Reproduzierbare Charakterisierung von nützlichen und störenden Reflexionen
von bedrucktem Papier zu emittierenden elektro-optischen Anzeigen.
Eine Implementierung der Methode von Sharp-Little aus dem Jahr 1920.

Reproducible characterization of intended and unwanted reflections
from printed paper to emissive electronic displays.
An implementation of the Sharp-Little method from 1920.

Which of those berries you should NOT eat ?













Evolution and optimization of the visual system - over millions of years - as a means of survival in the respective existing environment.

- **Friend - Foe recognition;**
  Fight, flight, submission, neutrality.

- **Food recognition & classification;**
  edibility, ripe / unripe.

- **Sustainment of species;**
  Choice of partner: state of health.

- **Social aspects;**
  Communication, greeting, courtship, moods, hierarchy, dominance, ...

Critical decisions must be made quickly and unerringly

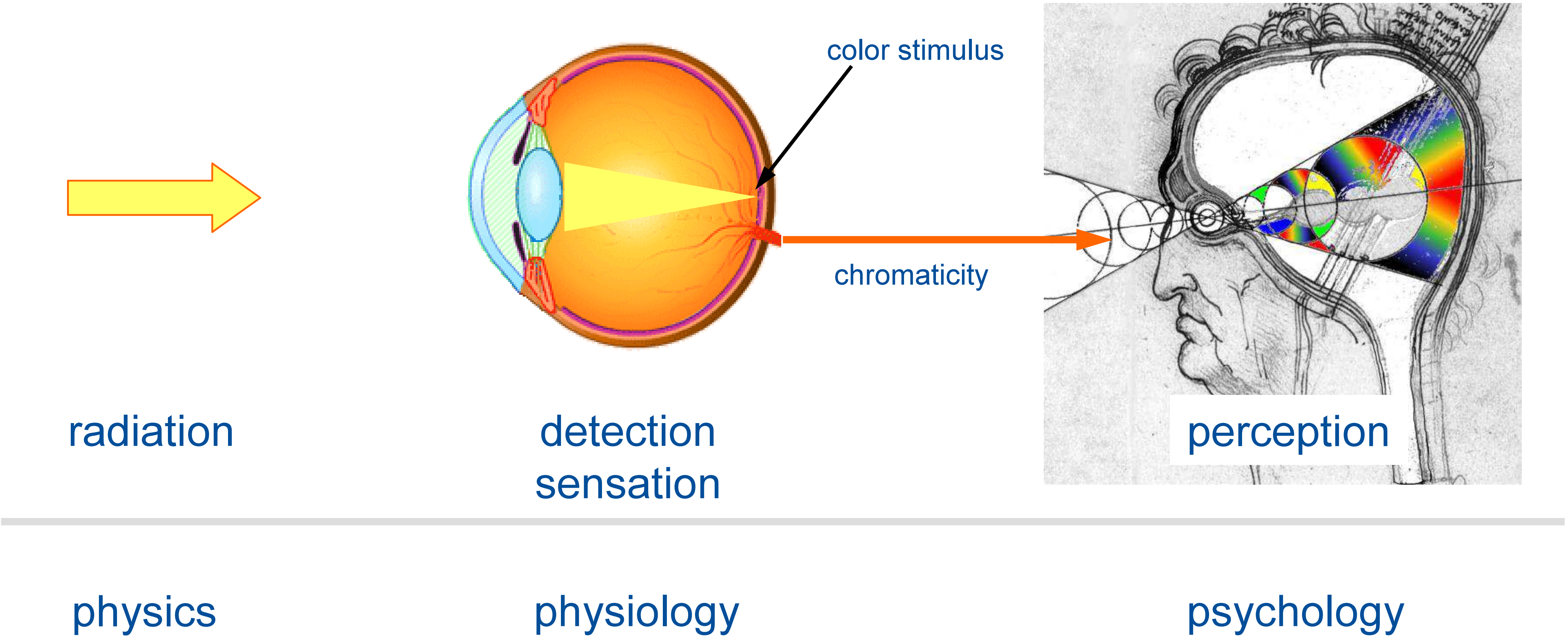
All characteristics that have contributed to the survival of our ancestors are preserved in our current visual system.

Sensation - Perception

Color - a characteristic of visual perception that can be described by attributes of hue, brightness (or lightness) and colorfulness (or saturation or chroma) stimulated by light (= electro-magnetic radiation in the wavelength range from ~360 nm to ~800 nm.

Color is a visual perception enabling the discrimination of two adjacent otherwise featureless parts of the visual field with one single resting eye.

according to DIN 5033



Color – a visual sensation ➔ perception

Sensation: Sensory receptors are specialized neurons that respond to specific types of stimuli. When sensory information is detected by a sensory receptor, sensation has occurred.

Perception: requires organization (classification) and interpretation of incoming sensory information**.**

- Visual stimulus: ***reflected light*** in most cases**,**

  coloration caused by selective absorption during the process of reflection: surface/object colors

- ***scattered light***: skies, water, milk, ...
- ***emitted light***
  - thermal excitation, e.g. flames: candle, fire, gas flame, ...,
    - thermo-nuclear excitation: stars, sun,
  - electrical discharges: e.g. lightning,
  - electro-luminescense (LED, OLED, ...)
  - bio-luminescense: e.g. fireflies, glow-worms.

Monochromatic stimuli are characterized by their wavelength in vacuum**,** λ_0.

Identification of subtle clues

matte - scattering - surface

glossy - mirror like - surface

Appearance

ASTM

*"**Appearance of an object**, the collected visual aspects ….*
***Perceived appearance**: visual perception including size, shape, color, texture, gloss, transparency / opacity, etc., ..."*

The **visual appearance of objects** is given by the way in which they reflect and transmit light.

The **color of objects** is determined by the parts of the spectrum of incident white light that are reflected or transmitted without being absorbed.

Additional appearance attributes are based on the **directional distribution** of reflected or transmitted light described by attributes like glossy, shiny versus dull, matte, clear, distinct, etc..

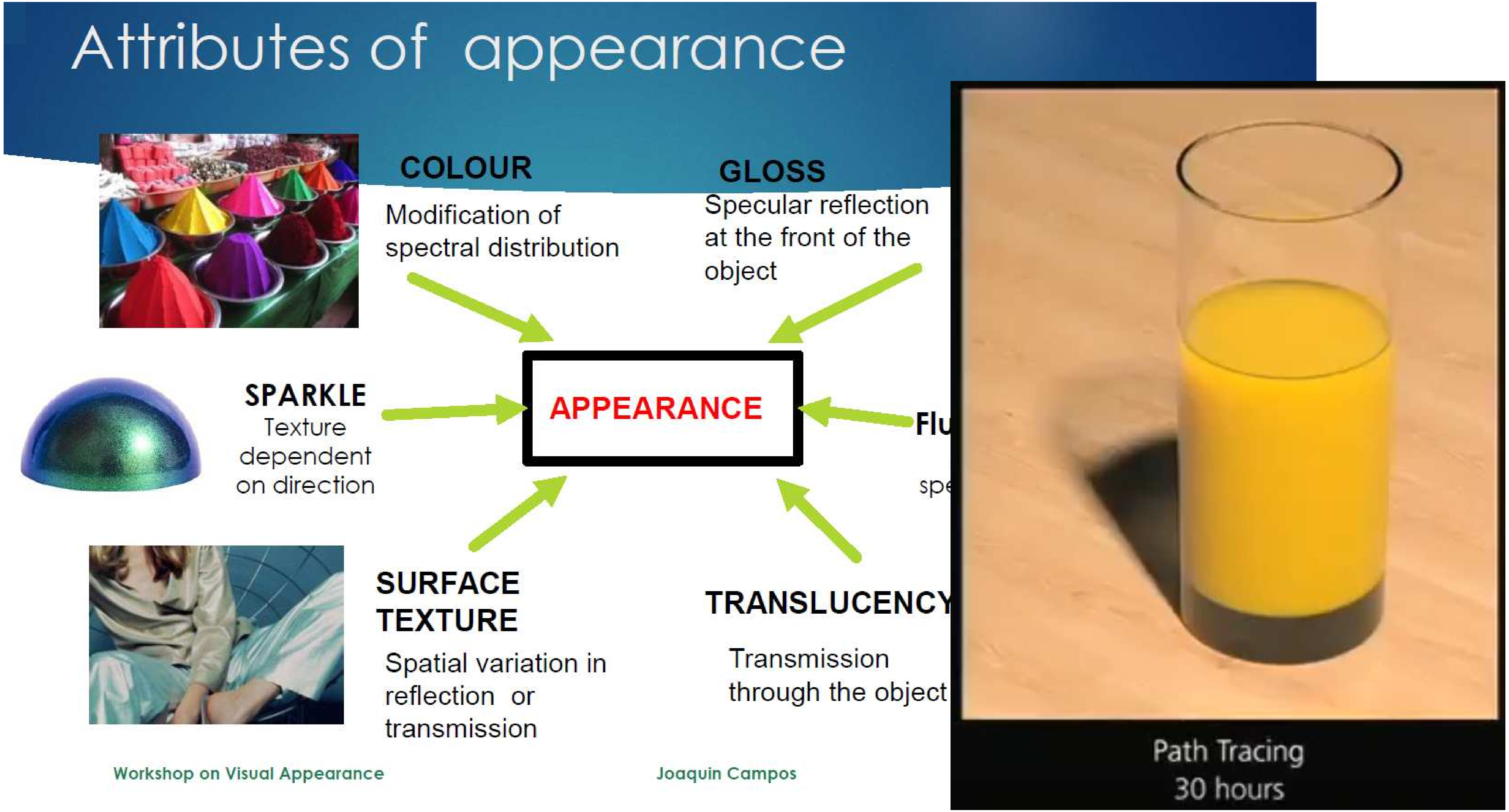
The reflective properties are determined by the **micro-topography** of surfaces (e.g. scales of hair fibers).

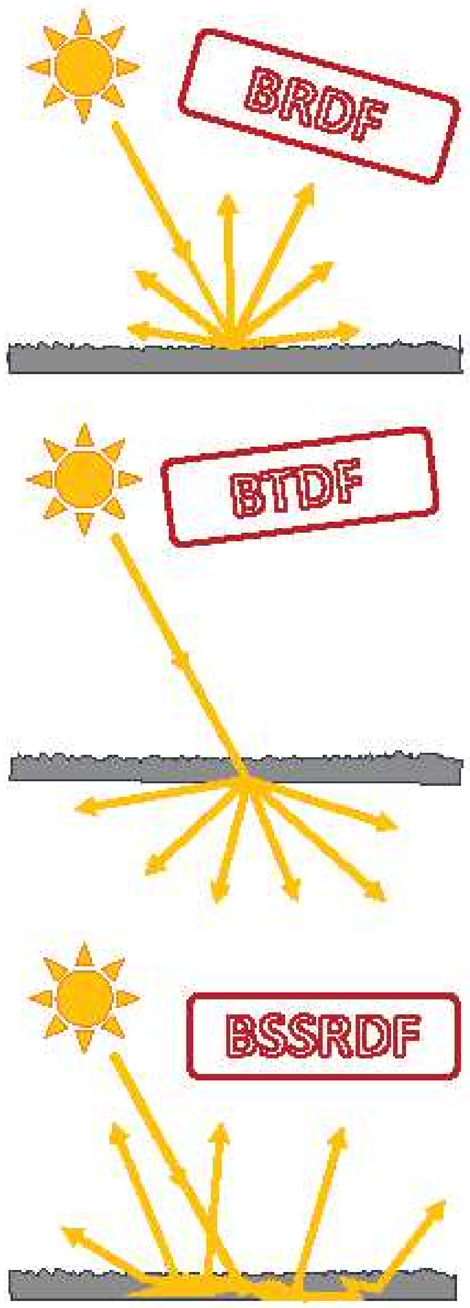
Structures on the surface typically range between some 10 mm and 0,1 mm (the detection limit of the human eye is at ~0,07 mm).

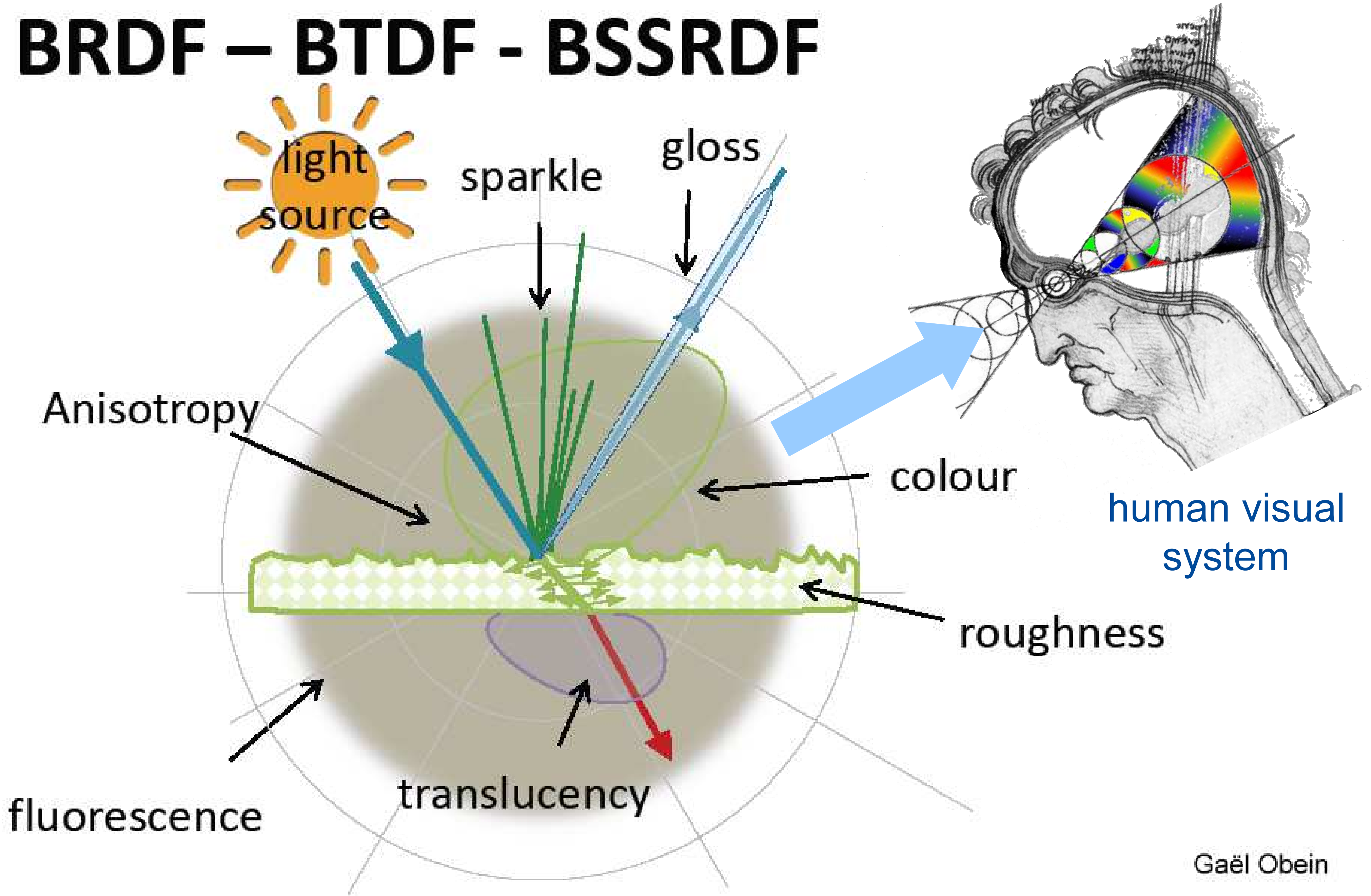
Smaller structures and features cannot be seen directly, but their effect becomes apparent in images reflected in the surface:

- structures at and below 0,1mm **reduce the distinctness of image (DOI)**,
- structures in the range of 0,01 mm **induce haze** and even
- smaller structures (< 10 µm) **reduce the gloss** of the surface.

