CIE Div.1/ICC/ISO Workshop on Colorimetry, Graphic Arts and Colour Management
4 July 2013, University of Leeds, UK

Status quo of CIE work on colour rendering indices

Hirohisa Yaguchi
Chiba University, Japan
Chair of the CIE TC1-90 "Colour Fidelity Index"

Importance of color rendering of light sources in imaging industries

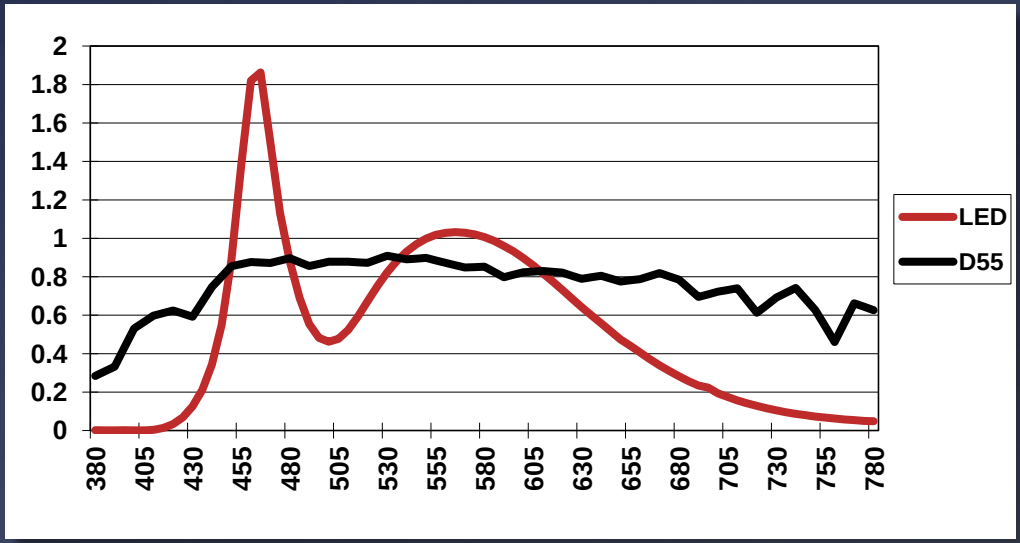
* Light sources for viewing surface colours are evaluated by a Color Rendering Index (CRI). ISO TC 130 references CRI calculations in its standards for measurement and viewing, but newer types of illumination now being used, especially LEDs, have created the need to re-define the CRI calculation.

ISO3664 Viewing Conditions

ISO viewing condition	Reference illuminant and chromaticity tolerance	Illuminance / luminance	Colour rendering index (according to CIE 13.3)	Metamerism index (according to ISO 23603)	Illumination uniformity (min:max)	Surround luminous reflectance/ luminance/ illuminance
Critical comparison Prints (P1)	CIE Illuminant D50 (0,005)	2 000 lx ± 500 lx (should be ± 250 lx)	General index: □ 90 Special indices for samples 1 to 8: □ 80	Visual: C or better (should be B or better) UV: < 1,5 (should be < 1)	For surfaces up to 1m x 1m □0.75 For surfaces greater than 1m x 1m □ 0.6	< 60 % (neutral and matt)
Transparencies Direct viewing (T1)	CIE Illuminant D50 (0,005)	1 270 cd/m2 ± 320 cd/m^2 (should be ± 160 cd/ m^2)	General index: □ 90 Special indices for samples 1 to 8: □ 80	Visual: C or better (should be B or better)	□0,75	5 % - 10 % of the luminance level (neutral and extending at least 50mm on all sides)
Practical appraisal of prints (P2)	CIE Illuminant D50 (0,005)	500 lx ± 125 lx	General index: □ 90 Special indices for samples 1 to 8: □ 80	Visual: C or better (should be B or better) UV: < 1,5 (should be < 1)	□0,75	< 60 % (neutral and matt)
Transparencies Projection viewing (T2)	CIE Illuminant D50 (0,005)	1 270 cd/ m^2 ± 320 cd/ m^2	General index: □ 90 Special indices for samples 1 to 8: □ 80	Visual: C or better (should be B or better)	□0,75	5 % - 10 % of the luminance level (neutral and extending at least 50 mm on all sides)

