Celebrating the 20th anniversary of the Light&Lighting laboratory

Ghent, September 12, 2017

CIE CRI:

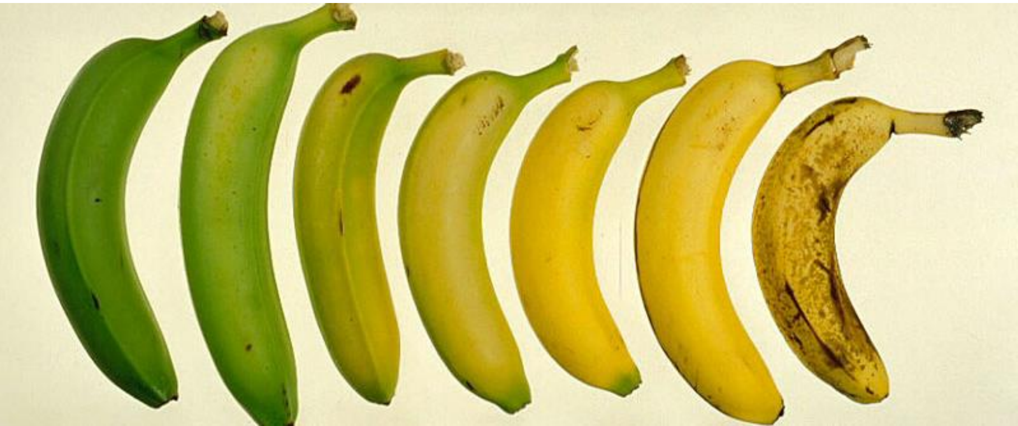
Hello Rf, goodbye Ra ?!

