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Multi-laser illumination designs for skin chromophore mapping

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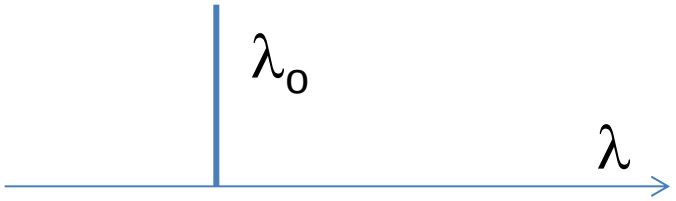
ALT'2016, Galway, 12/09/2016

Why? Motivation

- Our lab in Riga develops and tests «simple» optical techniques and prototypes for clinical use, focusing on skin
- Laser illumination of skin in clinical diagnostics:
  - laser-Doppler flowmetry
  - laser speckle contrast imaging
  - both for skin microcirculation assessment
  - single-wavelengh
- Unusual: illumination simultaneously by several laser lines
- Laser RGB projectors? Too powerful, large-sized, expensive
- Spectral lamps? Not found suitable so far
- Biophotonics? To construct **distribution maps of skin chromophores** (melanin, hemoglobin, etc.) by converting several **monochromatic** spectral images of the target area

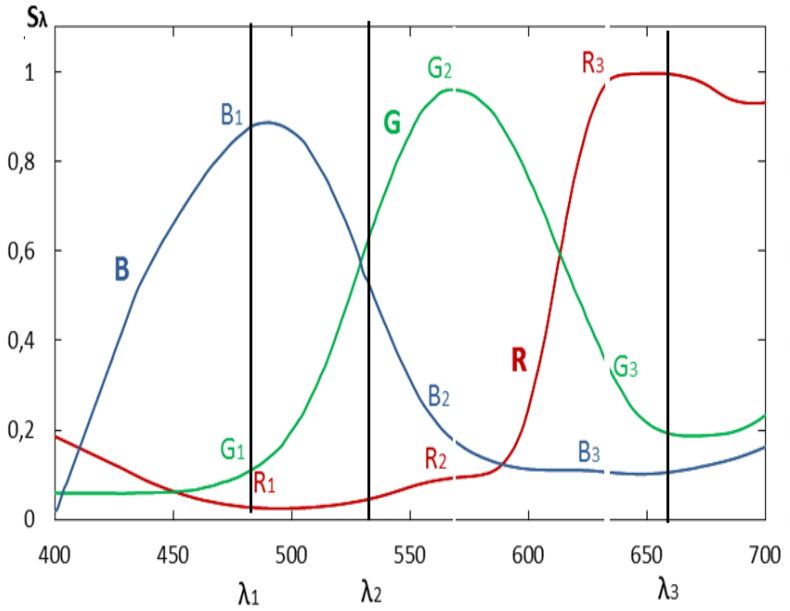
Spectral imaging

- **Spectral image**: an image representing reflection from the object within one specific spectral interval
- **Two ways** to obtain spectral images:
  - By **spectral filtering** of detected light at broadband illumination (e.g. by interference band-pass filters, liquid crystal filters, ...)
  - By narrowband **spectral illumination** (e.g. by color LED or broadband source via band-pass filter) ; the narrower, the better
- **Monochromatic** spectral imaging ($\Delta\lambda << 1$ nm) – complicated to realize by filtering, but relatively easy by **illumination that comprises only one spectral line** (e.g. by a laser beam)



Extraction of 3 monochromatic spectral images from single RGB image data

- Illuminate simultaneously by 3 wavelengths λ_1, λ_2, λ_3
- Ensure uniform illumination of the object and linear photoresponse of the image sensor
- Exploit the RGB sensitivity curves of the sensor for λ_1, λ_2, λ_3 (manufacturer's or measurement data)
- Correct the crosstalk between the R-, G- and B-outputs

