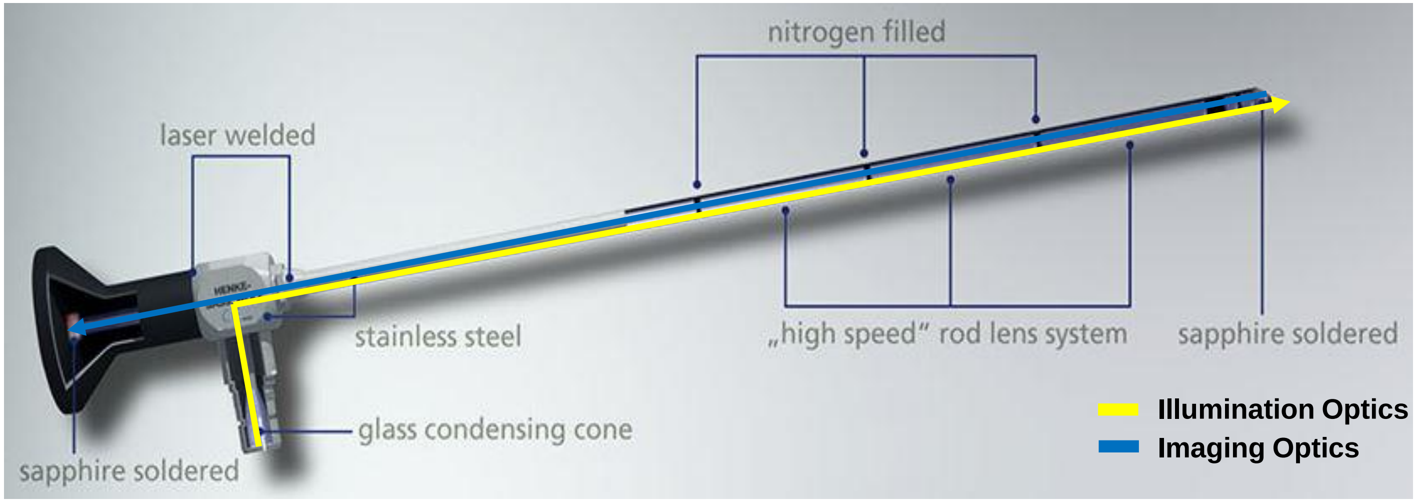
Challenges when designing LED-based illumination systems for medical applications



Content

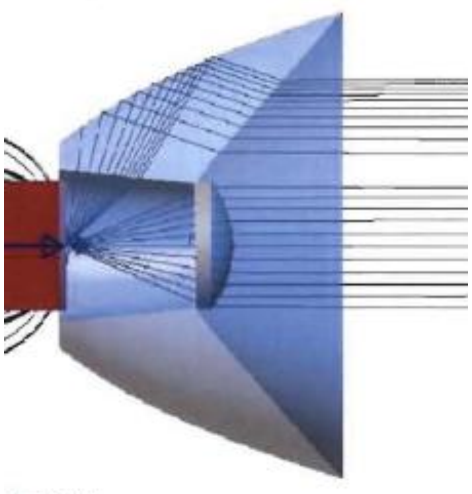
- Introduction

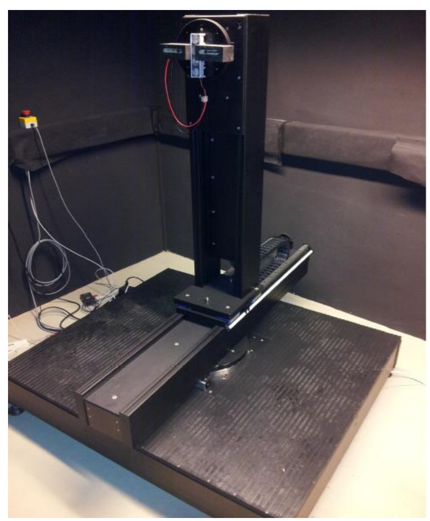
- Project EDISON
  - measurements of light sources and endoscopes
  - analysis of intensity losses
  - optical simulations

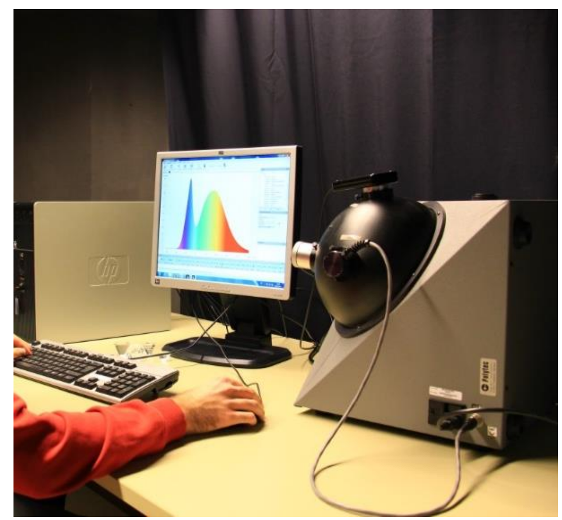
- Illumination optimised according to reflection properties of human tissues

- Project Wound Healing

Lighting Technologies in the Black Forest





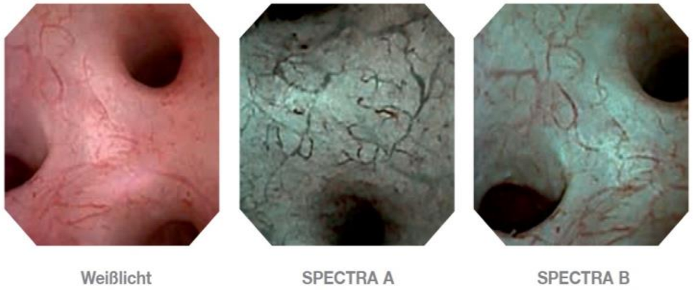


State of the Art – Light Sources

- LEDs are systematically replacing Xenon and Halogen lamps in medical devices
  - produce less heat and their spectral emission in the visible range can be tuned

- LED selected with high Ra, mostly R9 (blood) or R13 (skin)
  - but optical properties of biological tissues vary and may be highly reflective (fat), highly absorptive of blue/green light (blood) or may have fluorescent properties (collagen)

- Very few LED-based tunable illumination units available
  - selection criteria of wavelength filtering are not scientifically based



Quelle: KARL STORZ; Highlights 2016 - Telepräsenz Bildgebende Systeme, Dokumentation, Beleuchtung, Gerätewagen: "Innovative Visualisierungsmodi in 2D und 3D"; 2016

GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung
FORSCHUNG AN FACHHOCHSCHULEN

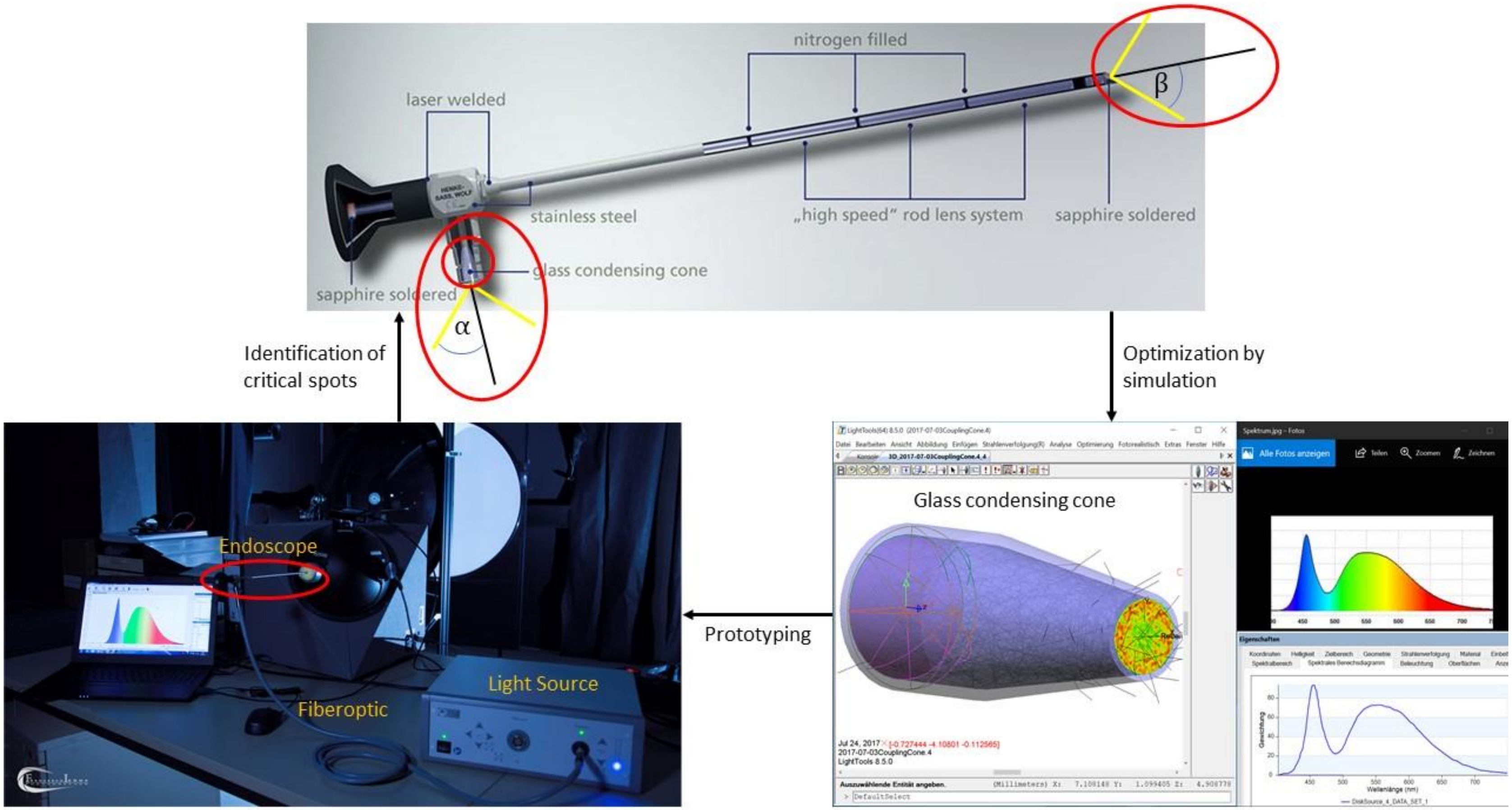
Paola Belloni and Alexander Gärtner

Aim: enhancing efficiency while reducing the volume of the fiber optics inside the endoscope

Standard illumination optics in rigid endoscopes will be redesigned and optimised taking into account constructive and production related boundary conditions.