An example of CRI of a white LED

Spectral irradiances of a white LED and the reference daylight illuminant D55



Special color rendering indices

No.1	No.2	No.3	No.4
80	94	92	70
No.5	No.6	No.7	No.8
78	85	82	65
No.9	No.10	No.11	No.12
13	80	65	56
No.13	No.14	No.15	R_a
85	96	78	81

Average CRI

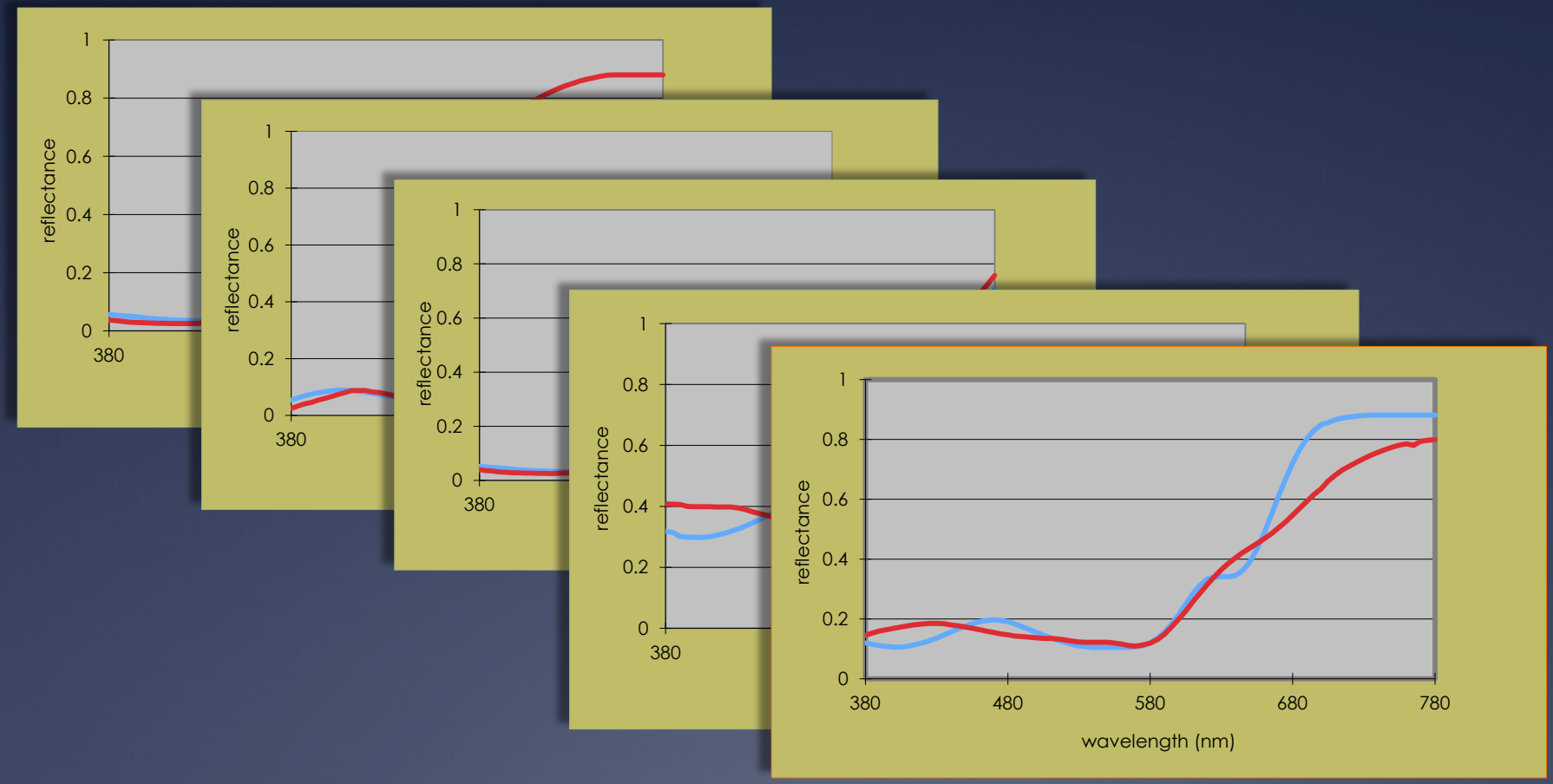
ISO3664 Viewing Conditions

ISO viewing condition	Reference illuminant and chromaticity tolerance	Illuminance / luminance	Colour rendering index (according to CIE 13.3)	Metamerism index (according to ISO 23603)	Illumination uniformity (min:max)	Surround luminous reflectance/ luminance/ illuminance
Critical comparison Prints (P1)	CIE Illuminant D50 (0,005)	2 000 lx ± 500 lx (should be ± 250 lx)	General index: □ 90 Special indices for samples 1 to 8: □ 80	Visual: C or better (should be B or better) UV: < 1,5 (should be < 1)	For surfaces up to 1m x 1m □0.75 For surfaces greater than 1m x 1m □ 0.6	< 60 % (neutral and matt)
Transparencies Direct viewing (T1)	CIE Illuminant D50 (0,005)	1 270 cd/m2 ± 320 cd/m^2 (should be ± 160 cd/ m^2)	General index: □ 90 Special indices for samples 1 to 8: □ 80	Visual: C or better (should be B or better)	□0,75	5 % - 10 % of the luminance level (neutral and extending at least 50mm on all sides)
Practical appraisal of prints (P2)	CIE Illuminant D50 (0,005)	500 lx ± 125 lx	General index: □ 90 Special indices for samples 1 to 8: □ 80	Visual: C or better (should be B or better) UV: < 1,5 (should be < 1)	□0,75	< 60 % (neutral and matt)
