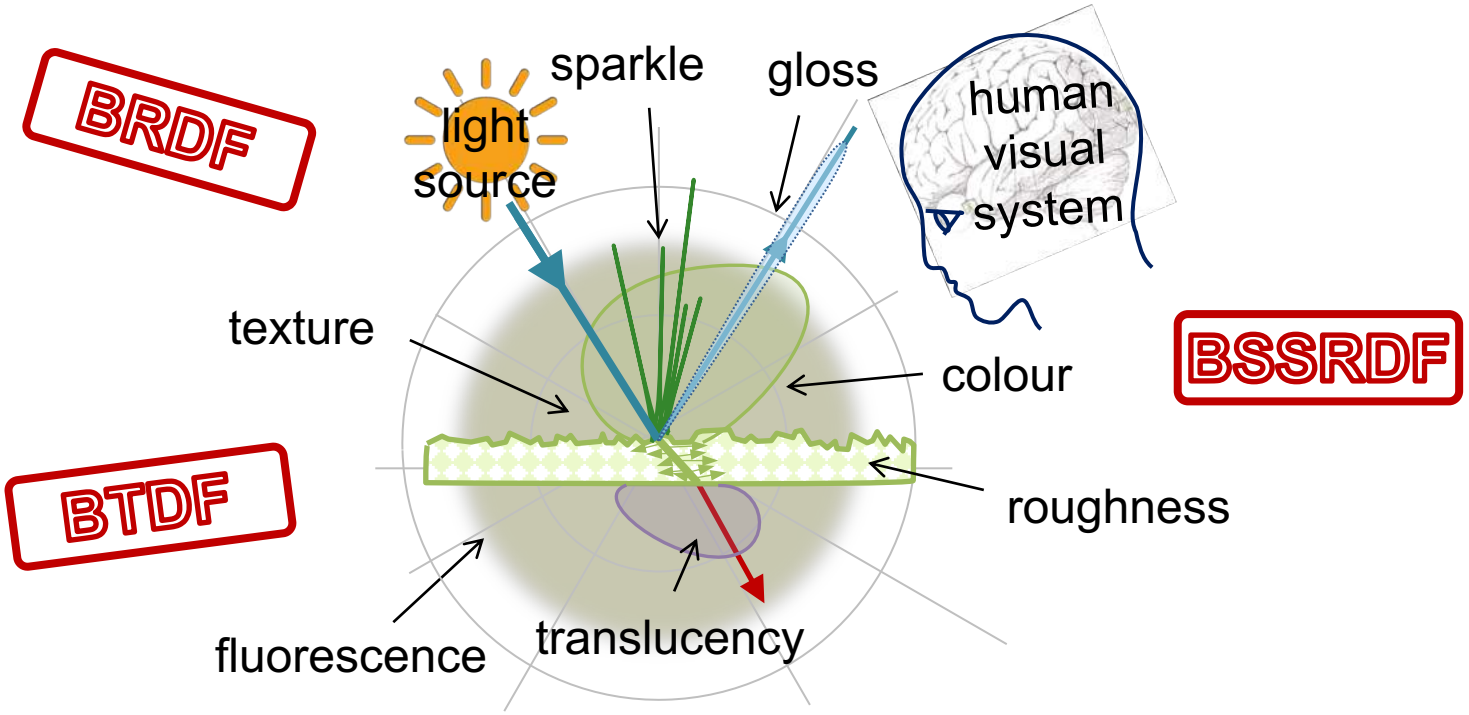
Traceability & references for the measurement of appearance

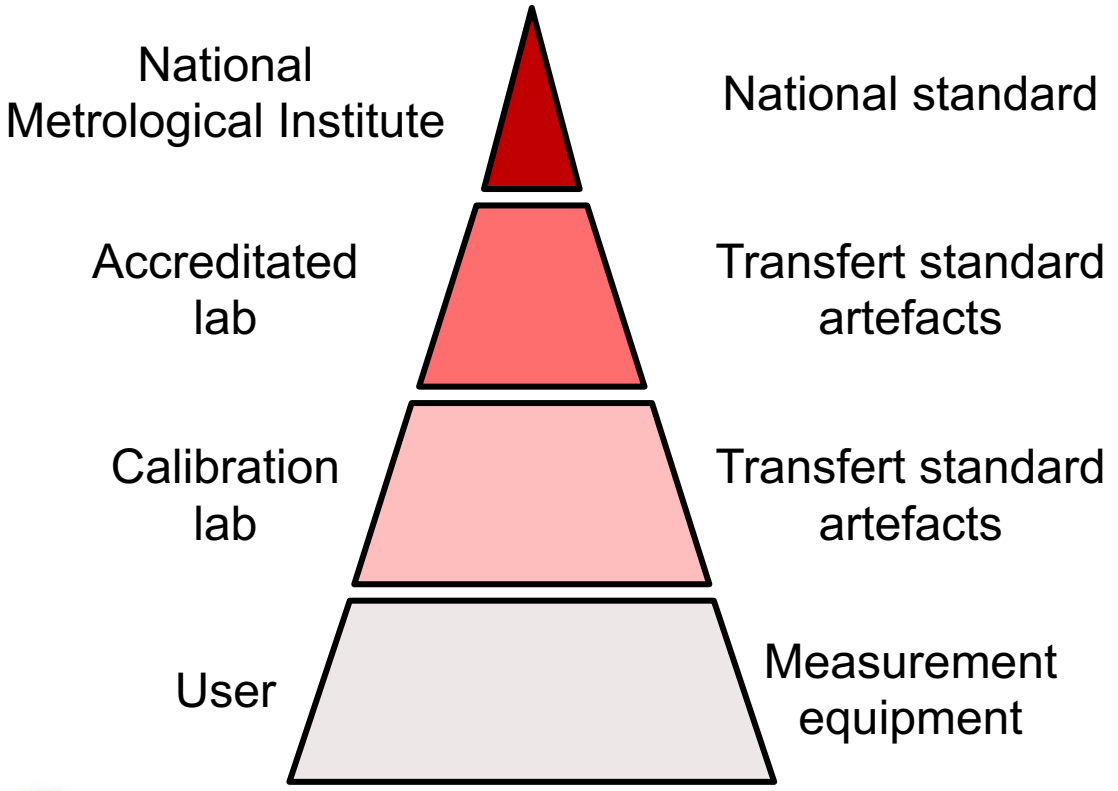
Review of latest developments at
Europeans National Metrological Institutes (NMIs)

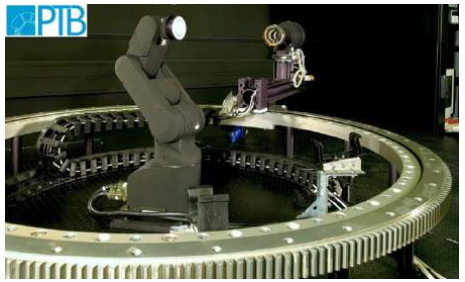


Gaël Obein
Cnam (FR)

Traceability & references for the measurement of appearance

Review of latest developments at
Europeans **National Metrological Institutes (NMIs)**





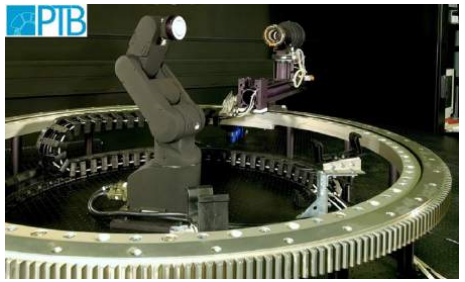
Traceability chain

Traceability & references for the measurement of appearance

Review of latest developments at
Europeans **National Metrological Institutes (NMIs)**

National Metrological Institute

National standard



Traceability chain

LABORATOIRE NATIONAL DE MÉTROLOGIE ET D'ESSAIS — LNE

CSIC
Consejo Superior de Investigaciones Científicas

PTB Physikalisch Technische Bundesanstalt

NPL National Physical Laboratory

NIST National Institute of Standards and Technology U.S. Department of Commerce

Traceability & references for the measurement of appearance

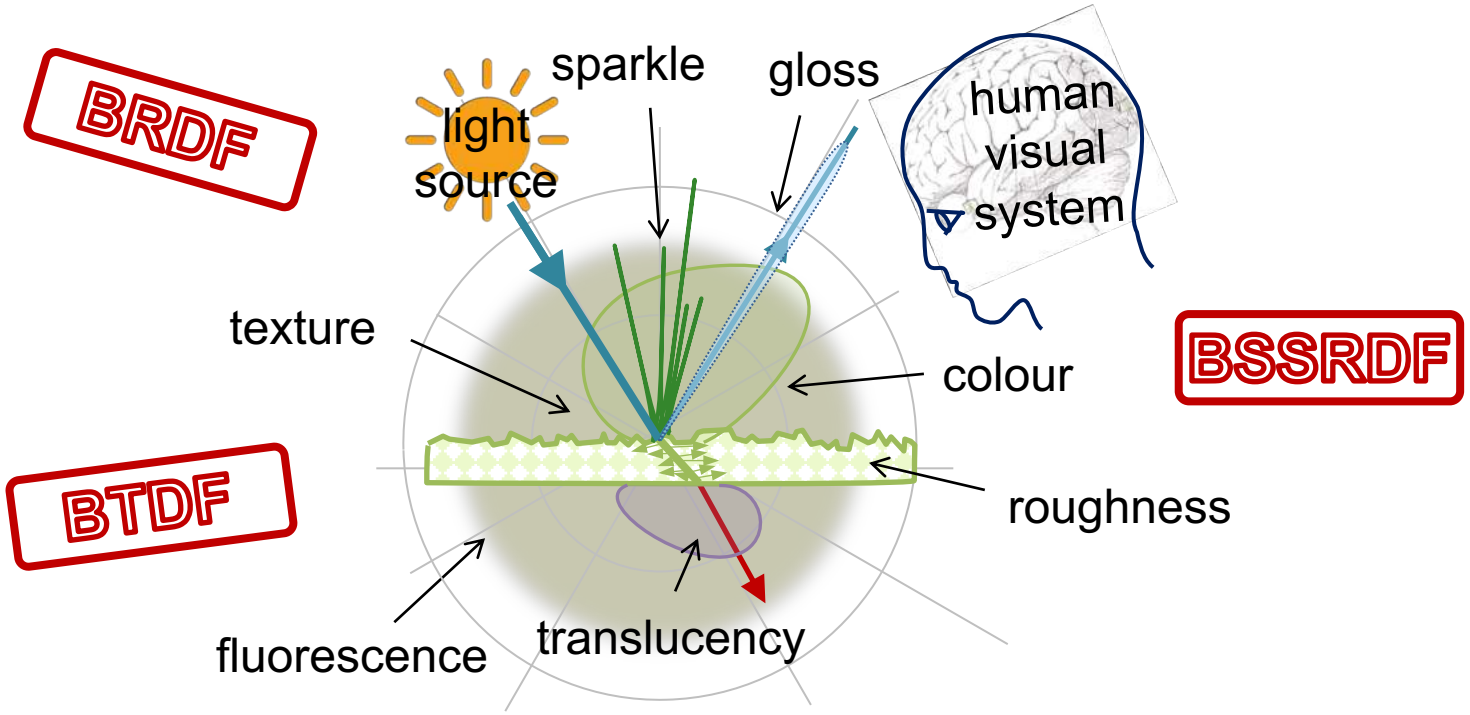
Review of latest developments at
Europeans **National Metrological Institutes (NMIs)**

National Metrological Institutes :

- Realize and maintain at the highest level of accuracy of the primary quantities for a given country (meter, second, reflectance)
- Establish procedures and measurement protocols to ensure the transfer and the dissemination of these quantities through the traceability chain,
- Develop new quantities when requested by industrial needs

Traceability & references for the measurement of appearance

Review of latest developments at Europeans National Metrological Institutes (NMIs)



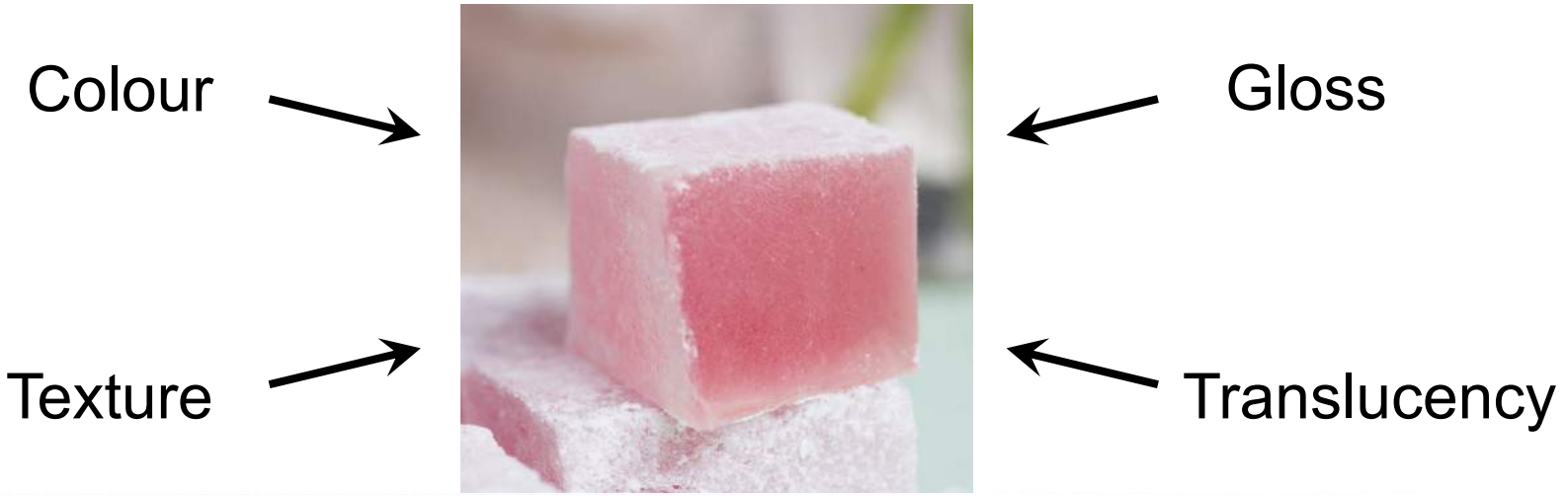
Gaël Obein
Cnam (FR)