Edison: Project development

Analysis of the optical interfaces and losses



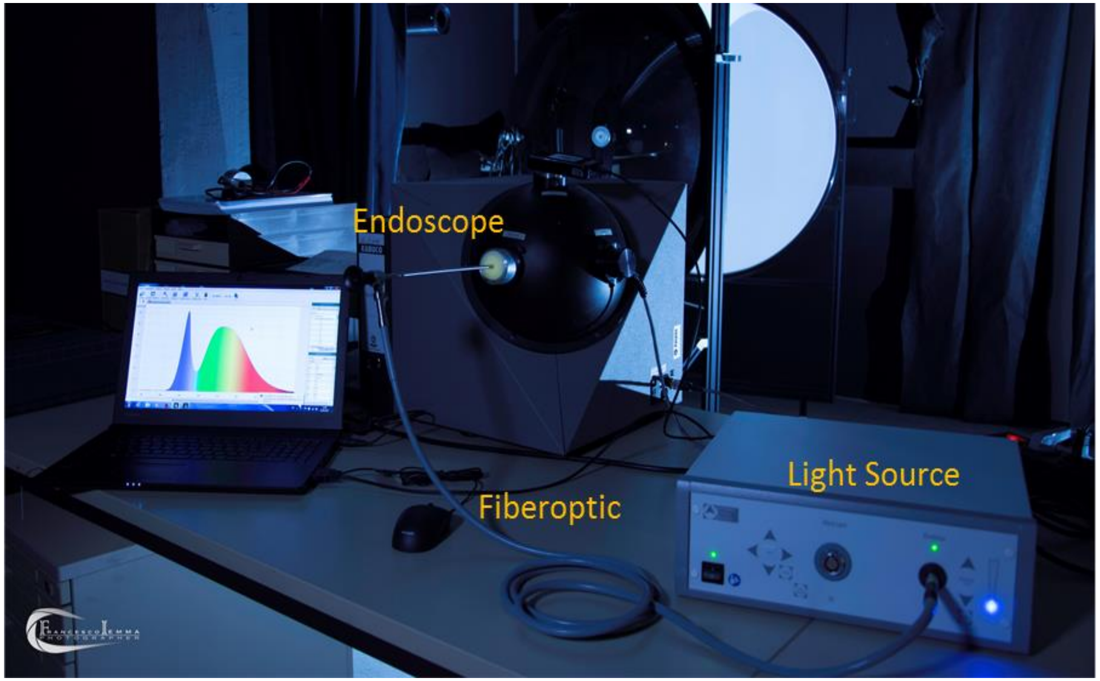
Prototype measurements

Optical simulations/optimisation

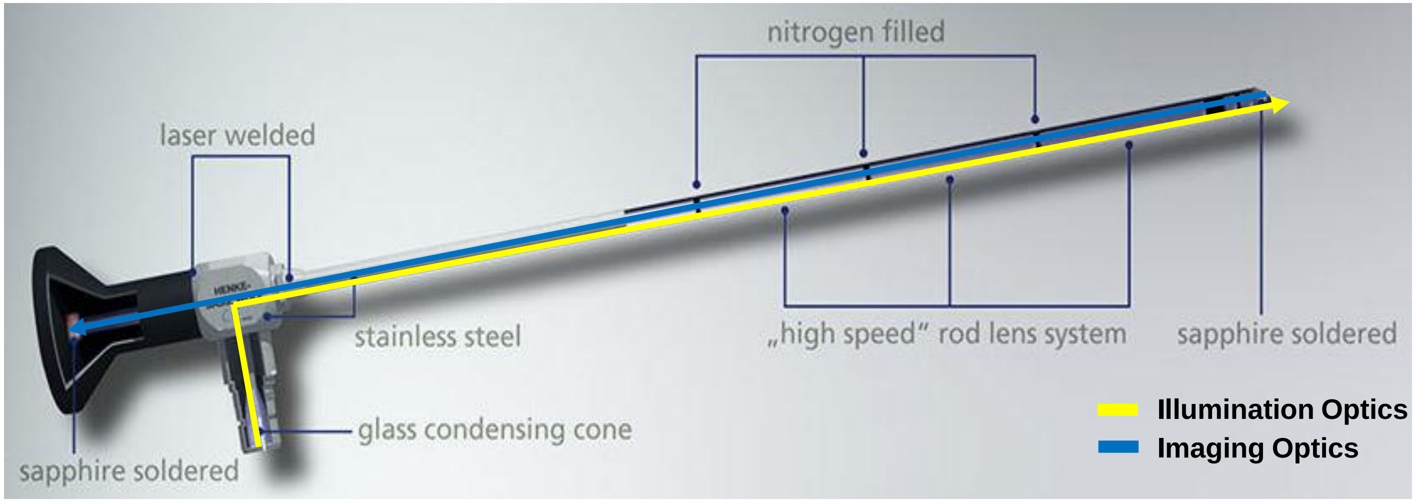
Measurement setup

Equipment:

- Fiberoptic is connected to light source and endoscope
- Endoscope is fixed into auxiliary adapter and mounted on the integrating sphere
- Measurements are performed with an integrating sphere (ø=25 cm) and a spectrometer from GL optics



Rigid endoscope with external light sources



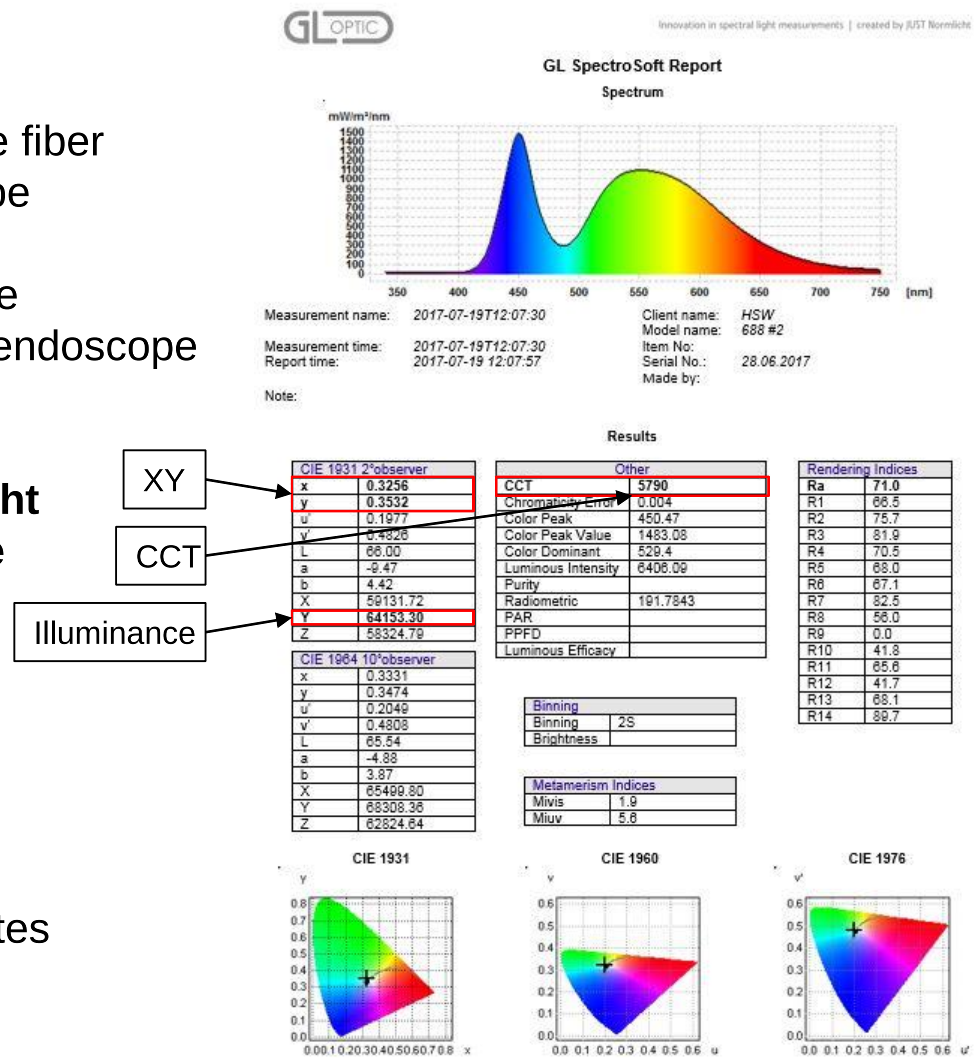
Objectives and measurements

Objectives:

- Identify losses bending the fiber optics inside the endoscope
- Identify losses between the light source input and the endoscope output
- Analyse **three** different **light sources (a,b,c)** und **three endoscopes**

Parameters:

- Illuminance
- Color Temperature
- XY-Chromaticity Coordinates



Measurement name: 2017-07-19T12:07:30
Measurement time: 2017-07-19T12:07:30
Report time: 2017-07-19 12:07:57
Note:

Client name: HSW
Model name: 688 #2
Item No:
Serial No.: 28.06.2017
Made by:

Results

CIE 1931 2°observer	
x	0.3256
y	0.3532
u'	0.1977
v'	0.4826
L	66.00
a	-9.47
b	4.42
X	59131.72
Y	64153.30
Z	58324.79

CIE 1964 10°observer	
x	0.3331
y	0.3474
u'	0.2049
v'	0.4808
L	65.54
a	-4.88
b	3.87
X	65499.80
Y	68308.36
Z	62824.64

Other	
CCT	5790
Chromaticity Error	0.004
Color Peak	450.47
Color Peak Value	1483.08
Color Dominant	529.4
Luminous Intensity	6406.09
Purity	
Radiometric	191.7843
PAR	
PPFD	
Luminous Efficacy	

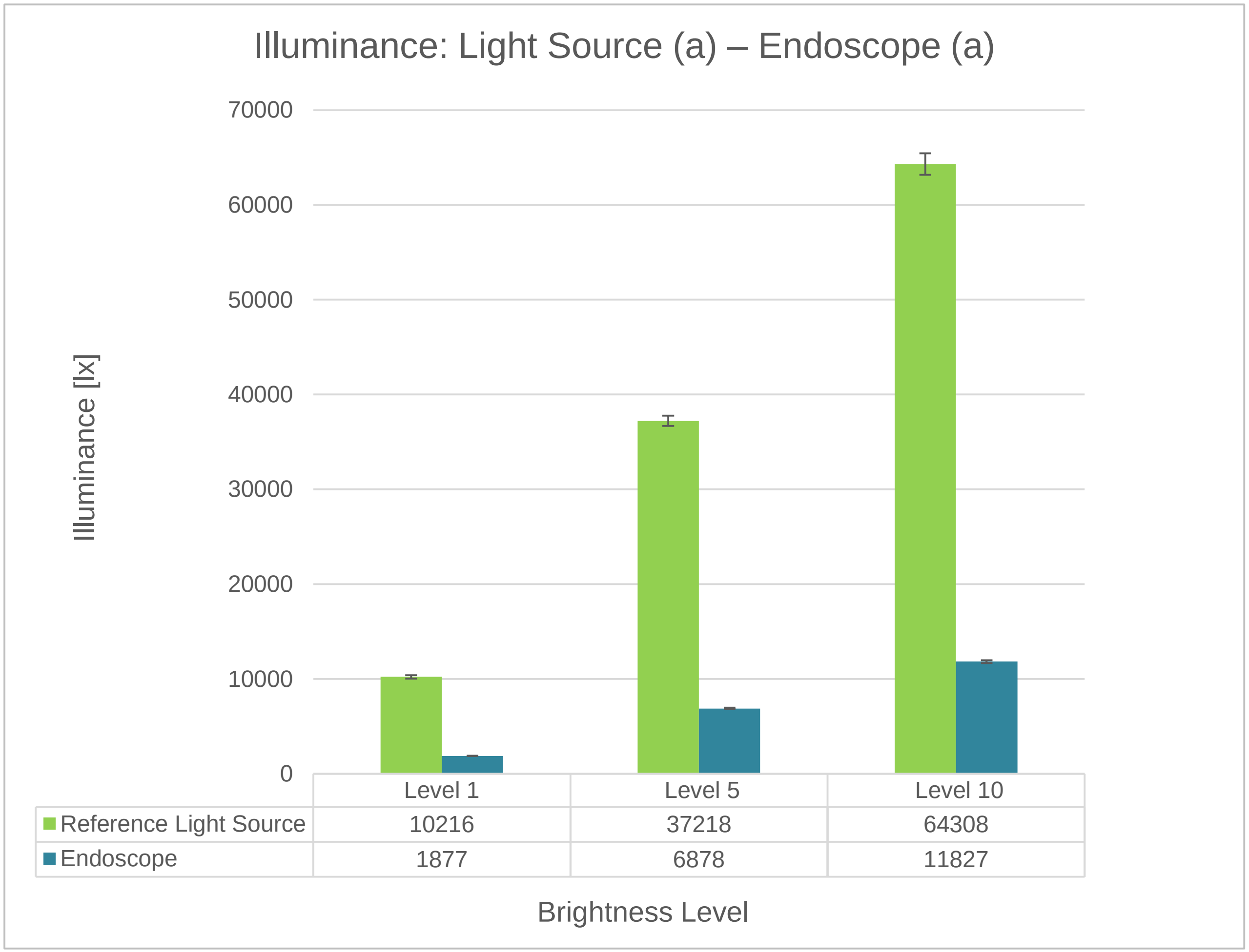
Binning	
Binning	2S
Brightness	

Metamerism Indices	
Mivis	1.9
Miuv	5.6

Rendering Indices	
Ra	71.0
R1	66.5
R2	75.7
R3	81.9
R4	70.5
R5	68.0
R6	67.1
R7	82.5
R8	56.0
R9	0.0
R10	41.8
R11	65.6
R12	41.7
R13	68.1
R14	89.7