Transparencies Projection viewing (T2)	CIE Illuminant D50 (0,005)	1 270 cd/ m^2 ± 320 cd/ m^2	General index: □ 90 Special indices for samples 1 to 8: □ 80	Visual: C or better (should be B or better)	□0,75	5 % - 10 % of the luminance level (neutral and extending at least 50 mm on all sides)

Metamerism Index

- To evaluate how the spectral power distribution of daylight simulators coincide with the reference daylights.
- Prepare 5 pairs of metamer for the reference illuminant, then calculate the color difference between a pair of metamer.
- ISO/CIE specifies 5 pairs of metamer for each of D50, D55, and D65, D75. (ISO 23603:2005, *Standard method of assessing the spectral quality of daylight simulators for visual appraisal and measurement of colour*)

5 pairs of metamer(D55)



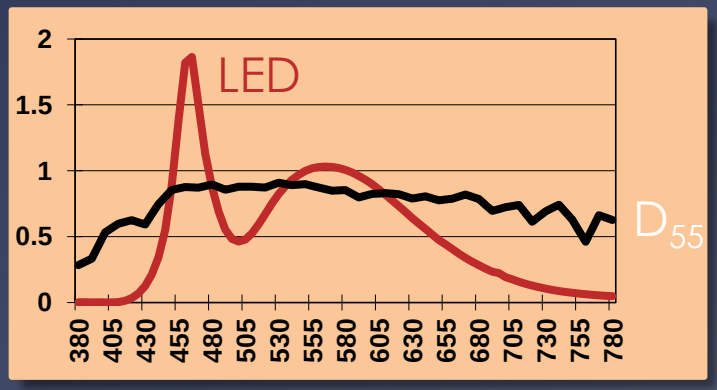
Metamism index

$$MI_{\text{vis}} = \frac{\sum_{i=1}^{5} \Delta E_i}{5}$$

An example of metamism indices

$$MI_{vis} = \frac{\sum_{i=1}^{5} \Delta E_i}{5}$$

No.	1	2	3	4	5	MI_{vis}
ΔEi	2.43	1.92	2.64	4.65	4.64	3.26



MI_{vis}	class
<0.25	A
0.25~0.5	B
0.5~1.0	C
1.0~2.0	D
>2.0	E

Purposes of color rendering

- Color fidelity, color difference
  - Color reproduction in imaging (ISO3664)
  - CIE color rendering index, Ra
  - Metamrism index
- Preference, harmony, memory
  - Showcase lighting, cosmetics, skin color
  - Conspicuity, contrast, colorfulness, memory color
- Color discrimination
  - Visual inspection, color vision test
  - Detection threshold, categorical color, color name

CRI-CAM02UCS
nCRI(CRI2012)

CQS

FCI

GAI

MCRI

CCRI

How does CIE manage with color rendering for white light sources?