Total Visual Appearance



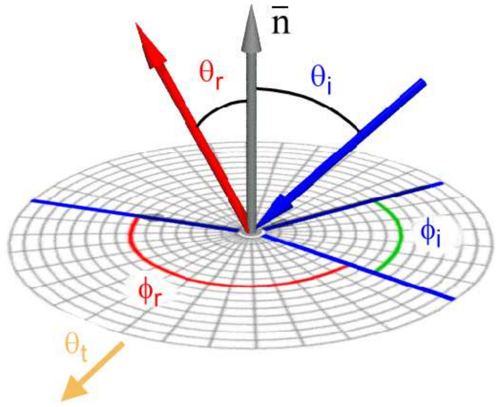




BSSRDF: Bidirectional Scattering Surface Reflectance Distribution Function

Directional Scanning

$$dL_s(\theta_s,\phi_s) = B\left(\theta_i,\phi_i,\theta_s,\phi_s;\lambda,\vec{p}\right)\; dE(\theta_i,\phi_i)$$



The scattering properties of surfaces are generally and completely described by the ***bidirectional scatter distribution function*** **(BSDF)** which is a function of the direction of light incidence, the direction of observation, the wavelength of light and its state of polarization.

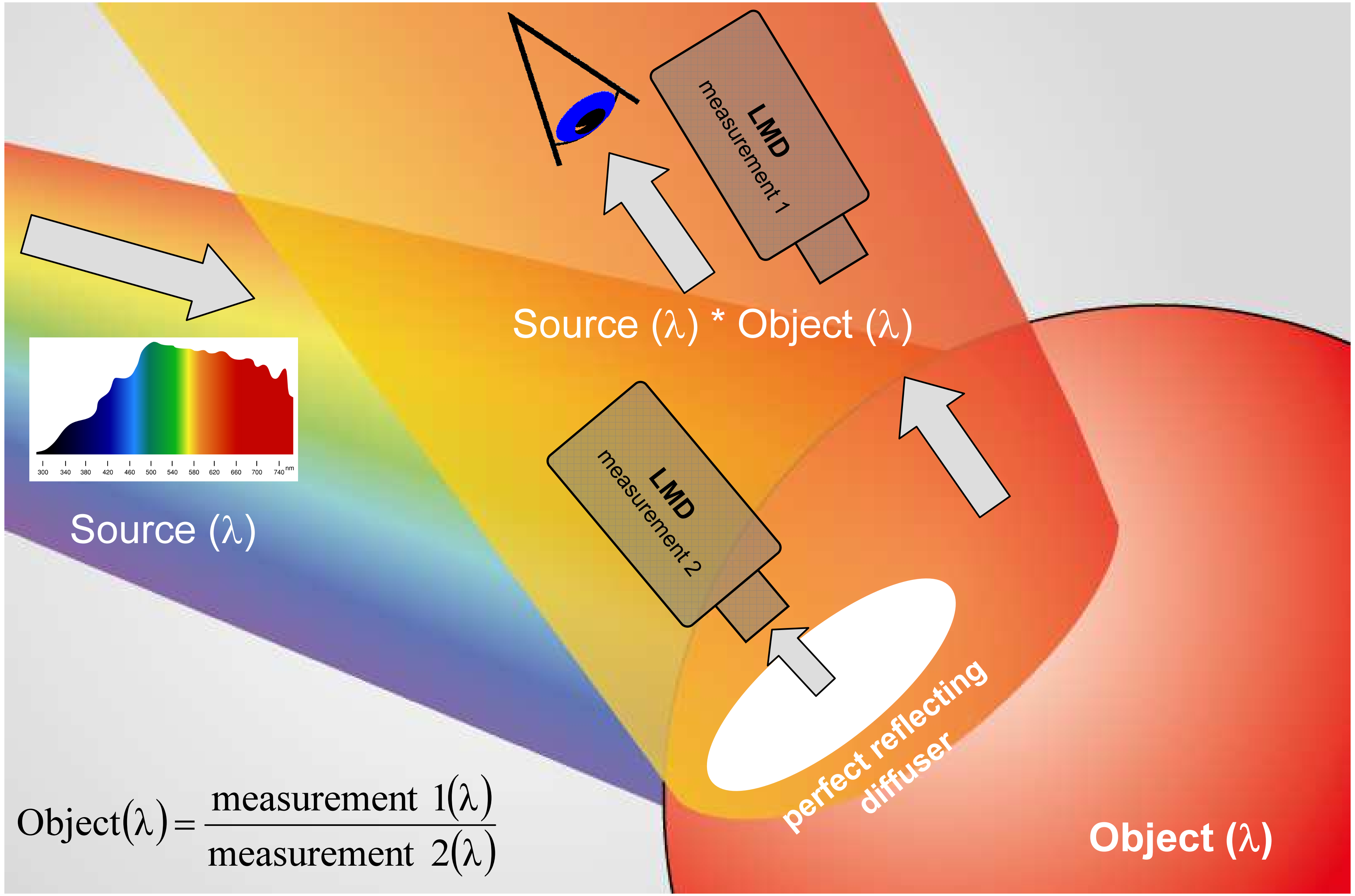
Assessment and evaluation of the reflective properties of surfaces can be realized by

- **mechanical** (**motorized) scanning of a range of observation directions** with photometric or spectro-radiometric receivers for one direction of light incidence. This can be done with complex, and bulky high-precision mechanisms (gonio-photometer or gonio-spectroradiometer).

Scanning of the directions of observation **without moving parts**:

- **optical scanning (conoscopy),**
- analysis of the spreading of a point- or line-source of illumination (**PSF - LSF approach**),
- hemispherical projection and imaging ("**imaging hemisphere**").

Spectral Reflectance Factor of Objects

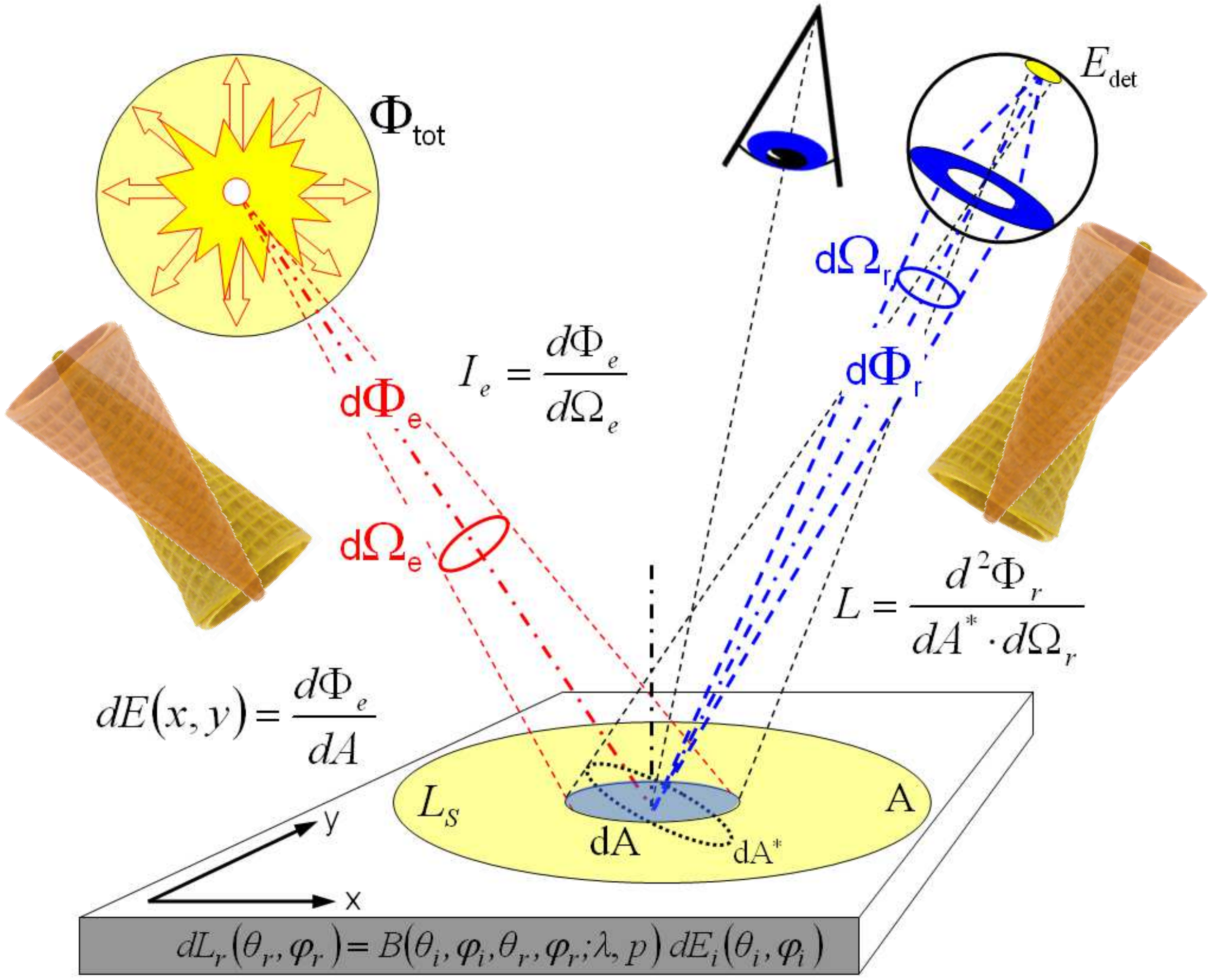


$$\text{Object}(\lambda) = \frac{\text{measurement } 1(\lambda)}{\text{measurement } 2(\lambda)}$$

object color - surface color - Körperfarbe

Items to be specified

- geometrical details of illumination:
  in-plane and directional distribution;
- spectral power distribution;
- temporal aspects (stability, modulation, etc.).



LMD specification (geometry):

- direction of observation / measurement;
- aperture;
- measurement field angle;
- ...

There is an intricate entanglement of illumination, object and LMD.

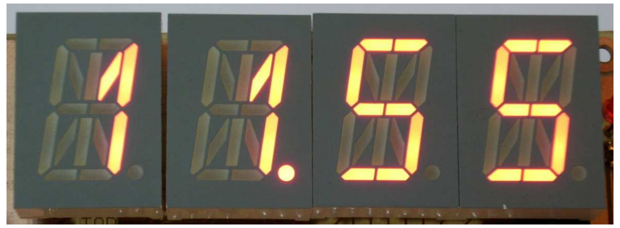
Reproducibility requires specification of all details.

Display

Presentation of haptic
or visual information.

Electro-optical Display

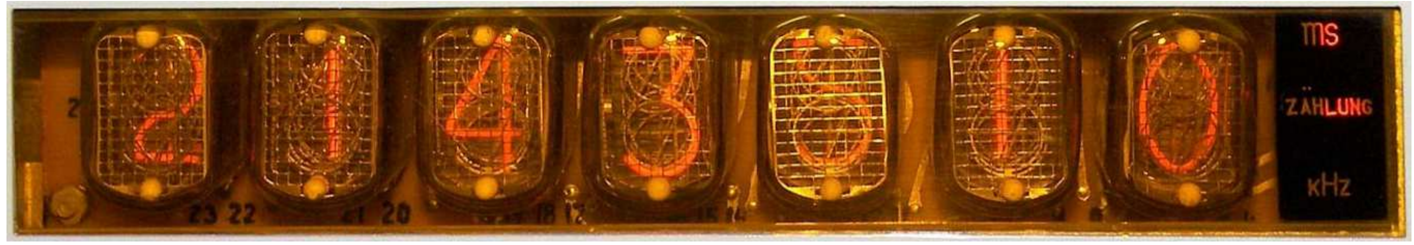
Visual presentation of electrically supplied information:
Alphanumeric characters, signs, symbols, etc., static information.

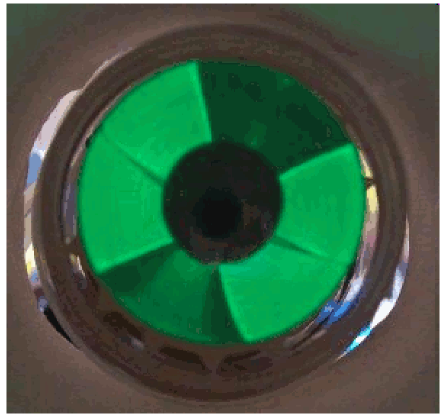


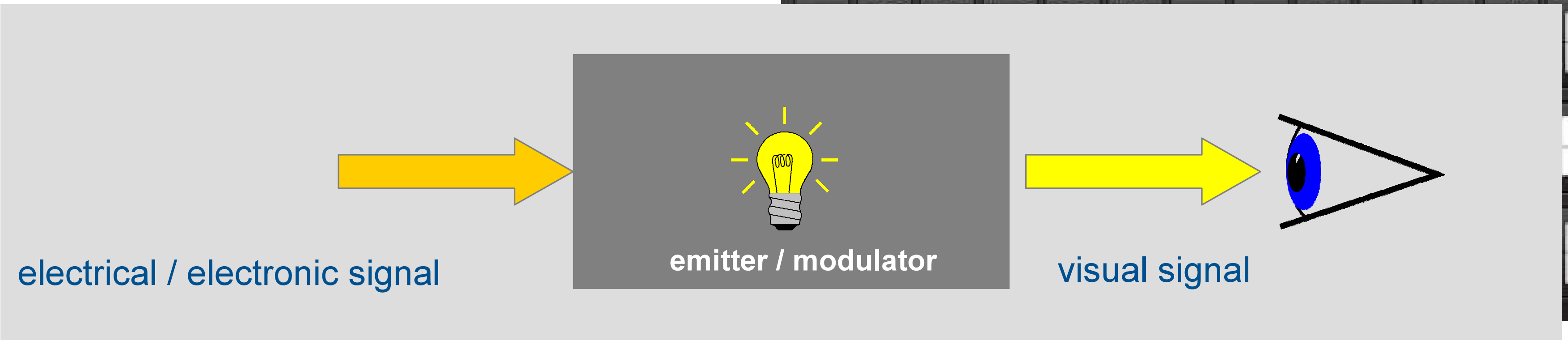
Display Screen

Matrix of picture elements with random selection for display of arbitrary image content, moving images.