Parameters extracted from the protocol

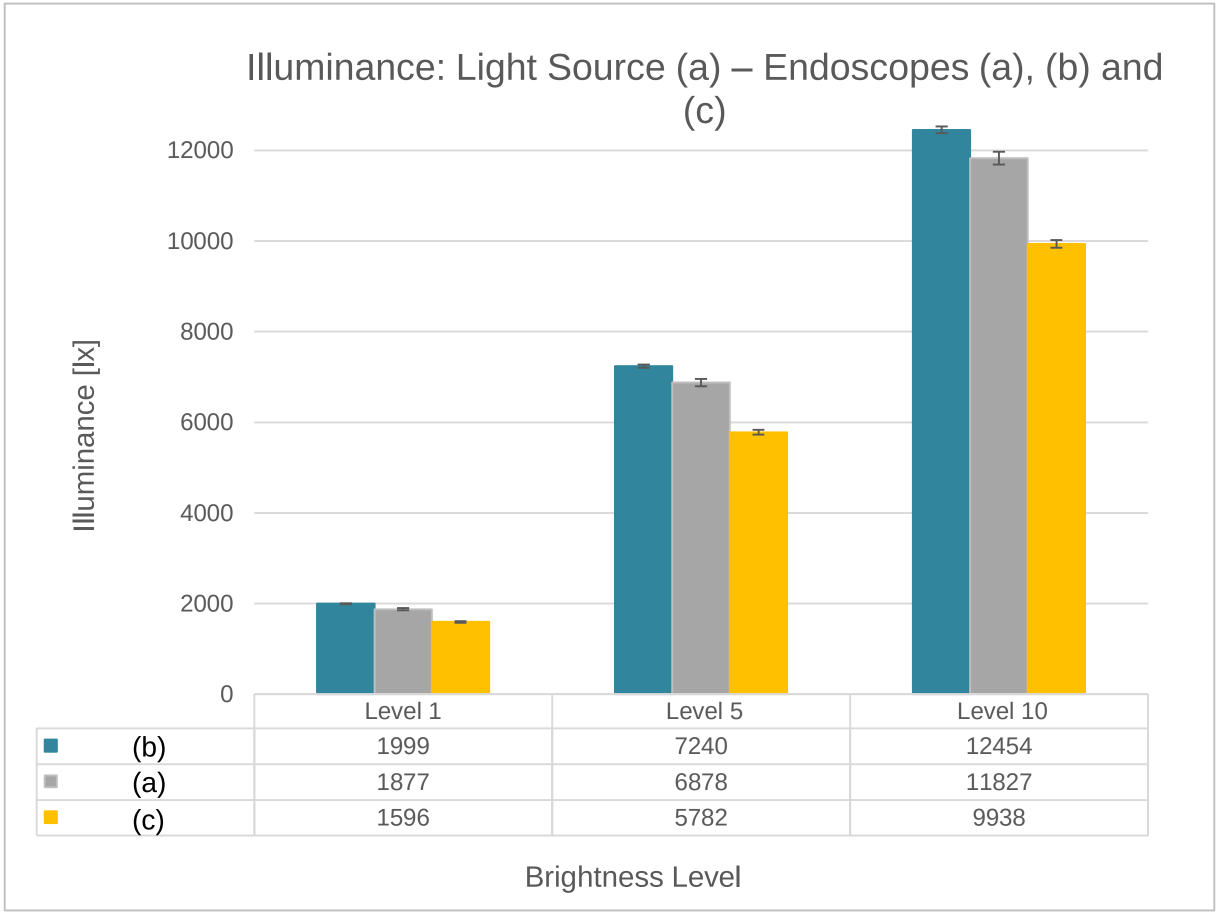
Measurements: Intensity losses



Brightness	Loss [%]
Level 1	81,63
Level 5	81,52
Level 10	81,61

Measurements: Intensity losses

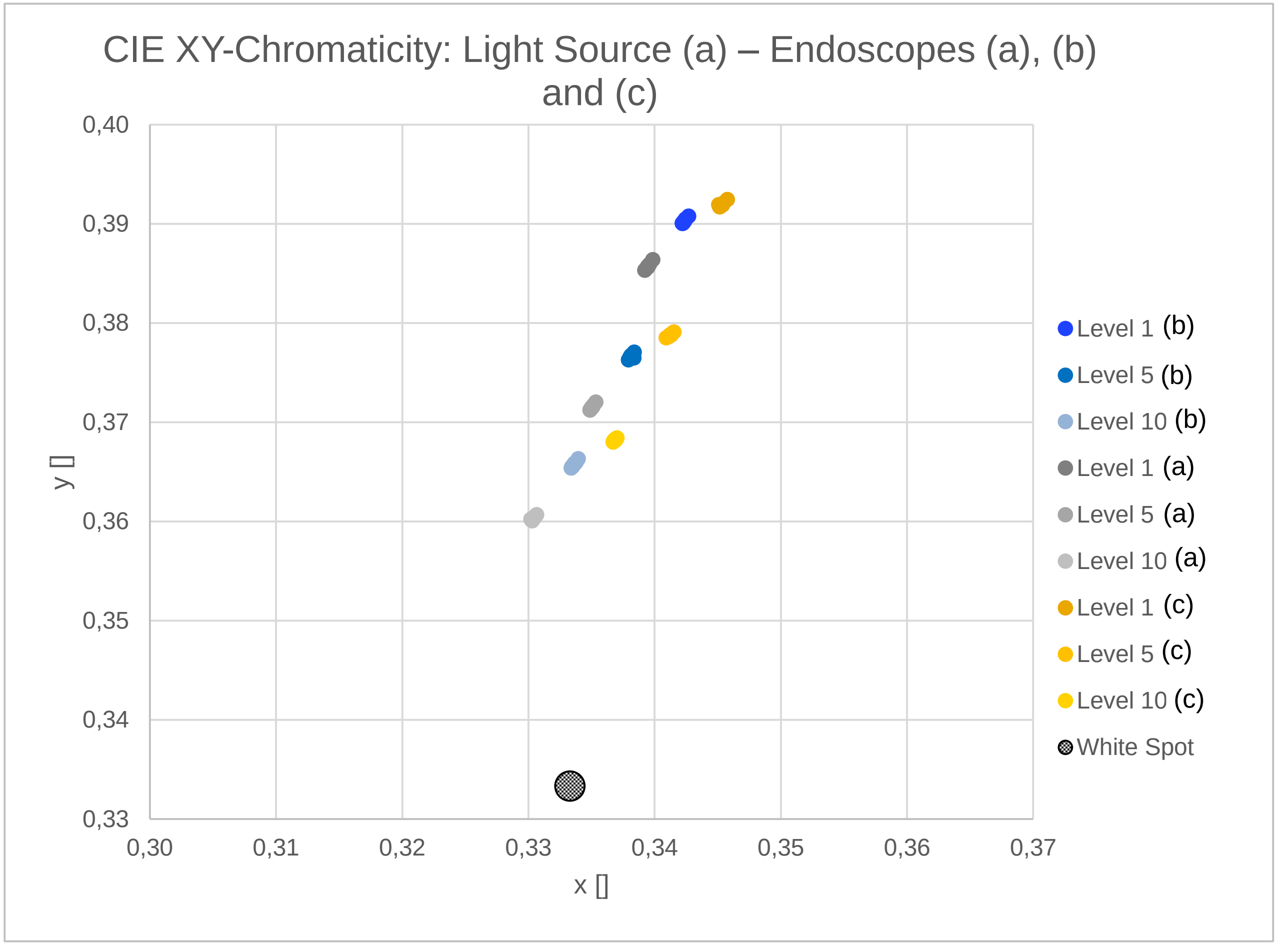
Analysis of additional endoscopes (state of the art)



	Level 1	Level 5	Level 10
(b)	1999	7240	12454
(a)	1877	6878	11827
(c)	1596	5782	9938

→ Overall ca 80 % of the light source intensity is lost before leaving the endoscope !

Measurements: Chromaticity



All endoscopes demonstrate a similar shift changing the brightness levels

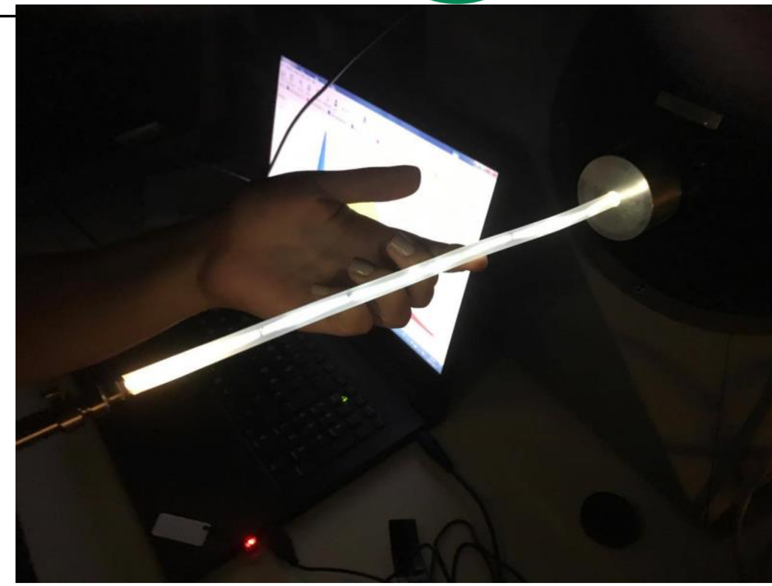
Measurements – Fiber bundle

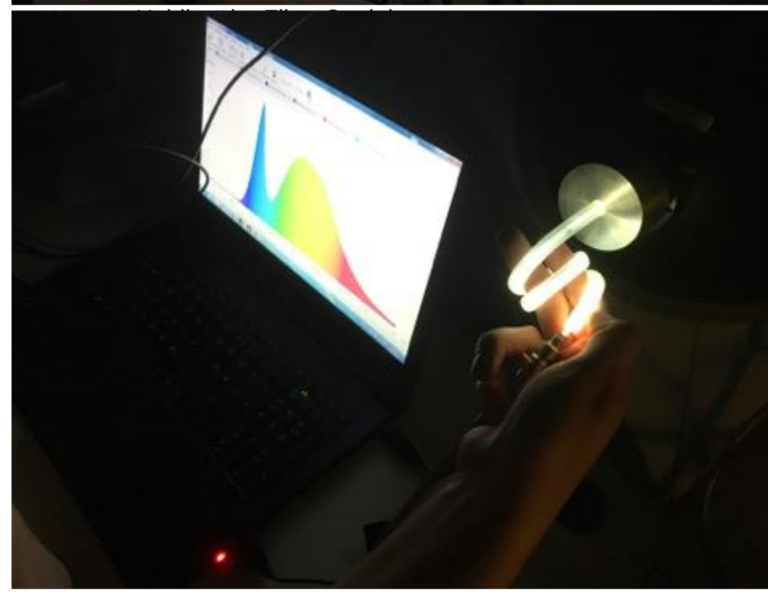
Are intensity losses caused by bending the fiber bundle ?