TC1-90

- Color fidelity, color difference
  - Color reproduction in imaging (ISO3664)
  - CIE color rendering index, Ra
  - Metamrism index

CRI-CAM02UCS
nCRI(CRI2012)

TC1-91

- Preference, harmony, memory

CQS

  - Showcase lighting, cosmetics, skin color
  - Conspicuity, contrast, colorfulness, memory color
- Color discrimination

FCI

MCRI

  - Visual inspection, color vision test
  - Detection threshold, categorical color, color name

GAI

CCRI

Terms of Reference of new TCs

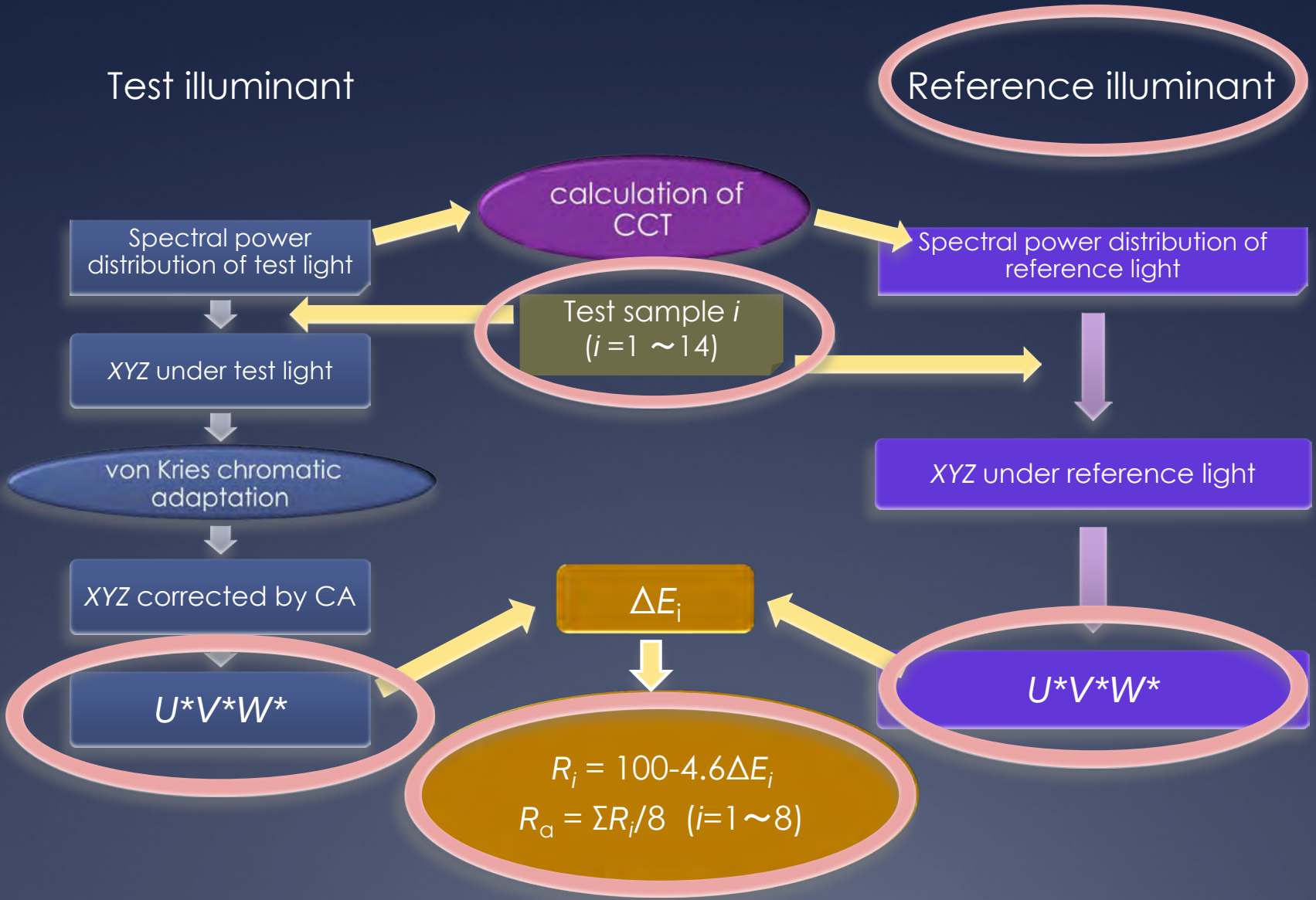
TC1-90: Colour Fidelity Index

* To evaluate available indices based on colour fidelity for assessing the colour quality of white- light sources with a goal of recommending a single colour fidelity index for industrial use.