Traceability & references for **the measurement of appearance**

Definition of the measurand

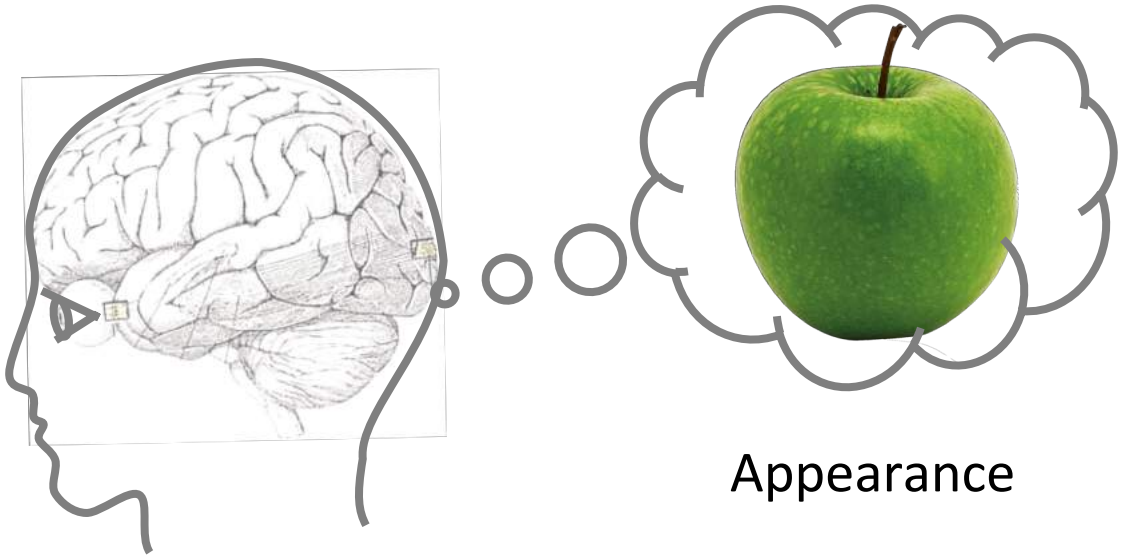
Appearance is the visual sensation through which an object is perceived to have attributes such as size, shape, colour, texture, gloss, transparency, opacity, etc.

CIE 175:2006



Traceability & references for **the measurement of appearance**

Physical Stimulus

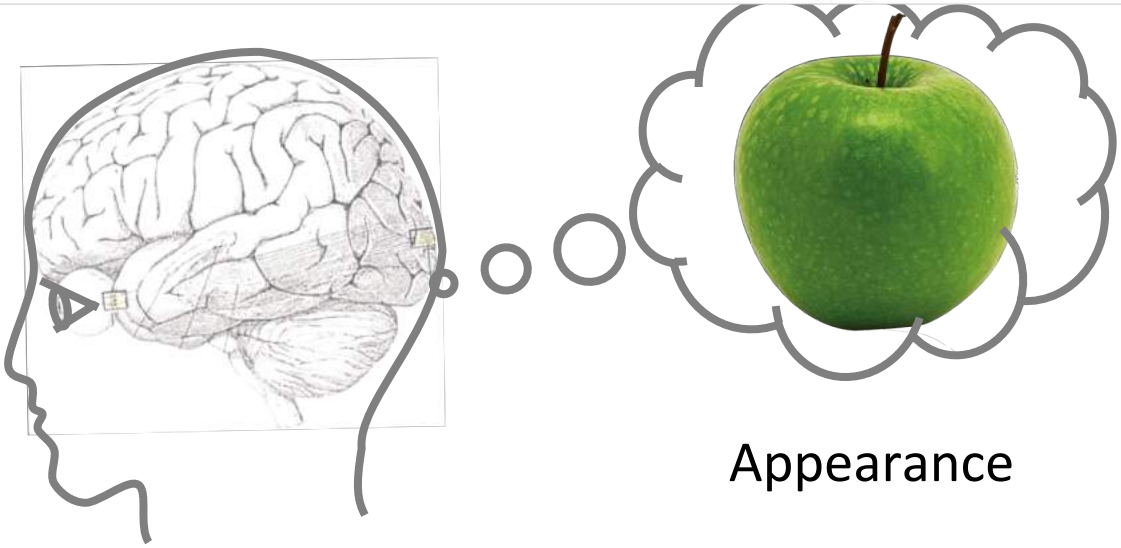


Appearance

Appearance is a visual quantity
Measurand is not accessible by direct measurement

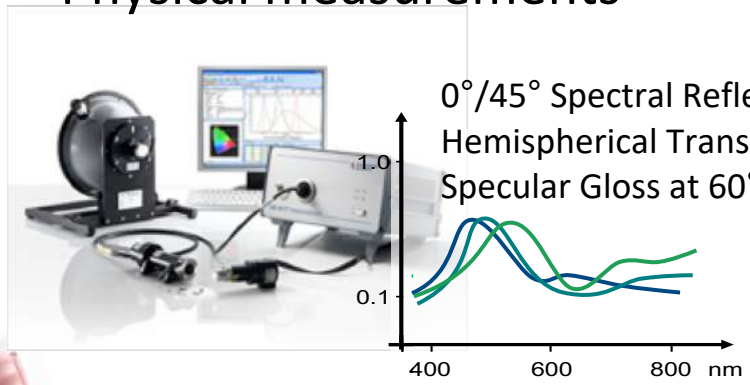
Traceability & references for **the measurement of appearance**

Physical Stimulus



Appearance

Physical measurements

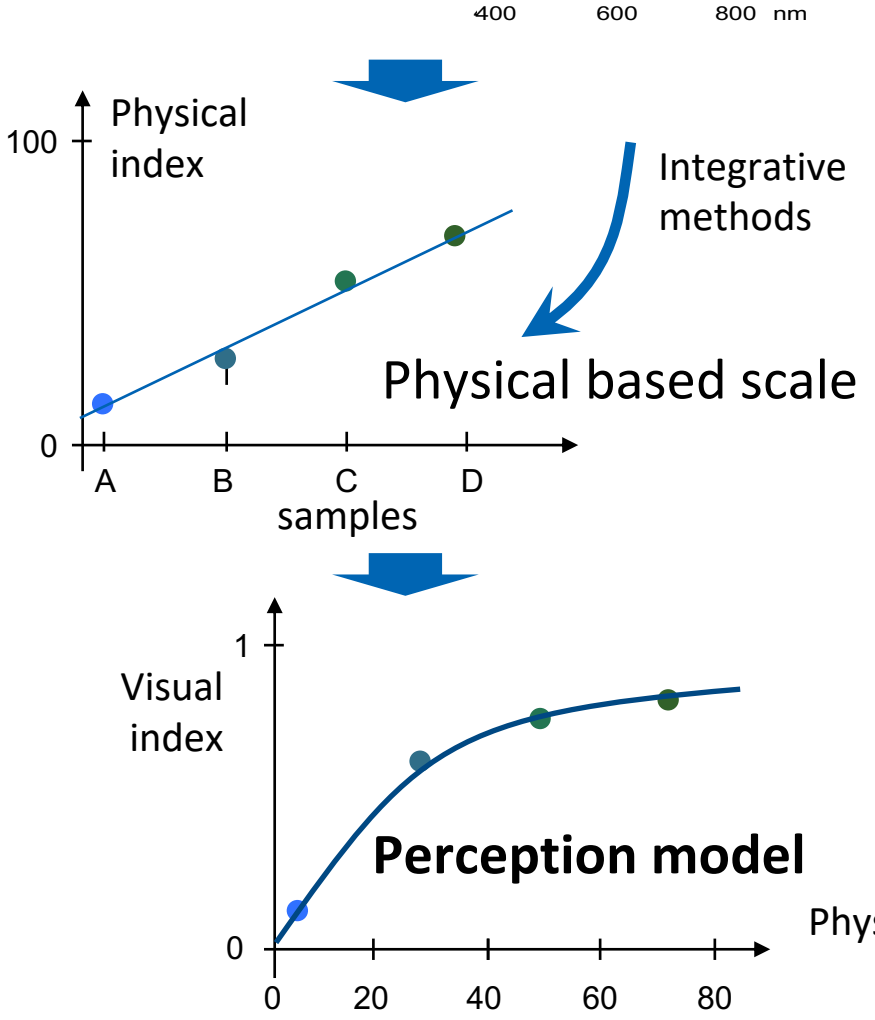


0°/45° Spectral Reflectance
Hemispherical Transmittance
Specular Gloss at 60° inc

Psychophysical measurements

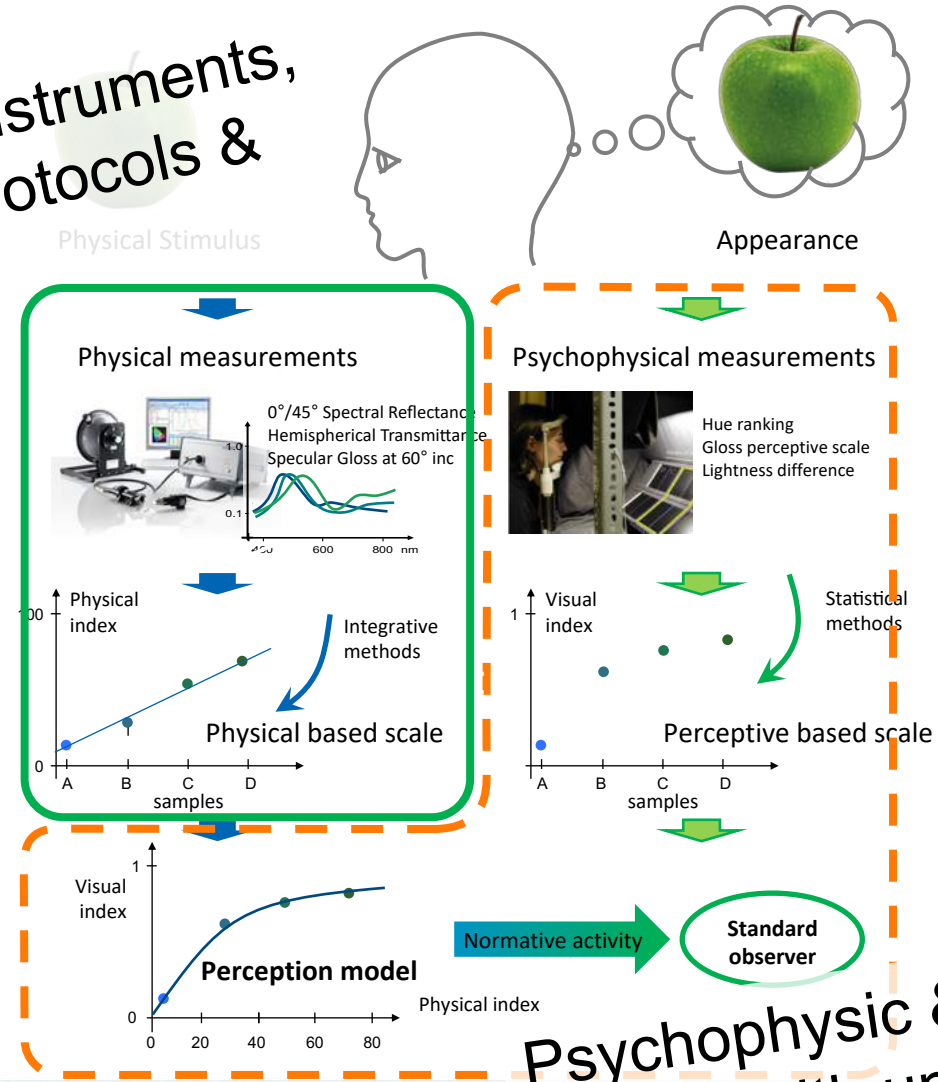
Hue ranking
Gloss perceptive scale
Lightness difference

Traceability & references for **the measurement of appearance**



Traceability & references for **the measurement of appearance**

Development of instruments, measurements protocols & transfer artefacts

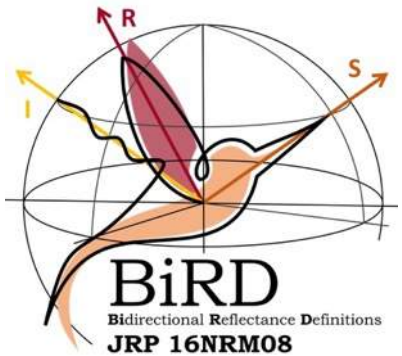


Psychophysic & measurement scales (with uncertainty)

Outlines

EURAMET

JRP – IND 52 xReflect



- (Pre – introduction)
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- State of the art of primary metrology for
  - BRDF
  - Goniochromatism and iridescence
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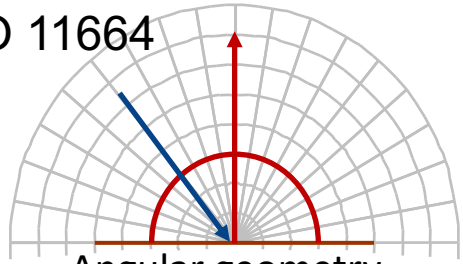
  - Sparkle
  - Fluorescence
- Future works (overview)
- Conclusion

cie
International Commission on Illumination
Commission Internationale de l'Eclairage
Internationale Beleuchtungskommission

Context in 1965

Standard measurement geometries

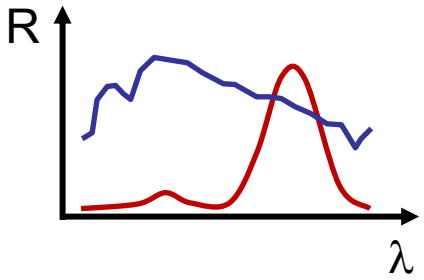
ISO 11664



Angular geometry (0/45° or 0/diff)