Prof. K. Smet

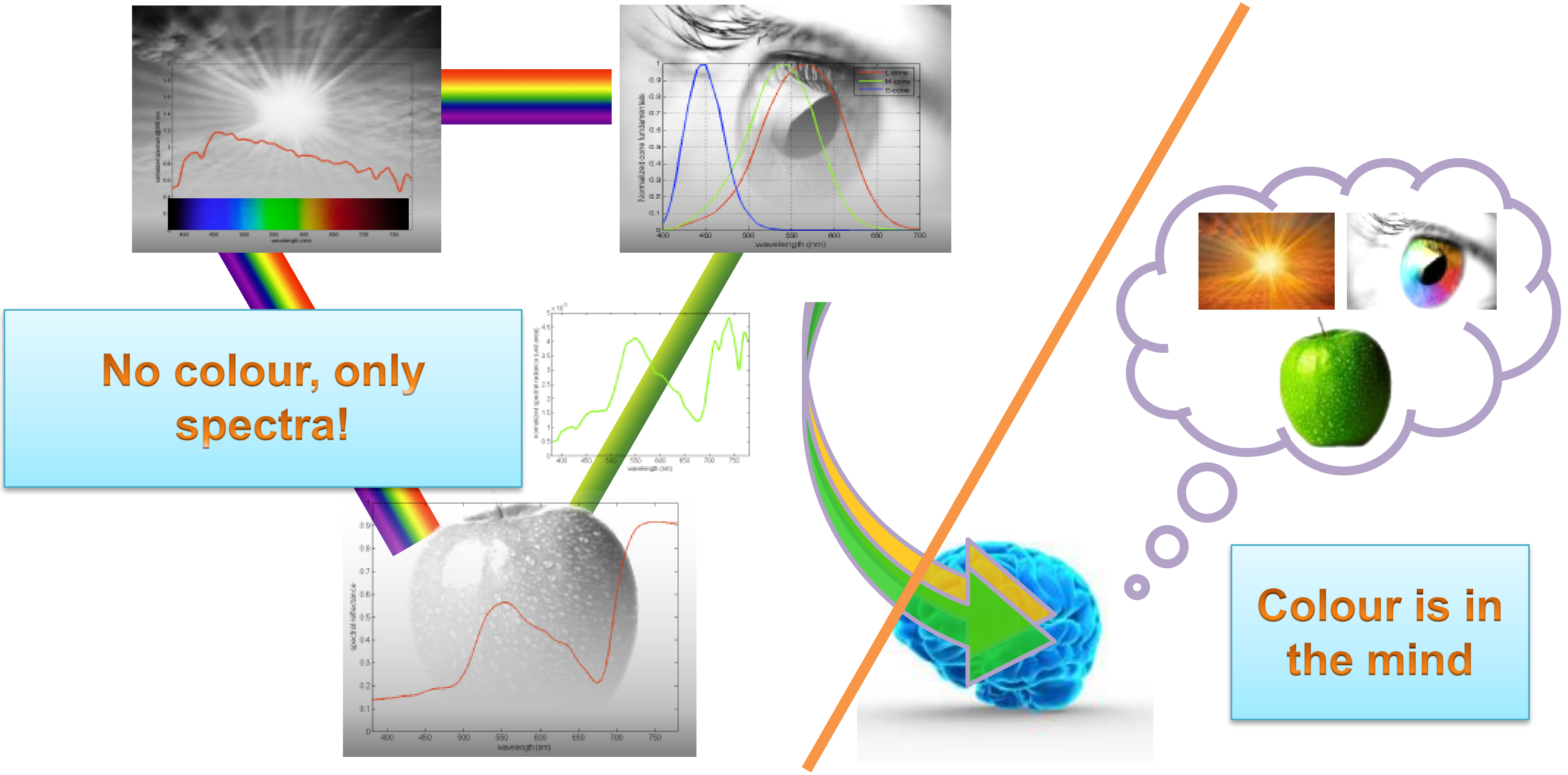
Colour Perception

Colour Perception

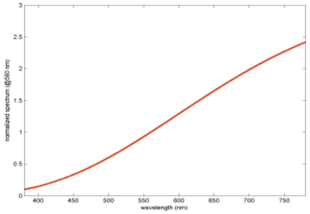
Inform about
object
identity and state



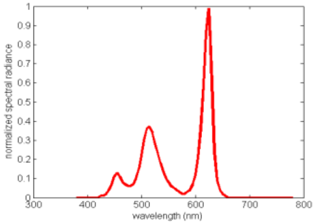
Colour Perception



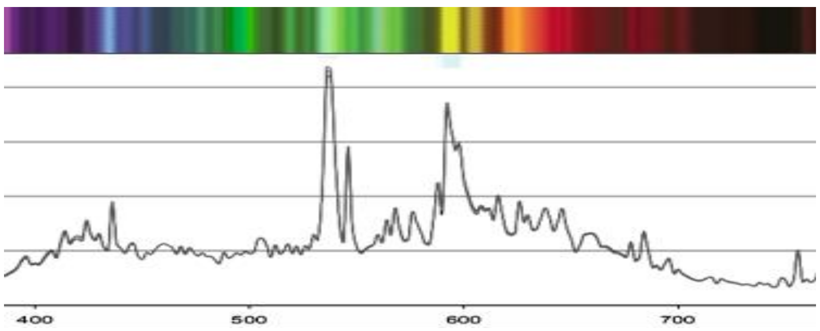
Colour rendition



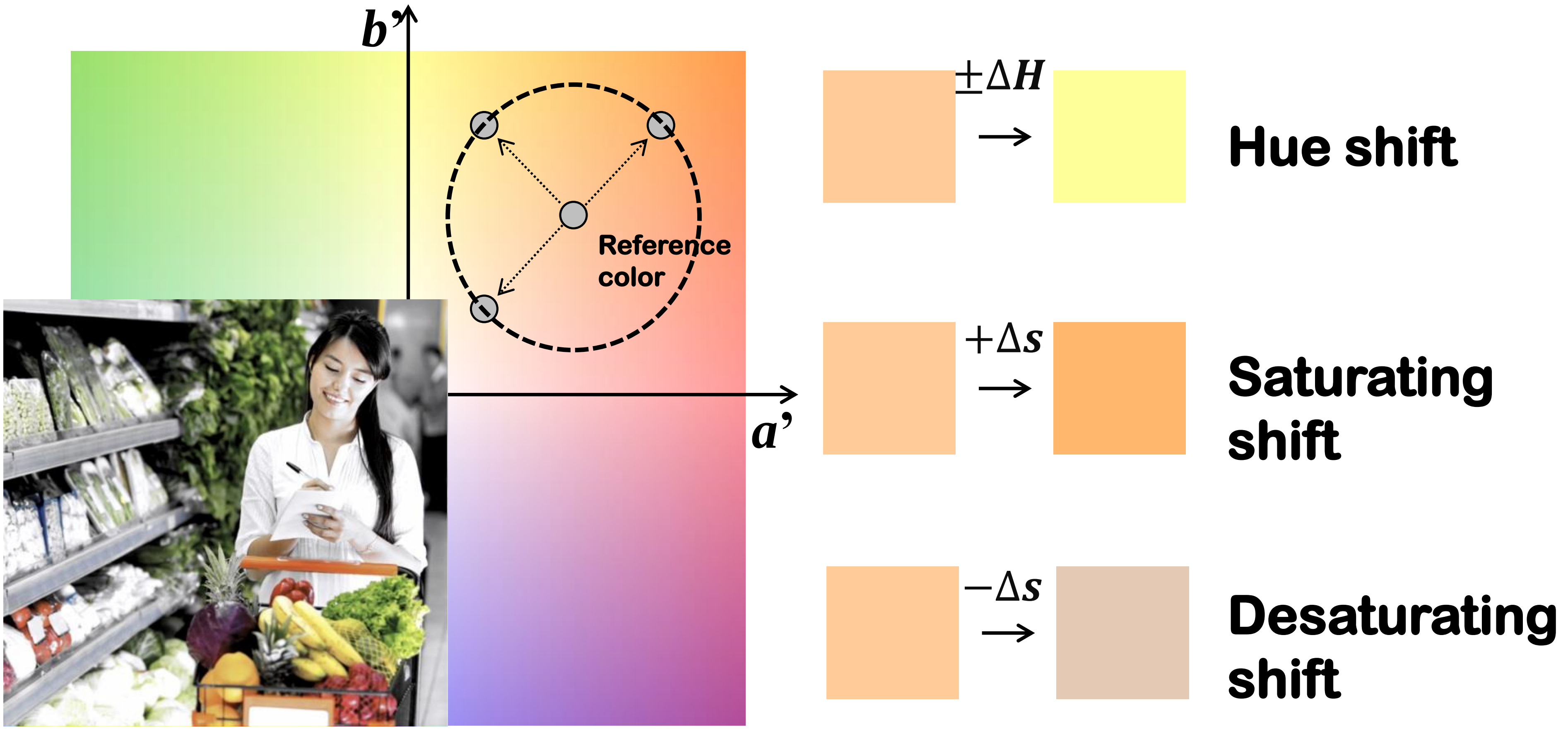
Colour rendition



How do we measure color rendition?



A light source can induce different types of color distortions



$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta H)^2 + (\Delta s)^2}$$

Color rendering (fidelity), CIE Ra

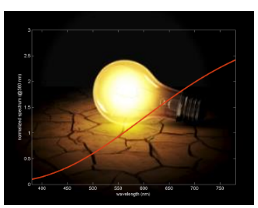
Color rendering: "*Effect of an illuminant on the color appearance of objects by conscious or subconscious comparison with their color appearance under a reference illuminant*"

Ra

(CIE13.3 1995)