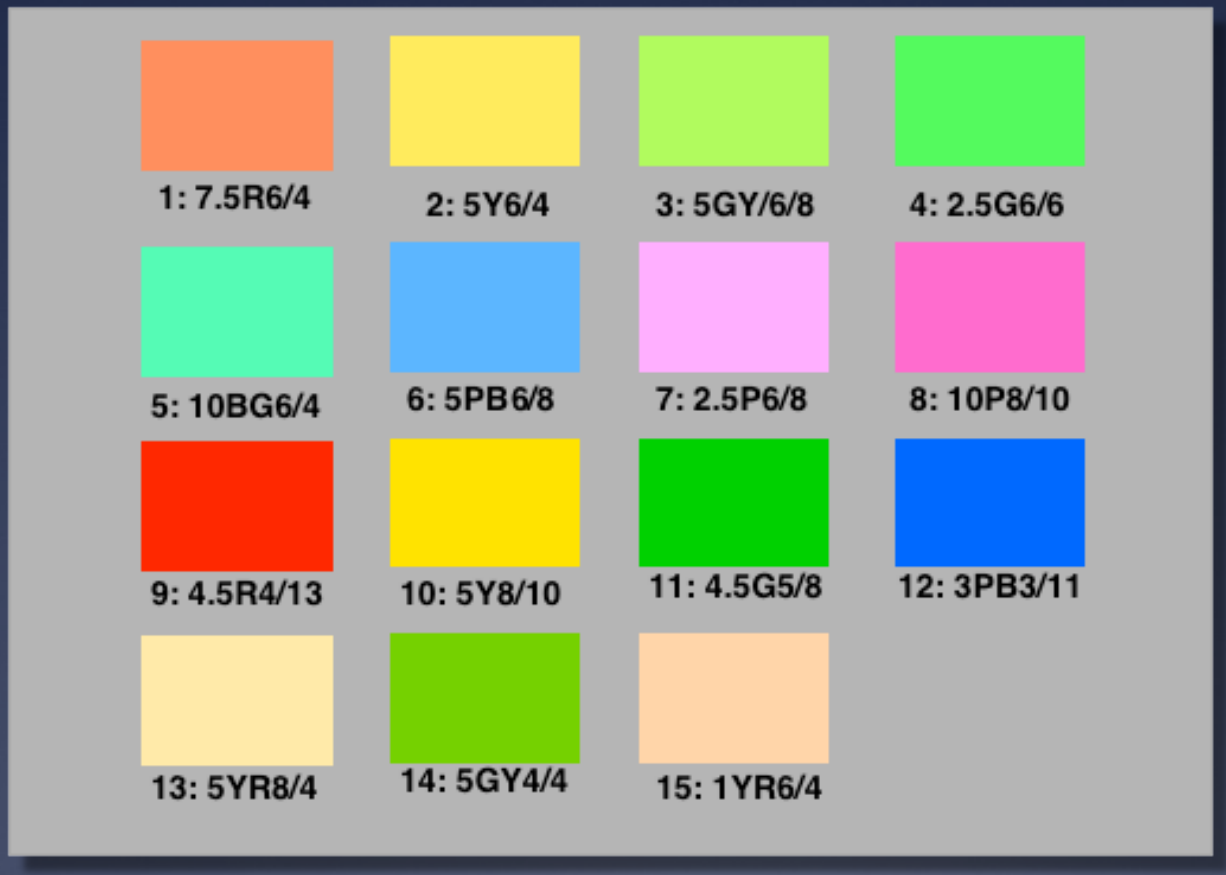
TC1-91: New Methods for Evaluating the Colour Quality of White-Light Sources