Portable spectrophotometer

Spectral reflectance

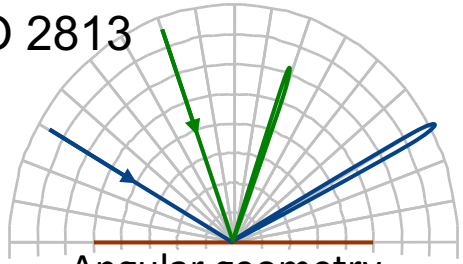


Calibration tiles

Context in 1965

Standard measurement geometries

ISO 2813



Angular geometry (60°, 20° & 85°)

Glossmeter

Gloss value

$G_{60°}$ = 98 gu

Calibration tiles

Context in 2015

Goniochromatism

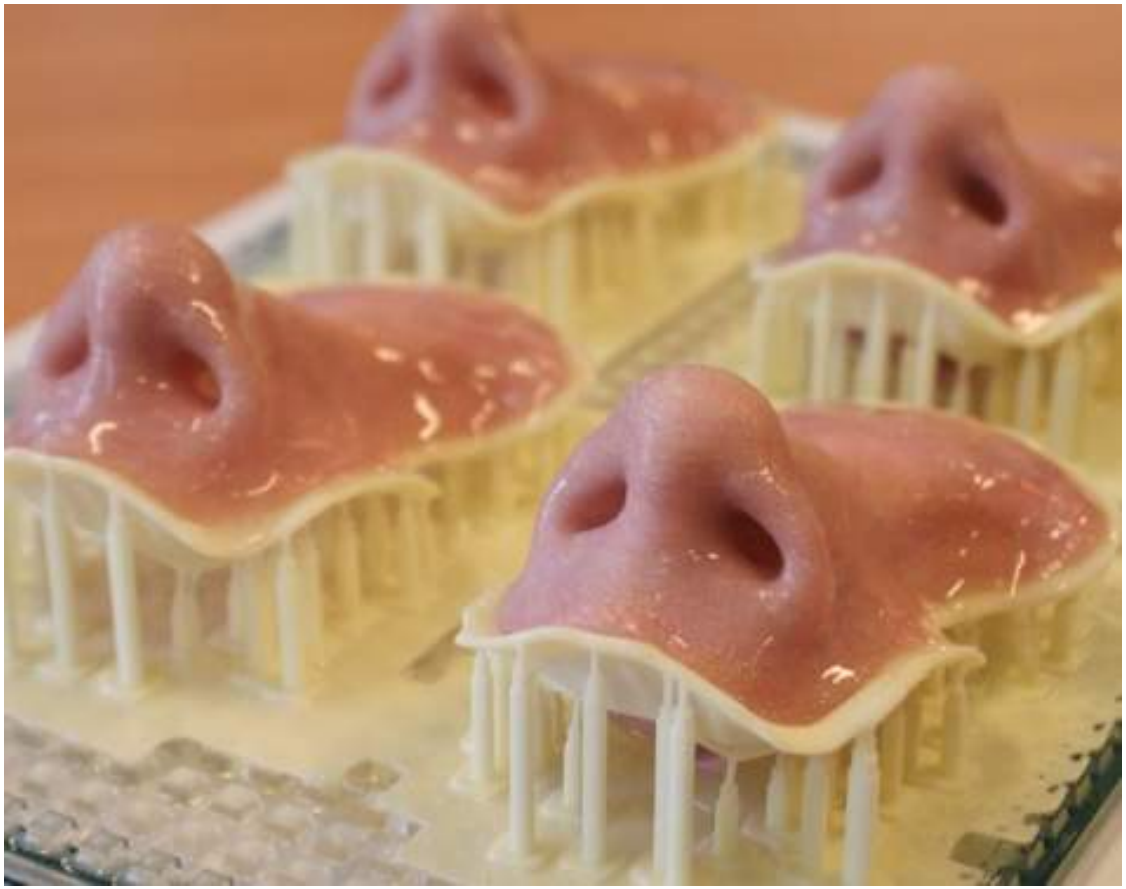
Context in 2015

Sparkle and graininess

Context in 2015

Gloss and anisotropy

Context in 2015



Translucidity in reflection and transmission

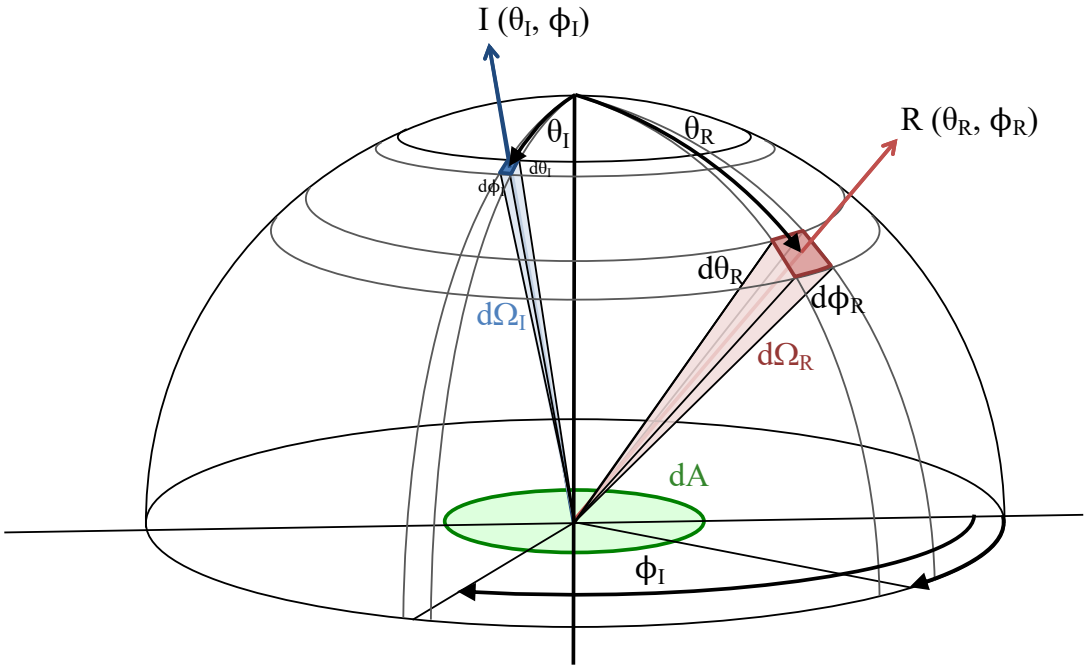
Context in 2015

Physically based virtual prototyping

Quantity

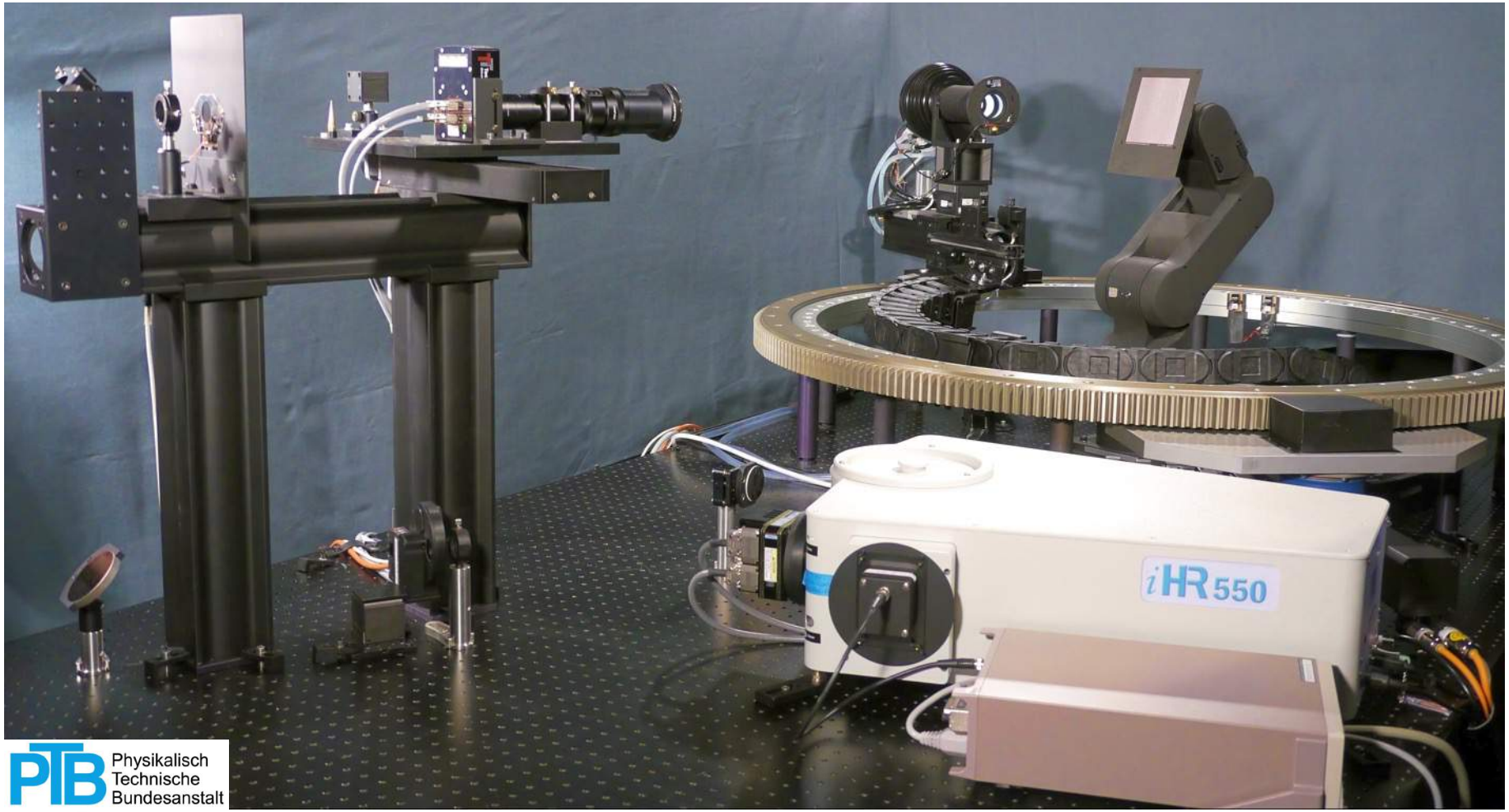
0°/45°
0°/Diff

BRDF
Bidirectional Reflectance Distribution



$$f(\theta_\mathbf{I}, \varphi_\mathbf{I}, \theta_\mathbf{R}, \varphi_\mathbf{R}, \Omega_\mathbf{R}, \lambda, \sigma) = \frac{\mathrm{d}L(\theta_\mathbf{I}, \varphi_\mathbf{I}, \theta_\mathbf{R}, \varphi_\mathbf{R}, \Omega_\mathbf{R}, \lambda, \sigma)}{\mathrm{d}E(\theta_\mathbf{I}, \varphi_\mathbf{I}, \lambda, \sigma)}$$

Goniospectrophotometer



(as we are talking about it… 😏)

~~Goniometer~~

~~Gonioreflectometer~~

Goniospectrophotometer

~~Goniophotometer~~

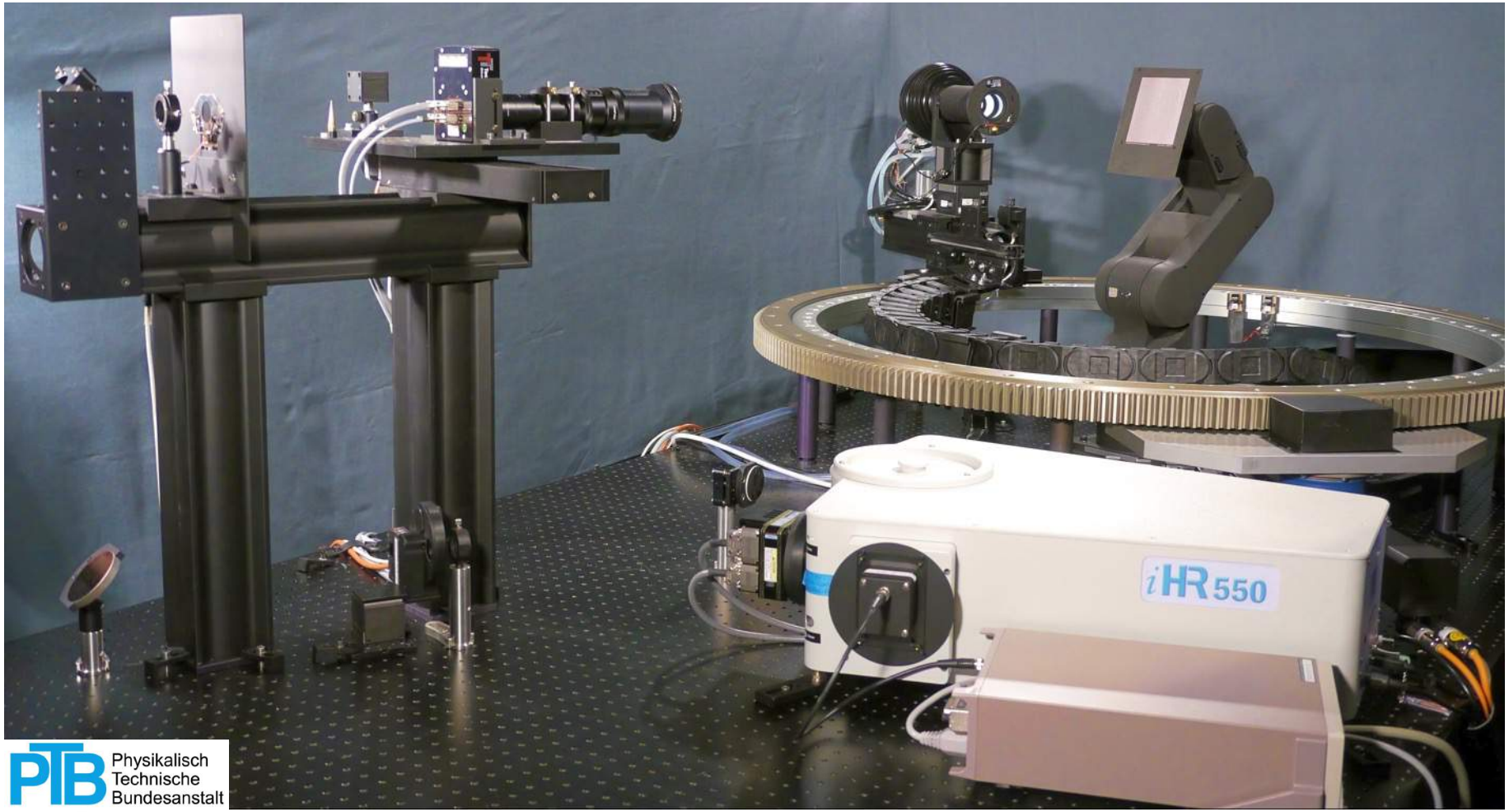
~~Gonioradiometer~~

~~Goniospectroradiometer~~

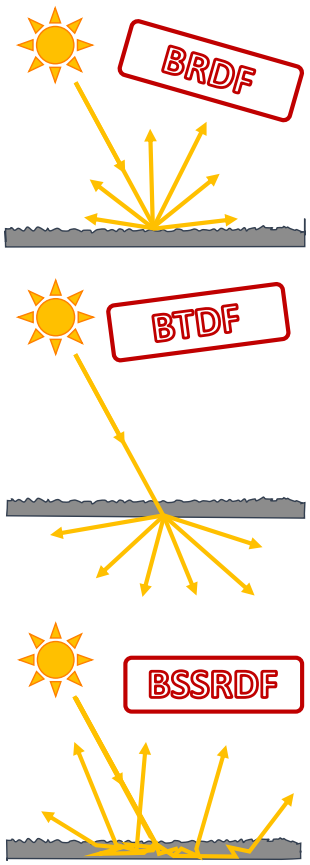
Decision taken by **CIE TC2-85** (Sept 2016 – Prague)