Test lamp

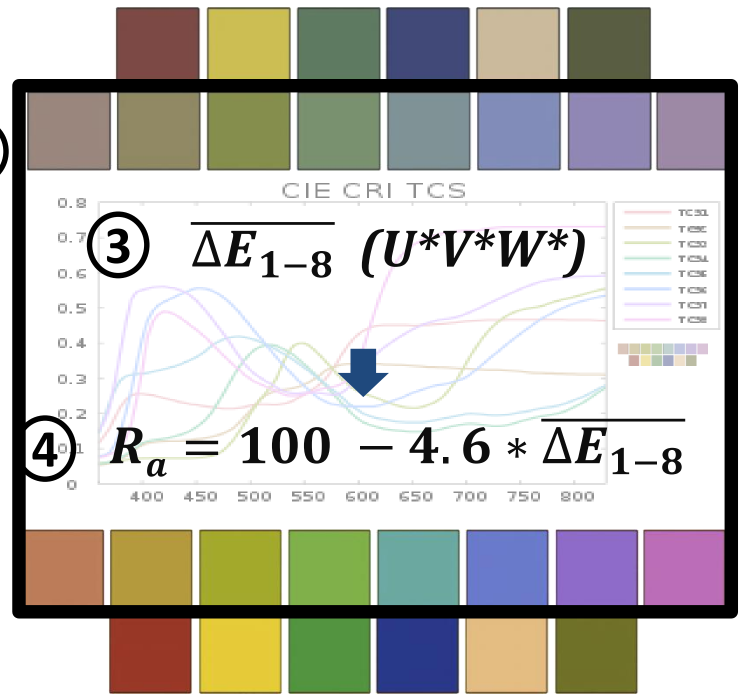
① ***same CCT reference illuminant***



Planckian
CCT < 5000 K

Daylight
CCT ≥ 5000 K

②



CIE Ra >> IES Rf >> CIE Rf

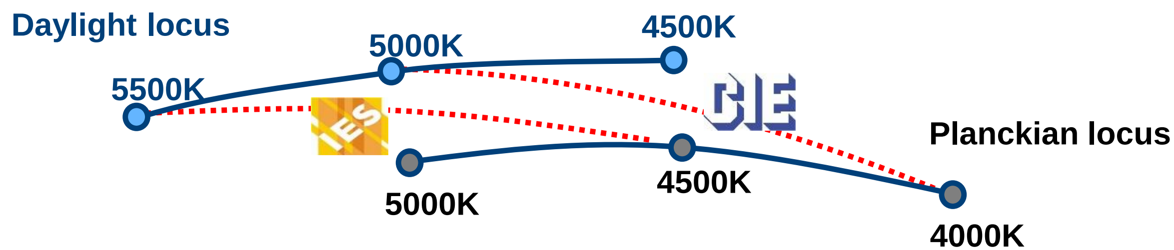
①

same CCT reference illuminant

Planckian
CCT < 5000 K

Daylight
CCT ≥ 5000 K

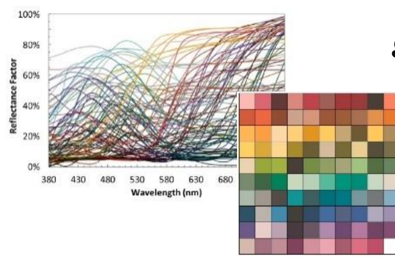
same CCT reference illuminant



Important updates: sample set & color space

②

8 spectrally non-uniform Munsell samples



99 spectrally uniform samples

*

* Some CIE spectral are slightly different from IES samples due to extrapolation differences beyond 400 nm and 700 nm

③

$\overline{\Delta E_{1-8}}$ *(U*V*W*)*

$\overline{\Delta E_{1-99}}$ *(CAM02-UCS)*

④

$$R_a = 100 - 4.6 * \overline{\Delta E_{1-8}}$$

$$R_a = 10 * log(exp((100 - c * \overline{\Delta E_{1-99}})/10) + 1)$$

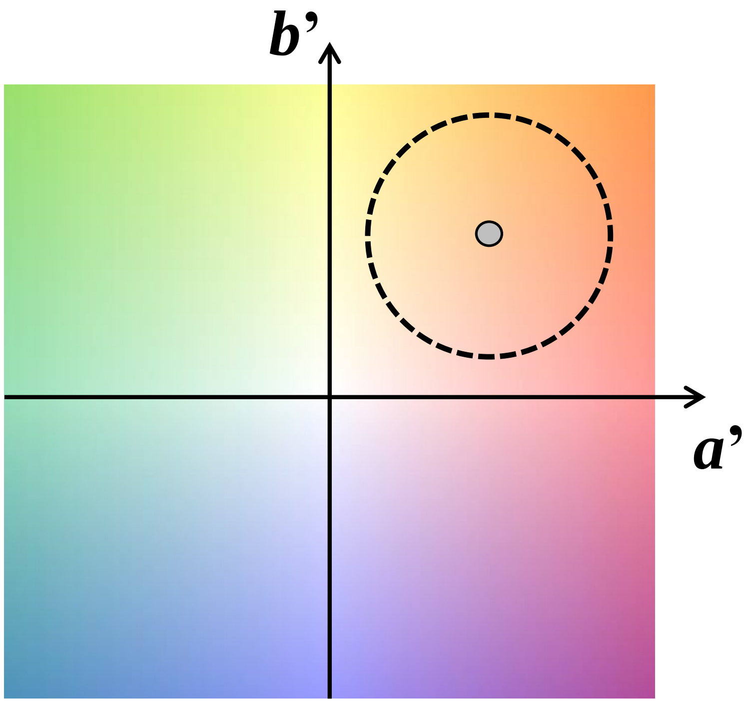
c_{IES} = 7.54

c_{CIE} = 6.73

Color rendering (fidelity)

What CRI conveys:

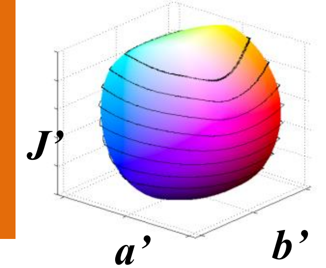
- (average) magnitude of color fidelity / color shift



What CRI does NOT convey:

- Direction/type of color shifts
- Difference in color for any specific object
- How one source will make things look compared to another
- Information on color discrimination, preference, naturalness, …