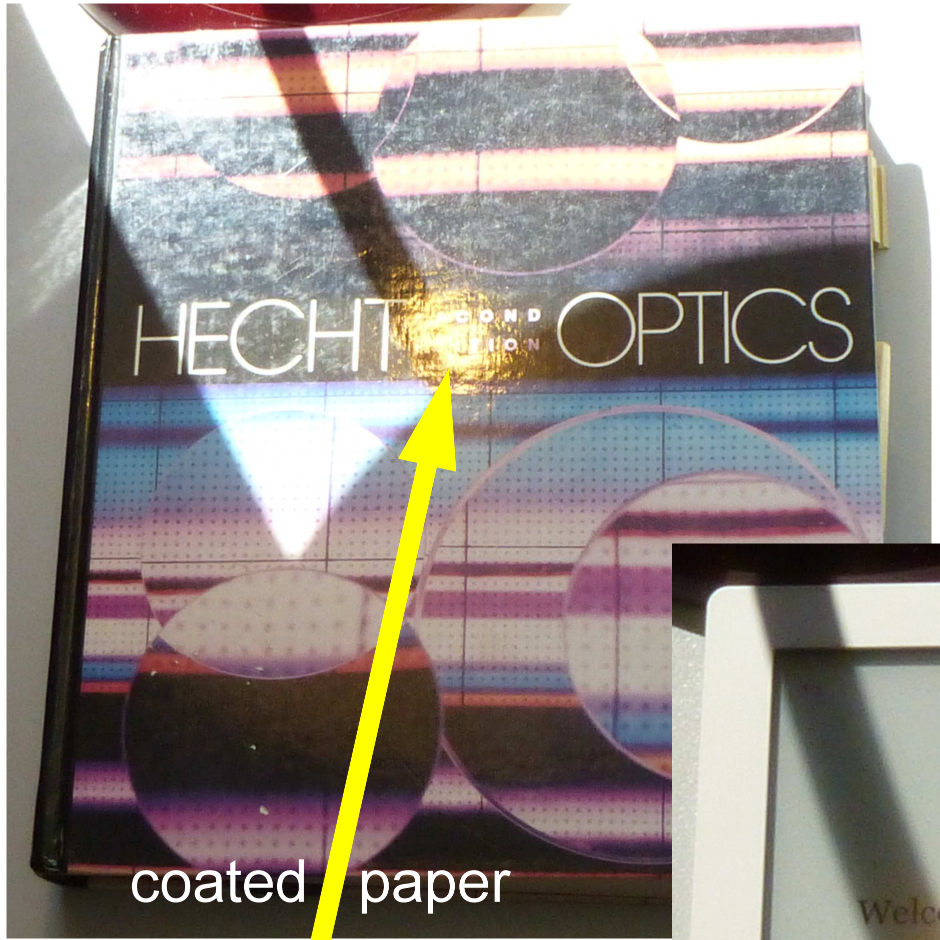
Electro-Optical Displays: Emissive vs. Reflective





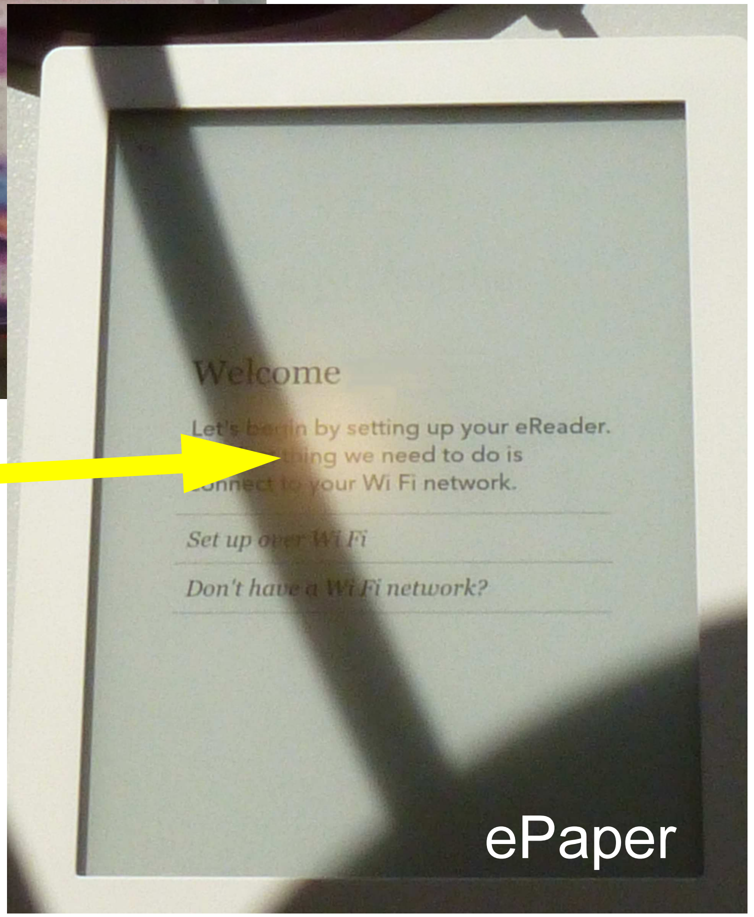


Intended vs. disturbing Reflections



directional
off-specular
illumination
by sun;

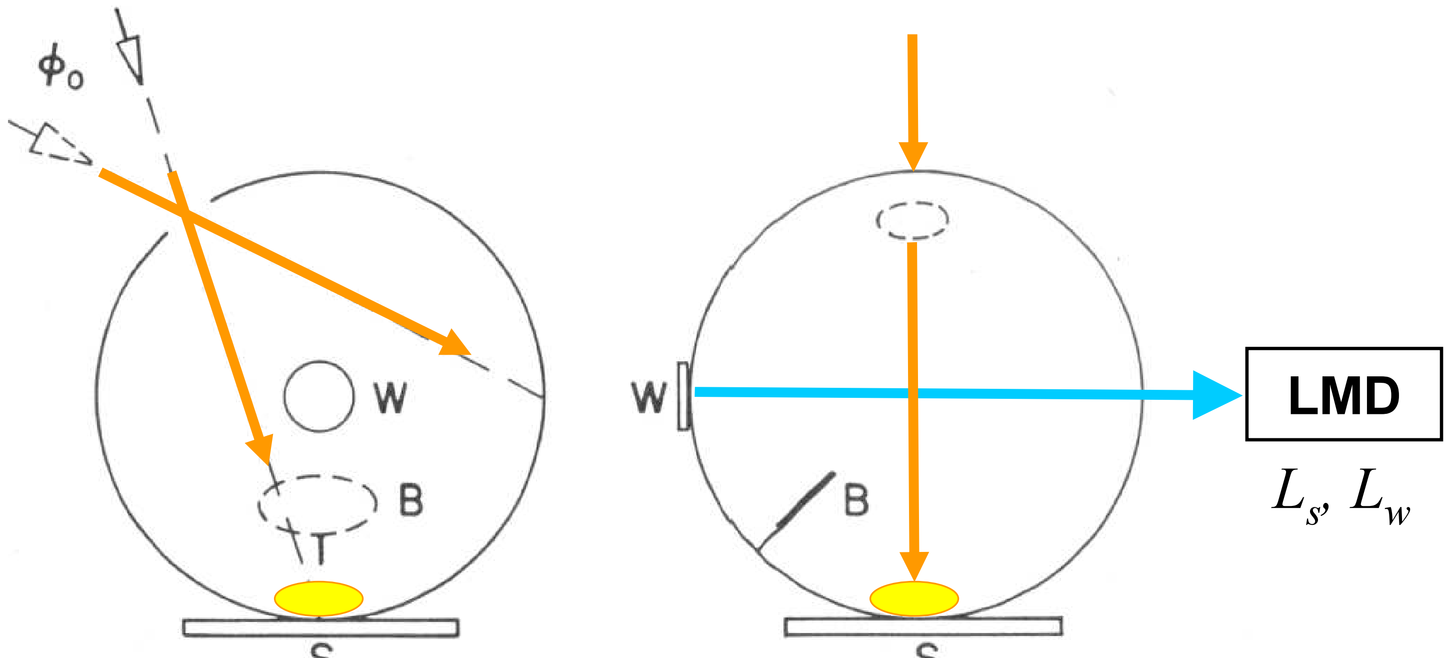
high illuminance.



incandescent lamp
in specular direction
➔ glare - gloss

OLED display

History of the Integrating Sphere



Budde 1976

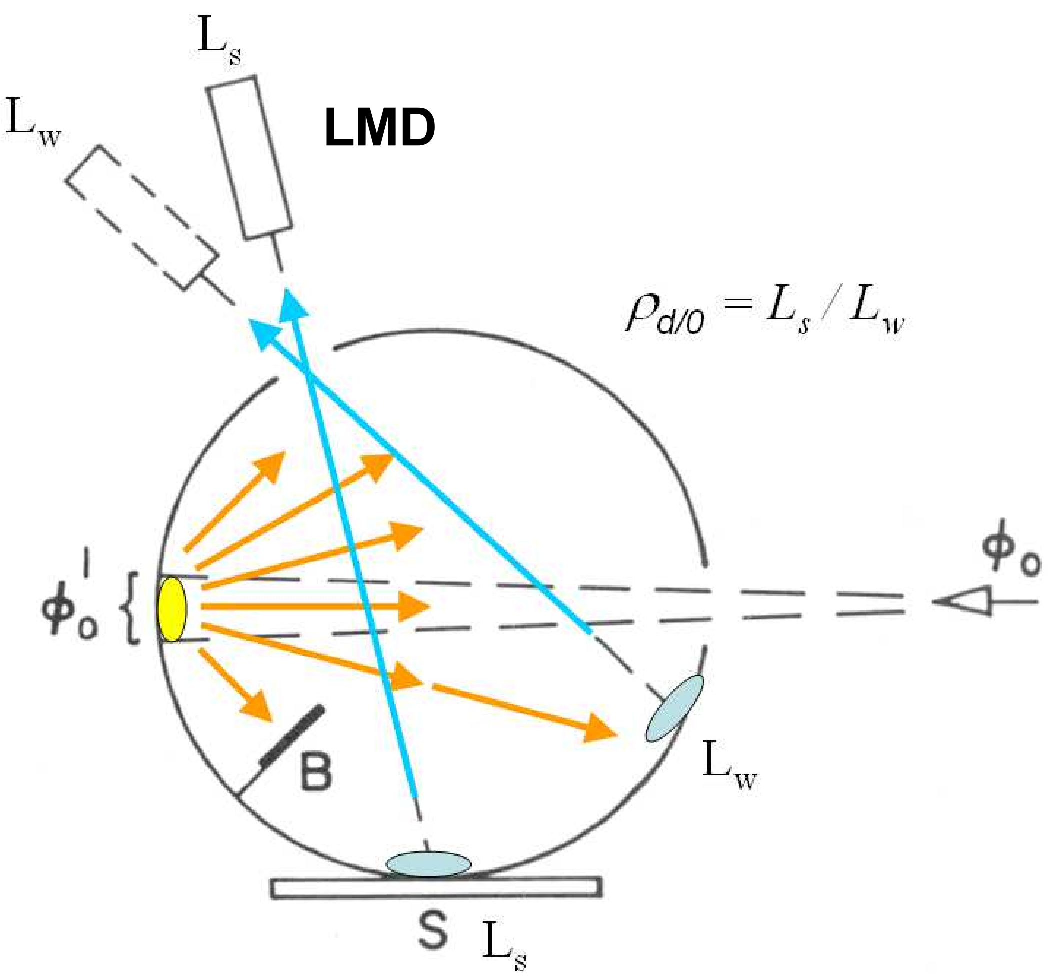
$$\rho_{d/0} = L_s / L_w$$

R. Ulbricht: "Das Kugelphotometer: Darstellung seiner Theorie, Ausbildung und Anwendung, unter besonderer Berücksichtigung der Fehlerquellen", 1920
Measurement of total flux

A. H. Taylor: "A simple portable instrument for the absolute measurement of Reflection and Transmission Factors, Sci. Pap. Bur. Stand. 17, 1(1920)5

C. H. Sharp, W. F. Little: "Measurements of reflection factors, Trans. Illum. Eng. Soc. 15, No.9, 802 (1920)

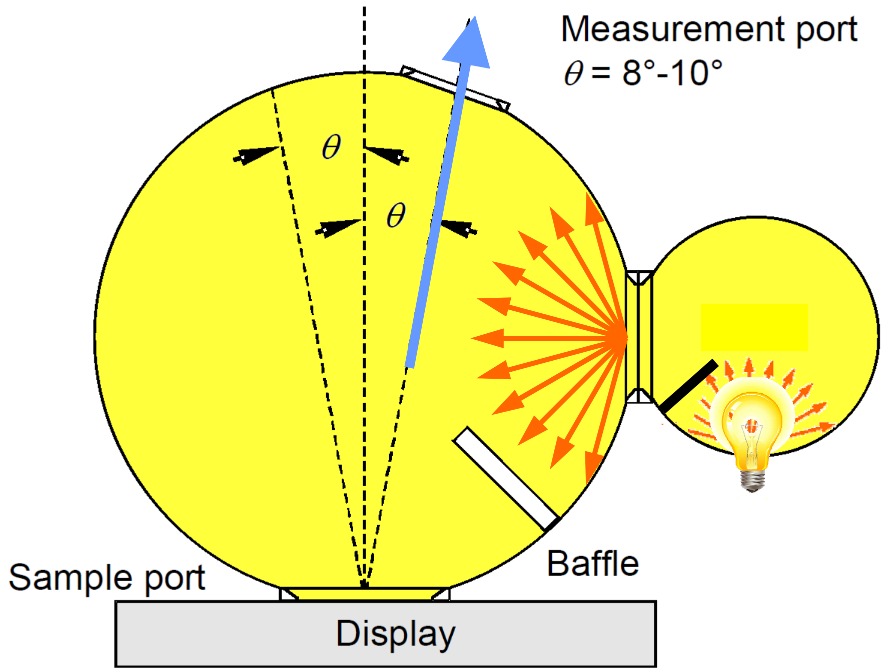
W. Budde: "Calibration of Reflectance Standards", Journal of research of the National Bureau of Standards - A. Physics and Chemistry, Vol. BOA, No. 4, July-August 1976



L_w from direct and hemispherical illumination,
L_s from hemispherical illumination only.