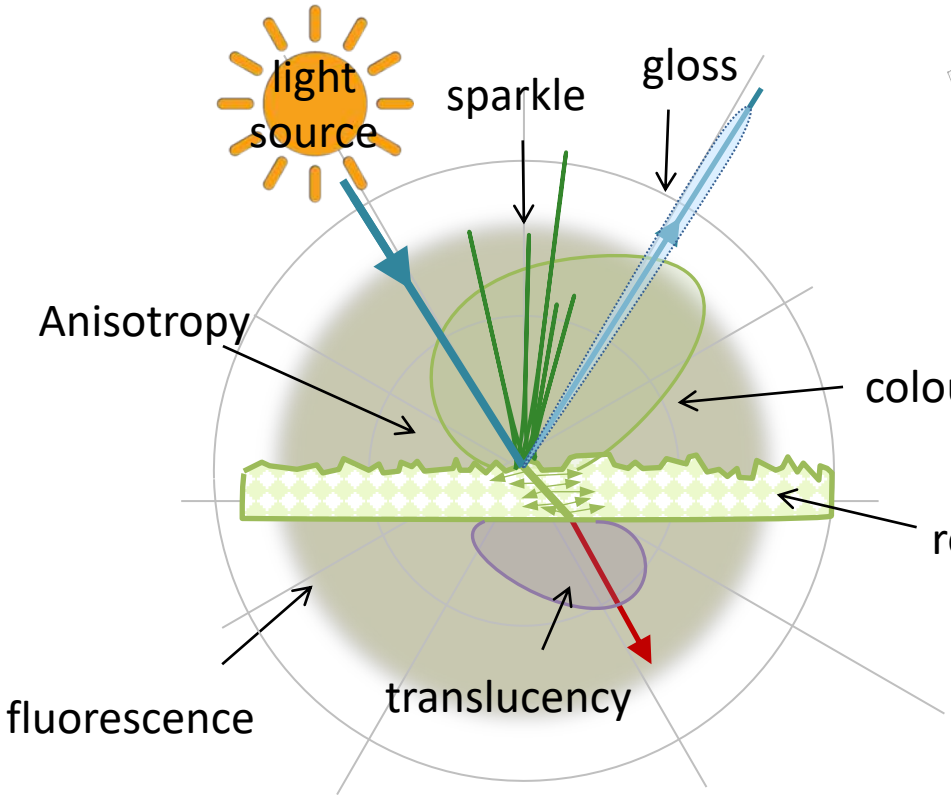
"Recommendation on the geometrical parameters for the measurement of the Bidirectional Reflectance Distribution Function (BRDF)"

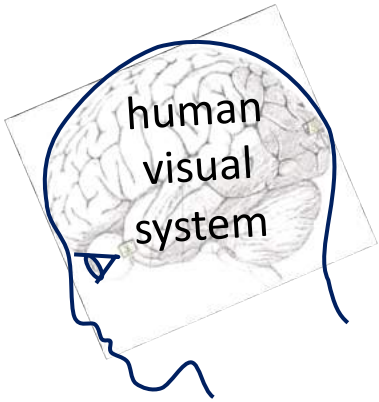
Goniospectrophotometer

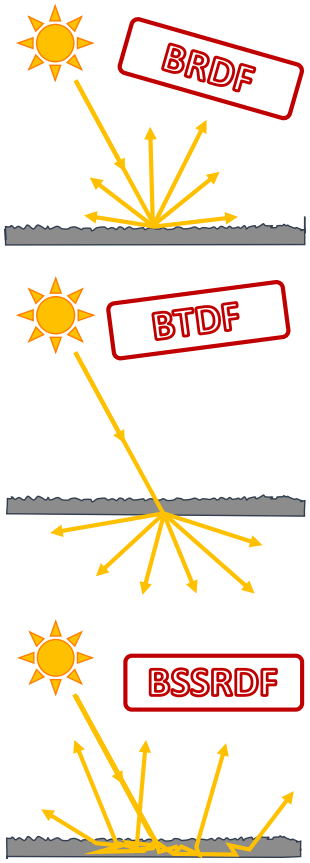


BRDF – BTDF - BSSRDF









BRDF – BTDF - BSSRDF

All these measurements can't be performed at the highest level with a single equipment

Coordinated effort at the European metrological level

EURAMET

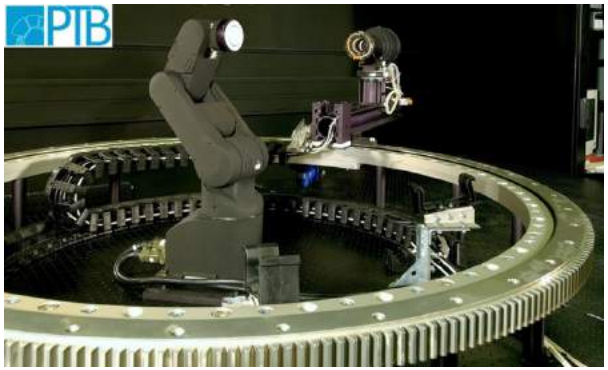
EMPIR EURAMET

The EMPIR initiative is co-funded by the European Union's Horizon 2020 research and innovation programme and the EMPIR Participating States

Ongoing coordinated action at EU level

PTB

CMI (CZ), CNAM (FR), CSIC (ES), INRIM (IT), Aalto (FI), MSL (NZ), PTB x2 (GE), METAS (CH), CMI (CZ)



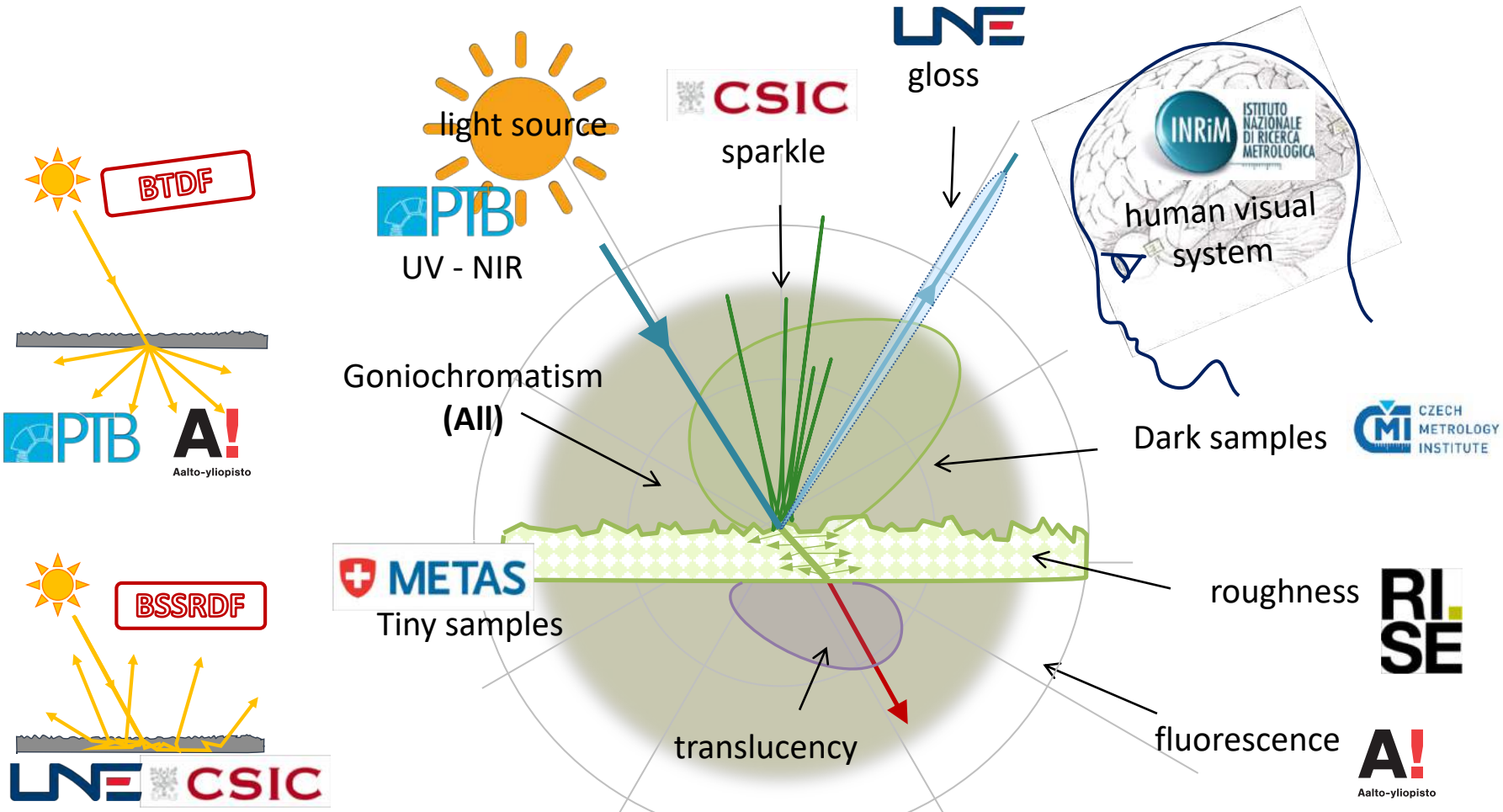
JRP – IND 52 xDReflect

BiRD Bidirectional Reflectance Defi JRP 16NRM08

BxDiff

2005 2013 2016 2017 2019 2020 2022

Ongoing coordinated action at EU level

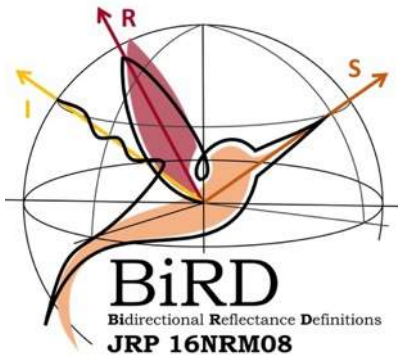


Young and complementaire primary facilities

Outlines

EURAMET

JRP – IND 52 xReflect



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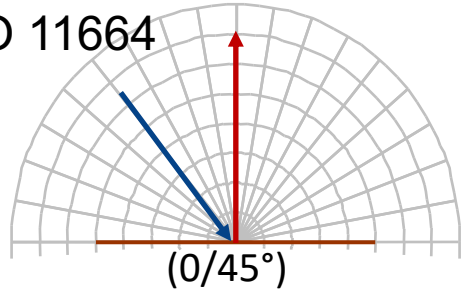
cie
International Commission on Illumination
Commission Internationale de l'Eclairage
Internationale Beleuchtungskommission

Control of primary Reflectance scales

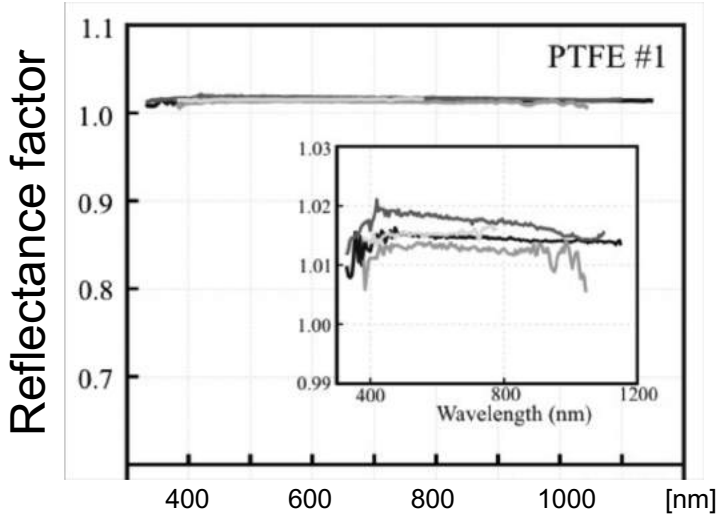
Comparison between NIST and PTB

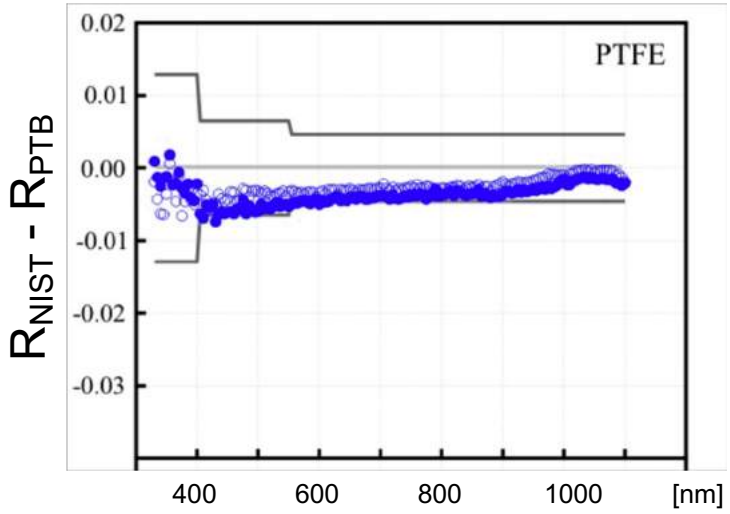
PTFE



Agreement :

0.5%





C. C. Cooksey, M. E. Nadal, D. W. Allen, K. O. Hauer, and A. Höpe, "Bidirectional reflectance scale comparison between NIST and PTB," Appl. Opt. **54**, 4006–4015 (2015).