* To evaluate available new methods for evaluating the colour quality of white-light sources with a goal of recommending methods for industrial use. (Methods based on colour fidelity shall not be included: see TC1-90)

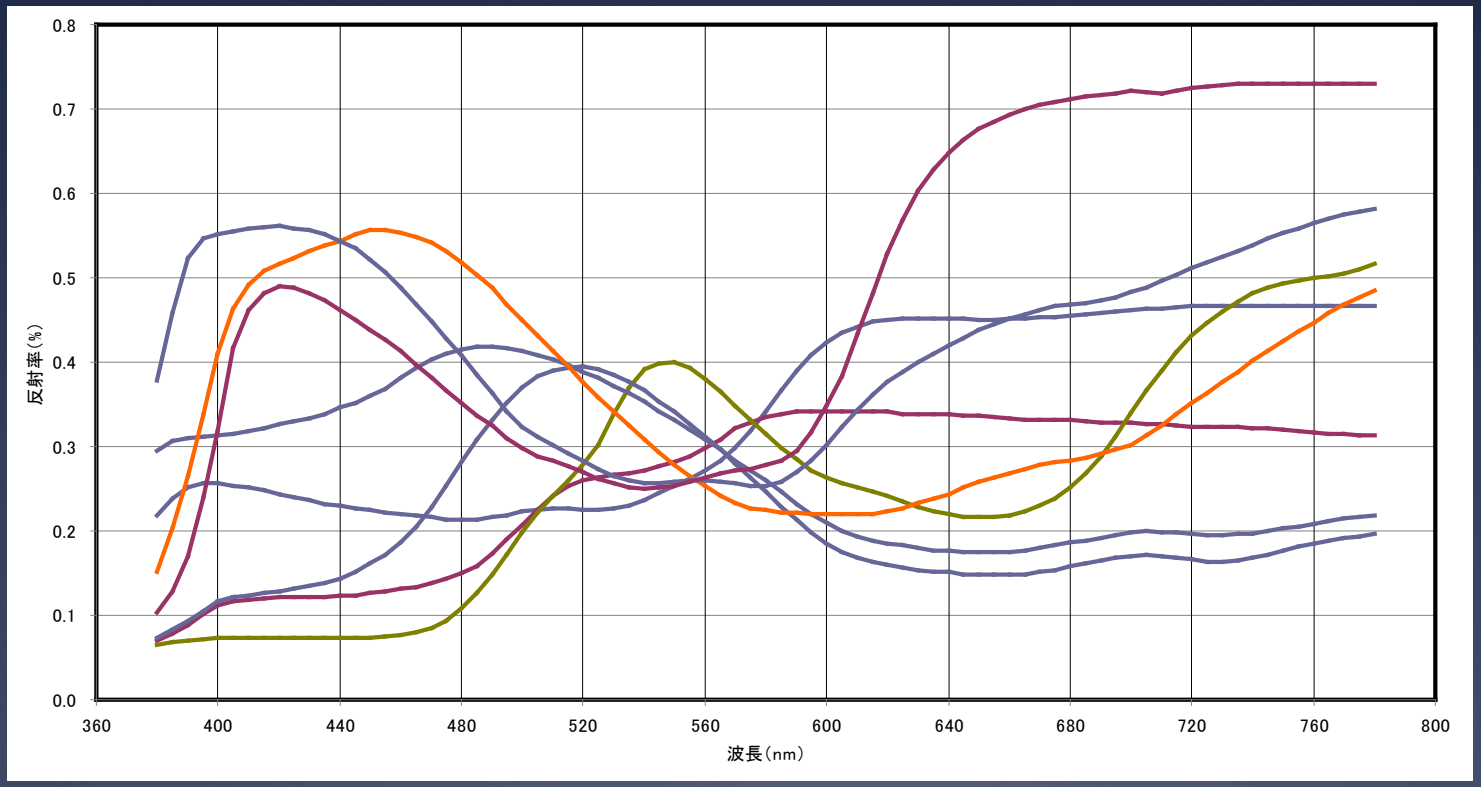