Photometric cube descibed by Buckley in 1920.

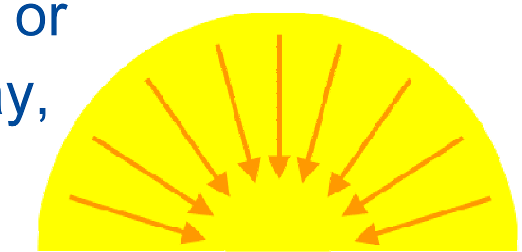
IEC 62341-6-2:2015 Organic light emitting diode (OLED) displays Part 6-2: Measuring methods of visual quality and ambient performance



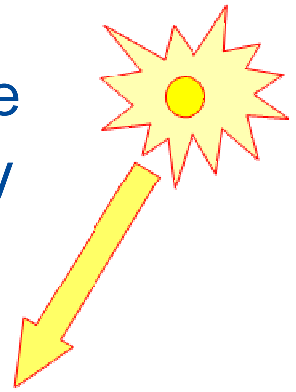
from IEC 62341-6-2

Ambient ***indoor room illumination***, and ***outdoor illumination of clear sky daylight***, on a display, shall be approximated by the combination of two illumination geometries.

➲ ***Uniform hemispherical diffuse illumination*** will be used to simulate the background lighting in a room, or the hemispherical skylight incident on a display, with sun occluded.



➲ A ***directed source in a dark room*** will simulate the effect of directional illumination on a display by a luminaire in a room, or from direct sunlight (0.5° subtended angle).



... and Results

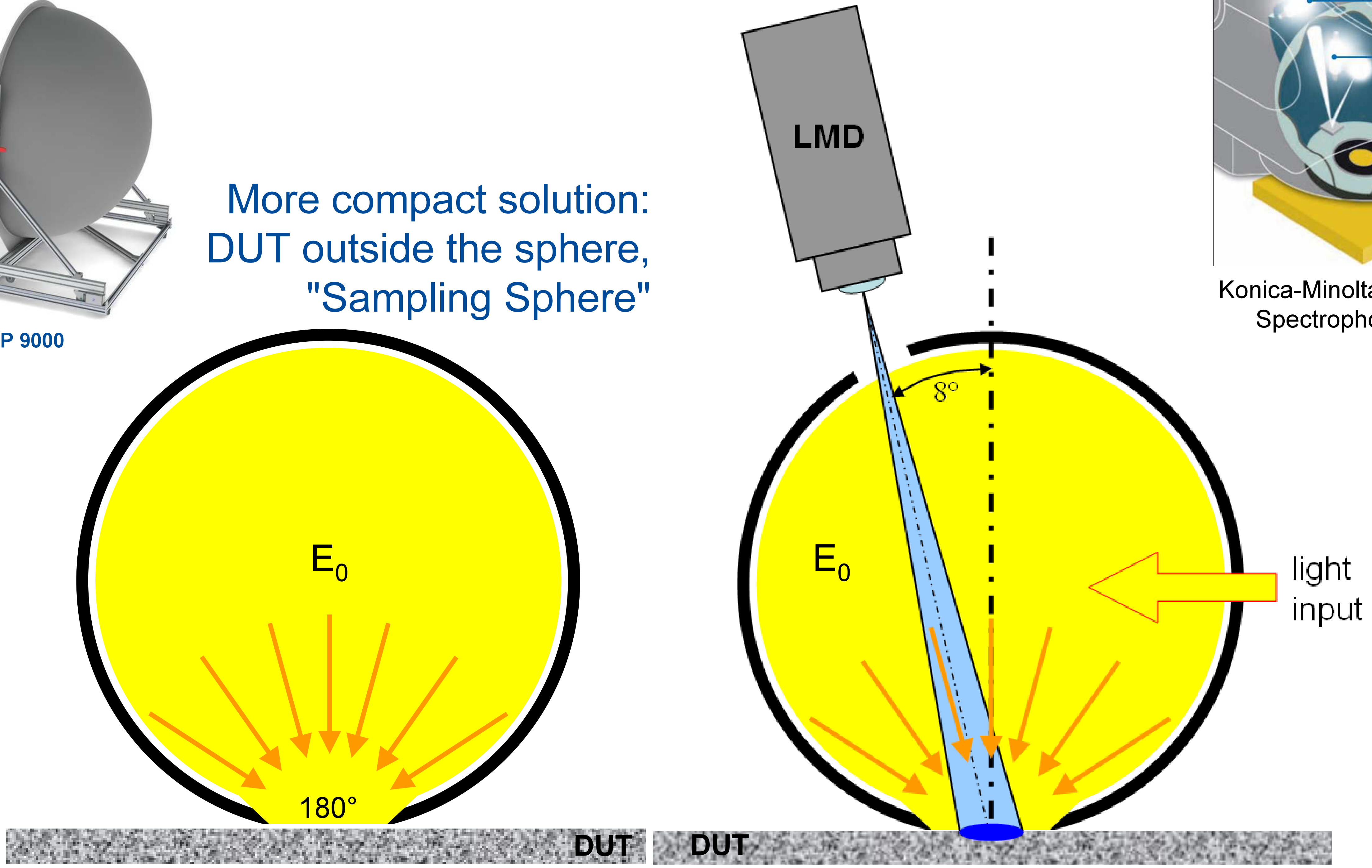
Uniform hemispherical diffuse illumination	
Indoors	
Illuminants: Light source closely approximating CIE Standard Illuminant A, CIE Standard Illuminant D65, or fluorescent lamp FL1.	
Results	**Illuminance levels**
Indoor contrast and color for a typical TV viewing room.	**60 lx** of hemispherical diffuse illumination, specular included.
Indoor contrast and color for typical office environment.	**300 lx**
Outdoors	
Illuminants: Light source closely approximating skylight with the spectral distribution of CIE Illuminant D75.	
Results	**Illuminance levels**
Daylight contrast and color	**15 000 lx** of hemispherical diffuse illumination, specular included.

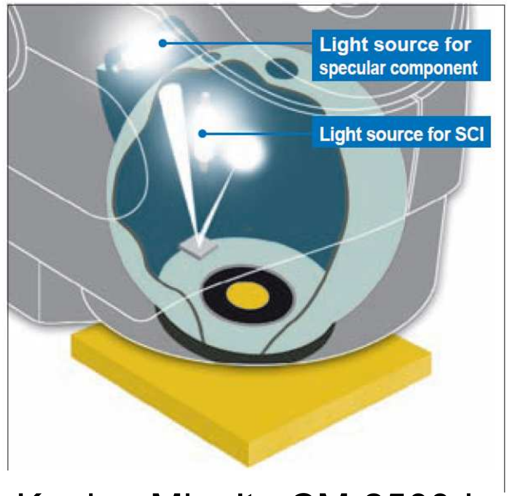
Directional illumination	
Indoors	
Illuminants: CIE Standard Illuminant A, CIE Standard Illuminant D65, or fluorescent lamp FL1	
Results	**Illumin. levels / geometry**
Indoor contrast and color for a typical TV viewing room.	**40 lx** angular subtense <8°
Indoor contrast or color for typical office environment.	**200 lx** with display in vertical orientation, angular subtense <8°
Outdoors	
Light source approximating CIE daylight Illuminant D50; angular subtense ~0.5°, @ inclination θ_s in vertical plane. LMD normal to display surface area.	
Results	**Illumin. levels / geometry**
Daylight contrast and color	**65 000 lx** at an inclination angle of θ_s = 45 ° to display normal.

Uniform Hemispherical Diffuse Illumination

Instrument Systems ISP 9000
190 cm inner diameter

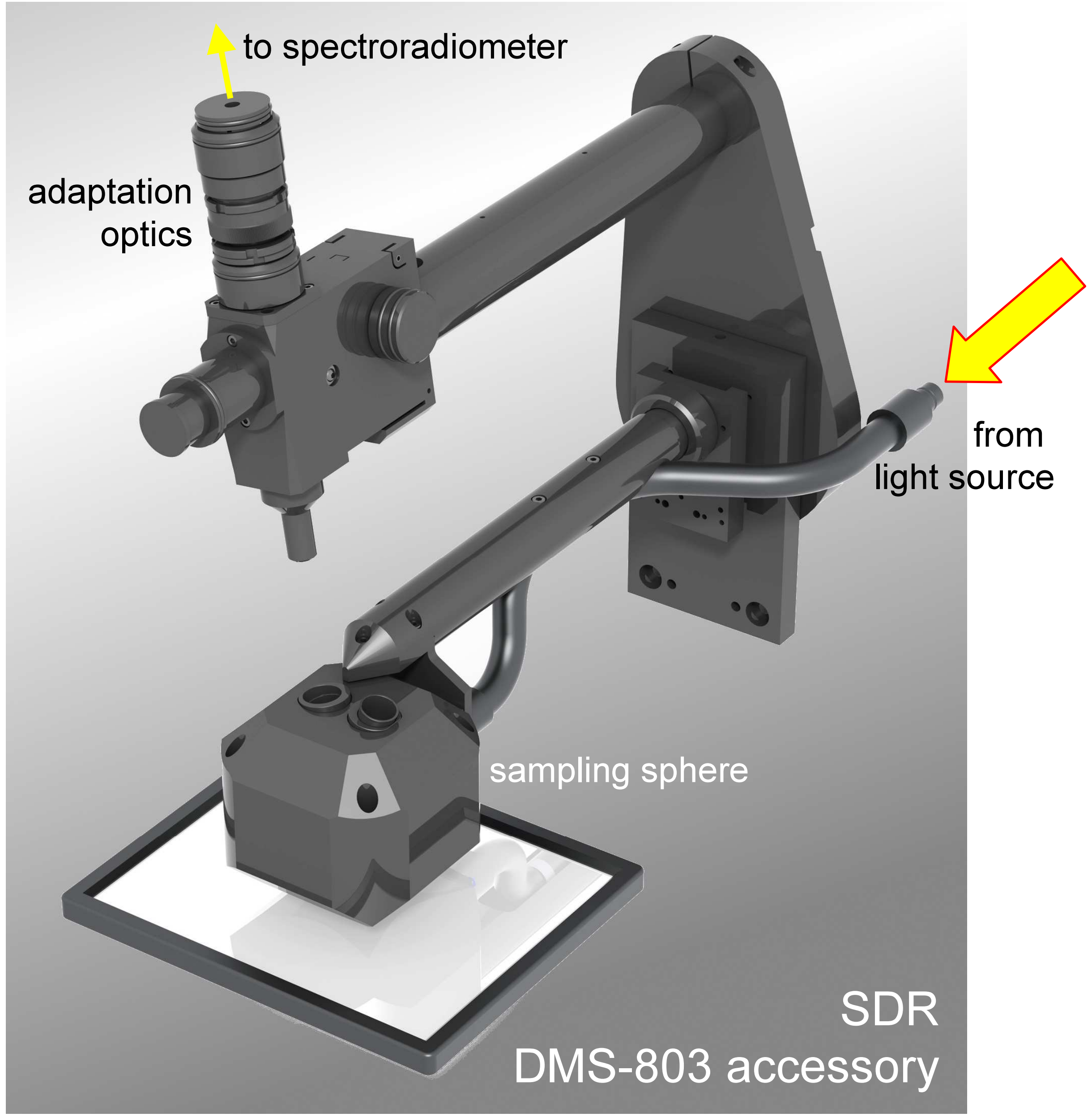
More compact solution:
DUT outside the sphere,
"Sampling Sphere"