Analysis of the same fiber bundle used to transport light trough the endoscope

- Measurements of the fiber bundle are performed by holding the fiber straight and wrapped around middle and index finger twice
- 20 measurements are carried out for each brightness level

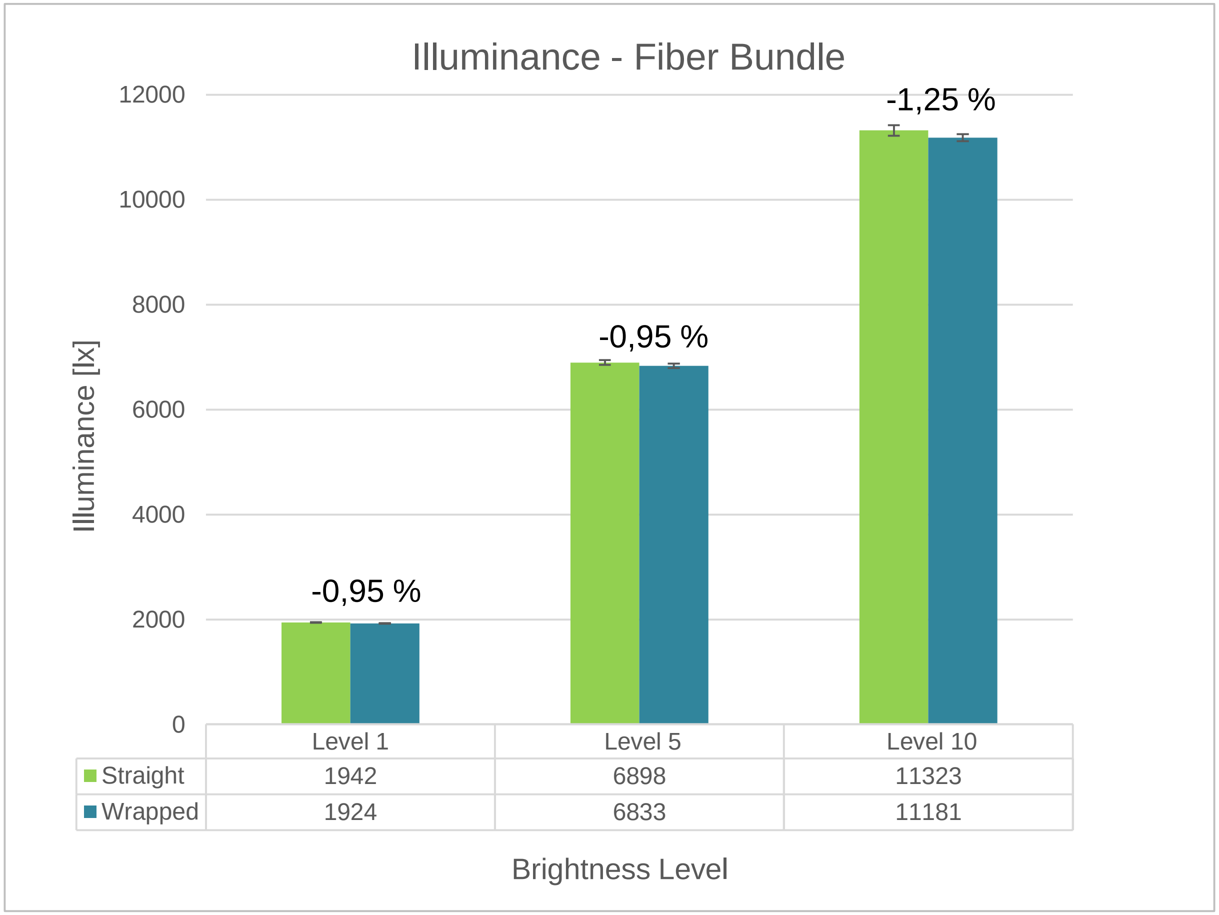
→ NO perceivable changes in intensity or chromaticity shift





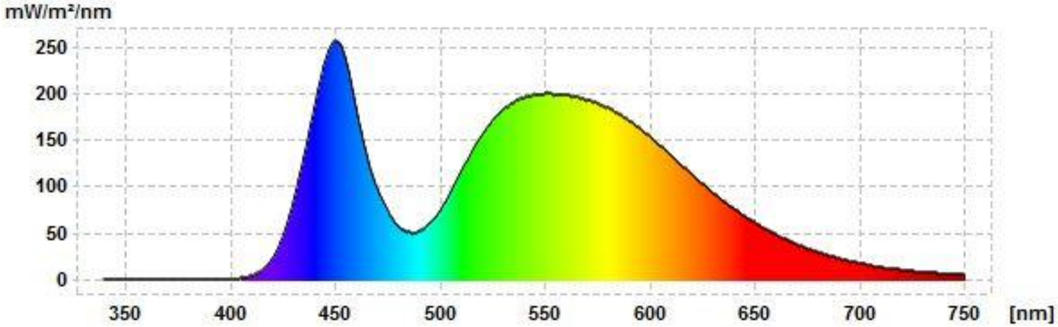
Measurements – Fiber bundle

- Results only show minor (negligible) changes (measurement inaccuracies <4 %)
- 10 measurements per bar are carried out

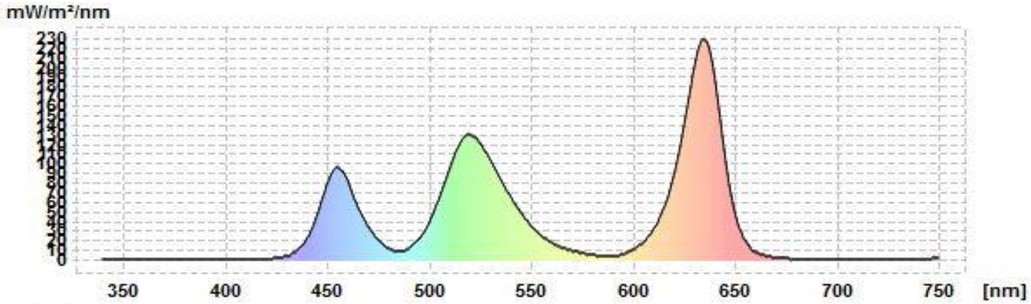


Measurements – Light Sources

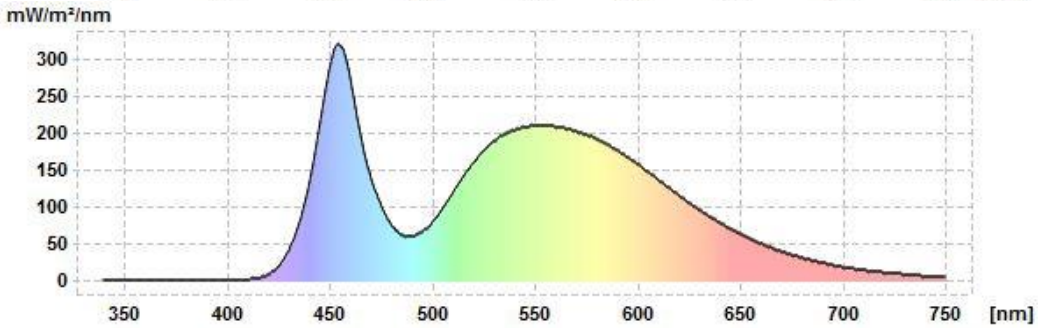
Very different spectral distribution (CCT, Ra, R9 etc..)



Light Source (a)

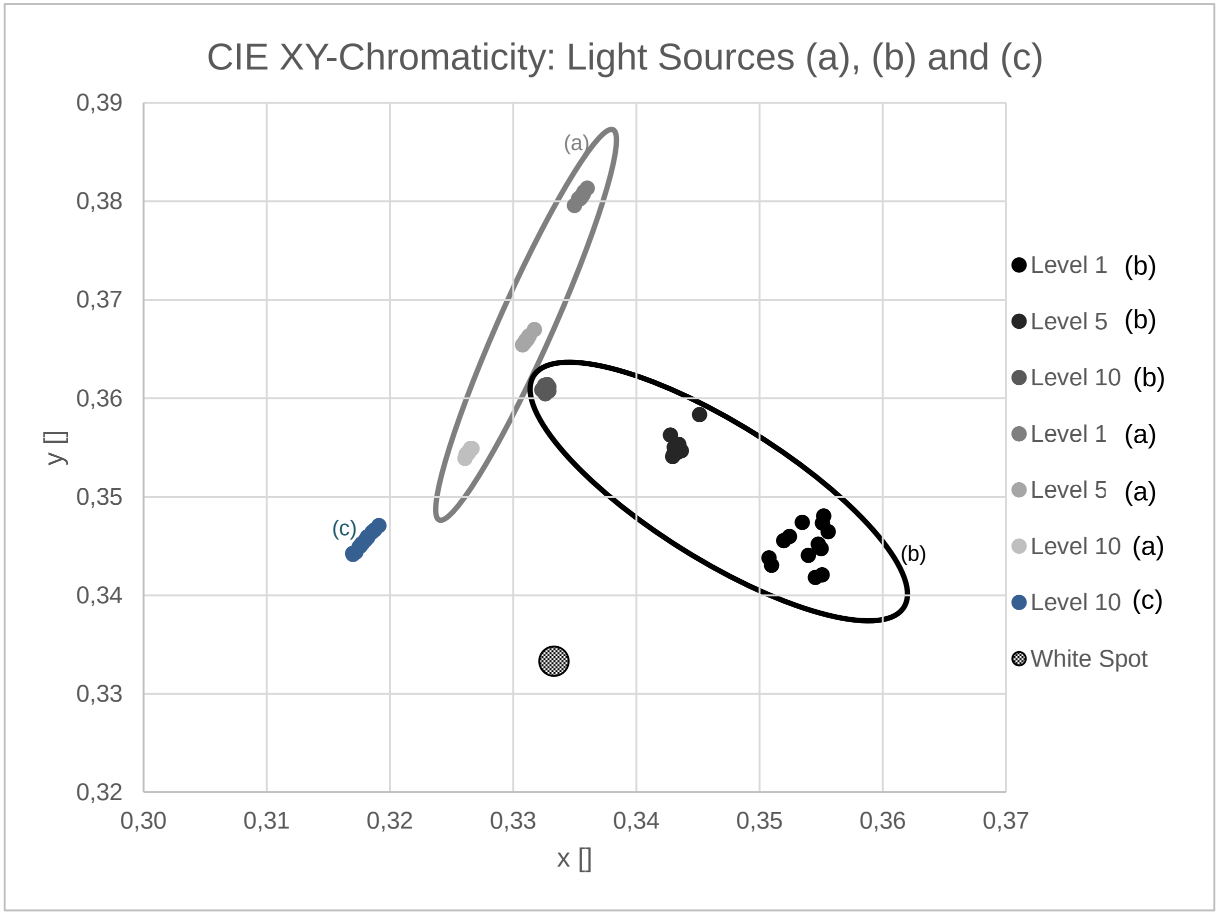


Light Source (b)



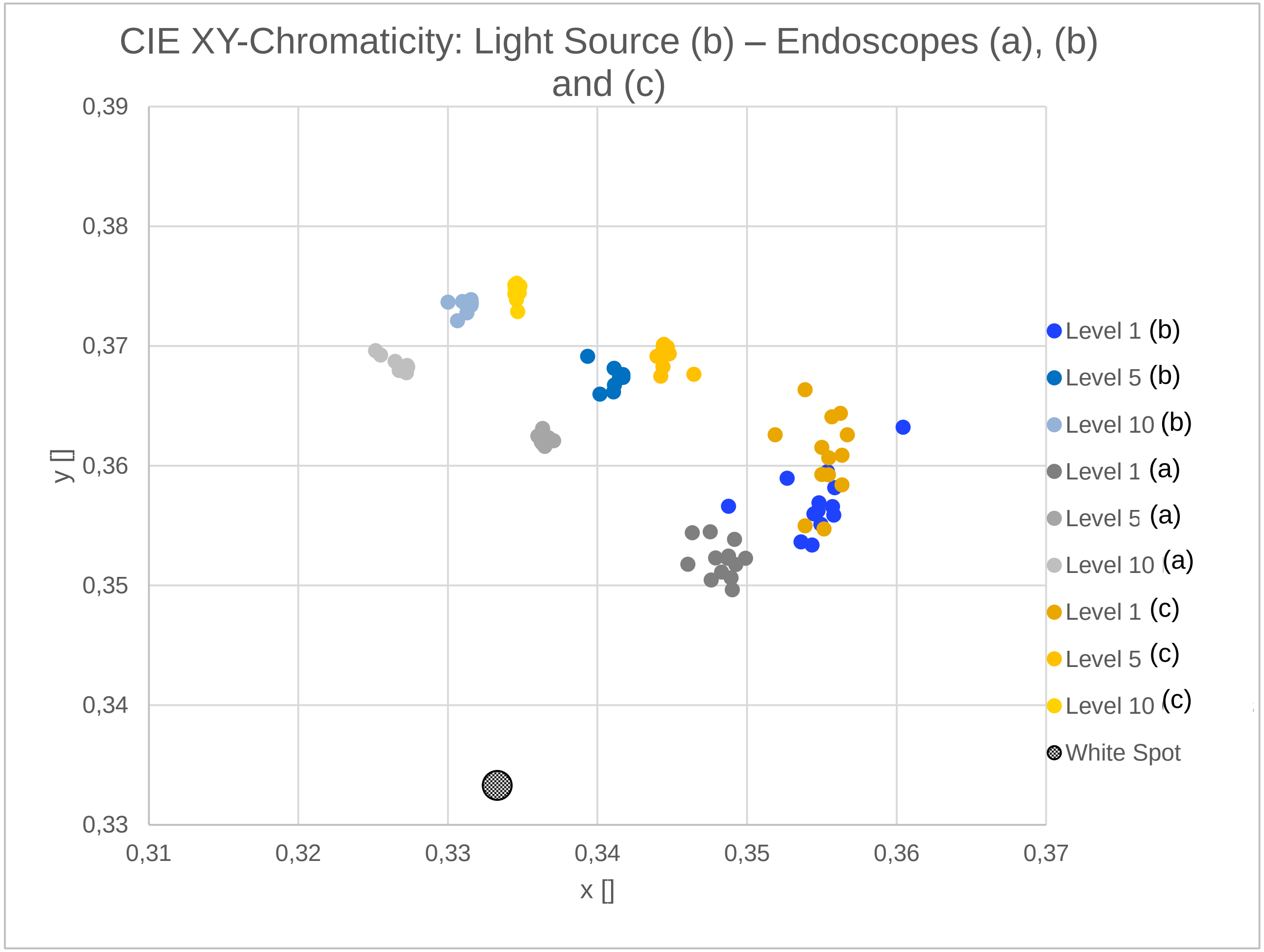
Light Source (c)