Control of primary BRDF scales

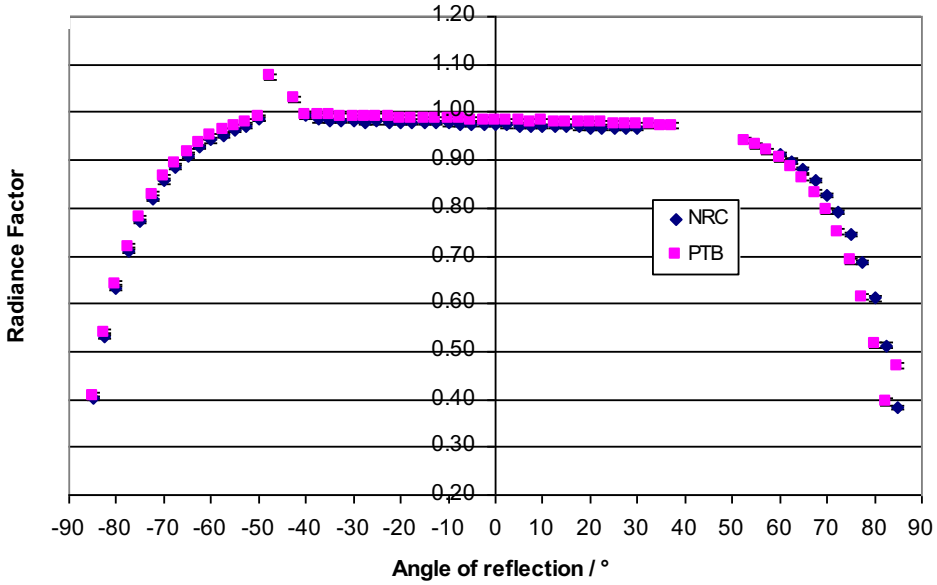
Comparison between PTB and NRC

Opal glass

λ = 550 nm

Agreement :

0.9% for θ_R < 60°

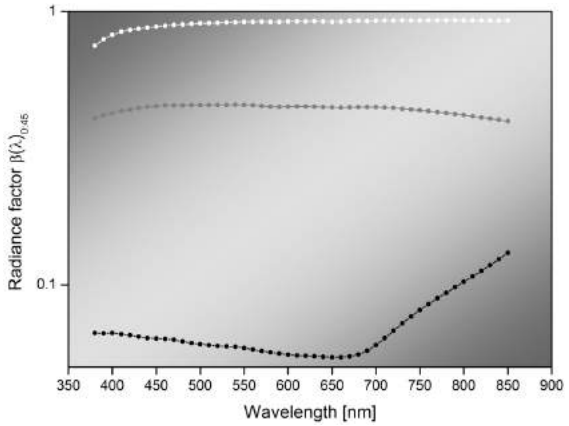


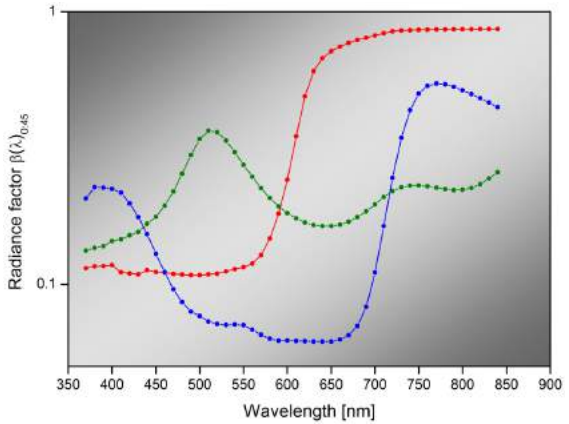
R. Baribeau, W. Neil, K-O Hauer and A Höpe, "Comparison of the bidirectional diffuse reflection scales of PTB and NRC in the V(λ)-range" , *NewRad proceedings* (2011)

Control of primary BRDF scales

Comparison of reflectance factor between 7 NMIs

6 isotropic samples : 88 % white, 40 % grey and 5 % dark grey, red, green and blue





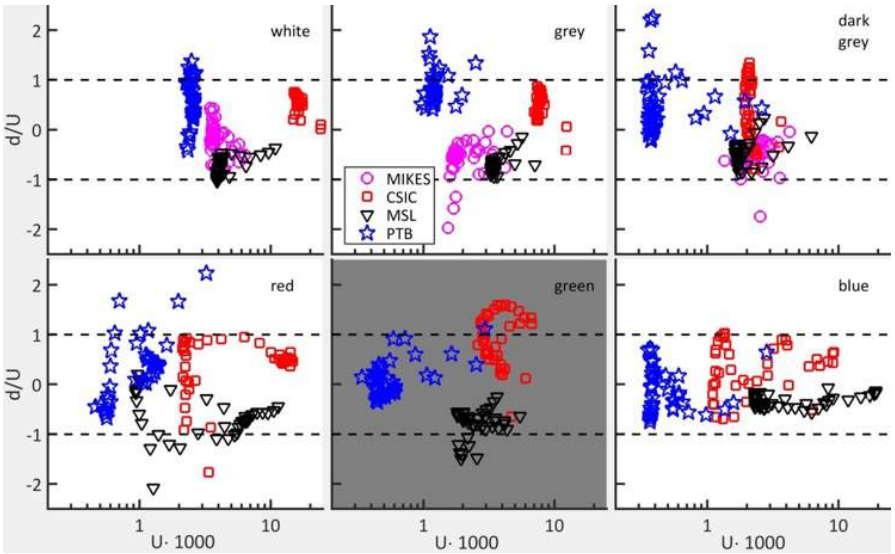
Configuration : 0° /45°,
spectral range : 380 nm ➞ 850 nm

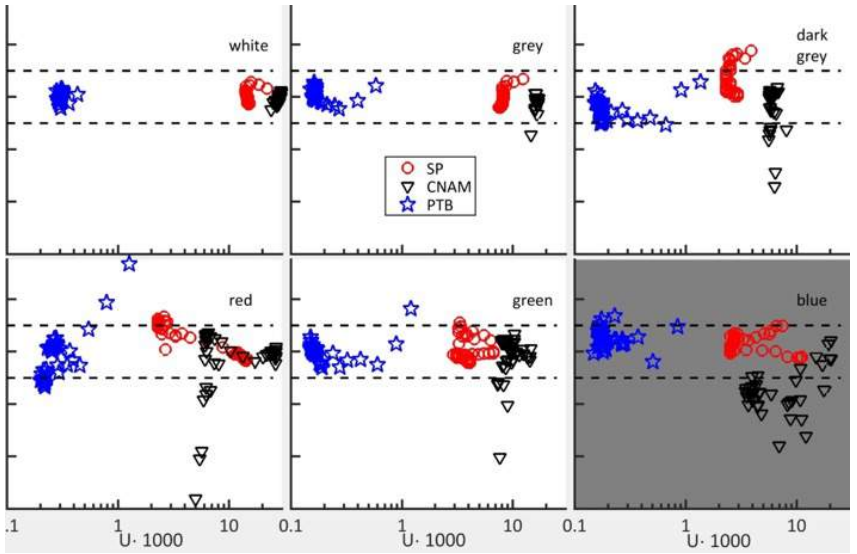
Control of primary BRDF scales

Comparison of reflectance factor between 7 NMIs

6 isotropic samples : 88 % white, 40 % grey and 5 % dark grey, red, green and blue

Agreement : **2% (worst for λ < 420 nm)**





C. Strothkämper, A Ferrero, A Koo, P. Jannson, G. Ged, G Obein, S Källberg, J. Audenaert, F Leloup, F Martinez Verdu, E Perales, A Schirmacher, J Campos, A "Multilateral Spectral Radiance Factor Scale Comparison", Applied Optics, **56**(7), p1996-2006, 2016

Goniochromatism

Goniochromatism

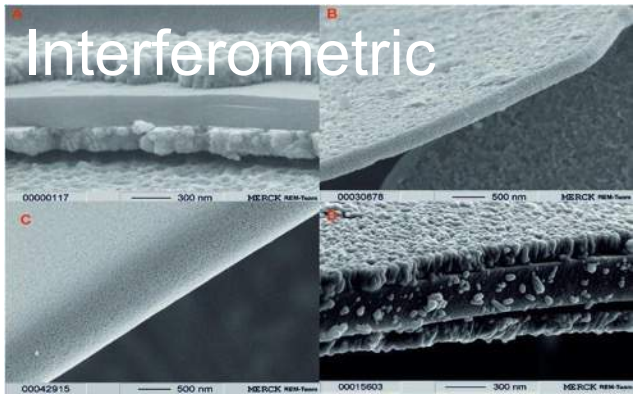
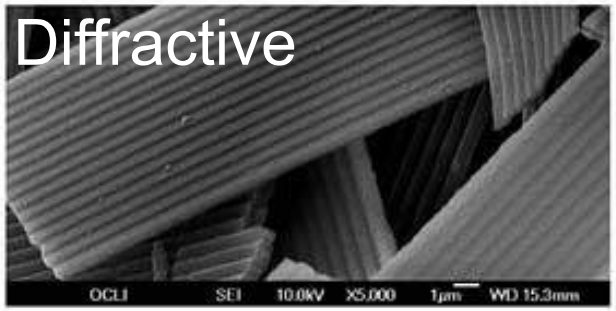
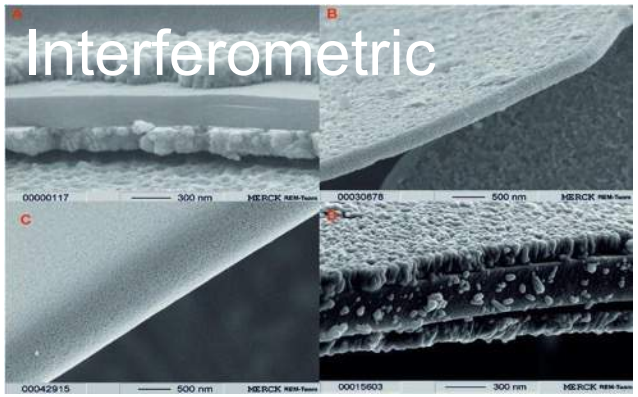
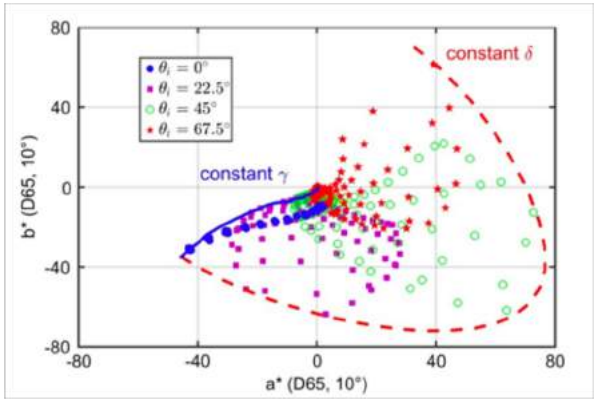


Figure 6 / SEM micrograph of diffractive pigment

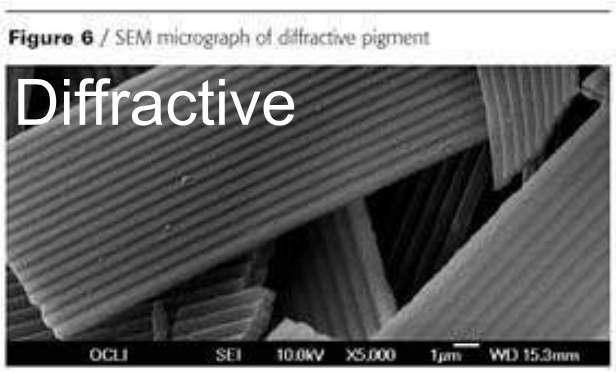


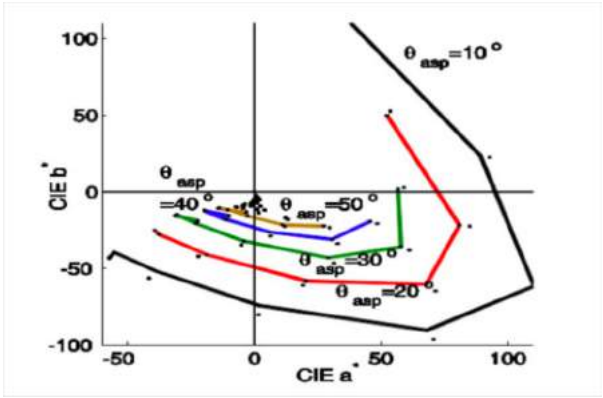
Goniochromatism





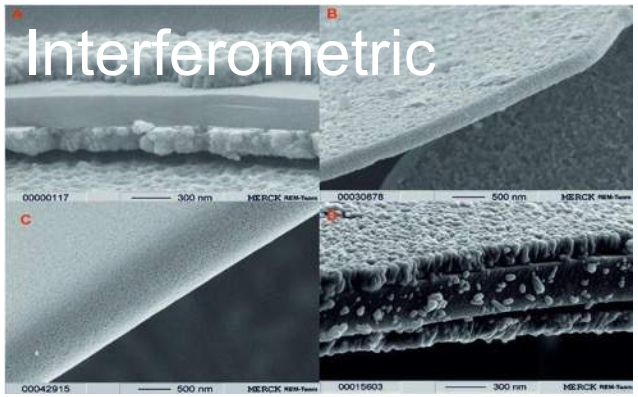
C. Strothkämper, K.-O. Hauer, Andreas Höpe, “How to Efficiently Characterize Special Effect Coatings”, J. Opt. Soc. Am A, **33**(1), p 1-8, 2016