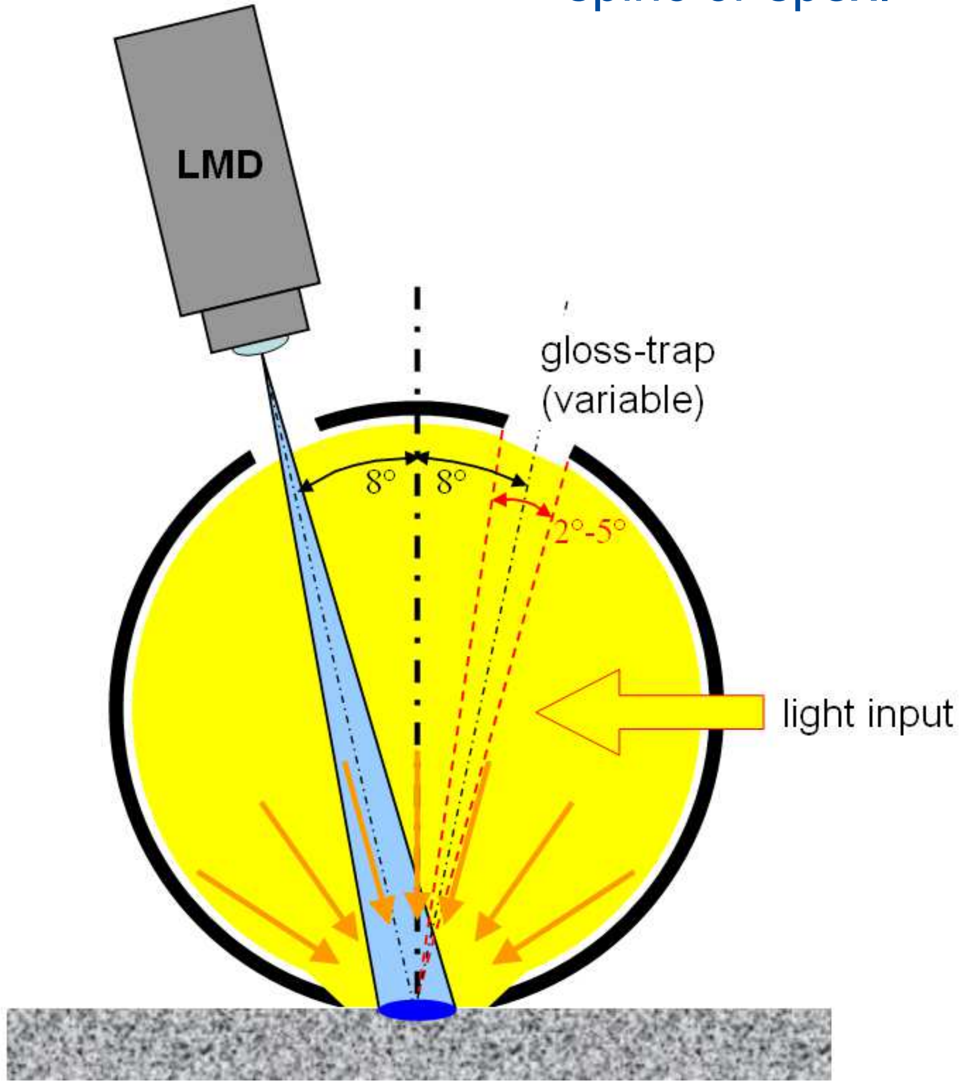


Konica-Minolta CM-2500d
Spectrophotometer

SDR: Measurement and evaluation of **spectral diffuse reflectance**

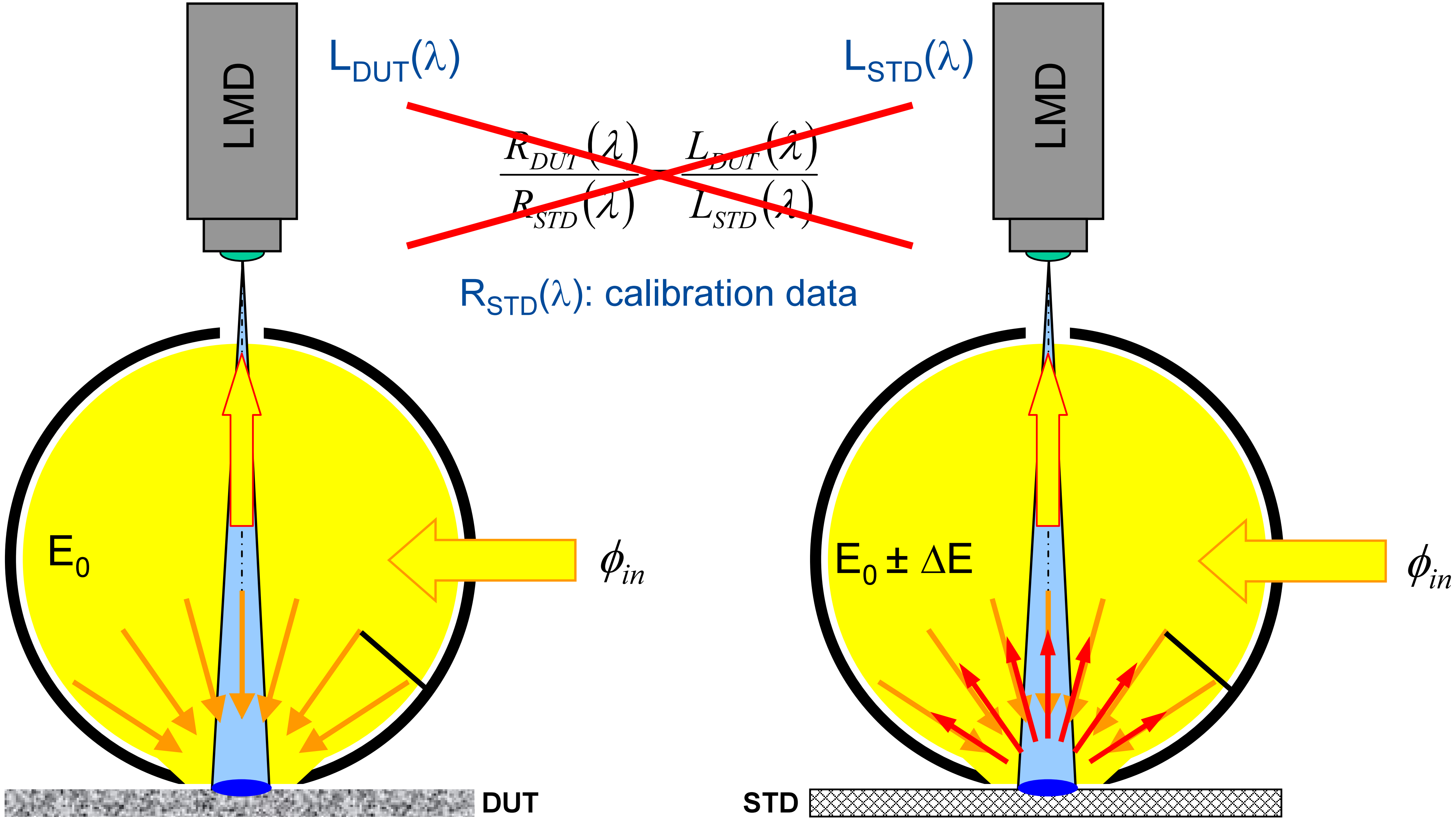


CIE d/8° geometry,
ideal isotropic ("diffuse") illumination,
spinc or spex.



Spectral Reflectance Factor

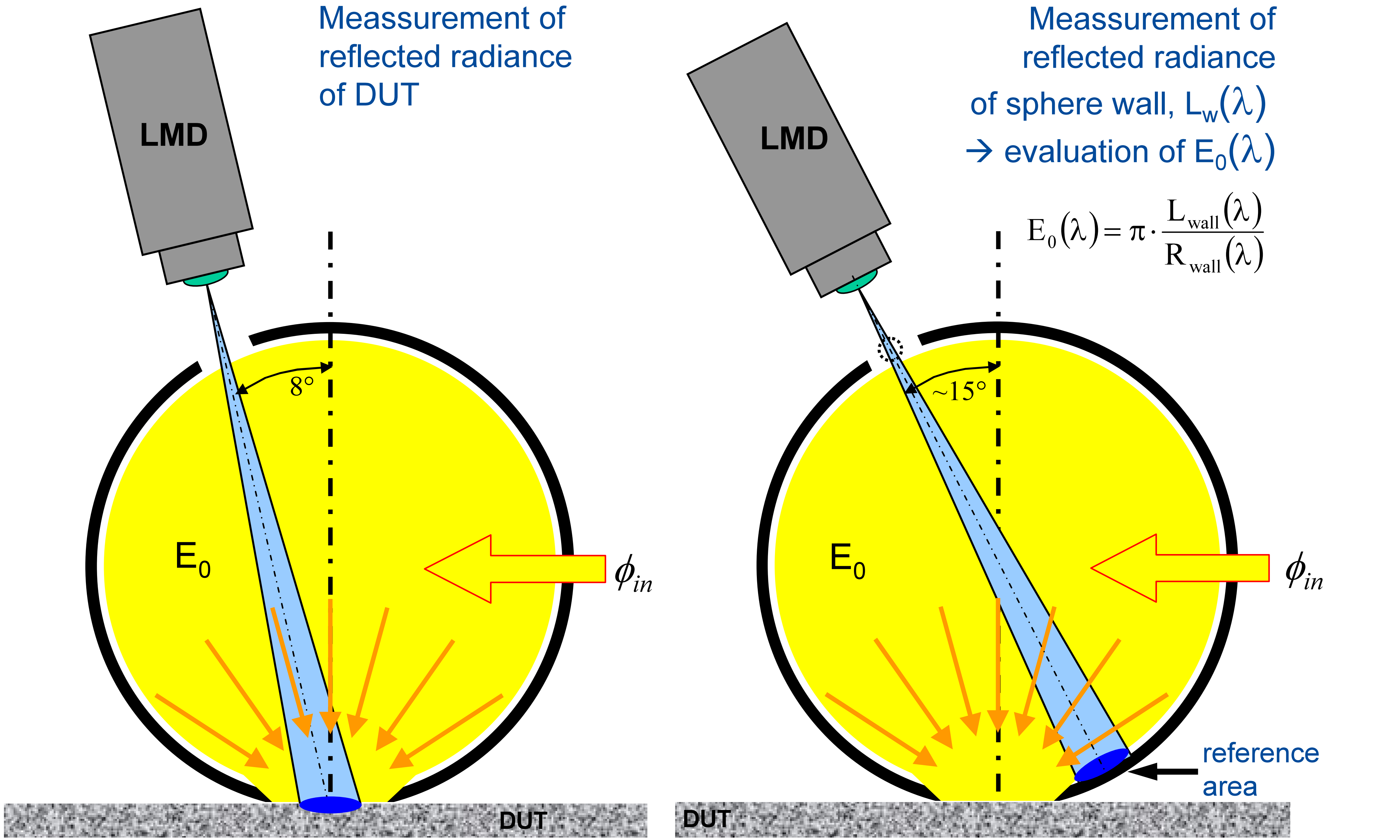
Ratio of reflected DUT radiant flux ... to that reflected in the same directions by a ***perfect reflecting diffuser* identically irradiated or illuminated** (CIE ILV 17-1059).



specimen, sample,
device under test

***perfect reflecting diffuser*,**
calibrated diffuse reflectance standard

Reflectance Factor

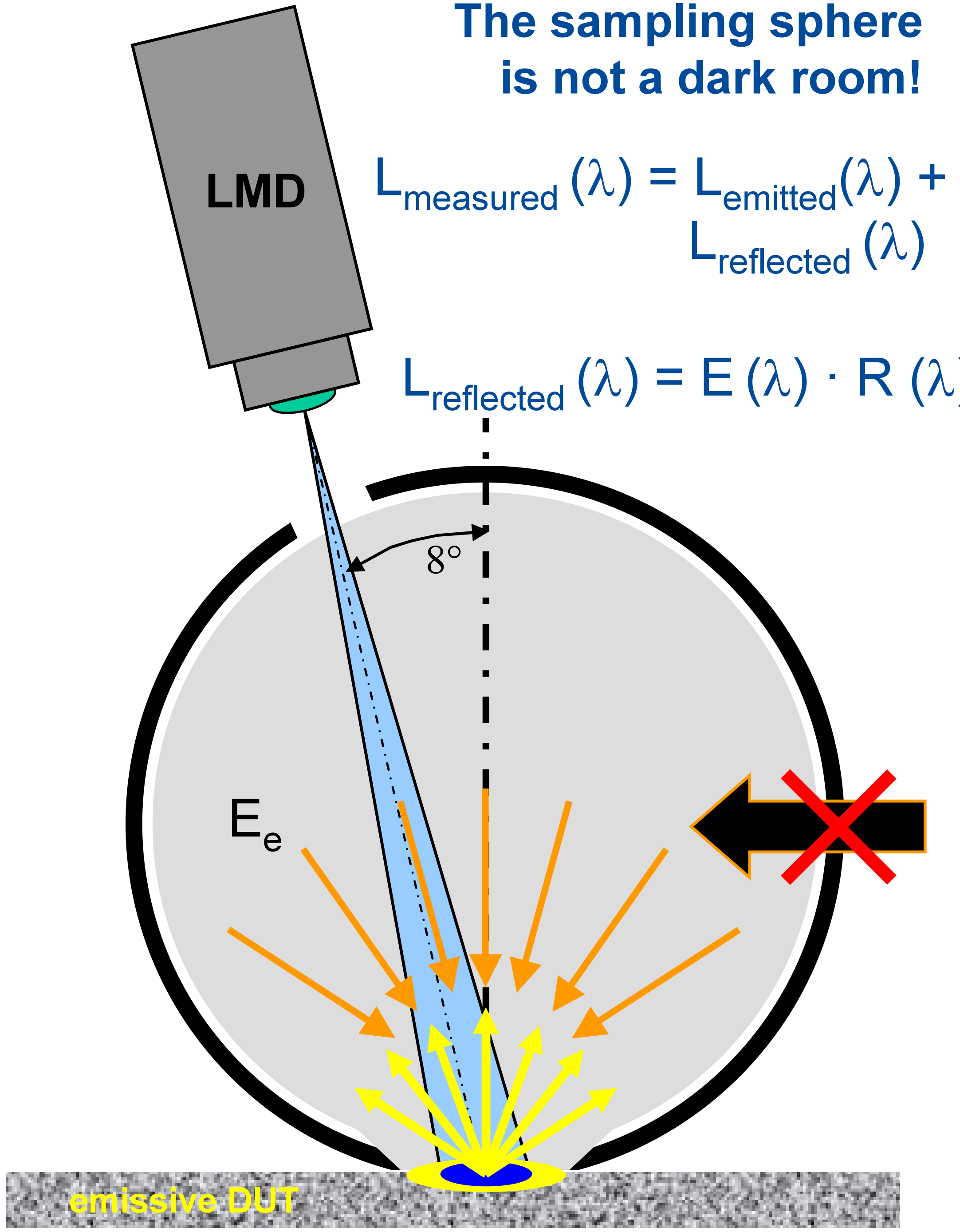


Emission and Sampling Sphere

The sampling sphere is not a dark room!