Measurements – Chromaticity light sources



- Stronger x-shift for RGB-light source and high scattering for smaller brightness levels

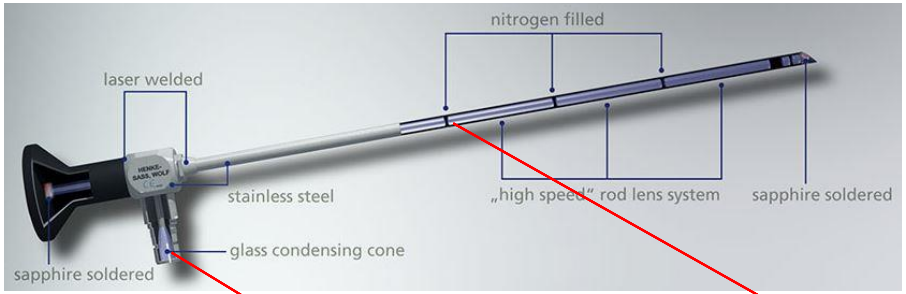
Measurements – Chromaticity light sources and endoscopes

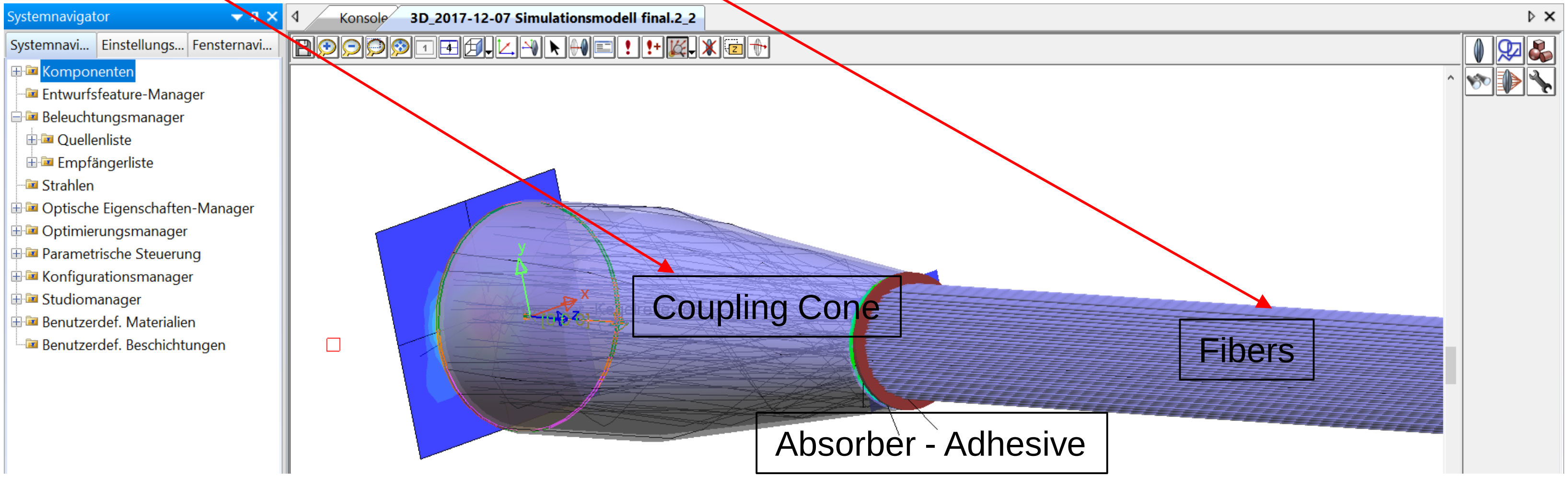


Bigger scattering for lower brightness levels of RGB-light source

Optical simulations

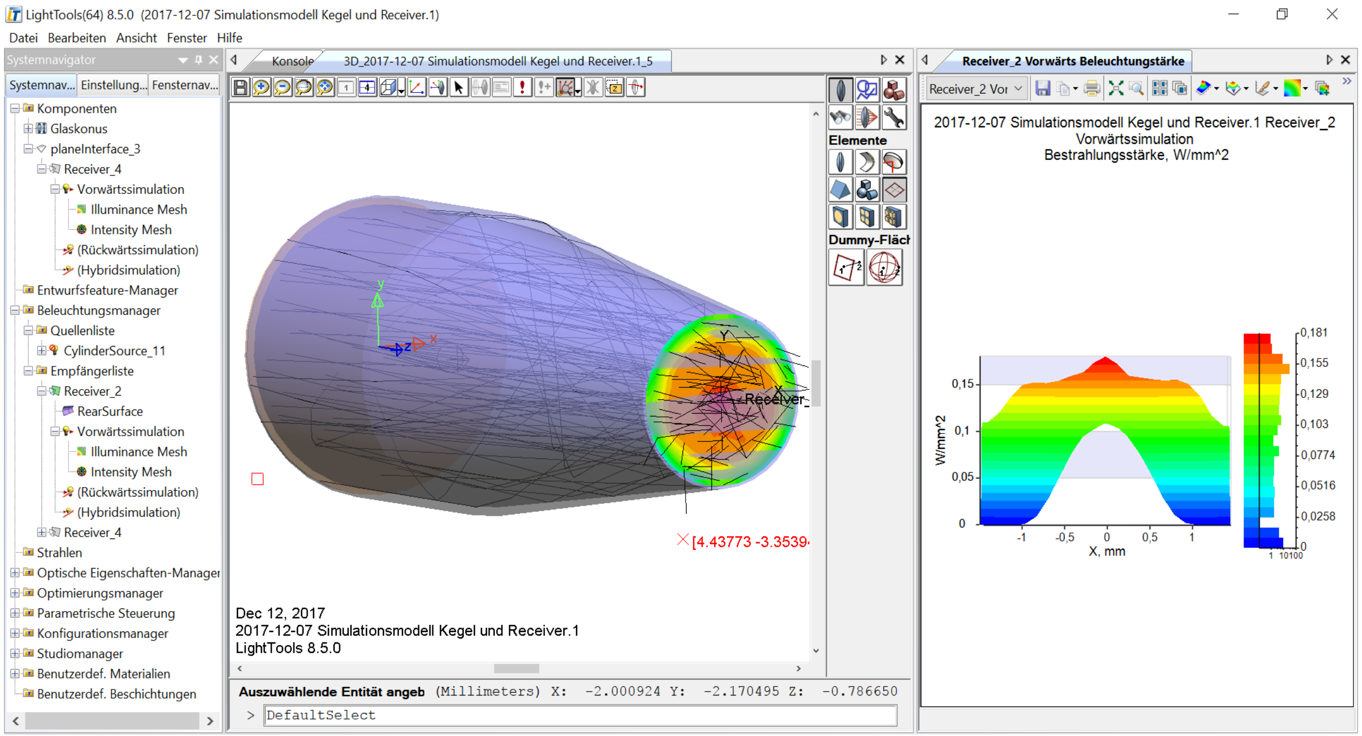
Analysis of all critical interfaces for light coupling and transport

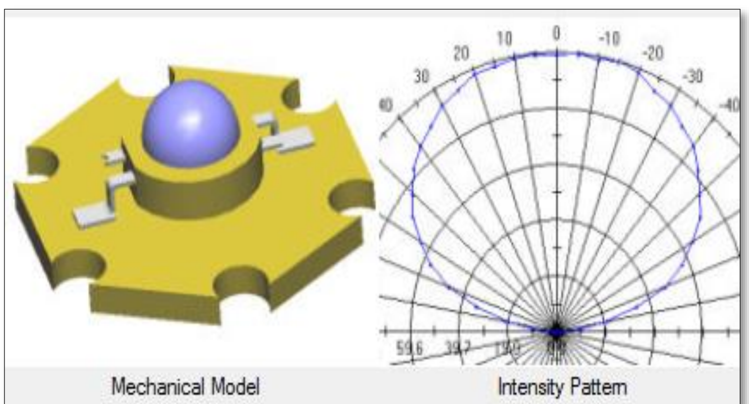




Software LightTools (Synopsis©)

Optical simulations – Light coupling

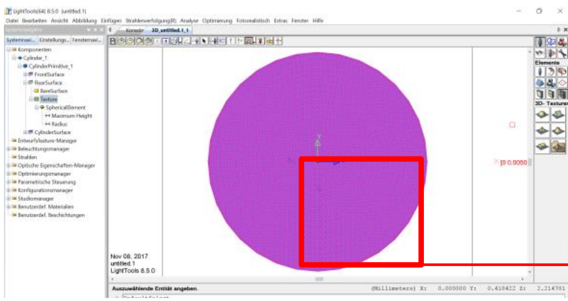


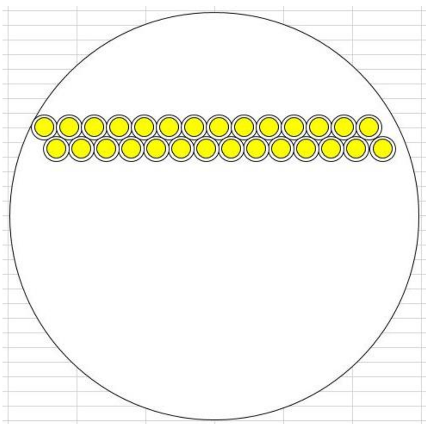


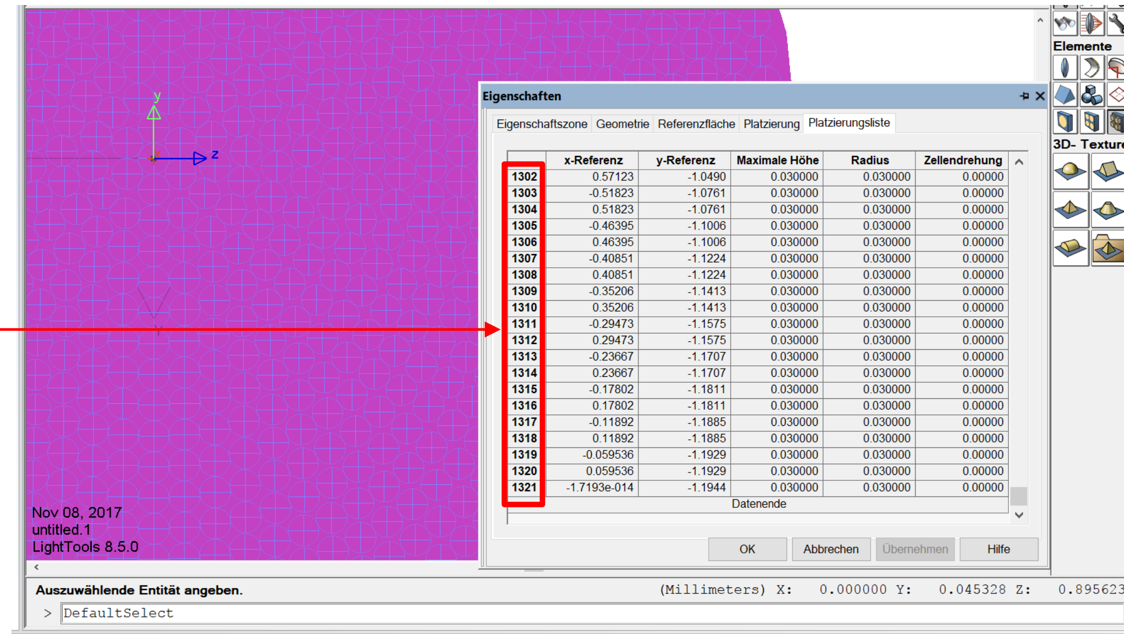
Intensity and uniformity of the light coupling is very much dependent on the light curve distribution (LCD) of the light source