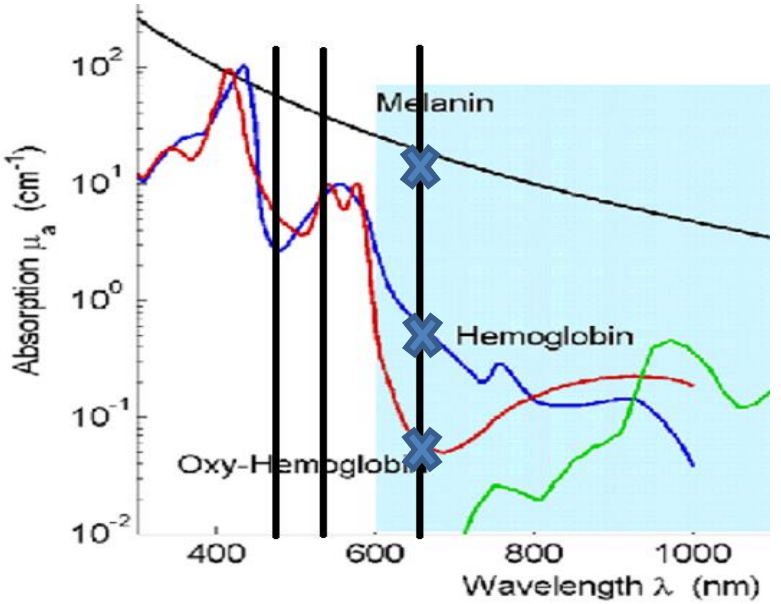


J.Spigulis, L.Elste. Method and device for imaging of spectral reflectance at several wavelength bands. **WO2013135311 (A1**), 2012

Advantages of monochromatic spectral imaging for skin chromophore mapping

(spectral line illumination *vs* LED band illumination)

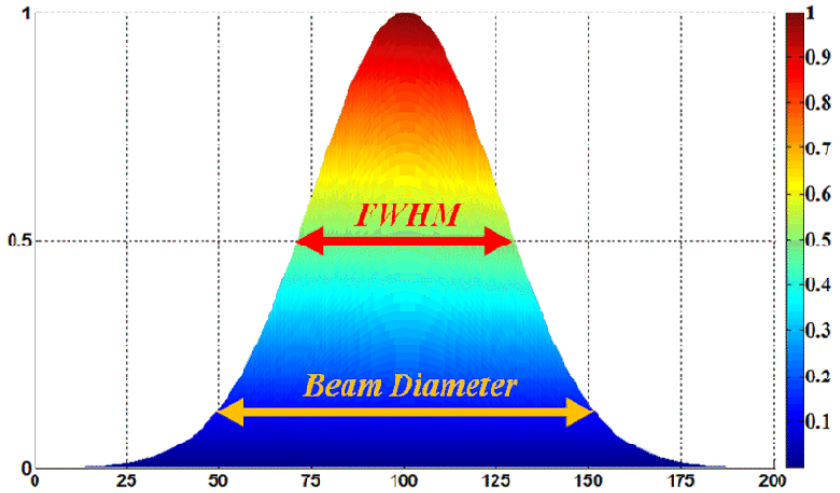
- Fixed chromophore extinction coefficients at the given λ → no need for integration over the spectral bands → simpler image processing (set of linear equations derived from the Beer's law)
- Digital RGB camera allows single-snapshot mapping of 3 main skin chromophores at simultaneous 3-line illumination (convenient use)
- Avoids motion artefacts (quality)

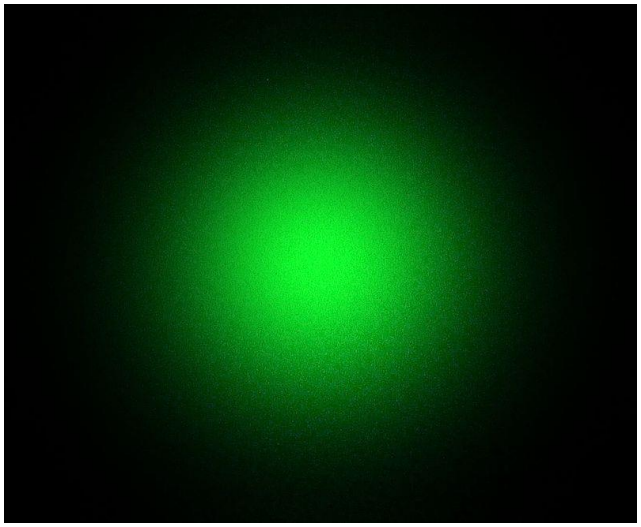


J.Spigulis, L.Elste. Single-snapshot RGB multispectral imaging at fixed wavelengths: proof of concept. *Proc.SPIE*, 8937, 89370L (2014).