$L_{measured}(\lambda) = L_{emitted}(\lambda) + L_{reflected}(\lambda)$

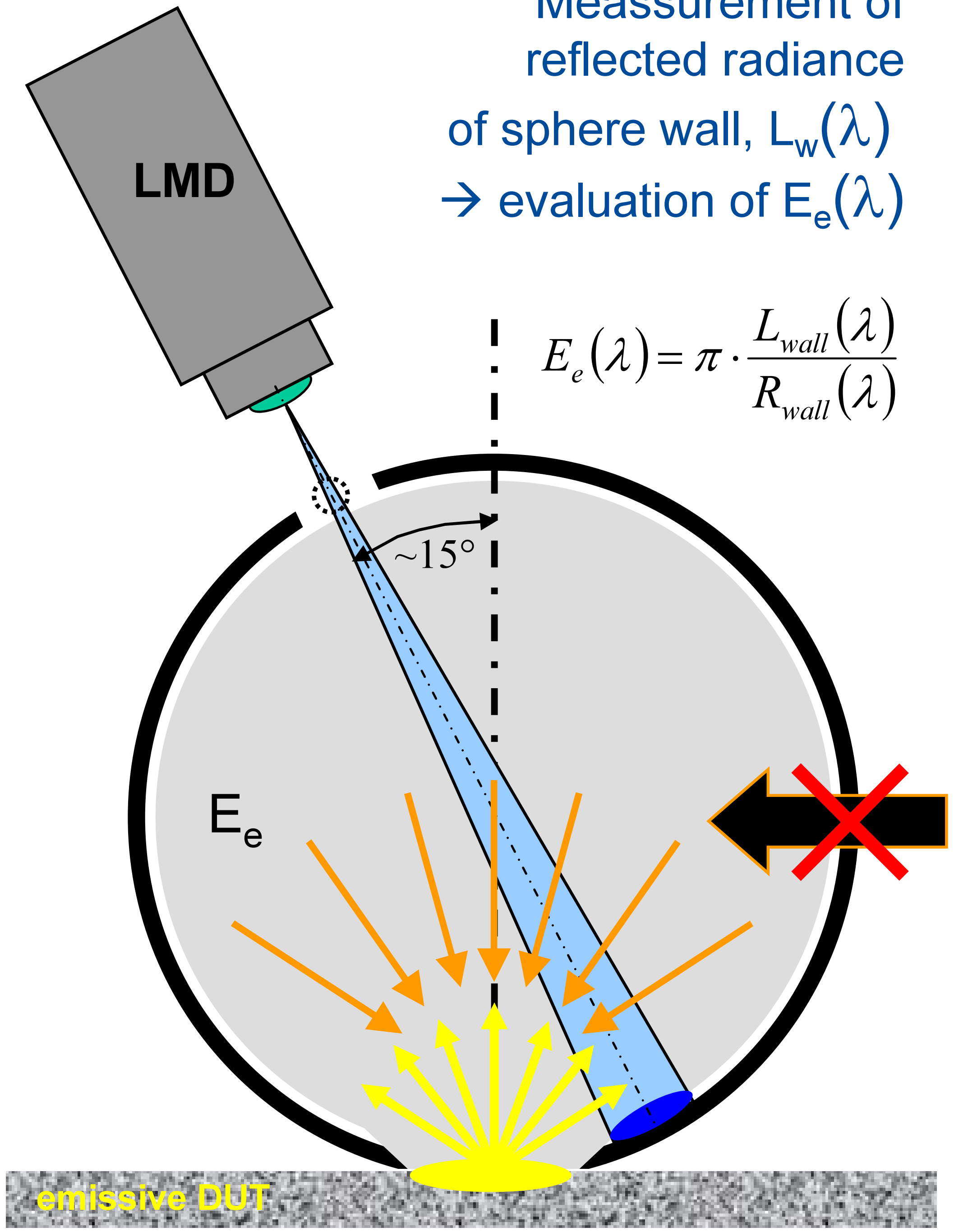
$L_{reflected}(\lambda) = E(\lambda) \cdot R(\lambda)$



Meassurement of reflected radiance of sphere wall, $L_w(\lambda)$

→ evaluation of $E_e(\lambda)$

$$E_e(\lambda) = \pi \cdot \frac{L_{wall}(\lambda)}{R_{wall}(\lambda)}$$



	Sphere calibration	Non-emissive	Non-emissive | 2 states	Emissive | 2 states
DUT example	---	Object surface	Reflective LCD, other reflective displays (e.g. ePaper)	LCD modules with BLU, OLED displays
Results	spectral correction factor for evaluation of irradiance	Reflectance, surface chromaticity	Reflectance, contrast	Reflectance, contrast, "ambient contrast"
Comment	required for operation of the SDR.	**Reflectance** and **surface chromaticity** of arbitrary objects measured under different hemispherical diffuse illumination conditions (spinc/spex).	**Reflectance** and **contrast** of reflective displays measured under different hemispherical diffuse illumination conditions (spinc/spex).	**Contrast** of transmissive and emissive displays measured under different hemispherical diffuse **ambient** illumination conditions (spinc/spex).
	Measured quantities			
	SDR ON			**SDR ON/OFF**
M1	L_{std} @ E_0	L_{DUT}	L_H	$L_{H,\ ON}$
M2	L_{sph} @ E_0			$L_{H,\ OFF}$
M3		L_{ref}	$L_{H,ref}$	$L_{H,ref,ON}$
M4				$L_{H,ref,OFF}$
M5			L_L	$L_{L,ON}$
M6				$L_{L,OFF}$
M7			$L_{L,ref}$	$L_{L,ref,ON}$
M8				$L_{L,ref,OFF}$
	Calculated results (from measured quantities)			
R1	k_{tot} (M1, 2)	$R(\lambda)$ (M1,3)	$R_H(\lambda)$ (M1,3)	$R_H(\lambda)$ (M1,2,3,4)
R2			$R_L(\lambda)$ (M5,7)	$R_L(\lambda)$ (M5,6,7,8)
				select E / E_0
R3			R_H, R_L	R_H, R_L
R4				CR = $CR_A(E=0)$ (M1-8)
R5			CR (M1,3,5,7) = R_H / R_L	$CR_A(E_0)$ (M1-8, E_0)
R6				$CR_A(E)$ (M1-8, E)
R7				$L(\lambda) = L_{emi}(\lambda) + L_{refl}(\lambda)$ → x, y (u',v') →

8 measurements

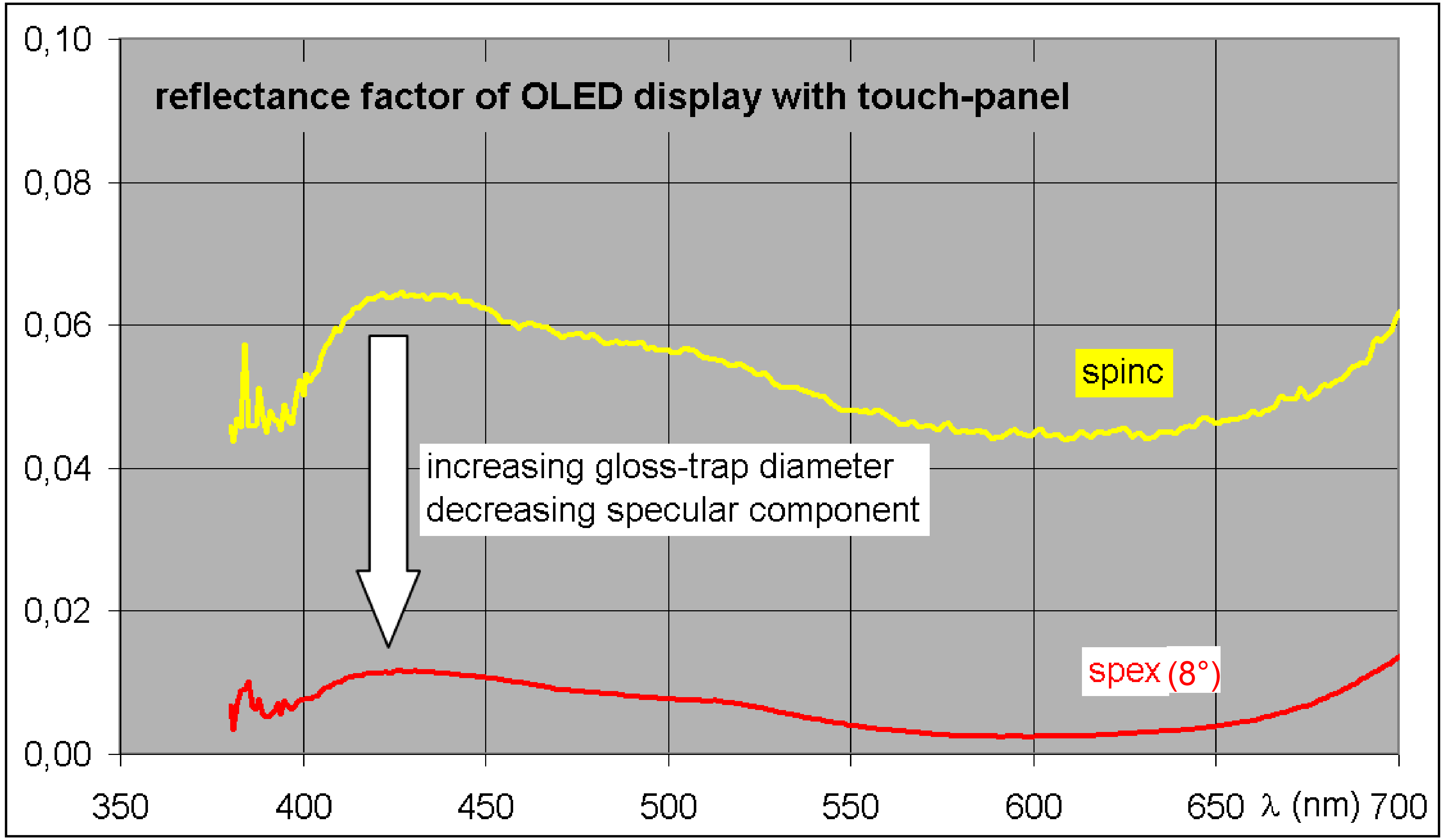
4 DUT mmnts
4 ref. mmnts

user selected spectrum & illuminance

further evaluation

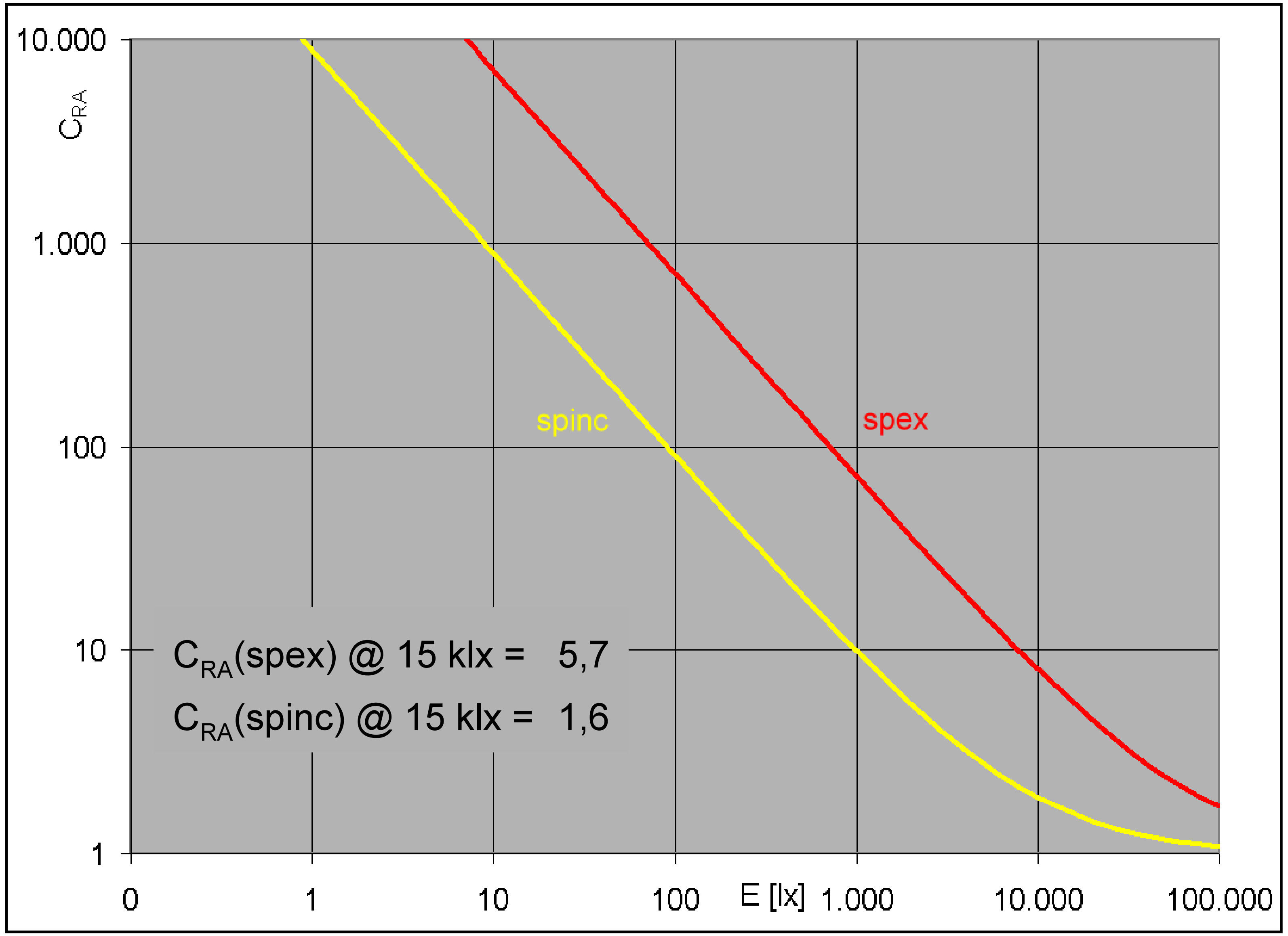
Spectral Diffuse Reflectance Factor

OLED display: $R_W = R_K$



Reflectance factor, $R_{W,K|spinc}$ = mean {R(λ) [380-700nm]} = 0,0523
Reflectance factor, $R_{W,K|spex}$ = mean {R(λ) [380-700nm]} = 0,0066