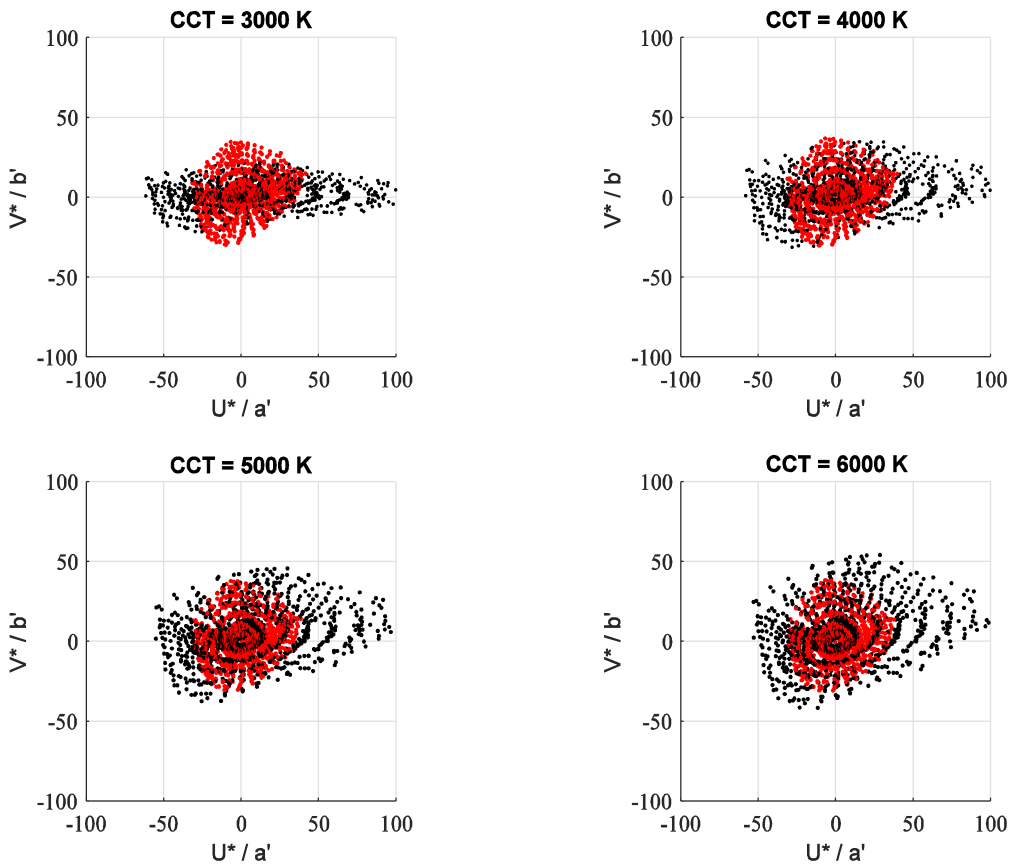
Color space improvement



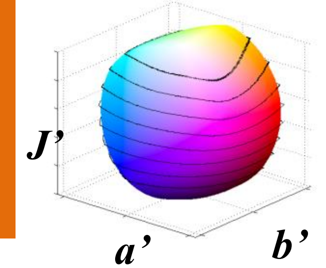
Replacement of outdated ***U*V*W**** with state-of-the-art **CAM02-UCS**:

- good (better) chromatic adaptation formula (CAT02)
- good (better) colour difference formula