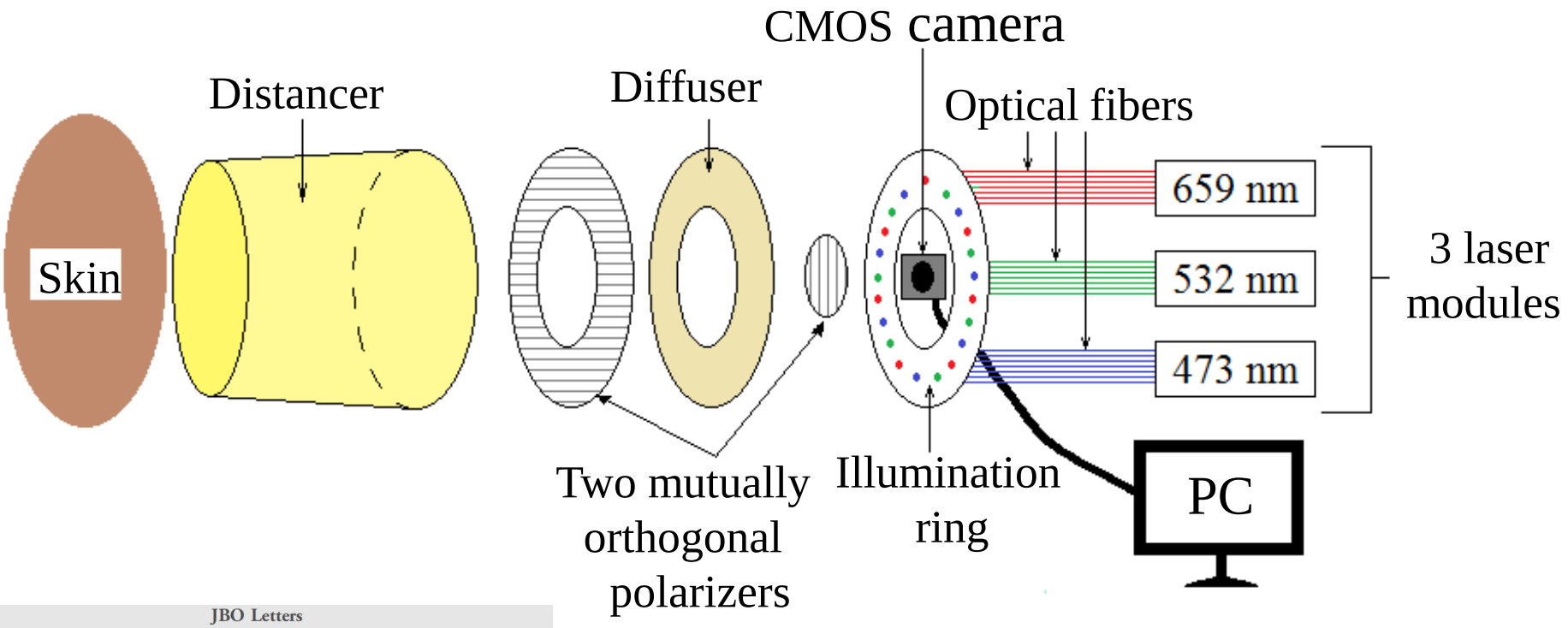
Multi-laser illumination

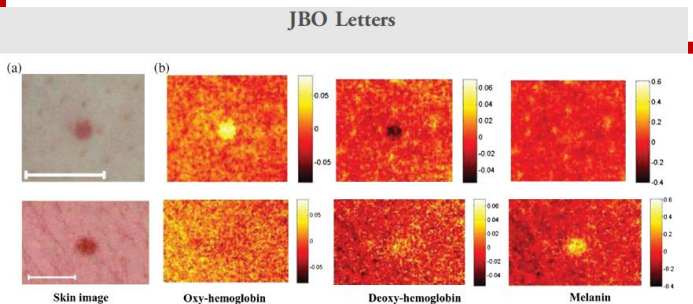
- Essential part of the proposed technology
- Uniform polarized illumination of the imaged area at several fixed wavelengths is needed
- Direct or expanded single laser beams – not well-adapted due to the Gaussian distribution
- Specific optical designs are to be developed