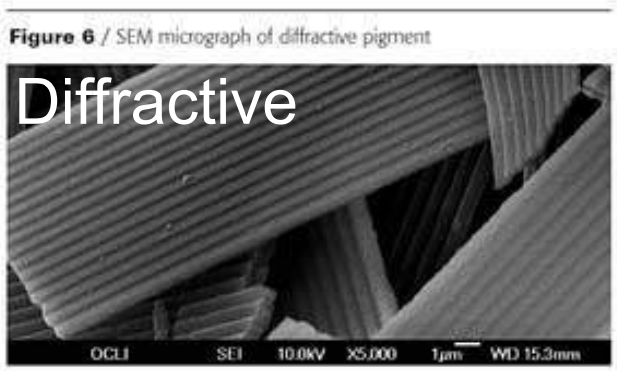
A. Ferrero et al, “Color characterization of coatings with diffraction pigments”, J. Opt. Soc. Am. A, **33**(5), p. 1978-1988, 2016

Goniochromatism



Colour travel can be well predicted with only 10 angular geometries. Geometries of ASTM E 2539 are okay (even if not optimals)

C. Strothkämper, K.-O. Hauer, Andreas Höpe, "How to Efficiently Characterize Special Effect Coatings", J. Opt. Soc. Am A, **33**(1), p 1-8, 2016

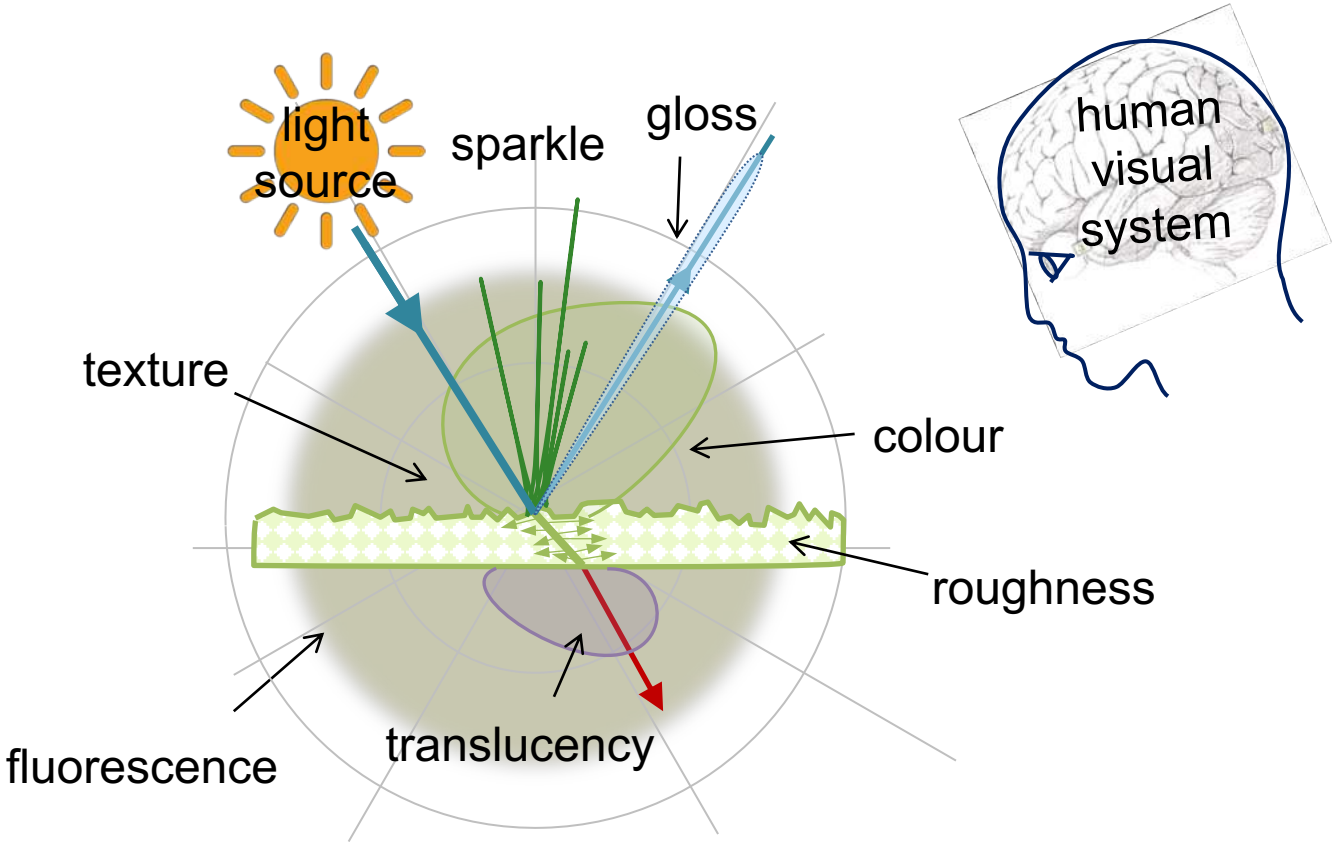


Colour travel can be predicted with a limited number of measurements but it depends upon the number of diffraction orders. ASTM E2539 not sufficient

A. Ferrero et al, "Color characterization of coatings with diffraction pigments", J. Opt. Soc. Am. A, **33**(5), p. 1978-1988, 2016

Gloss

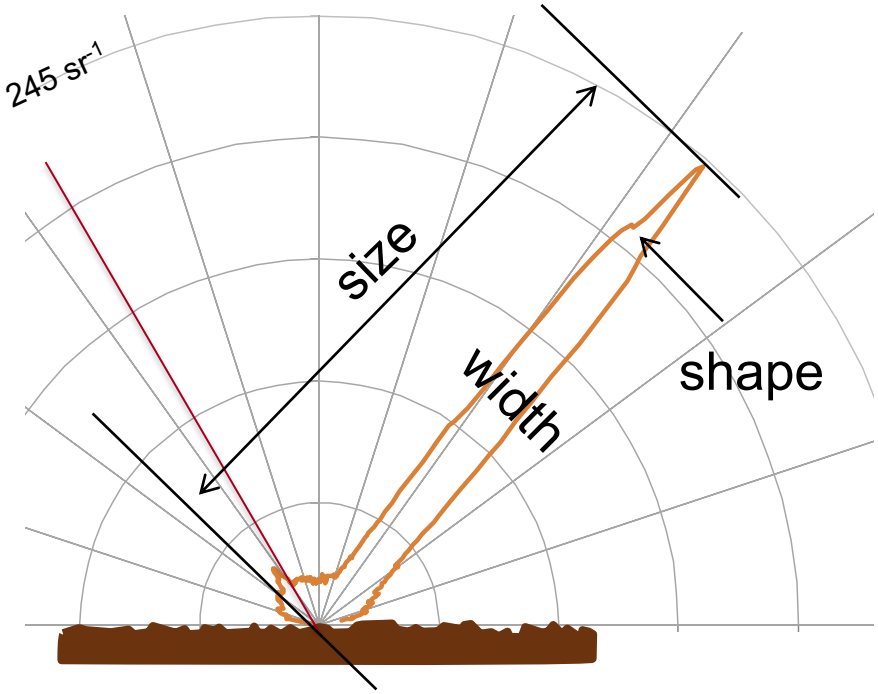
Gloss



Information on gloss is located in a particular area of the BRDF called the **specular peak**

Visual evaluation of gloss

When an observer evaluates the gloss, he tries to access the size, the width and the shape of the specular peak



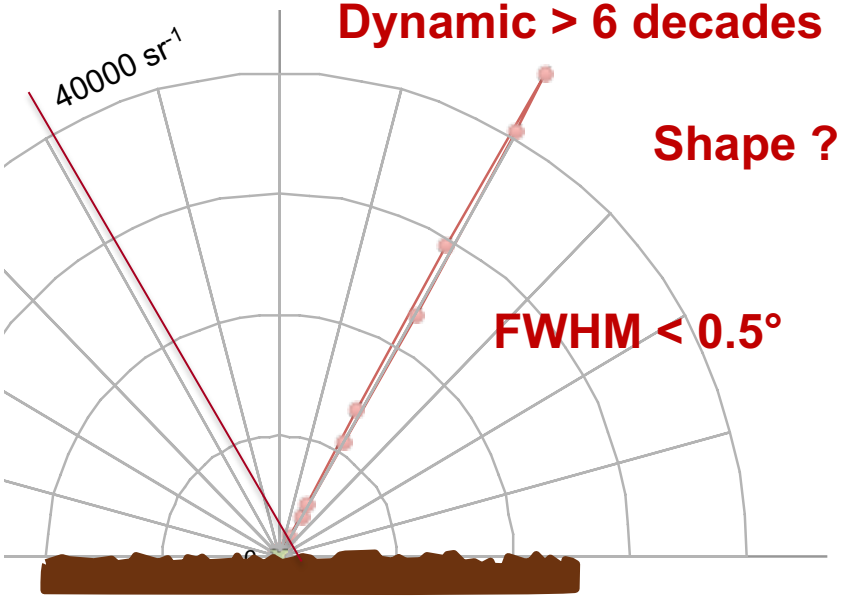
Grey samples from NCS® gloss scale, plane of incidence, $\theta_I = 40°$

Measurement of gloss

To access surface gloss, one needs to measure the height, width and shape of the specular.

but

high gloss surface shows narrow specular peak with huge dynamic



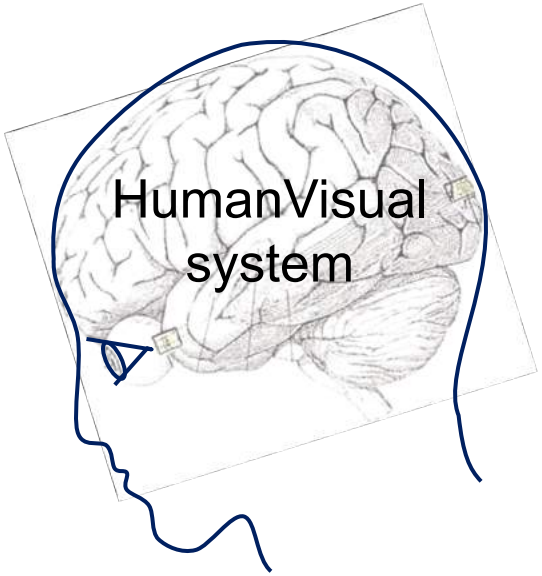
Black samples from 3C® gloss scale, plane of incidence, $\theta_i = 30°$

Development of a dedicated instrument (ConDOR)

A facility that measures the BRDF with an angular resolution better the human visual system, in order to study the specular peak of glossy surfaces

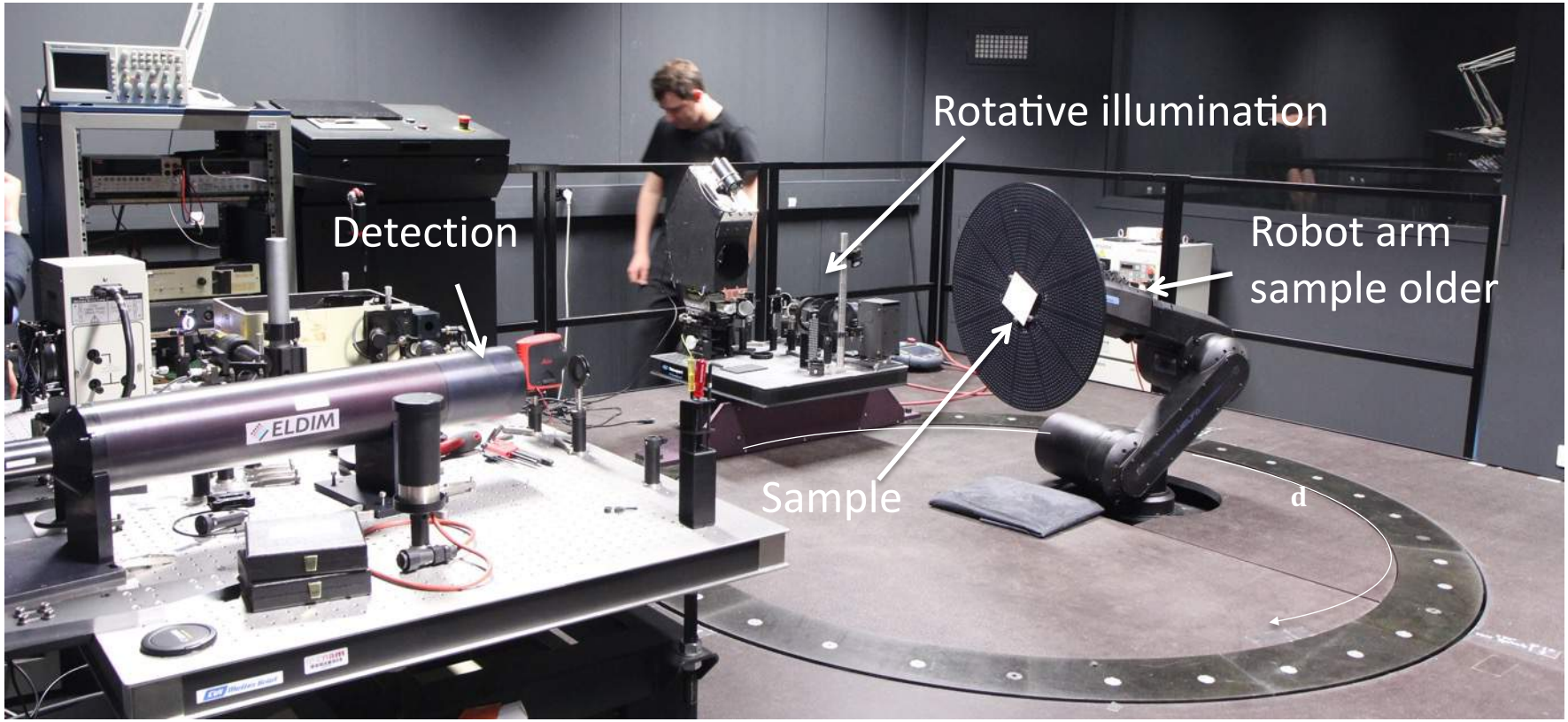
A resolution of 0,03°

- It is means light must be collected through an aperture of Ø = 0.5mm at a distance of 1 m from the sample
- It's about **40 000** points of measurement an angular sector of ±1,5° large