- good perceptual uniformity
- no CCT dependence

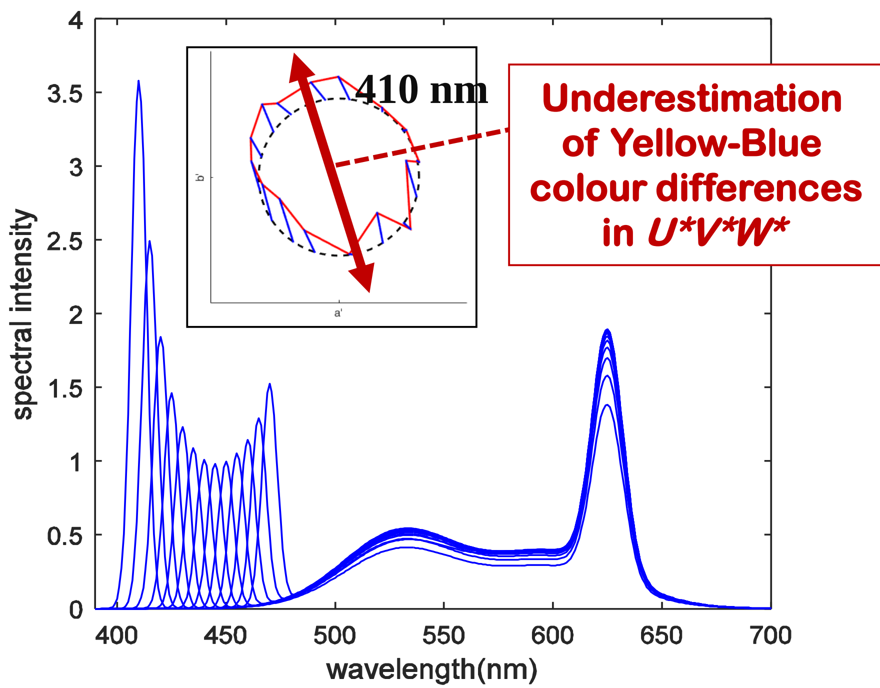


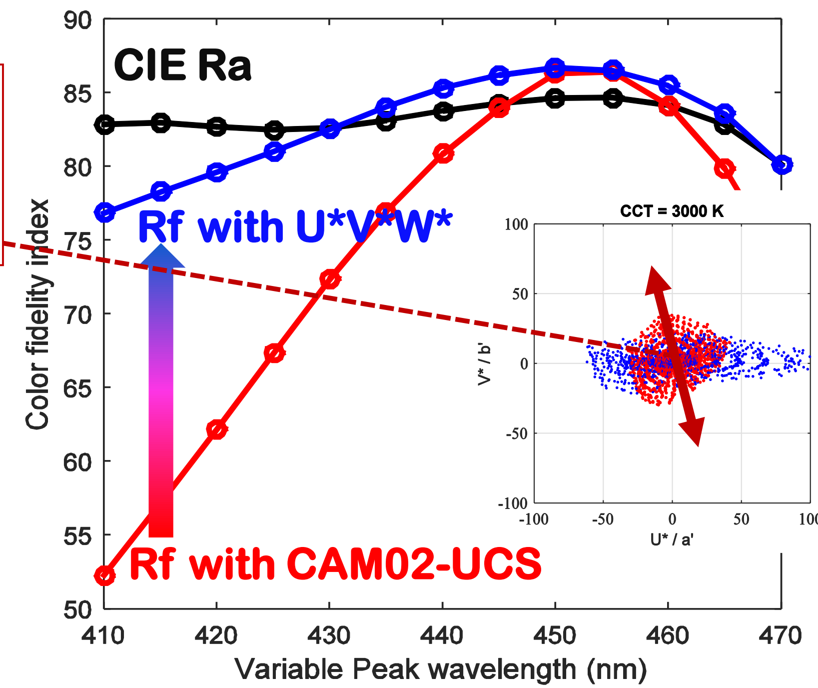
Color space improvement



Short wavelength sensitivity simulations:

- ❑ Warm-white phosphor LED (3000 K)
- ❑ Blue pump LED shifted from 410 nm to 480 nm



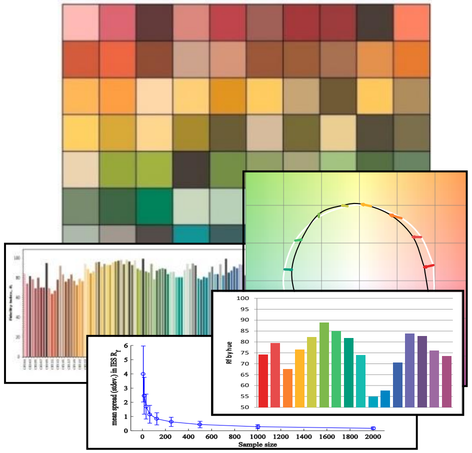


IMPORTANT impact of <u>colour space</u> on fidelity scores:

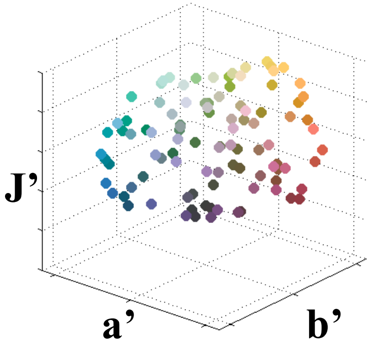
Drop is for the largest part a result of the update to the perceptually uniform CAM02-UCS space

Sample set improvement

Replacement of the CIE CRI Munsell test color samples (TCS) with *special* Color Evaluation Samples (CES):

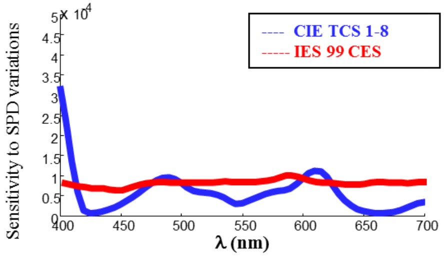


- ➢ **Larger sample size (8 → 99)**
  - ❑ More information
  - ❑ Better statistical accuracy



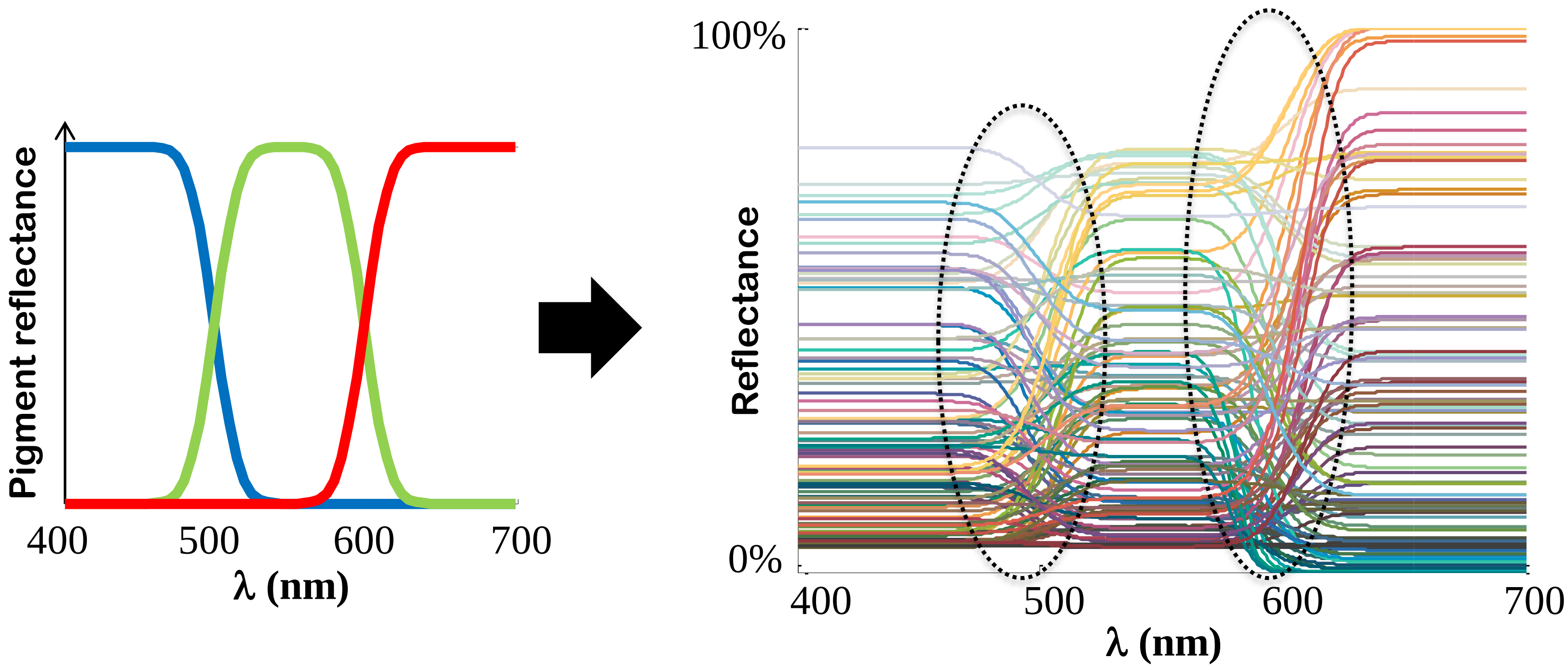
- ➢ **Uniformly distributed (3D) in color space**