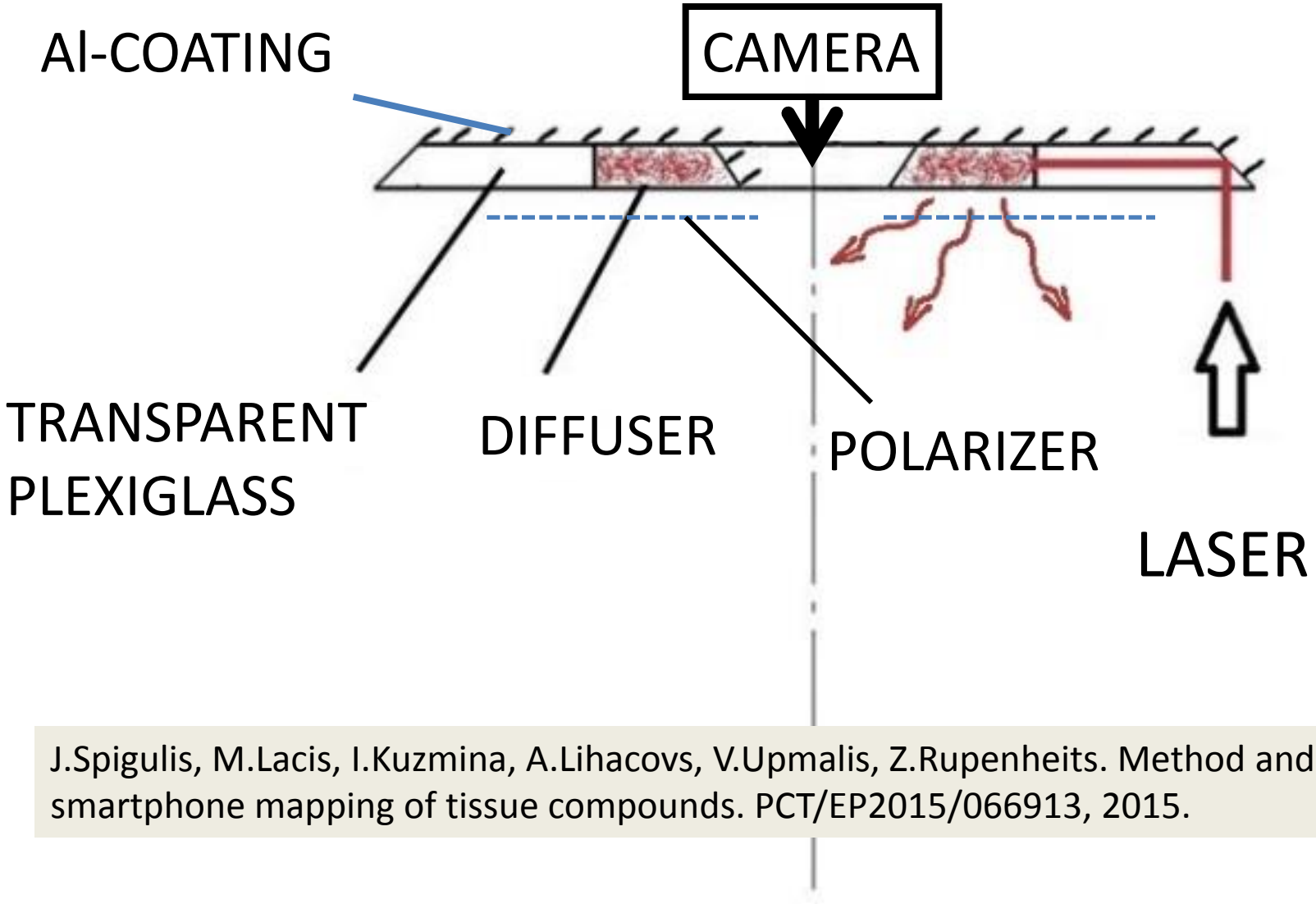
1. Fiber-based three laser illuminator





J.Spigulis, I.Oshina. Snapshot RGB mapping of skin melanin and hemoglobin. ***J.Biomed.Opt***., 20(5), 050503 (2015).