Optical simulations – Light transport

Simulation of fiber bundle : Geometry and optical transmission properties

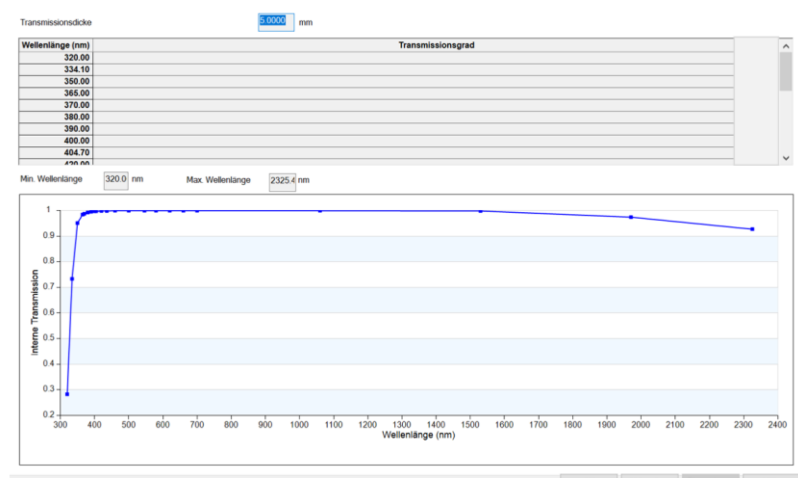






	x-Referenz	y-Referenz	Maximale Höhe	Radius	Zellendrehung
1302	0.57123	-1.0490	0.030000	0.030000	0.00000
1303	-0.51823	-1.0761	0.030000	0.030000	0.00000
1304	0.51823	-1.0761	0.030000	0.030000	0.00000
1305	-0.46395	-1.1006	0.030000	0.030000	0.00000
1306	0.46395	-1.1006	0.030000	0.030000	0.00000
1307	-0.40851	-1.1224	0.030000	0.030000	0.00000
1308	0.40851	-1.1224	0.030000	0.030000	0.00000
1309	-0.35206	-1.1413	0.030000	0.030000	0.00000
1310	0.35206	-1.1413	0.030000	0.030000	0.00000
1311	-0.29473	-1.1575	0.030000	0.030000	0.00000
1312	0.29473	-1.1575	0.030000	0.030000	0.00000
1313	-0.23667	-1.1707	0.030000	0.030000	0.00000
1314	0.23667	-1.1707	0.030000	0.030000	0.00000
1315	-0.17802	-1.1811	0.030000	0.030000	0.00000
1316	0.17802	-1.1811	0.030000	0.030000	0.00000
1317	-0.11892	-1.1885	0.030000	0.030000	0.00000
1318	0.11892	-1.1885	0.030000	0.030000	0.00000
1319	-0.059536	-1.1929	0.030000	0.030000	0.00000
1320	0.059536	-1.1929	0.030000	0.030000	0.00000
1321	-1.7193e-014	-1.1944	0.030000	0.030000	0.00000

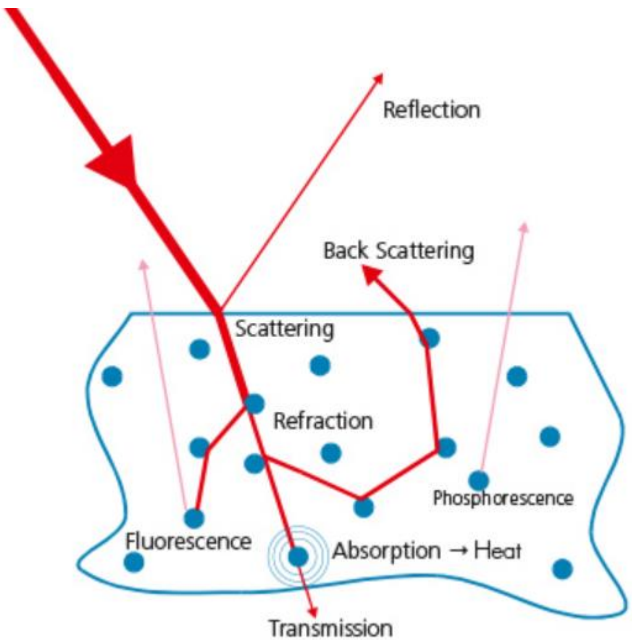
Datenende

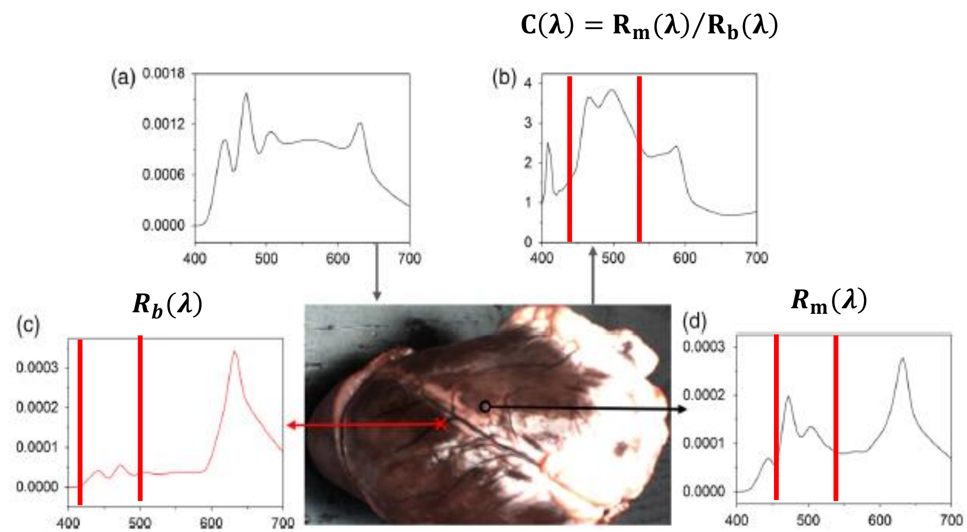


Less than 3 % of the input light is aborbed in the 300 mm lenght

Reflection properties of human tissues

- Physical interaction between light and human tissue is complex
- Only reflected light will be captured by a camera system or directly seen by the surgeon
- Reflection properties of the target tissues and their environement must be known
- Color and intensity contrast can be optimised



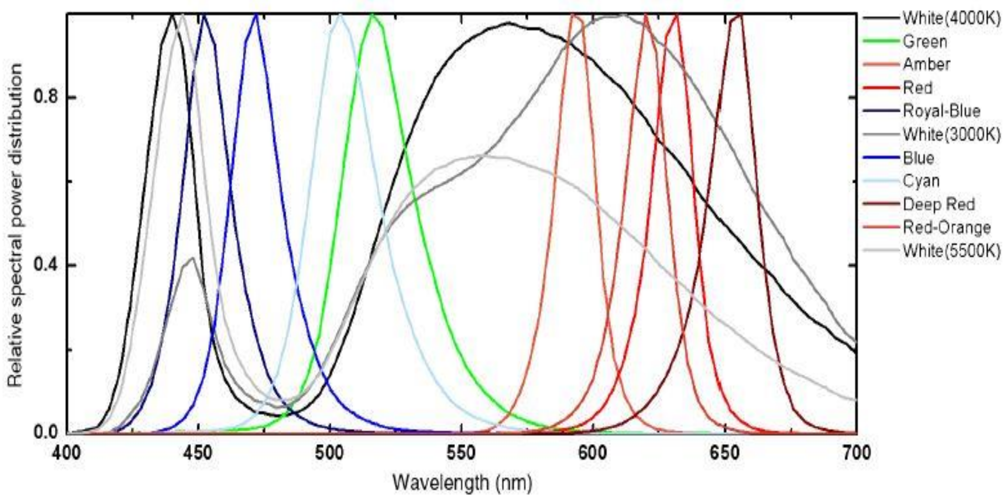


Color contrast C(λ) optimised

Quelle: J.Shen, H. Wang, Y. Wu, A. Li, C. Chen, Z. Zheng.: “Surgical lighting with contrast enhancement based on spectral reflectance comparison and entropy analysis” in Journal of biomedical optics 20(10), 105012-2015

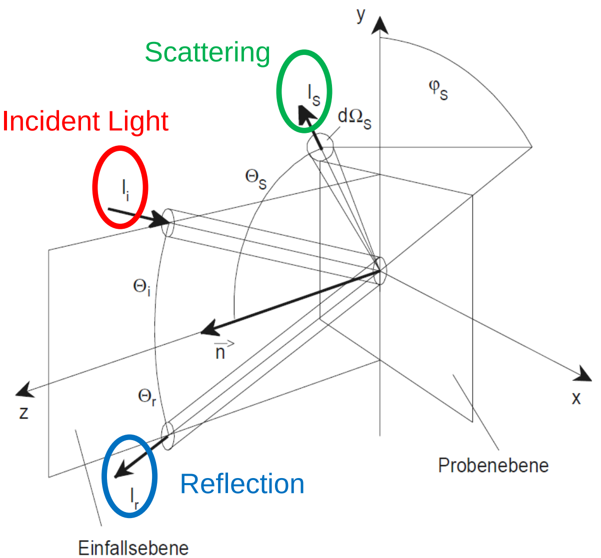
Ongoing research project

Development of a multispectral illumination units which spectral characteristics can be flexibly adapted to the specific diagnostic procedures



Quelle: Huihui Wang, Raymond H. Cuijpers, Ingrid M. L. C. Vogels, Ingrid Heynderickx, Ming Ronnier Luo, Zhenrong Zheng. 17-3: Simultaneous Optimization of Color Contrast and Color Rendering Index for Surgical Lighting. In: Journal of Biomedical Optics 20(1), 015005 (January 2015)

Measurements of bidirectional reflection distribution functions (BRDF) of representative biological tissues



- EX-vivo? IN-vivo?
- How to categorize human tissues? (liver, lung, nerves, fat)

HOCHSCHULE FURTWANGEN UNIVERSITY HFU

ITeM Institute of Technical Medicine

Prototype of an automated photobiomodulation treatment device for in vitro wound healing studies