- ➢ **Spectral or wavelength uniformity**
  - ❑ No wavelength bias
  - ❑ No selective spectral optimization



Sample set improvement

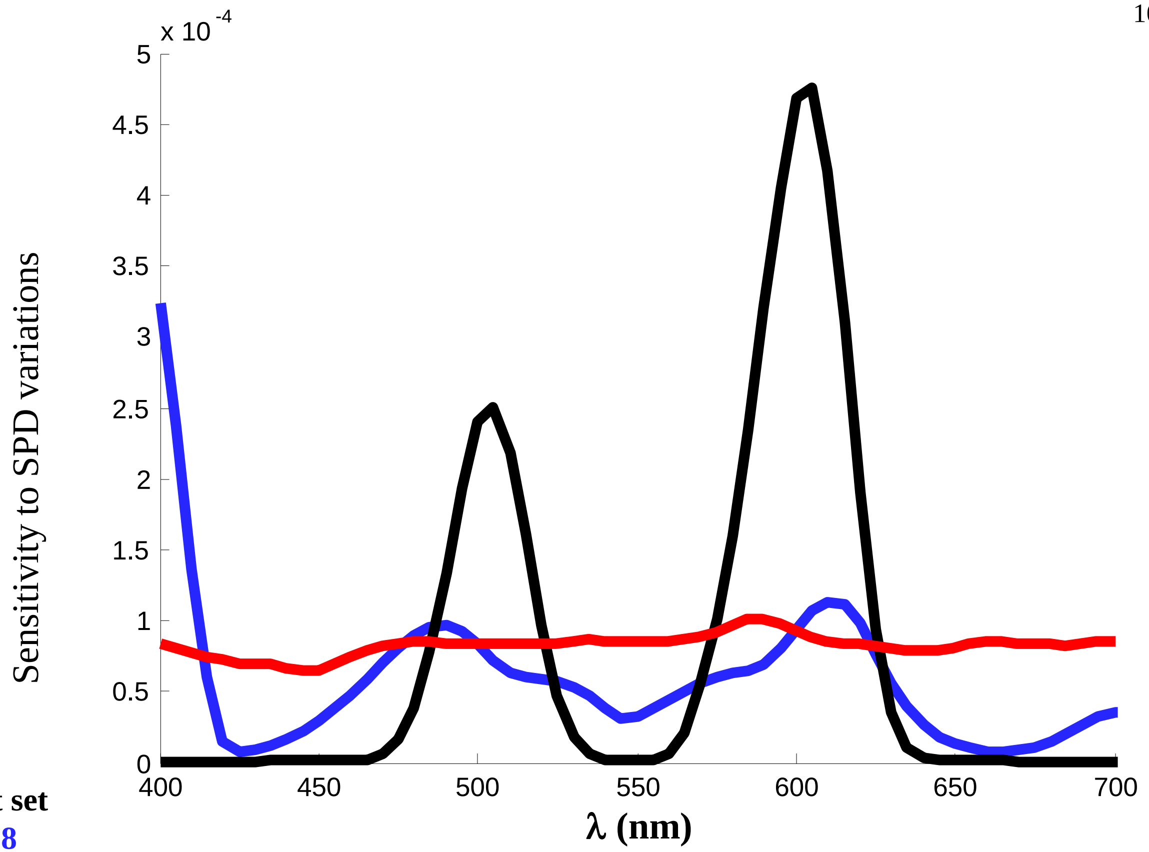
- **Wavelength uniformity**
  - ❑ We need to make sure that the sample set treats all wavelengths equally.
  - ❑ Why? It is possible to generate many colors with only 3 "pigments"!

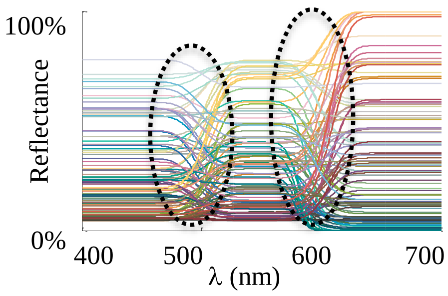


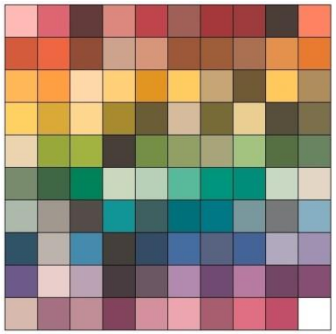
But the corresponding samples are mostly sensitive to a few wavelengths

Sample set improvement

- **Wavelength uniformity**
  - We can compute the "wavelength sensitivity" for a sample set (r'^2, r''^2...)