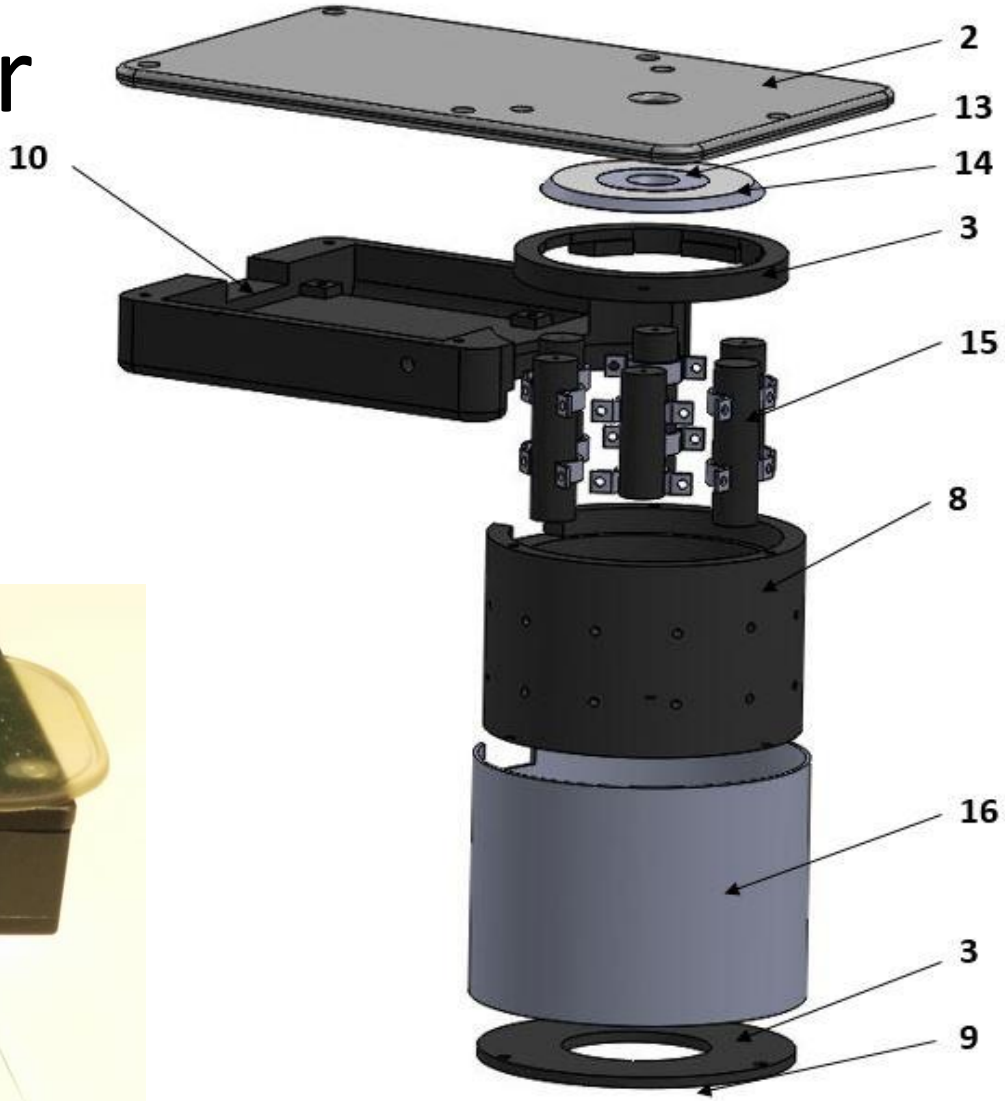
Radially irradiated ring-shaped disk diffuser as illumination source