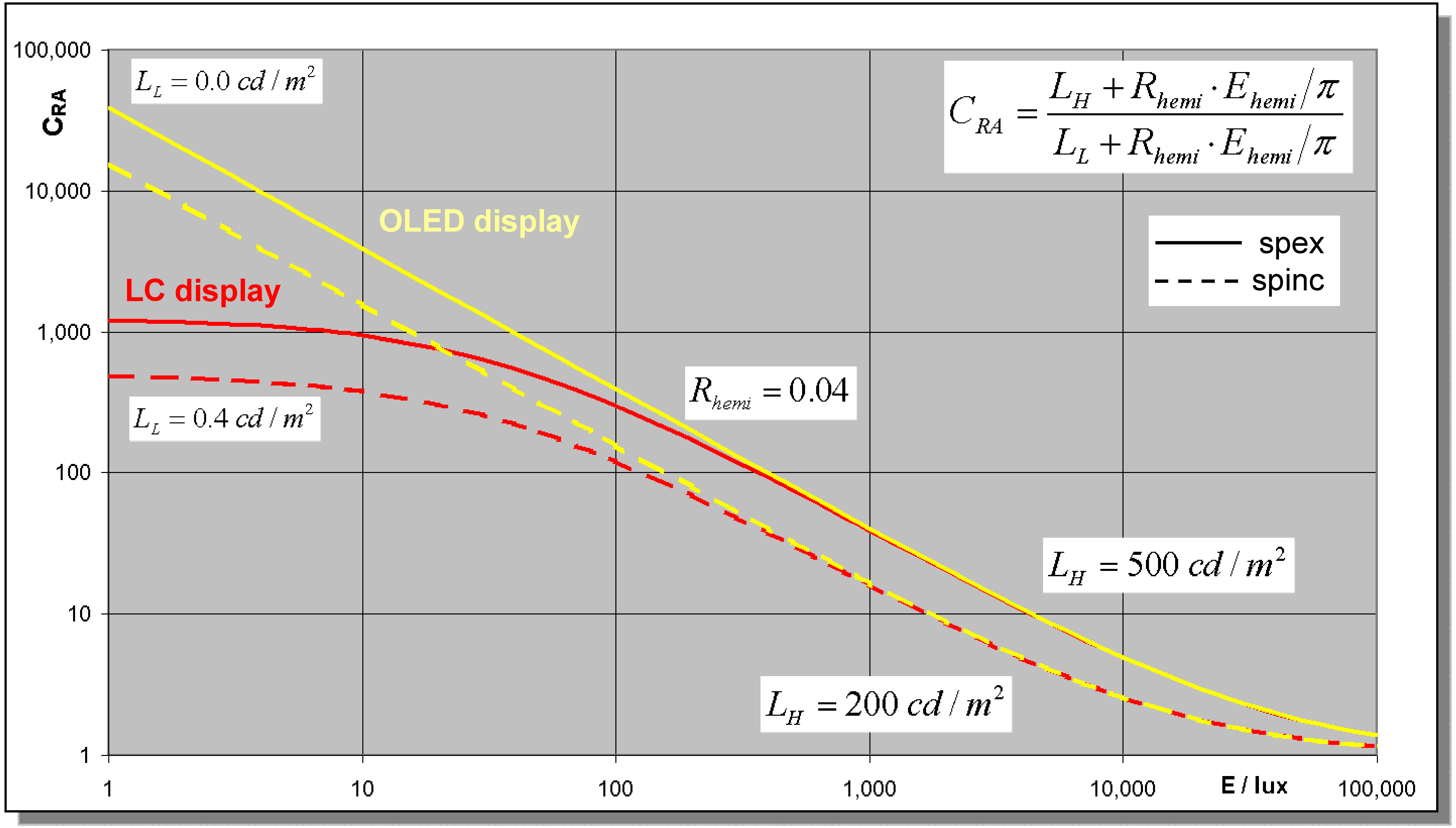
Contrast under Diffuse Ambient Illumination



$$C_{RA}(E) = \frac{L_{W,dark} + R_W\left(E/\pi - L_{ref,W,dark}\right)}{L_{K,dark} + R_K\left(E/\pi - L_{ref,K,dark}\right)} = \frac{L_{W,emi} + R_{W/K} \cdot E/\pi}{R_{W/K} \cdot E/\pi}$$

with $L_{W,emi}$ = 151 cd/m^2
$L_{K,emi}$ = 0,0 cd/m^2

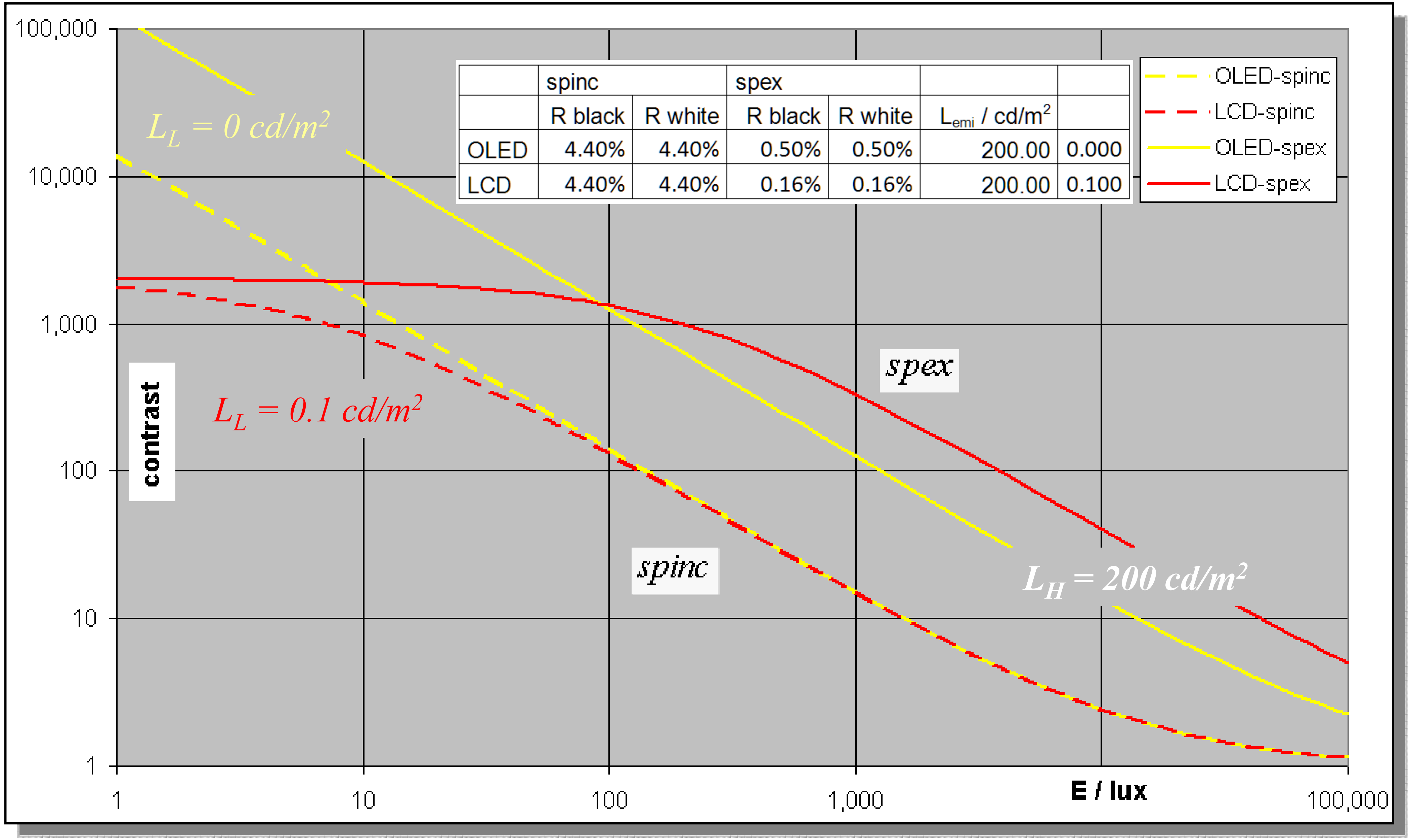
Disturbing Reflections



The **low-state luminance**, L_L, determines the contrast in dark surrounds (E < 100 lx),

the **high-state luminance**, L_H, determines the contrast under high ambient illuminance (E > 1 000 lx).

Controlling Unwanted Reflections

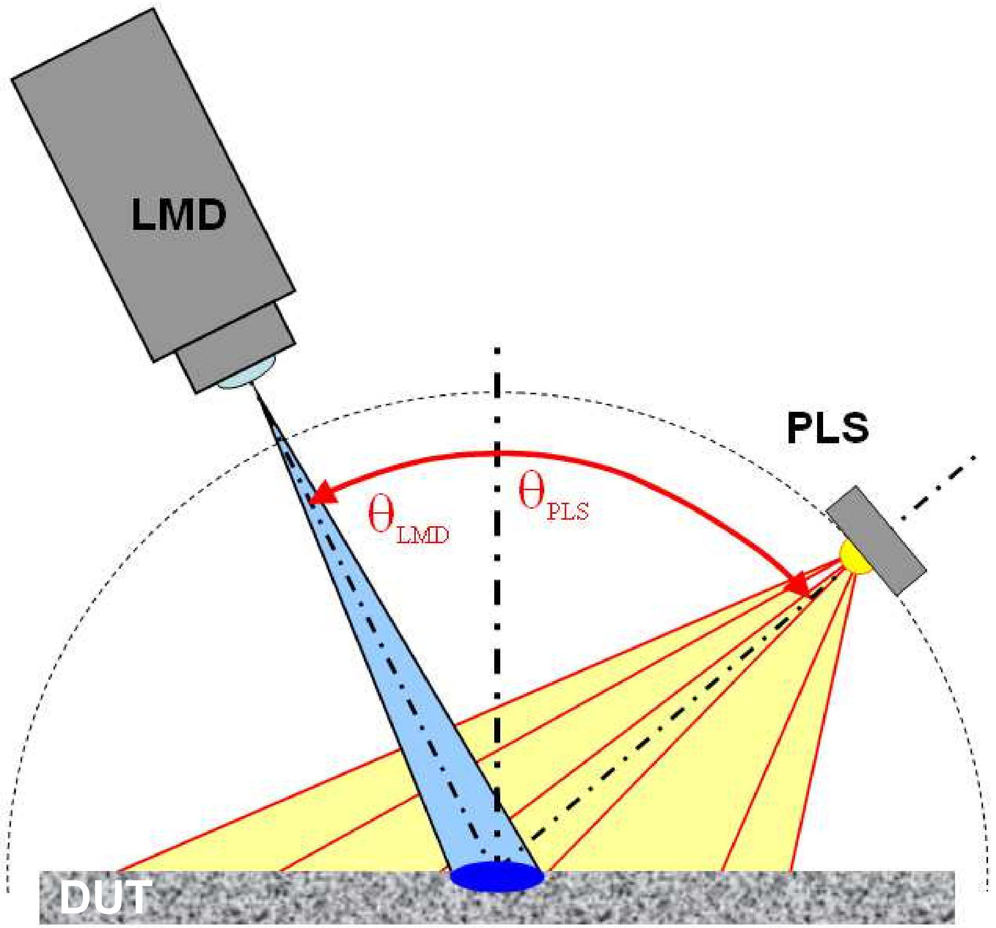


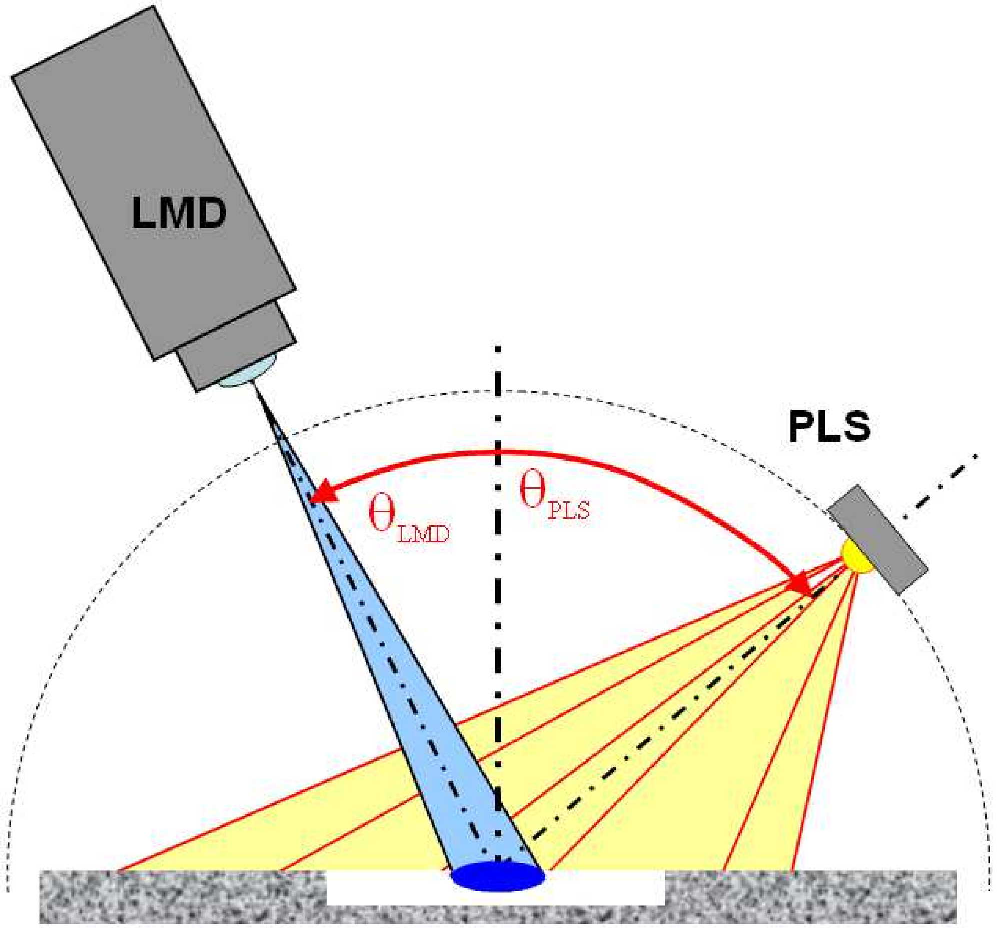
	spinc		spex			
	R black	R white	R black	R white	L_{emi} / cd/m^2	
OLED	4.40%	4.40%	0.50%	0.50%	200.00	0.000
LCD	4.40%	4.40%	0.16%	0.16%	200.00	0.100

The contrast improvement by **shading the display** with e.g. the head of the observer is obvious.

Display reflectance should be as low as possible for good performance under high illuminance.