Visual system has a resolution of 0,03°

ConDOR



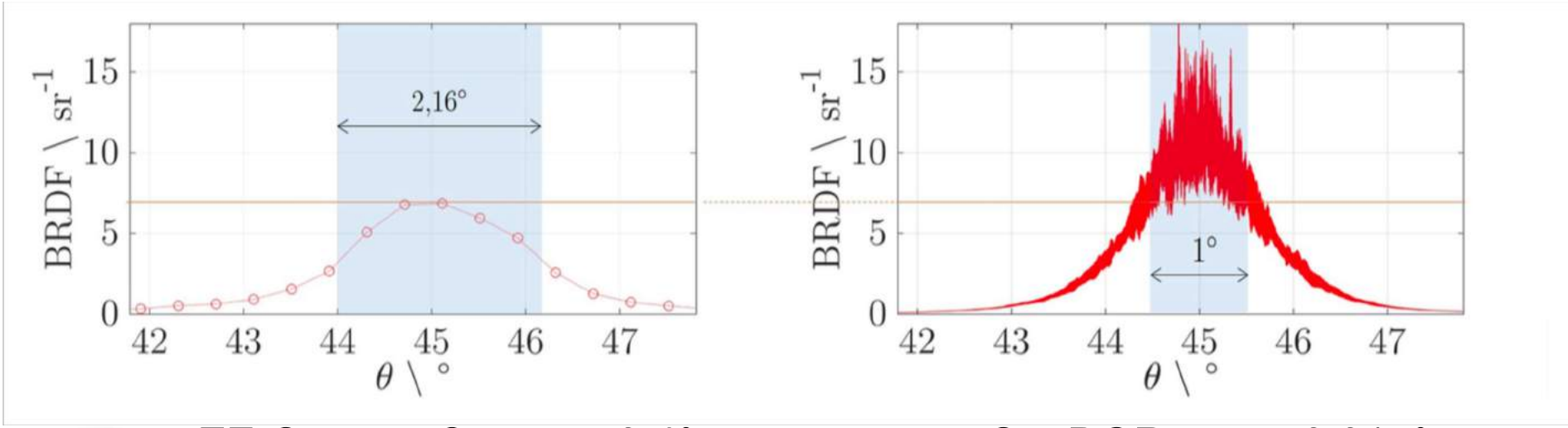
Spectral resolution ➛ $\Delta\lambda = V(\lambda)$
Angular resolution ➛ $\Delta\Omega < 0.2$ msr
Illumination area ➛ $\emptyset = 10$ mm

Exemple of results

©Obein

Black samples from 3C® gloss scale (75 gu)

Cut plane of incidence
$\theta_I = 45°$, $42 < \theta_R < 48°$

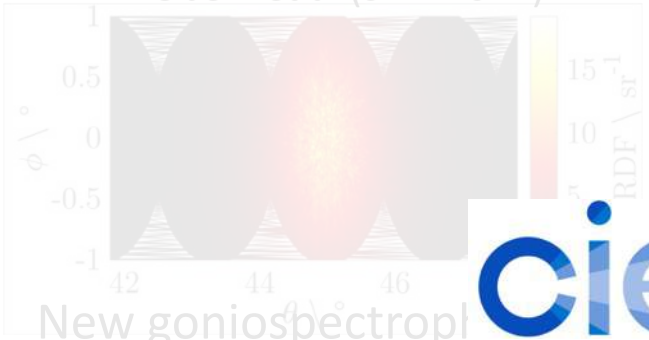


EZ-Contrast® , res = 0,4°

ConDOR, res = 0,015°

Toward a new route for the measurement of gloss ?

Obein et al (SPIE 2014)



New goniospectroph
to access specular peaks

Obein et al (JOV 2004)

Ji et al (JOSA 2006)

Previous studies

International Commission on Illumination
Commission Internationale de l'Eclairage
Internationale Beleuchtungskommission

JTC 17 (D1/D2/D8): Gloss measurement and gloss perception: A framework for the definition and standardization of visual cues to gloss

Start : Dec 2018

Chair : Frédéric Leloup, KU Leuven (BE)

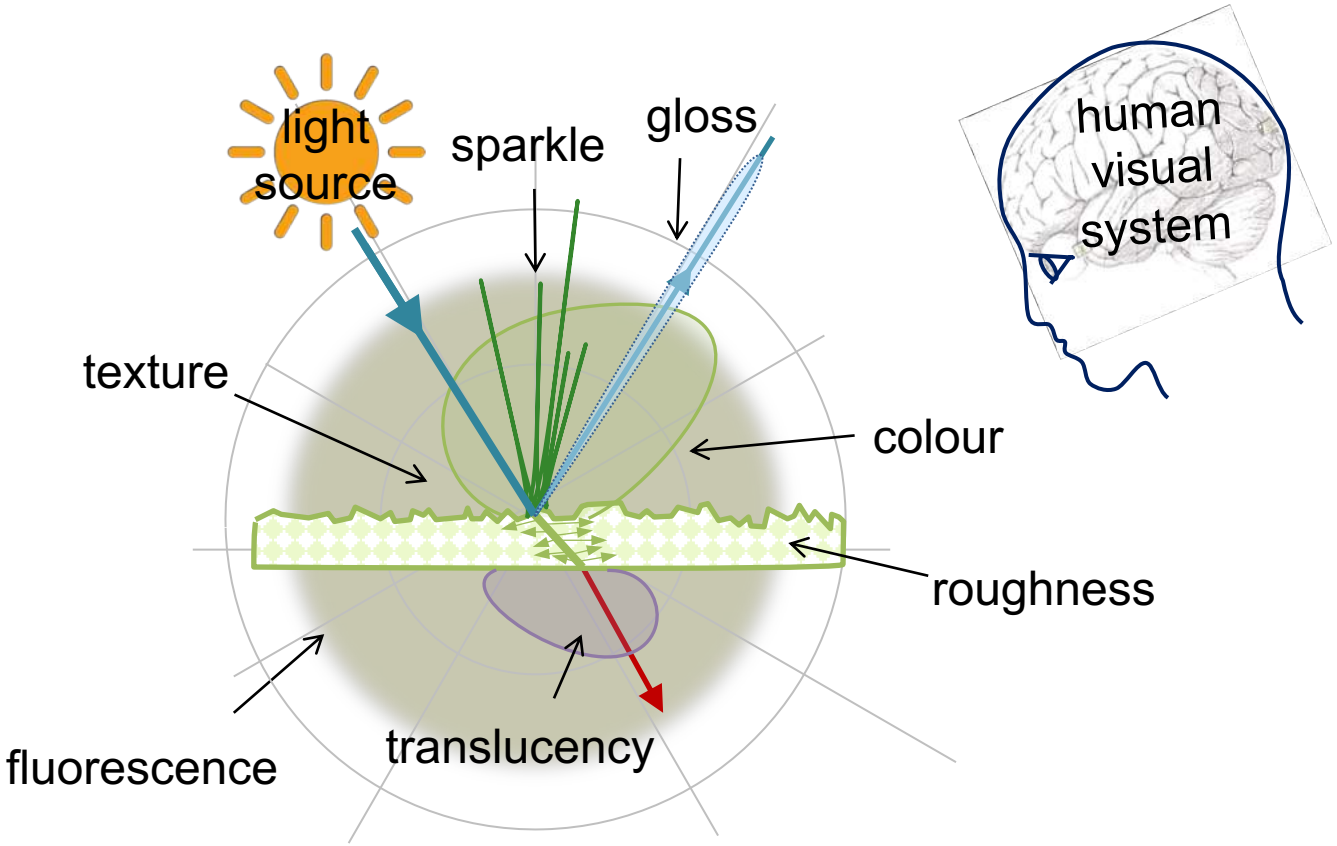
Ged et al (NewRad 2015)

New generation of gloss scales

New psychophysical studies ?

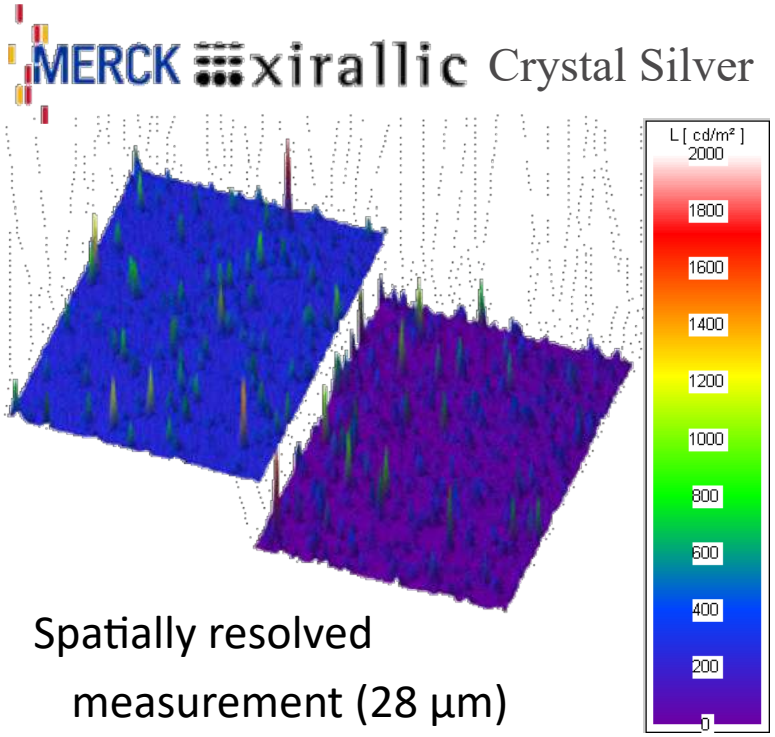
Sparkle

Sparkle


light source
sparkle
gloss
human visual system
texture
colour
roughness
fluorescence
translucency

Principle

Imaging systems

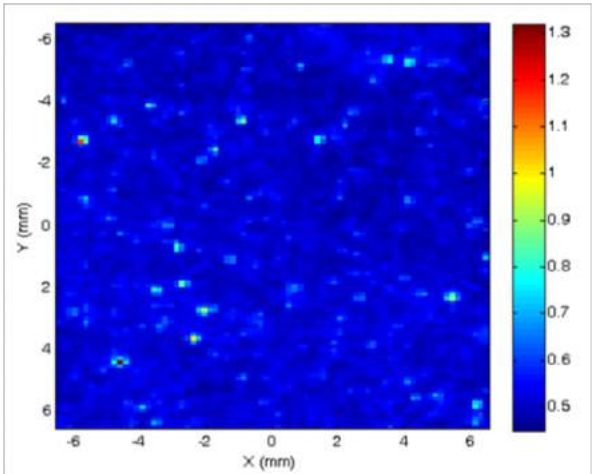


Spatially resolved measurement (28 µm)

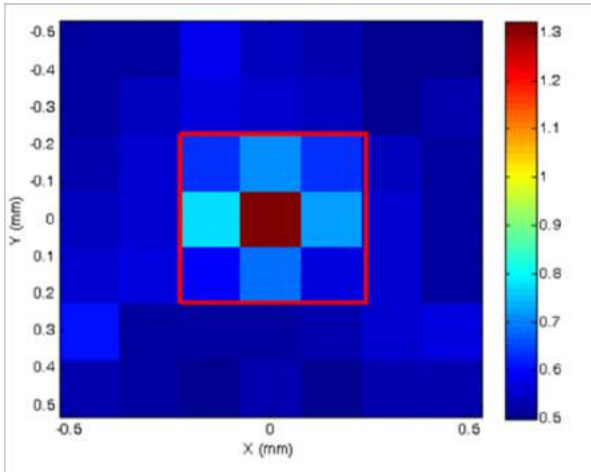
Angular resolution : narrow

Dynamic : 4 decades

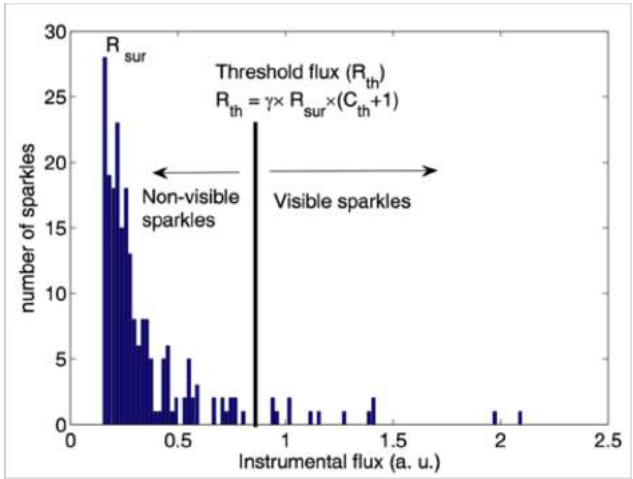
Method



a) Image of an effect coating within a 13 mm × 13 mm squared area.