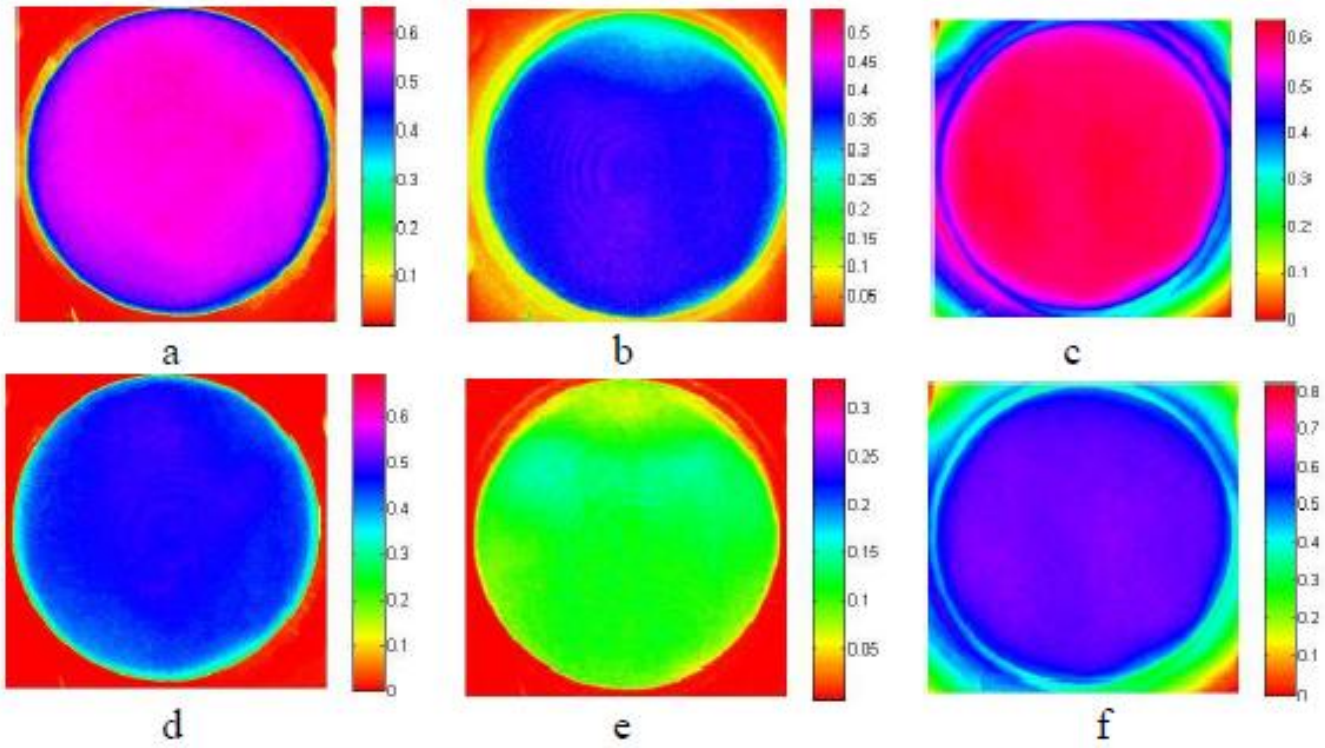
J.Spigulis, M.Lacis, I.Kuzmina, A.Lihacovs, V.Upmalis, Z.Rupenheits. Method and device for smartphone mapping of tissue compounds. PCT/EP2015/066913, 2015.

2. Smartphone add-on 6-laser illuminator

- 3 pairs of laser modules - 448 nm, 532 nm, 659 nm
- Acceptable uniformity
- First clinical data collected

