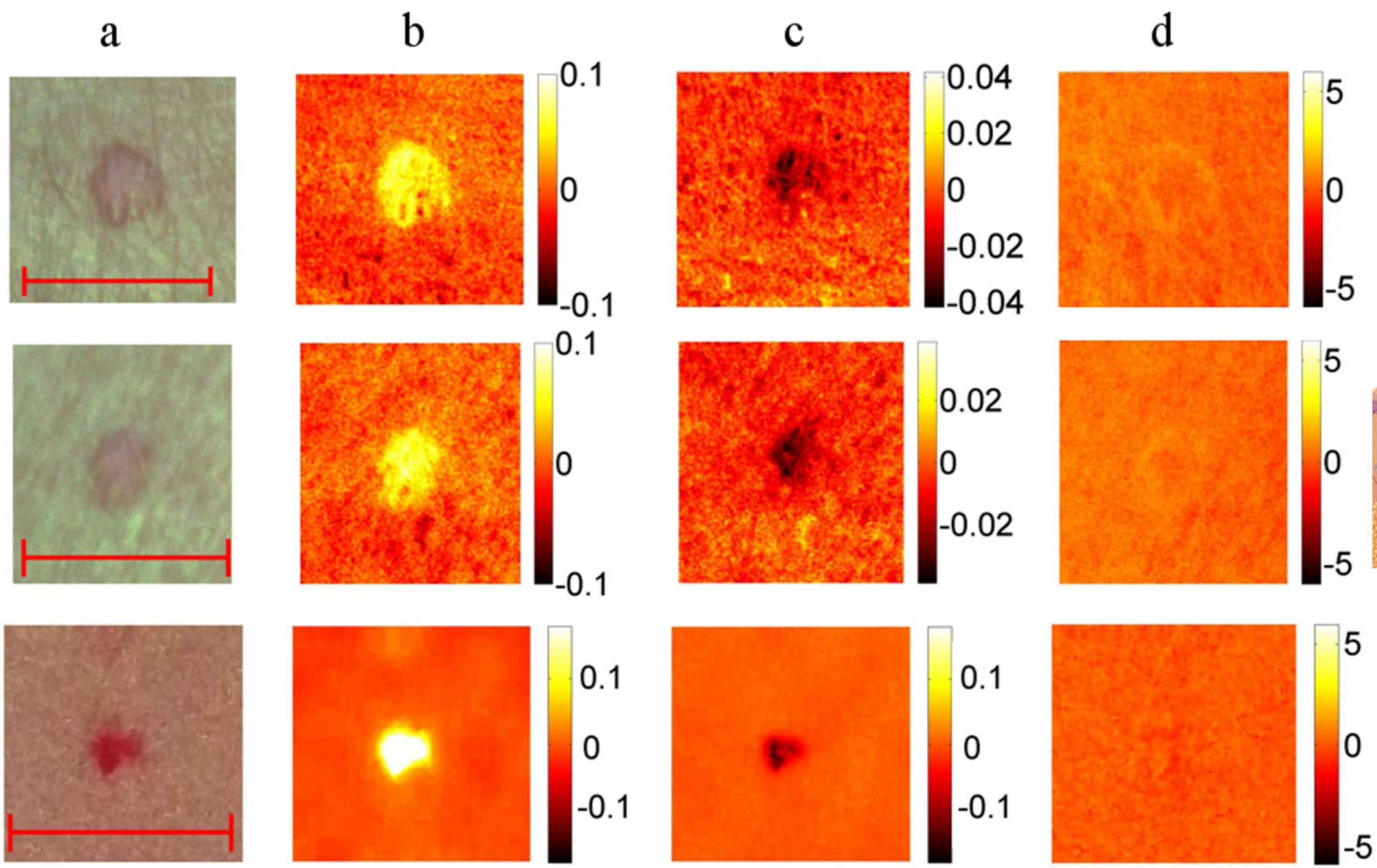
450nm, 532nm, 659nm

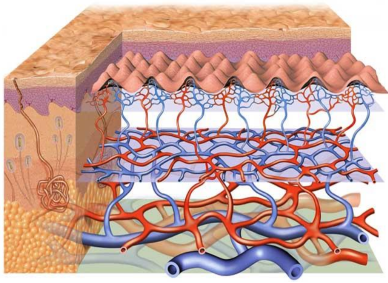


Method and device for smartphone mapping of tissue compounds. WO 2017/012675 A1, **2017**.

RGB image (a) and maps of chromophore content changes for 3 vascular hemangiomas:

b – oxy-hemoglobin, c – deoxy-hemoglobin, d – melanin

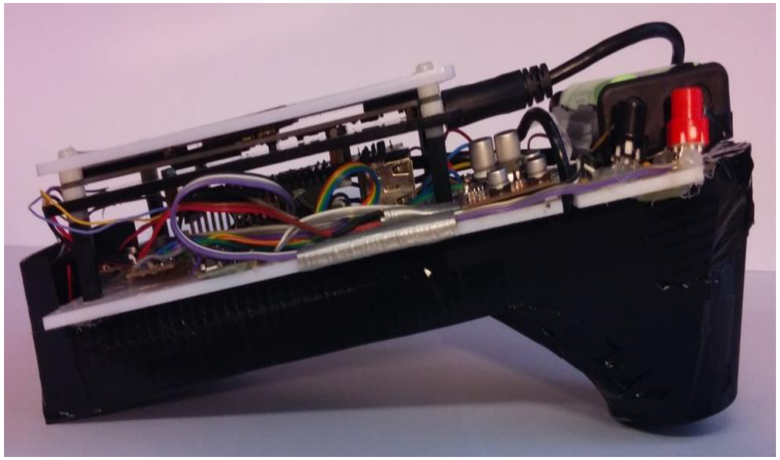




Spigulis J., et al. Smartphone snapshot mapping of skin chromophores under triple-wavelength laser illumination. *J.Biomed.Opt.*, **2017**, 22(9): 091508.