Jacquelyn Dawn Parente, Knut Möller, Paola Belloni, Margareta Müller

GEFÖRDERT VOM

Bundesministerium für Bildung und Forschung

FORSCHUNG AN FACHHOCHSCHULEN

ATMOS MedizinTechnik

Chronic wounds are a healing process dysfunction

<u>3+ months</u>

Pressure ulcer

Venous leg ulcer

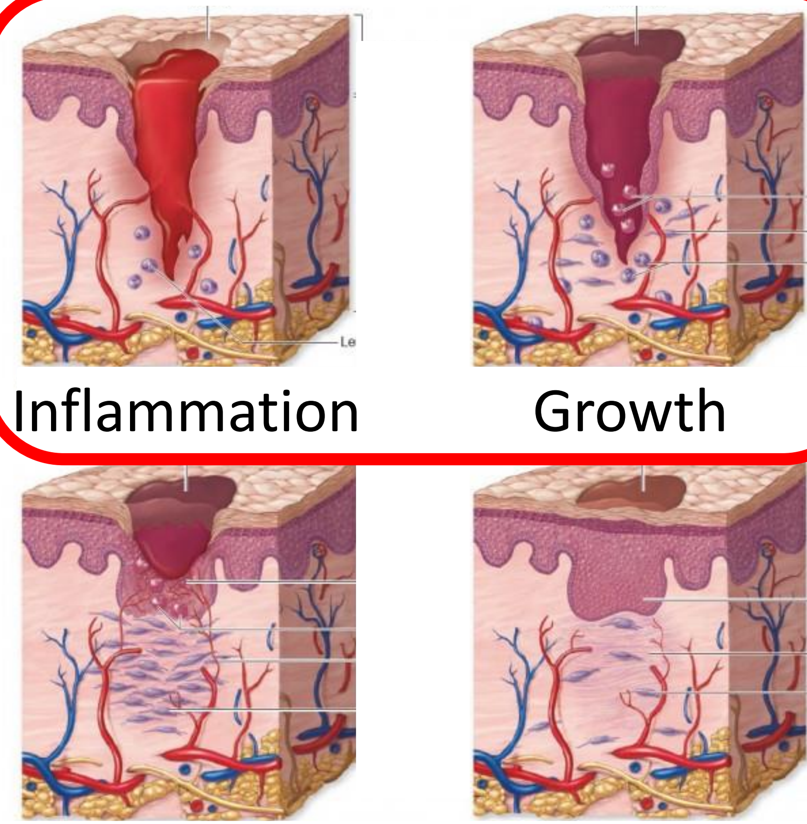
Diabetic foot ulcer

<u>In Germany (2014)</u>

800K diagnosis

200K new diagnosis

500K treated



Inflammation

Growth

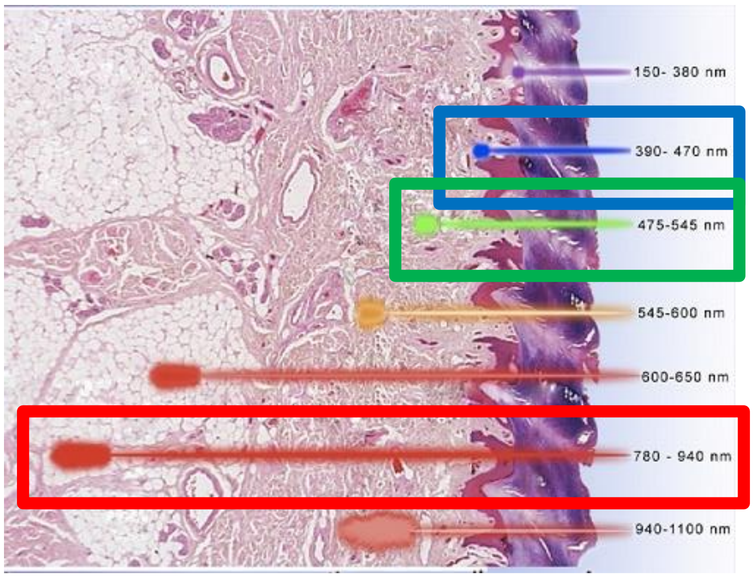
Blood vessels

Remodeling

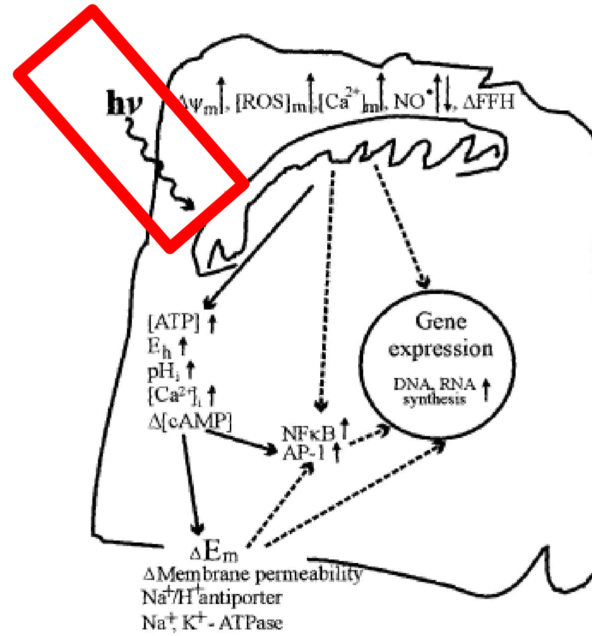
Heyer, K., Herberger, K., Protz, K., Glaeske, G., & Augustin, M. (2016). Epidemiology of chronic wounds in Germany: Analysis of statutory health insurance data. *Wound Repair and Regeneration*, *24*(2), 434-442.

FOCUS: Light therapy re-activates healing processes

Light (LED or LASER)



Photobiomodulation



Wavelength-dependent absorption at mitochondria.

Houreld, N. N. (2014). Shedding light on a new treatment for diabetic wound healing: a review on phototherapy. *The Scientific World Journal, 2014*.

Treatment parameter reporting is unverified

Literature reporting (2015)

1) Wavelength

3% no ‚medicine'

2) Irradiance [mW/m^2]

43% no ‚dose'

3) Exposure Time

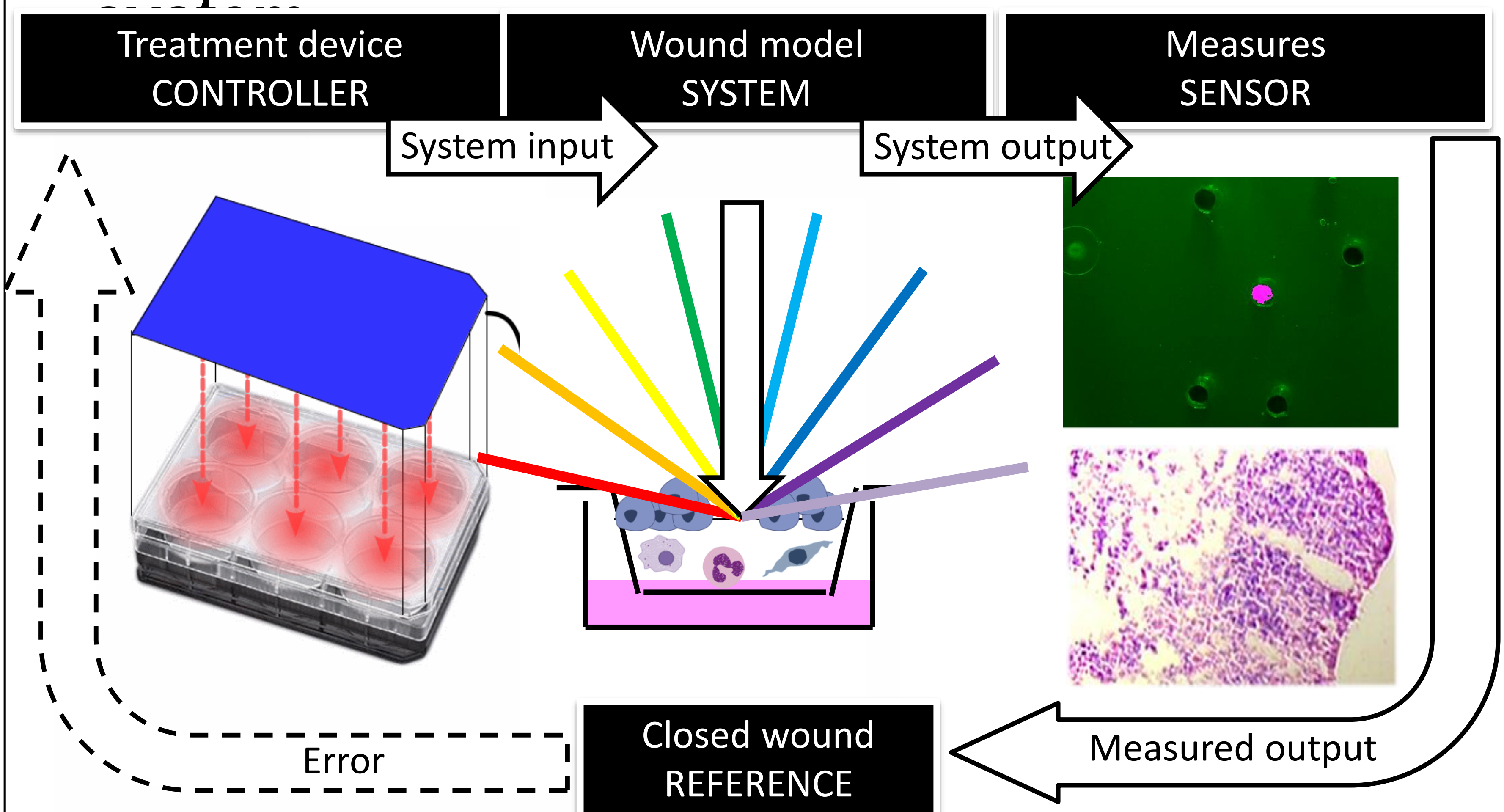
16% no ‚protocol'

Advanced wound care

- Optimal treatment parameters: **unknown**
- Standard protocols: **none**
- Combinations (light + mechanical + electrical): **none**

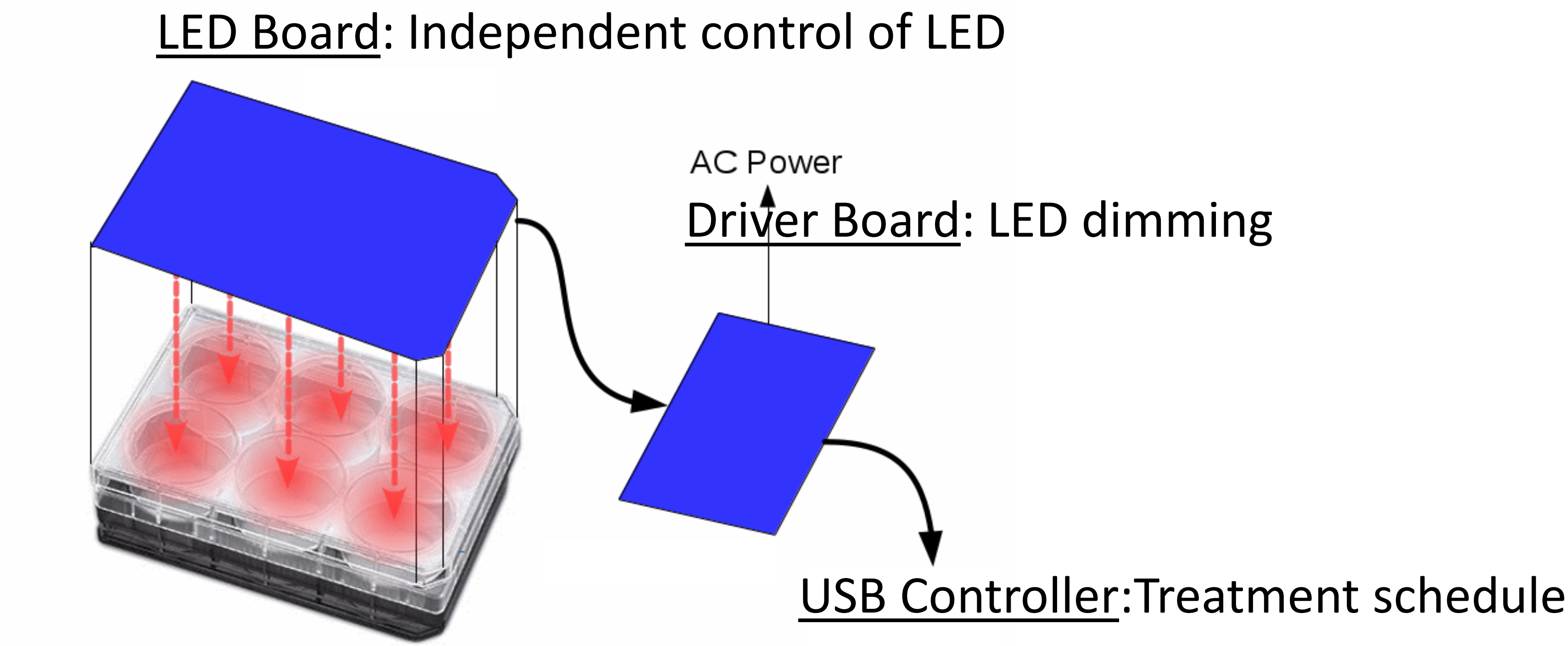
Hadis, M. A., Zainal, S. A., Holder, M. J., Carroll, J. D., Cooper, P. R., Milward, M. R., & Palin, W. M. (2016). The dark art of light measurement: accurate radiometry for low-level light therapy. *Lasers in medical science*, *31*(4), 789-809. Parente, J. D., Müller, M., & Möller, K. (2016). Methodologies of Biophysical Wound Healing Therapies. *Journal of Biomedical Science and Engineering*, *9*(10), 171.