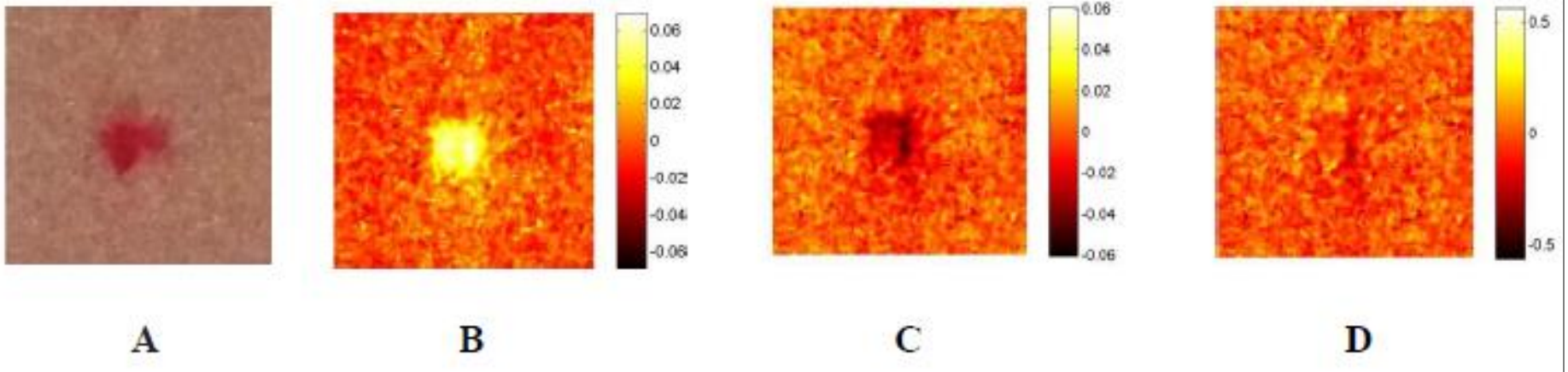


Uniformity of illumination



Uniformity of white paper illumination at different illumination-detection combinations: a – R-image at 659nm; b – G-image at 532nm; c – B-image at 448nm; d, e and f – R-, G- and B-images at simultaneous 3-wavelength illumination.

Skin chromophore distribution: hemangioma



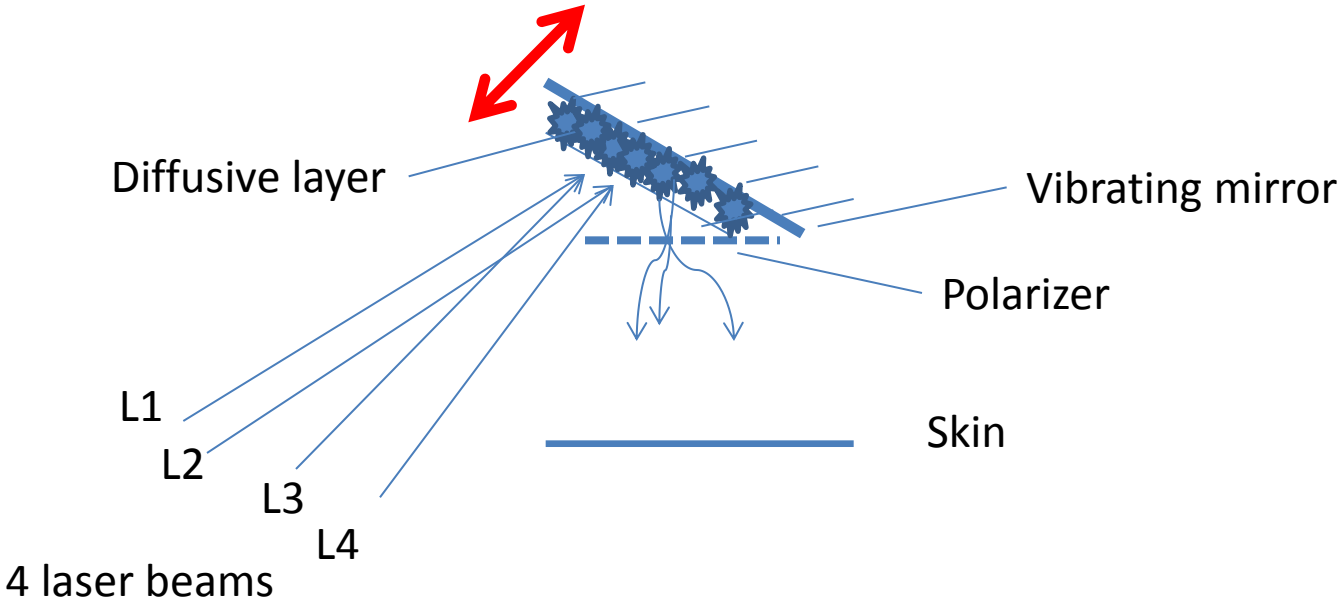
. RGB image (A) and the corresponding chromophore maps of skin hemangioma: B – oxy-hemoglobin, C – deoxy-hemoglobin, D – melanin.

J.Spigulis, I.Oshina and Z.Rupenheits, "Smartphone single-snapshot mapping of skin chromophores", *Biomedical Optics 2016*, OSA Technical Digest (online), JTu3A.46, (2016).