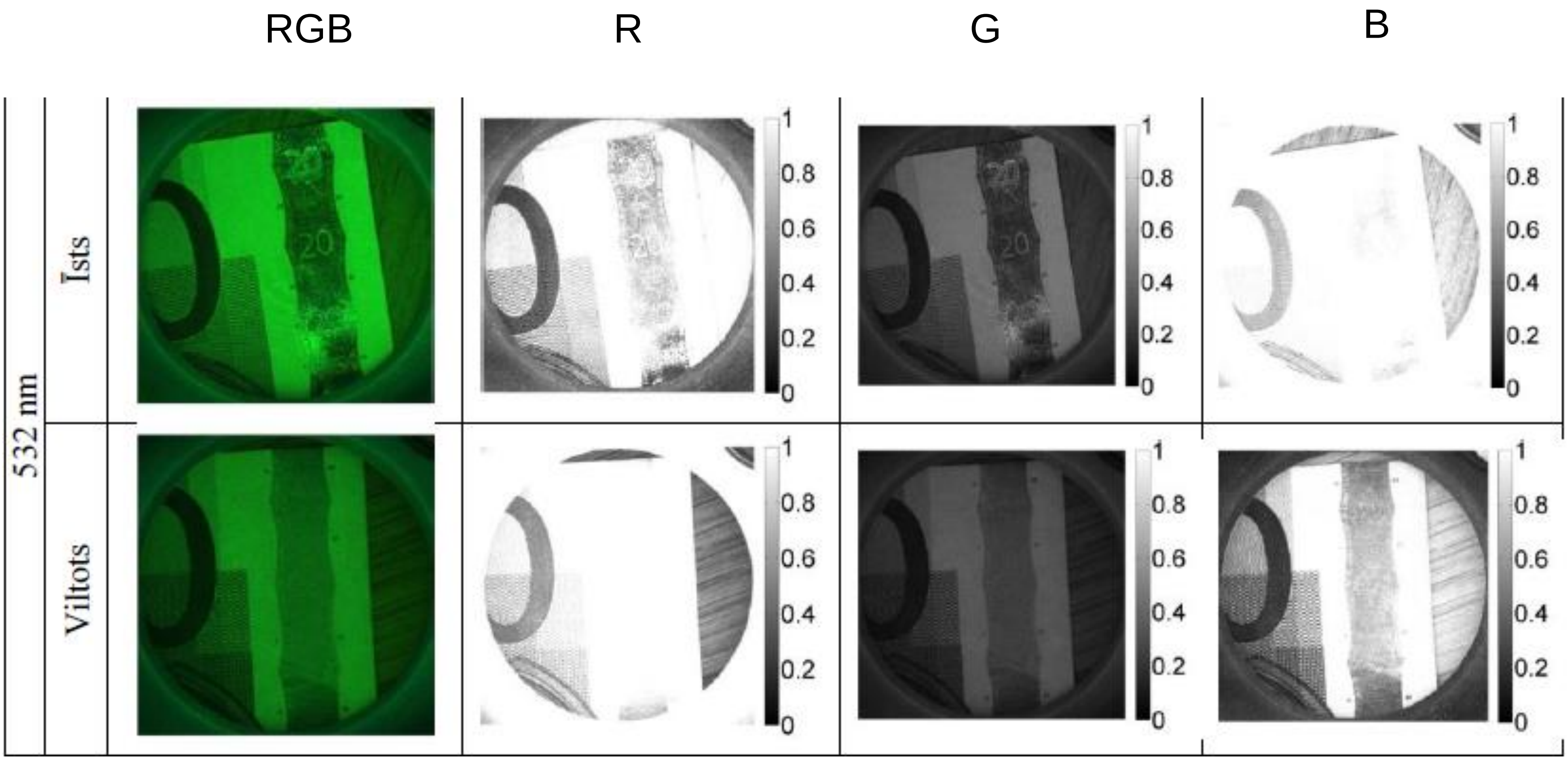
Under development

- **Double-snapshot** RGB imaging technique, each snapshot under different 3λ illumination → enables mapping up to 6 skin chromophores (patented)
- Quality improvement of the monochromatic spectral images by **laser speckle removal** (patented)
- First switchable **4λ and 5λ** laser illuminator prototypes created →
- Monochromatic spectral imaging for **counterfeit detection** (forensics)



Smartphone forensics:

532nm monochromatic spectral images of authentic (upper row) and counterfeit (lower row, withdrawn by Bank of Latvia) 20 EUR banknotes



Summary

- Spectral imaging and its modalities (hyper-, multi-) ensure non-contact assessment of human skin malformations and patient-friendly skin cancer screening
- Smartphones are useful tools for skin diagnostics if supplied with add-on narrowband illuminators
- Single-snapshot RGB data at triple-wavelengths laser illumination instantly provide distribution maps of three main skin chromophores
- For mapping more chromophores, n>3 wavelengths laser illumination systems are under development

Acknowledgments

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EIROPAS REĢIONĀLĀS ATTĪSTĪBAS FONDS

EIROPAS SAVIENĪBA

IEGULDĪJUMS TAVĀ NĀKOTNĒ

Thank You!

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