Calculation scheme of CIE CRI



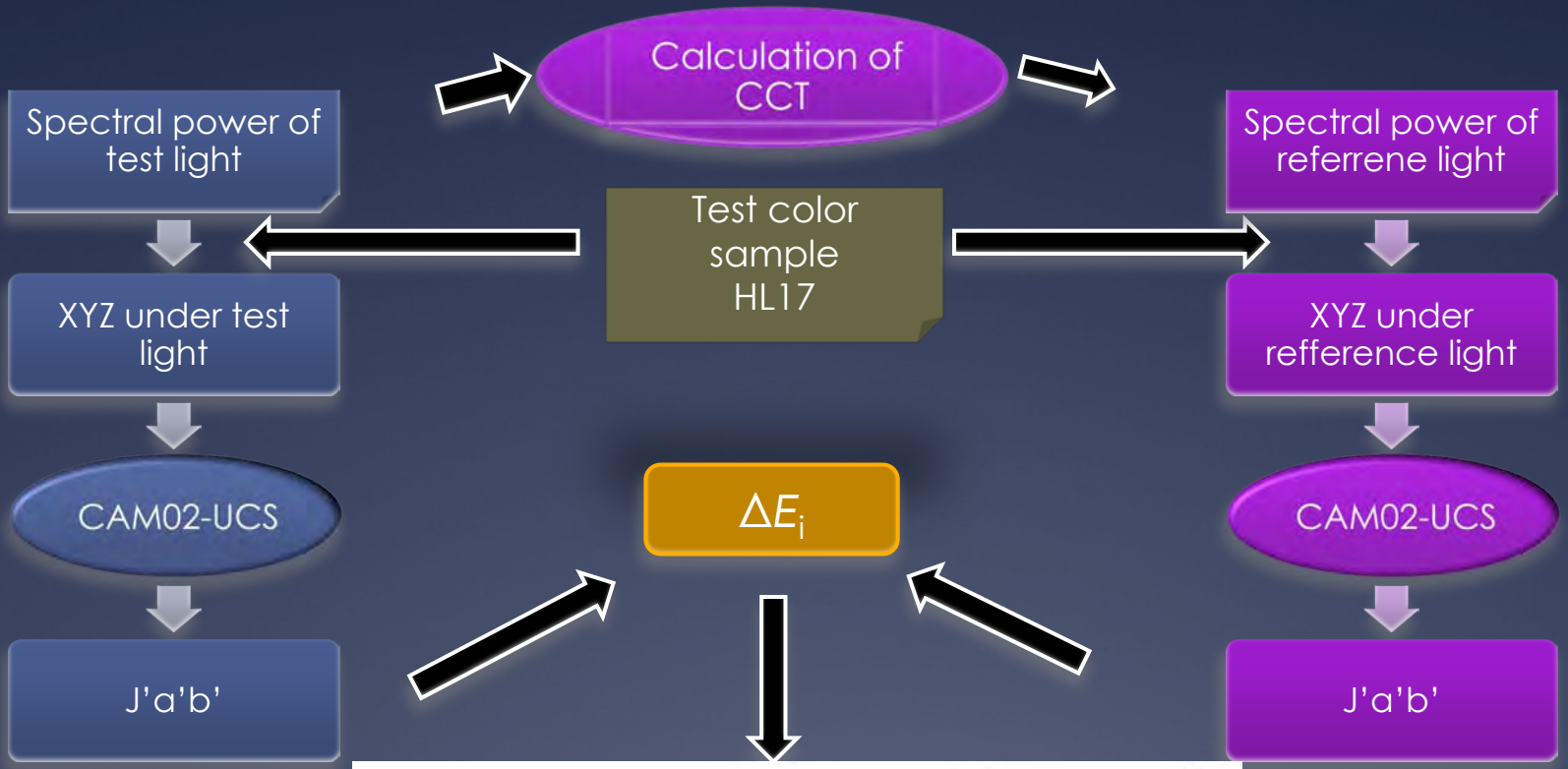
CIE-CRI test color samples



CIE Ra test color samples



Calculation scheme of nCRI



$$R_{a,2012} = 100 \cdot \left(\frac{2}{e^{k \cdot |\Delta E_{rms}|^{1.5}} + 1} \right)^2$$