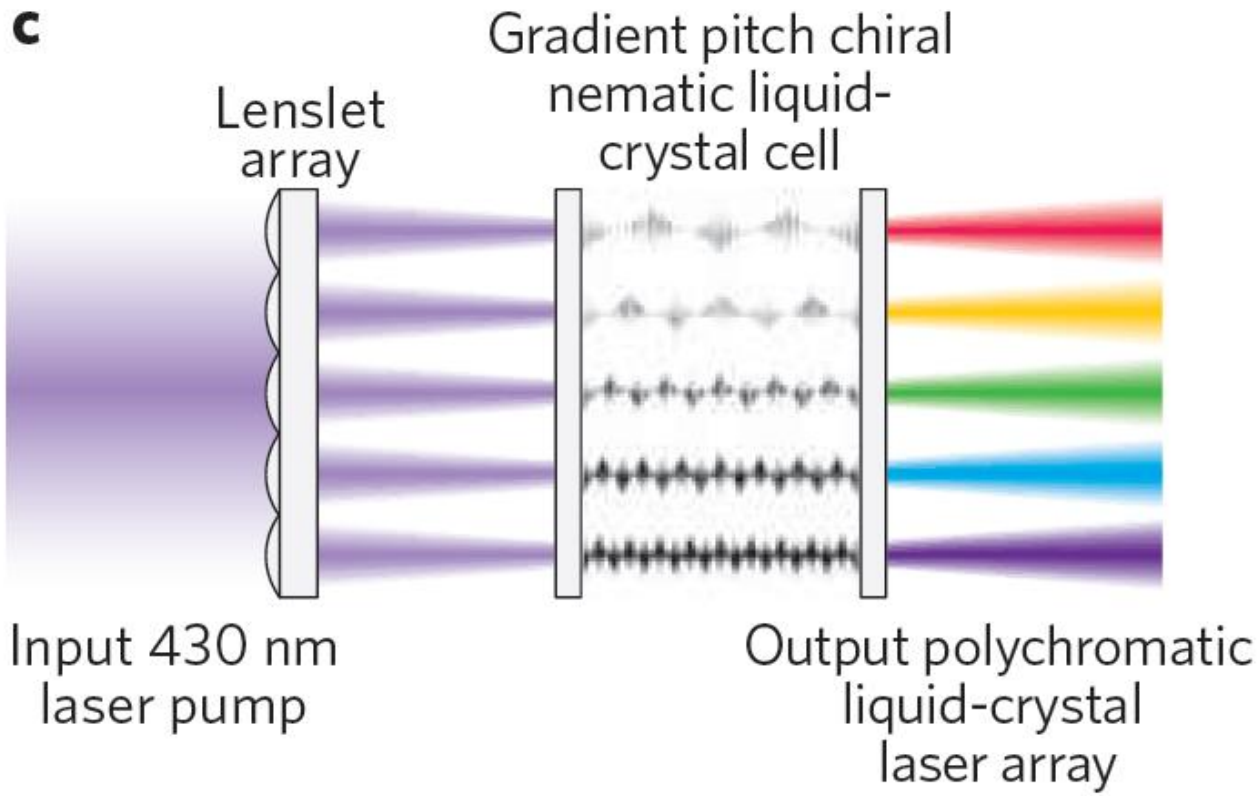
3. Speckle-free 4-wavelength design

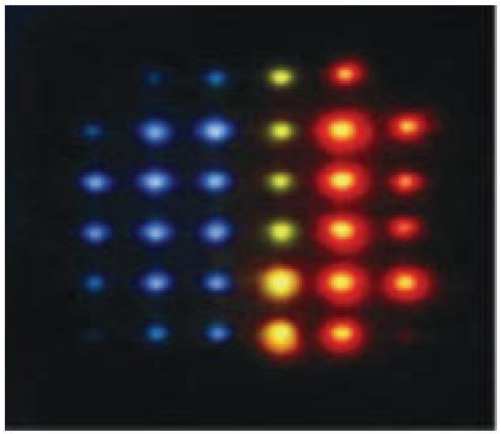
(under development)

- To map also bilirubin (4 chromophores), switchable 4-wavelength illumination is needed (2 sets of 3-λ)
- How to avoid laser speckles? «Smearing» by ~1kHz vibrations → 10 cycles during a 100 ms exposure



4. Liquid crystal laser illumination (?)





Summary

- Monochromatic spectral imaging by means of multi-line laser illumination shows potential for skin chromophore mapping
- 2 design options successfully tested in lab and clinic:
  - 21 fiber 3-laser tabletop system
  - 6 laser / 3 line smartphone add-on system
- 4 laser line illuminator with vibrating mirror under development
- Further studies in progress

Acknowledgments

This study and conference travel were supported by Latvian National research programme SOPHIS under the grant agreement # 10-4/VPP-4/11.

Thank You!

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