(b) Image of a single sparkle from the image in , within an area of interest of 1 mm × 1 mm. Red quare represents the aperture used in this work.



A. Ferrero, S. Bayón, “The measurement of Sparkle”, Metrologia, **52**, 317-323, 2015

Development of dedicated facilities

Regular goniospectrophotometer equiped with imaging based detection

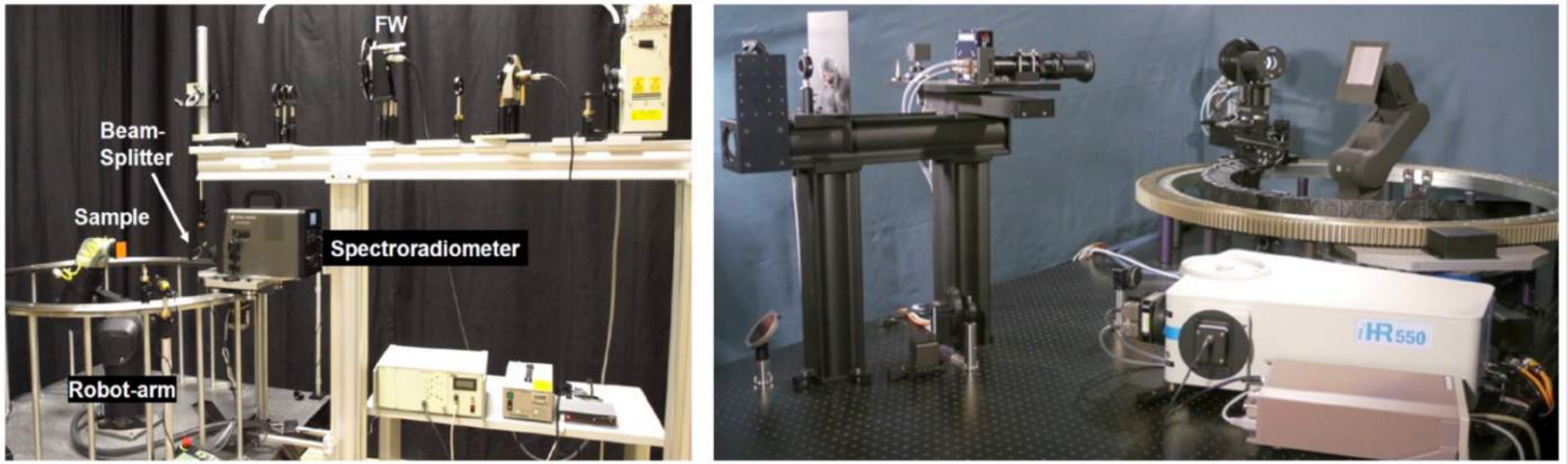


Figure 19 : Photo of the two goniospectrophotometers that has been equipped for sparkle measurement. Left, GEFE at CSIC. Right, ARGon3 at PTB.

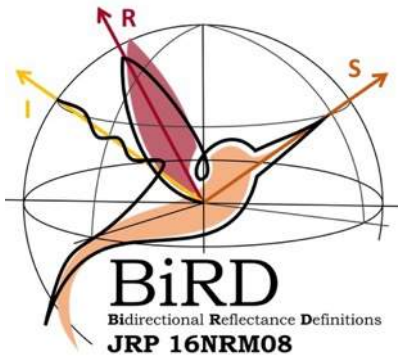
Fluorescence

© Aalto

Outlines

EURAMET

JRP – IND 52 xReflect



- (Pre – introduction)
- Introduction
- State of the art of primary metrology for
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  - Goniochromatism and iridescence
  - Gloss
  - Sparkle
  - Fluorescence
- **Future works (overview)**
- Conclusion

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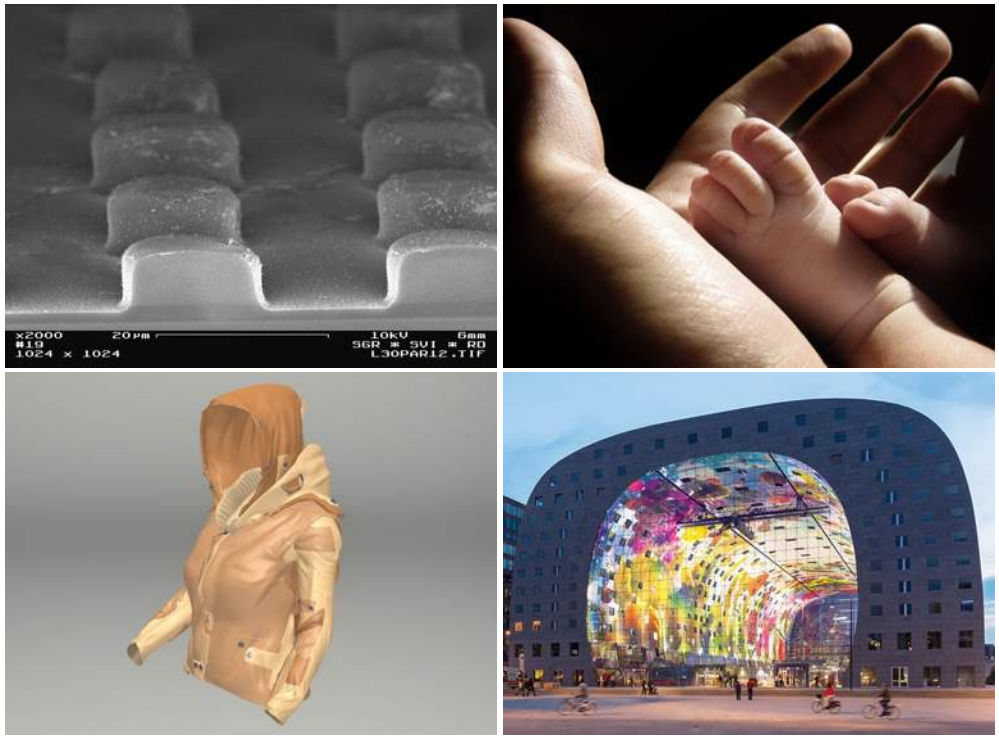
Internationale Beleuchtungskommission

Future Project

EMPIR EURAMET
The EMPIR initiative is co-funded by the European Union's Horizon 2020 research and innovation programme and the EMPIR Participating States



BxDiff

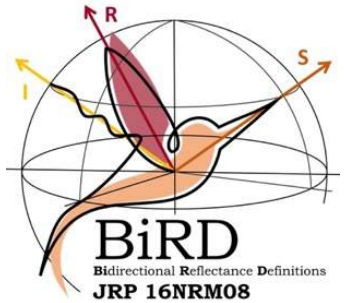
New quantities for the measurement of appearance

Context

Sept 2013 → **Aug 2016**

JRP – IND 52
xReflect

May 2017 → **April 2020**



May 2019 → **April 2022**

BxDiff
Call SIB

Consortium

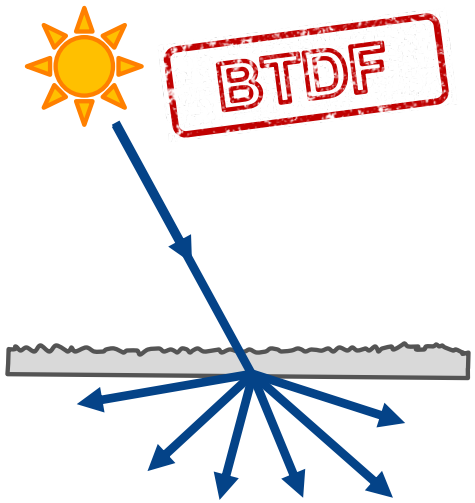
9 national metrological institutes

3 academics

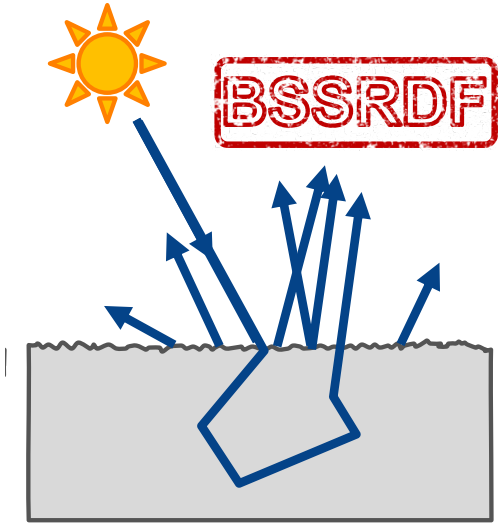
5 industrials

Proposal

1. Developing primary reference facilities and standard artefacts for the measurement and the dissemination of the Bidirectional Transmittance Distribution Functions (BTDF) as a traceable quantity,
2. Developing primary reference facilities and standard artefacts for the measurement and the dissemination of the Bidirectional Scattering Surface Reflectance Distribution Function (BSSRDF) as a traceable quantity



$f(\theta_I\ \varphi_I\ \theta_T\ \varphi_T\ \lambda\ \sigma)$



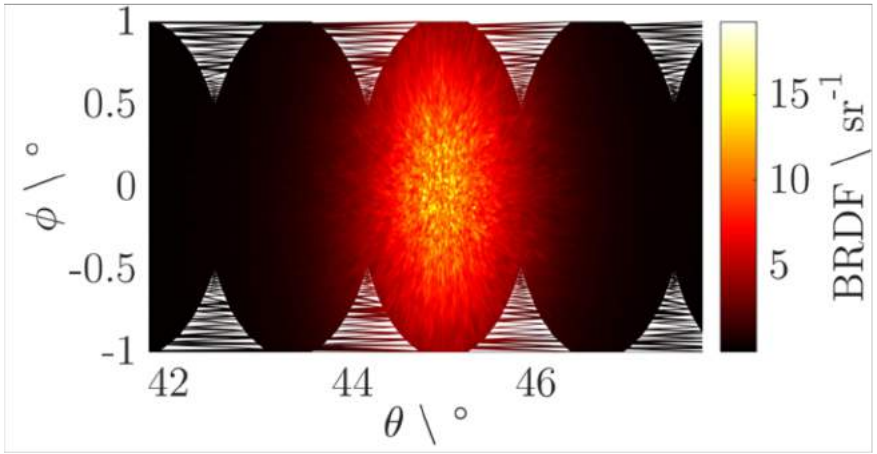
$f(\theta_I\ \varphi_I\ \theta_T\ \varphi_T\ x_I\ y_I\ x_R\ y_R\ \lambda\ \sigma)$

Proposal

3. Addressing advanced metrological issues related to Bidirectional Reflectance Distribution Function (BRDF) measurement, including polarization and speckle induced effects in order to reduce by a factor 2 the measurement uncertainty at the highest level

Polarisation

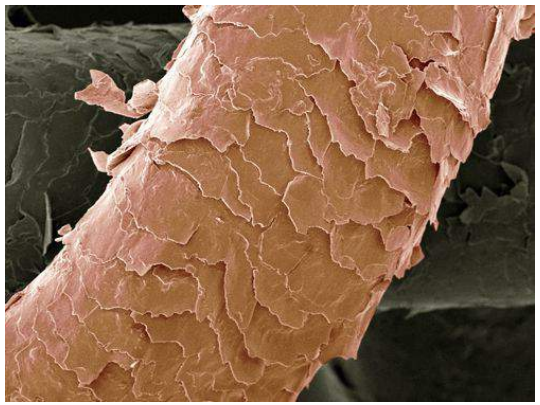
Speckle



ConDOR, res = 0,015°

Proposal

4. Establishing a full metrological traceability of the BRDF from tiny objects (micrometric scale) to regular objects (centimetric scale),



5. Engaging with industry, academics and end-users know-how transfer, measurement techniques and reference materials issued from the project, in order to strengthen the level of traceability in the field of spectrophotometry, thus allowing a better control of the appearance of manufactured objects.

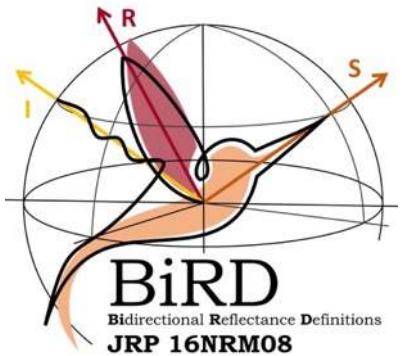
Stakeholders


Do you want to joint ?

Outlines

EURAMET

JRP – IND 52 xReflect



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Internationale Beleuchtungskommission

Conclusion (1/3)

Industrials need to control the appearance of their products
The visual effect generated are more and more complex

Measurement solutions must include a bi-directional approach (BRDF, BTDF)
New transfer artefacts must be thoughts to ensure traceability

Conclusion (2/3)

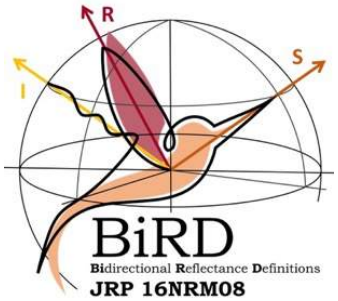
Since 2012 and thanks to Euramet and EU funds, the European metrology is addressing this demand and is structuring its labs to be complementary, applied and efficient

EMPIR EURAMET
The EMPIR initiative is co-funded by the European Union's Horizon 2020 research and innovation programme and the EMPIR Participating States

Important progresses have been made in connection with goniochromatism, gloss, sparkle, graininess, fluorescence (BRDF) characterisation (xDReflect)

JRP – IND 52 xDReflect

Main outputs are now at the normative level (BiRD)



Conclusion (3/3)

Future project will address transparency (BTDF), translucency (BSSRDF) and multiscale traceability

It will provide primary standards and transfer artefacts of these quantities, to ensure a better characterization and exploitation of the related visual effects.

JRP 18SIB03
“New quantitites for the measurement of appearance”
(BxDiff)

June 2019 to May 2022

Next meeting concerning BiRD/BxDiff will be at CNAM (Paris)
21/22 May 2019

You are welcome to attend

Thank you