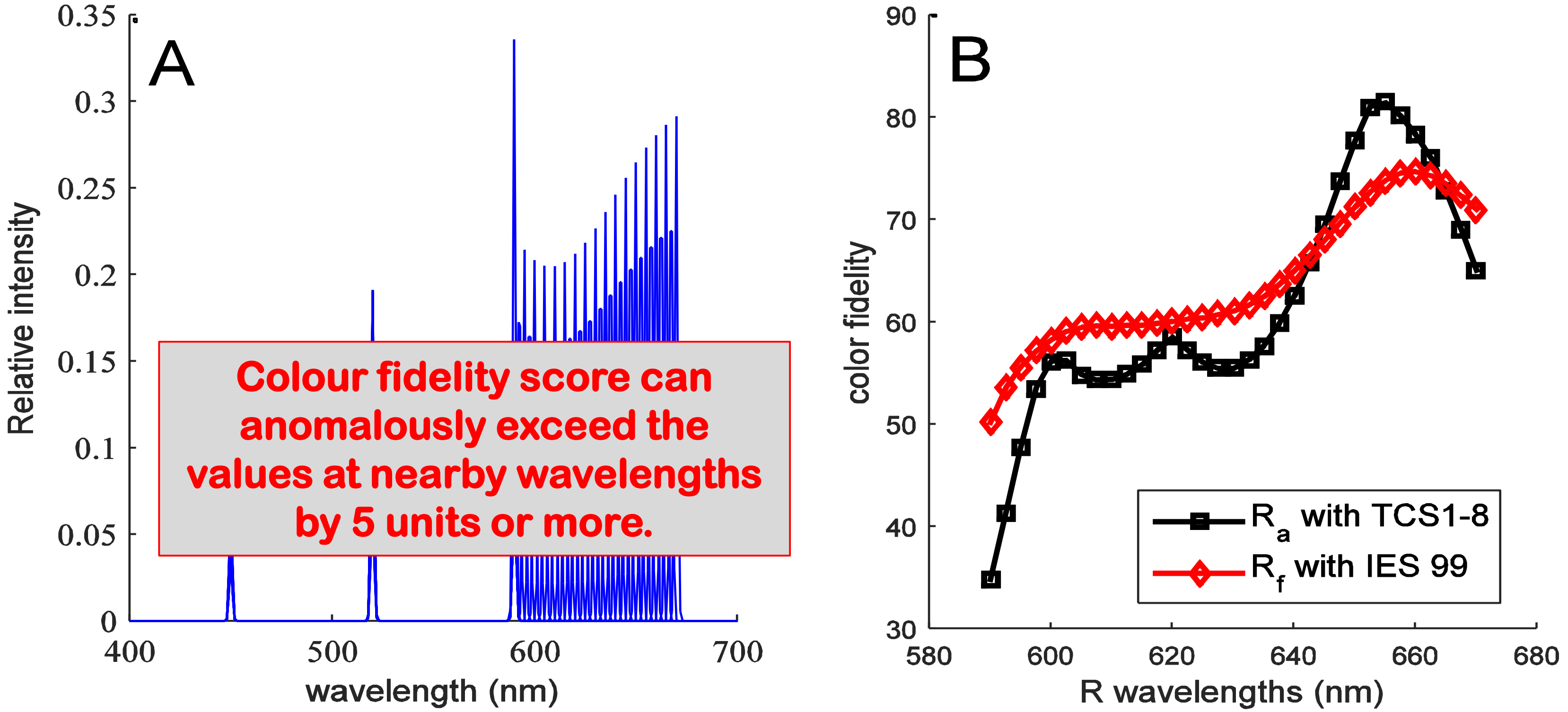




Black = 3-pigment set
Blue= CIE TCS 1-8
Red = IES 99 CES

Sample set improvement

- **Wavelength uniformity**
  - Example of selective spectral optimization of light source SPDs:
    - RGBA laser line source (3000 K)
    - Red peak wavelength shifts from 590 nm to 670 nm



Color rendering example

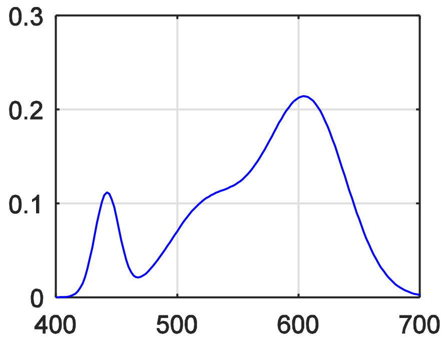
Comparison between an existing LED source and a possible narrowband source, having the same Ra but different Rf