APPROACH: Modeling + control of the wound system



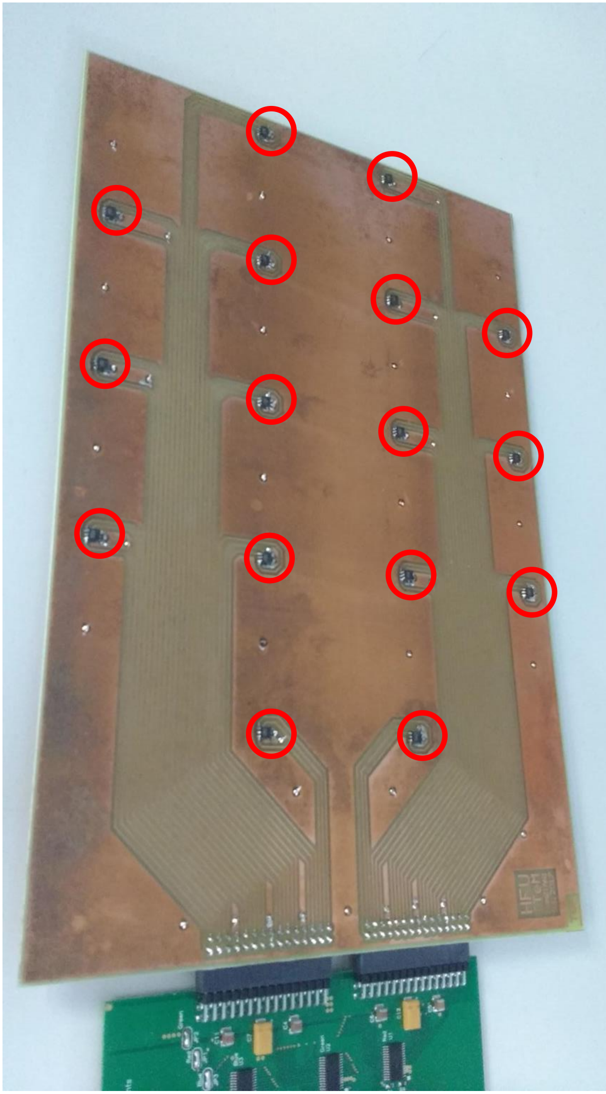
Parente, J. D., & Möller, K. (2017). A Control System Design to Establish Dose-Response Relationships in Wound Healing Therapy. *Journal of Biomedical Science and Engineering*, *10*(05), 76.

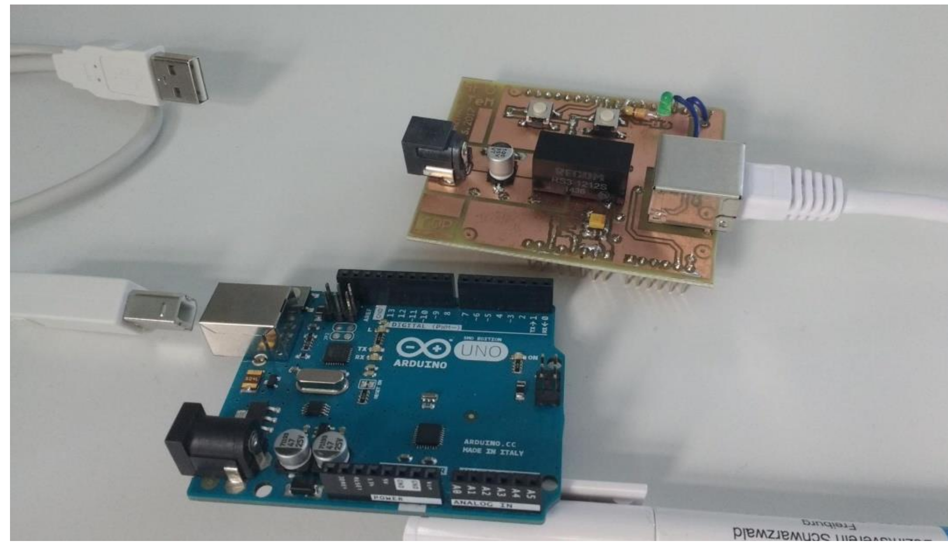
Prototype device: adjustable treatment parameters for automated and repeatable in vitro experiments.



- Prescribed parameters: Wavelength, Irradiance, Time
- Performance: Uniform treatment delivery to target surface
- Prototype: 2x2 RGB LED array (Results presented)

Prototype: Updated LED board and Arduino controller

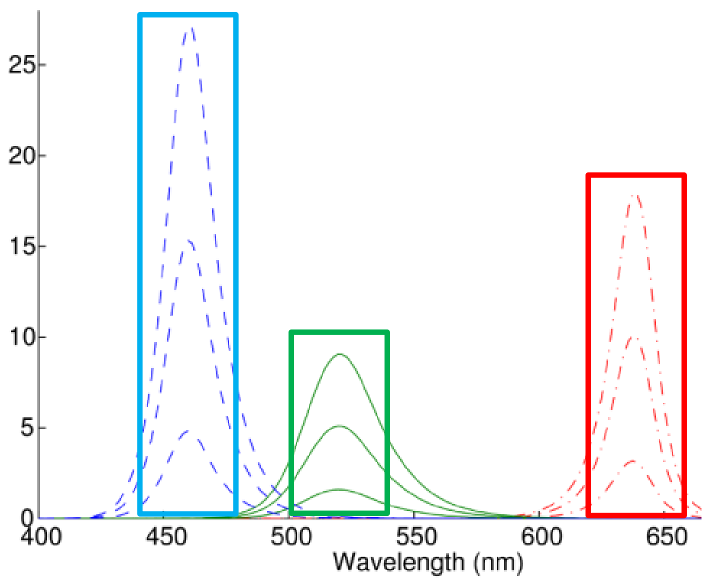




- RGB LED wavelengths
- Uniform irradiance
- Programmable schedules
- Functional in incubator !!!

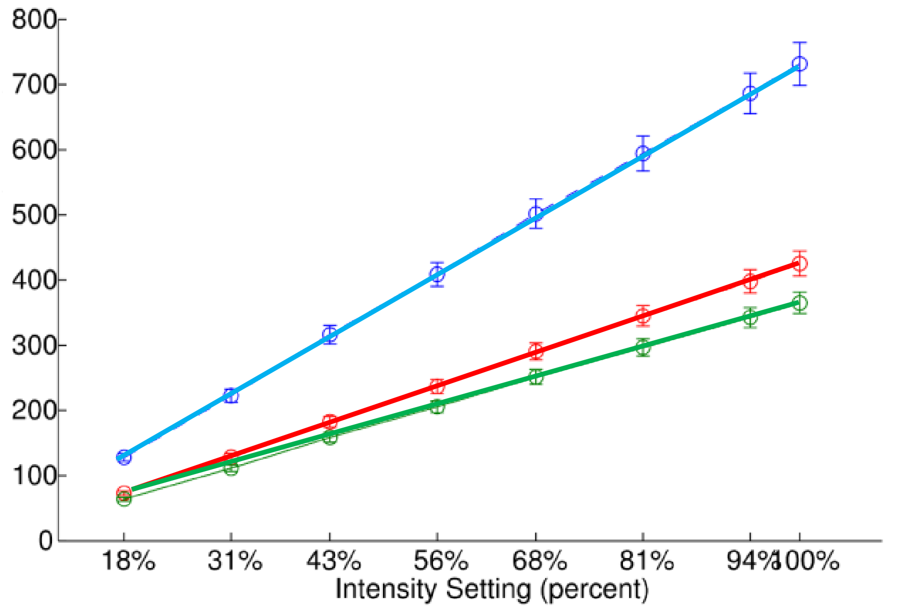
Irradiance measures [mW/m^2] at intensity settings.

1) Spectral irradiance



LED dimming (PWM method) does not alter wavelength.

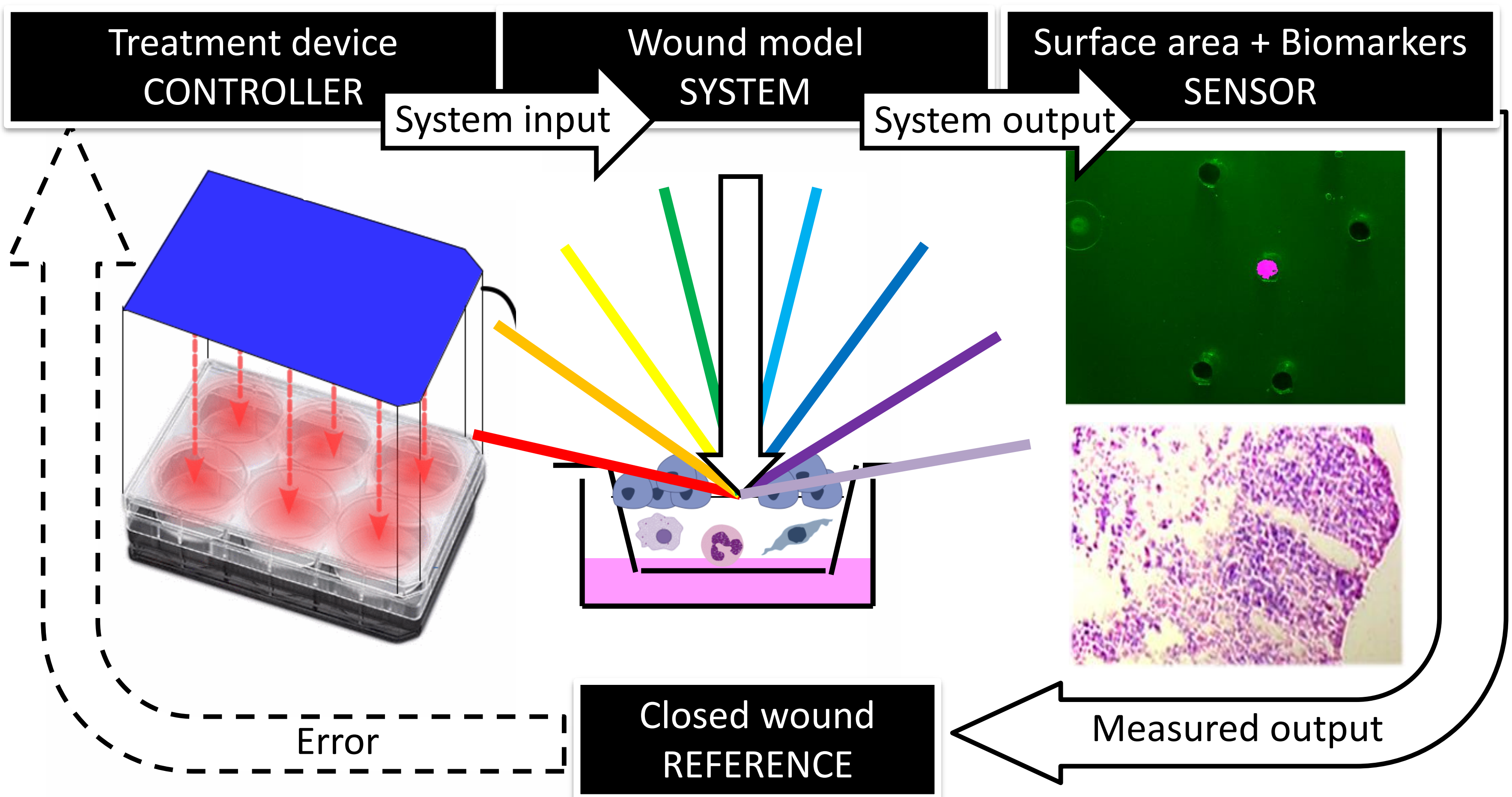
2) Integrated irradiance



Measurements determine device emission,

but not tissue absorption....

Ongoing studies to establish dose-response relationships to guide wound healing therapy



Parente, J. D., & Möller, K. (2017). A Control System Design to Establish Dose-Response Relationships in Wound Healing Therapy. *Journal of Biomedical Science and Engineering*, *10*(05), 76.

Thank you for
your attention