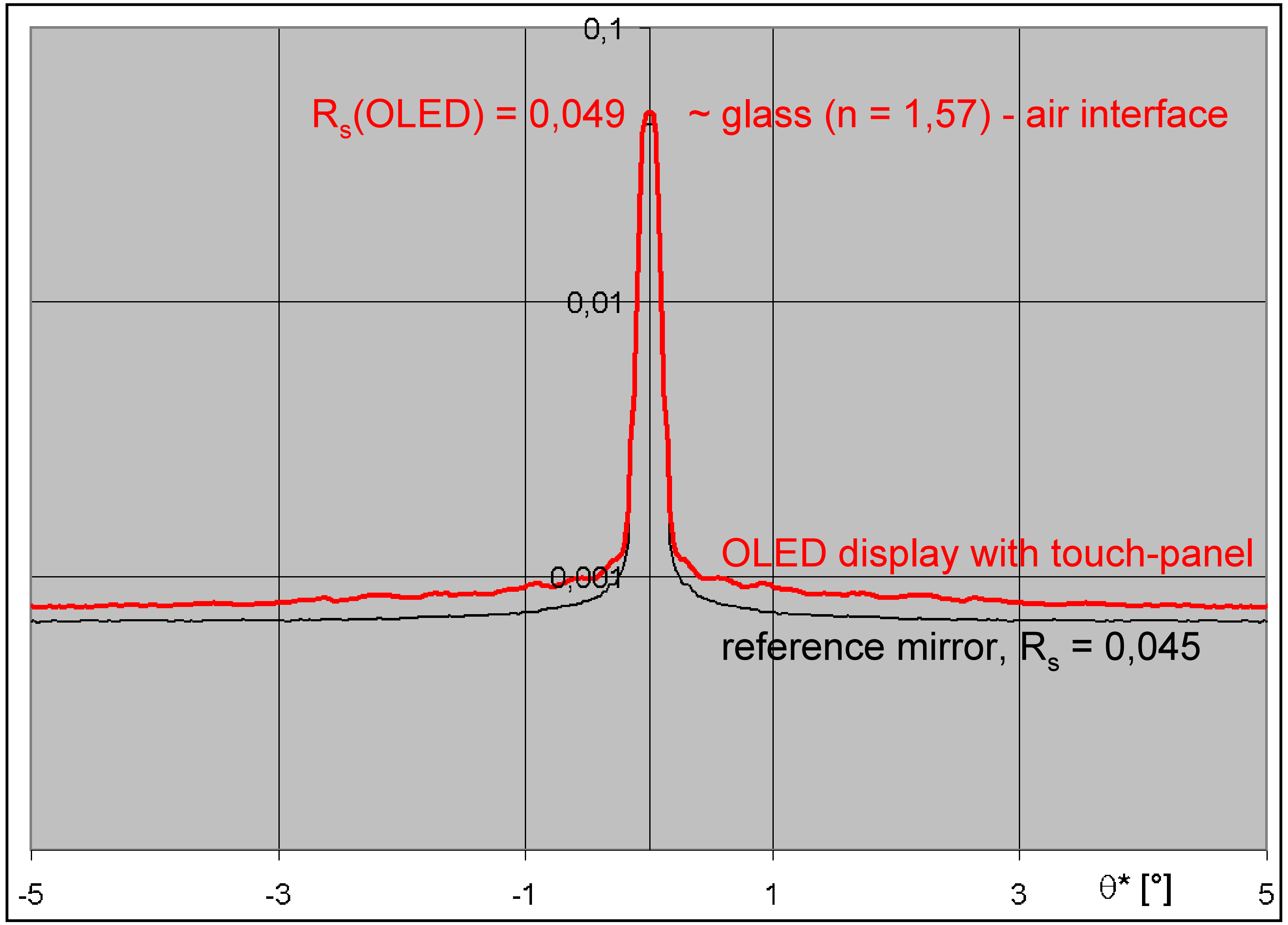
Spectral reflectance factor under directional illumination (@ specifed conditions of irradiance, illuminant/spectrum and angle of inclination), evaluated with calibrated diffuse reflectance standard.





perfect reflecting diffuser,
calibrated diffuse reflectance standard

Reflectance Distribution Function



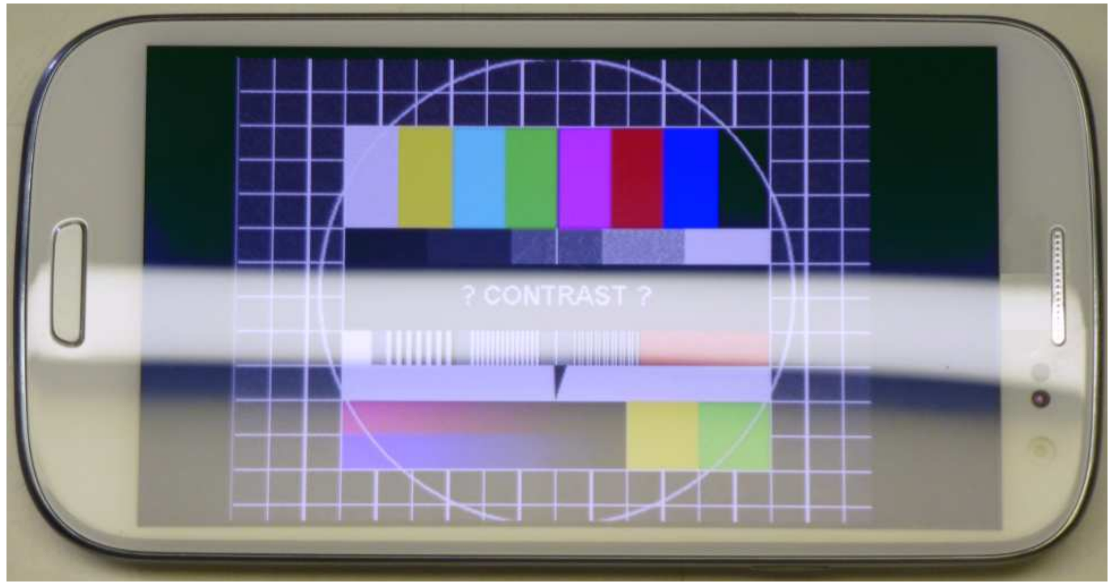
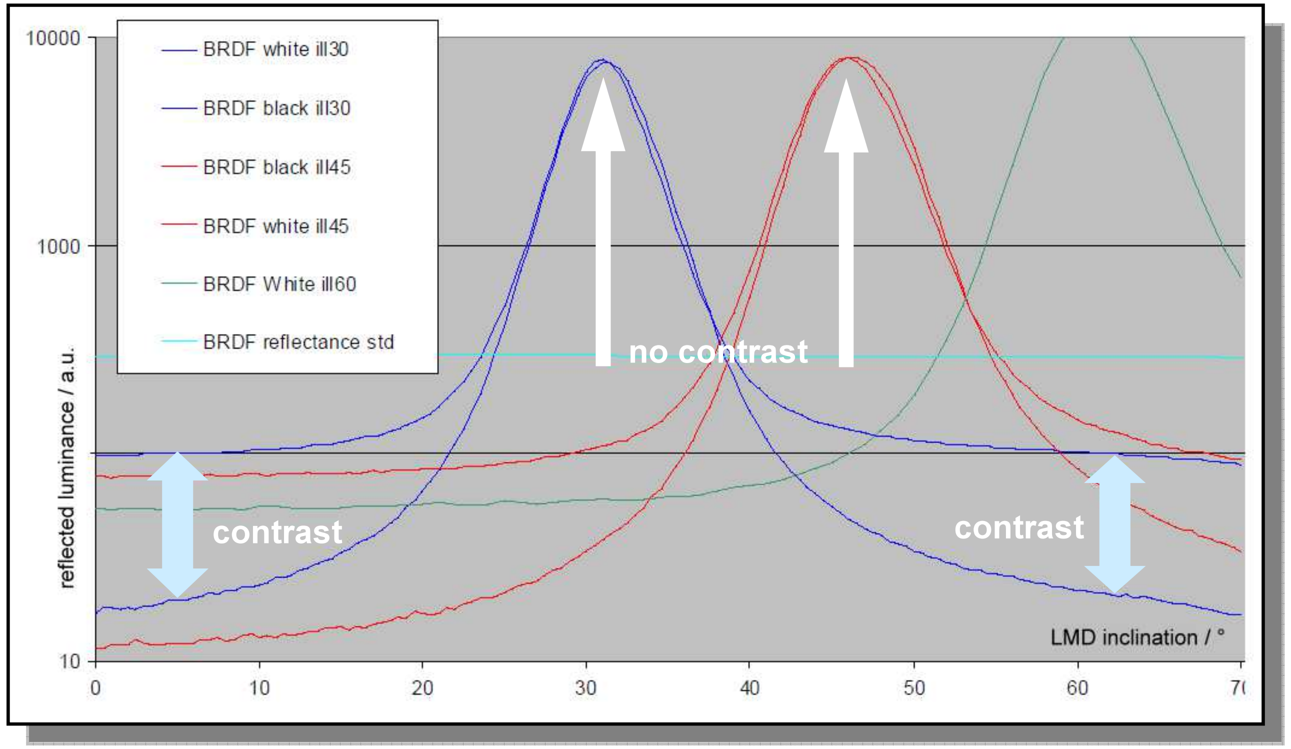


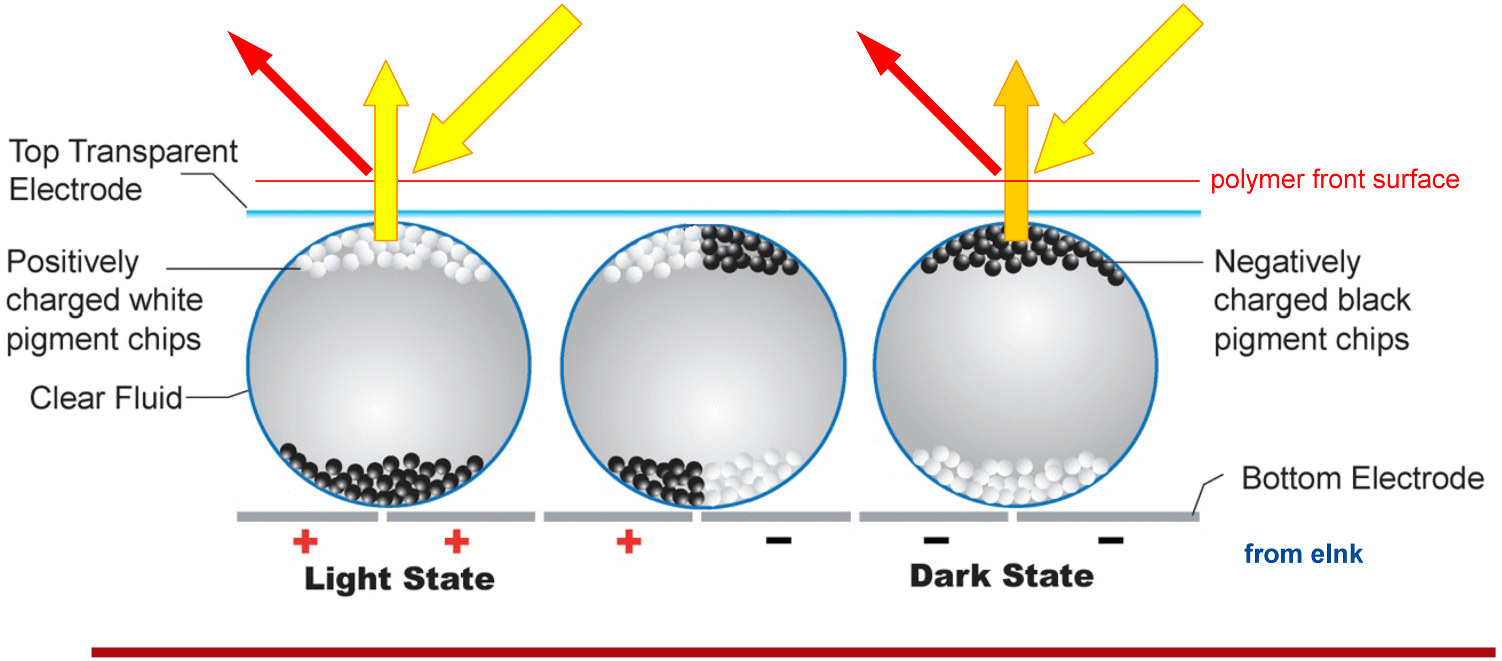
image of linear light source distinctly visible

θ_{PLS} = 15° θ_{LMD} = 10° - 20° $\theta^{*} = \theta_{LMD} - \theta_{PLS}$

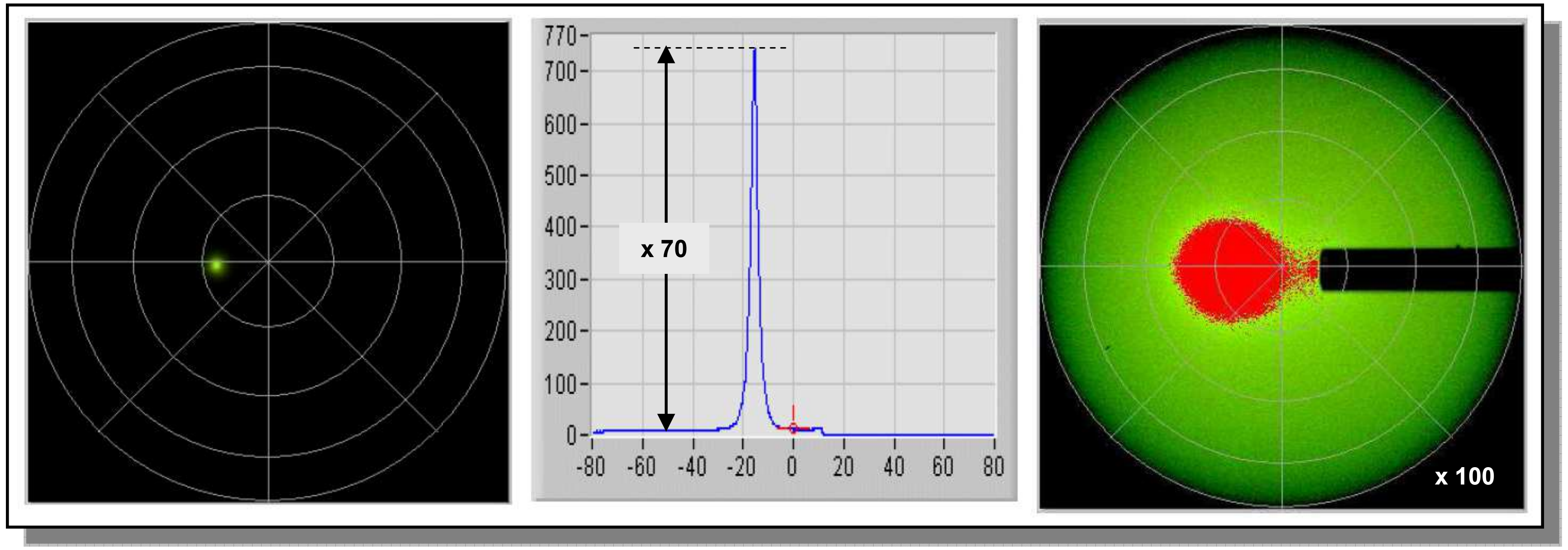
The display surface is a specular (mirror-like) reflector.

Reflectance Distribution Function





The characteristics of electrophoretic displays are similar to those of coated paper.



Reflective electro-phoretic displays provide visual information via modulation of light that is scattered into a wide range of directions (quasi-Lambertian).

The contrast in the specular direction is dominated by - unmodulated - surface reflections (~ 4% - 5%) and thus very small.

The unwanted reflections form front surface must be controlled (AG, AR coatings) to rescue contrast.

Conclusions

- The contrast under ambient illumination is significantly affected by the amount and the directional distribution of reflected light.

- Reproducible indoor and outdoor illumination conditions are specified by e.g. IEC 62341-6-2.

- After evaluation of the spectral reflectance factors all illuminance levels and illuminants can be applied to obtain the contrast and the chromaticities by calculation.

- With the SDR the DMS series of instruments offers the first implementation of the measurement process according to IEC 62341-6-2 under diffuse hemispherical illumination. Together with the directional PLS the complete measurement process can be carried out.

- Acquisition of the individual measurement steps is supported together with bookkeeping and evaluation by specific software.

Thank you for your attention !