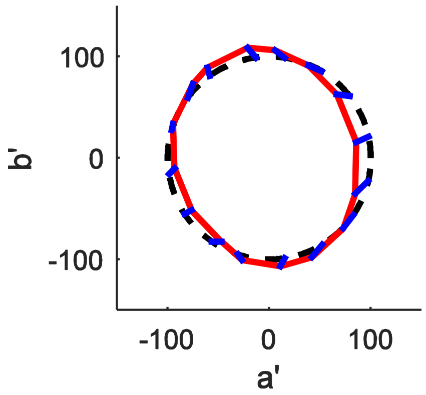
light source 1

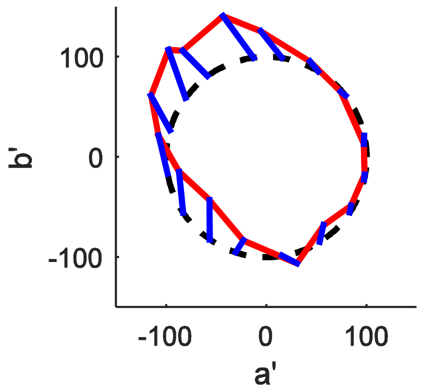
Ra = 81, Rf = 80

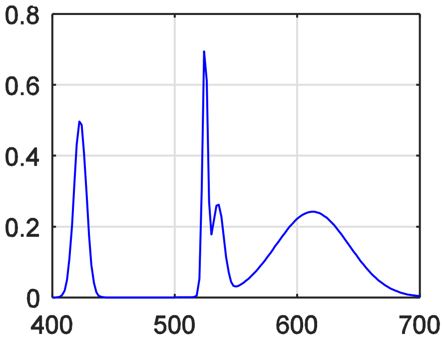
light source 2

Ra = 80, Rf = 49









Hyperspectral images rendered with IES 4900 Refset under 3000 K

Ra = 100, Rf = 100

Ra = 100, Rf = 100

Hyperspectral images rendered with IES 4900 Refset under 3000 K

Ra = 81, Rf = 80

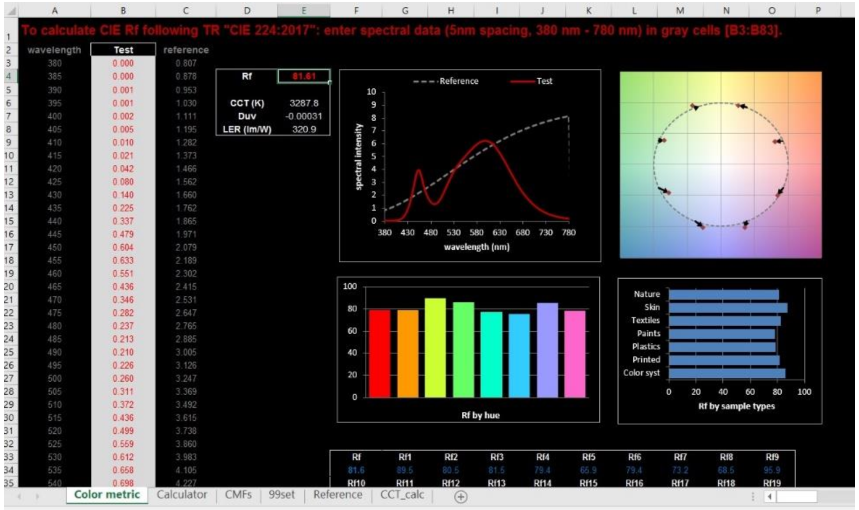
Ra = 80, Rf = 49

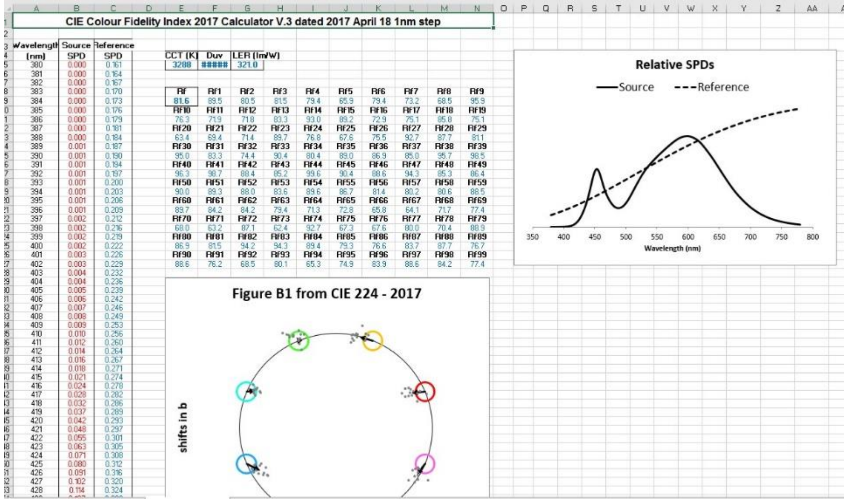
CIE Rf calculators

(Unofficial) Matlab and Excel calculators can be downloaded from: www.github.com/ksmet1977/CRI_CIE_Rf_2017/

A calculator for Python is also part of the *luxpy package* (install using pip: "pip install luxpy")

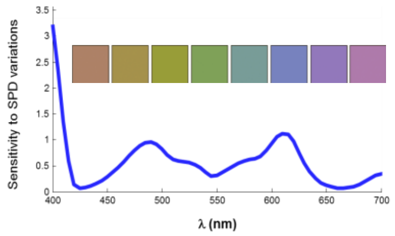
The official Excel calculators for 5nm and 1nm spectral data can be downloaded from CIE upon purchase of the CIE224:2017 technical report (http://www.cie.co.at/index.php?i_ca_id=1027)

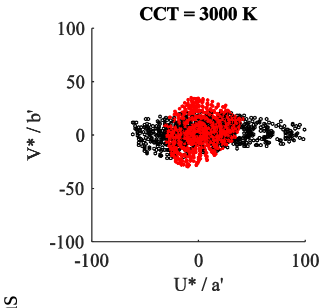


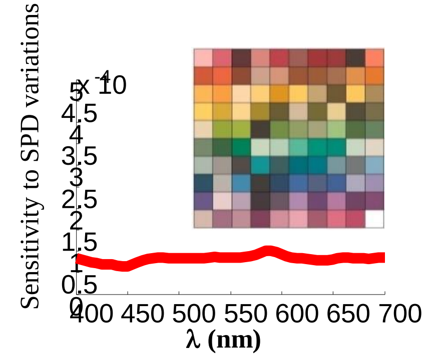


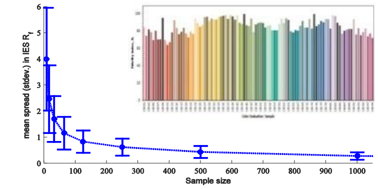
Summary

- **The CIE R_a** has **imperfect samples** and **outdated color science** leading to **inaccurate assessment** of color fidelity.
- The **new CIE R_f** fixes this by:
  - Improving the color space to the uniform and CCT independent CAM02-UCS
  - Improving the color samples:
    - **Spectral uniformity** eliminates wavelength bias ensuring selective spectral optimization becomes much harder.
    - **Larger, more varied sample set** provides more info and better statistical accuracy









Questions & comments ?

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<u>More info:</u>

- CIE. (2017). CIE224:2017, CIE 2017 Colour Fidelity Index for accurate scientific use. CIE, Vienna, Austria. ISBN 978-3-902842-61-9. (http://www.cie.co.at/index.php?i_ca_id=1027)

- Smet, Kevin A.G., David, Aurelien, & Whitehead, Lorne. (2016). On the importance of color space uniformity and sample set spectral uniformity for color fidelity measures, CIE2016 Proceedings, Melbourne, March, 3-5, 2016, OP22.

- Smet, Kevin A.G., David, Aurelien, & Whitehead, Lorne. (2016). Why color space uniformity and sample set spectral uniformity are essential for color rendering measures, 12(1-2), 39-50. *doi: 10.1080/15502724.2015.1091356*

- David, Aurelien, Fini, Paul T., Houser, Kevin W., Ohno, Yoshi, Royer, Michael P., Smet, Kevin A. G., . . . Whitehead, Lorne. (2015). Development of the IES method for evaluating the color rendition of light sources. *Optics Express, 23*(12), 15888-15906. *doi: 10.1364/OE.23.015888*

- IES. (2015). IES-TM-30-15: Method for Evaluating Light Source Color Rendition (pp. 26). New York, NY: The Illuminating Engineering Society of North America.