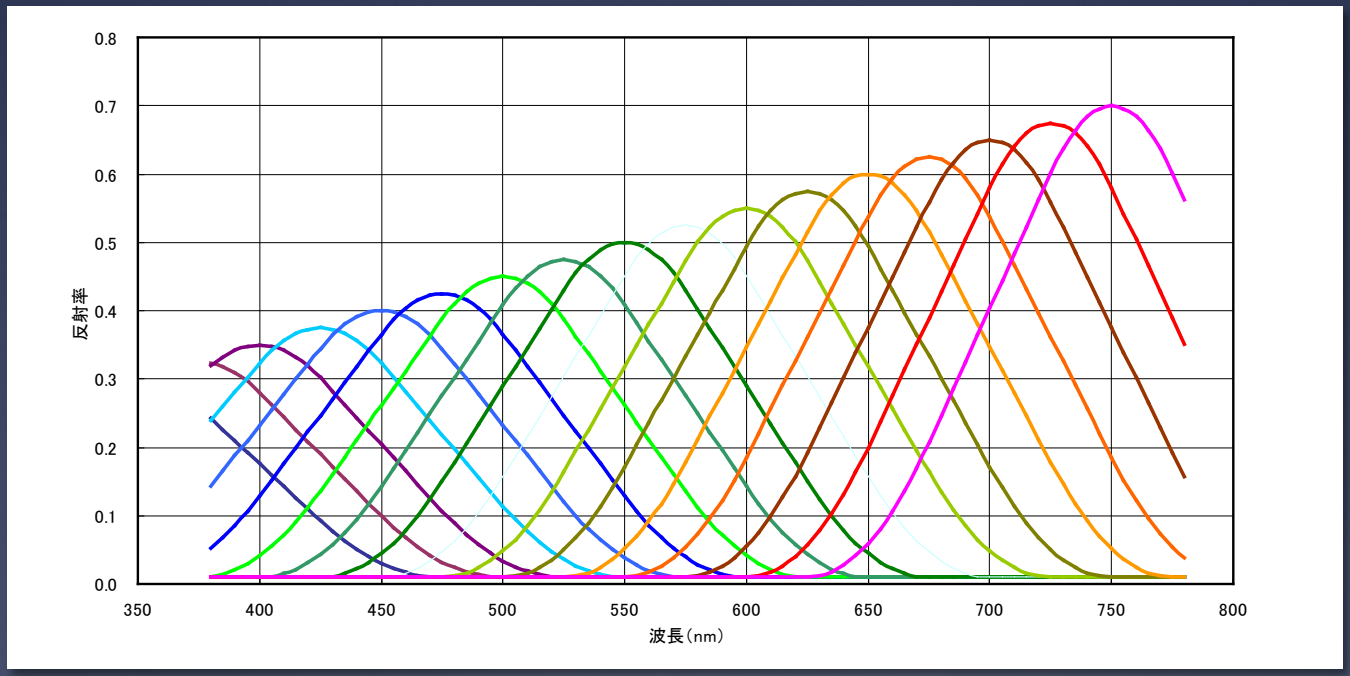
HL17 Sample Set

If $|\lambda - \lambda_{ci}| \geq 125\ nm$: $R(\lambda) = 0.015$

If $125\ nm > |\lambda - \lambda_{ci}| \geq 75\ nm$: $R(\lambda) = 0.015 + (R_{max,i} - 0.015) \cdot \left[\frac{1}{8750\ nm^2}\right] \cdot (125\ nm - |\lambda - \lambda_{ci}|)^2$

If $75\ nm > |\lambda - \lambda_{ci}| \geq 25\ nm$: $R(\lambda) = 0.015 + (R_{max,i} - 0.015) \cdot \left[\frac{8}{7} - \frac{2}{175\ nm} \cdot |\lambda - \lambda_{ci}|\right]$

If $25\ nm > |\lambda - \lambda_{ci}|$: $R(\lambda) = 0.015 + (R_{max,i} - 0.015) \cdot \left[1 - \frac{2}{4375\ nm^2} \cdot |\lambda - \lambda_{ci}|^2\right]$



CIECAM02-UCS

- M. R. Luo, G. Cui, and C. Li: Uniform Colour Spaces Based on CIECAM02 Colour Appearance Model, *Color Res. Appl.* 31, 320-330 (2006)
- Compression of lightness and colorfulness

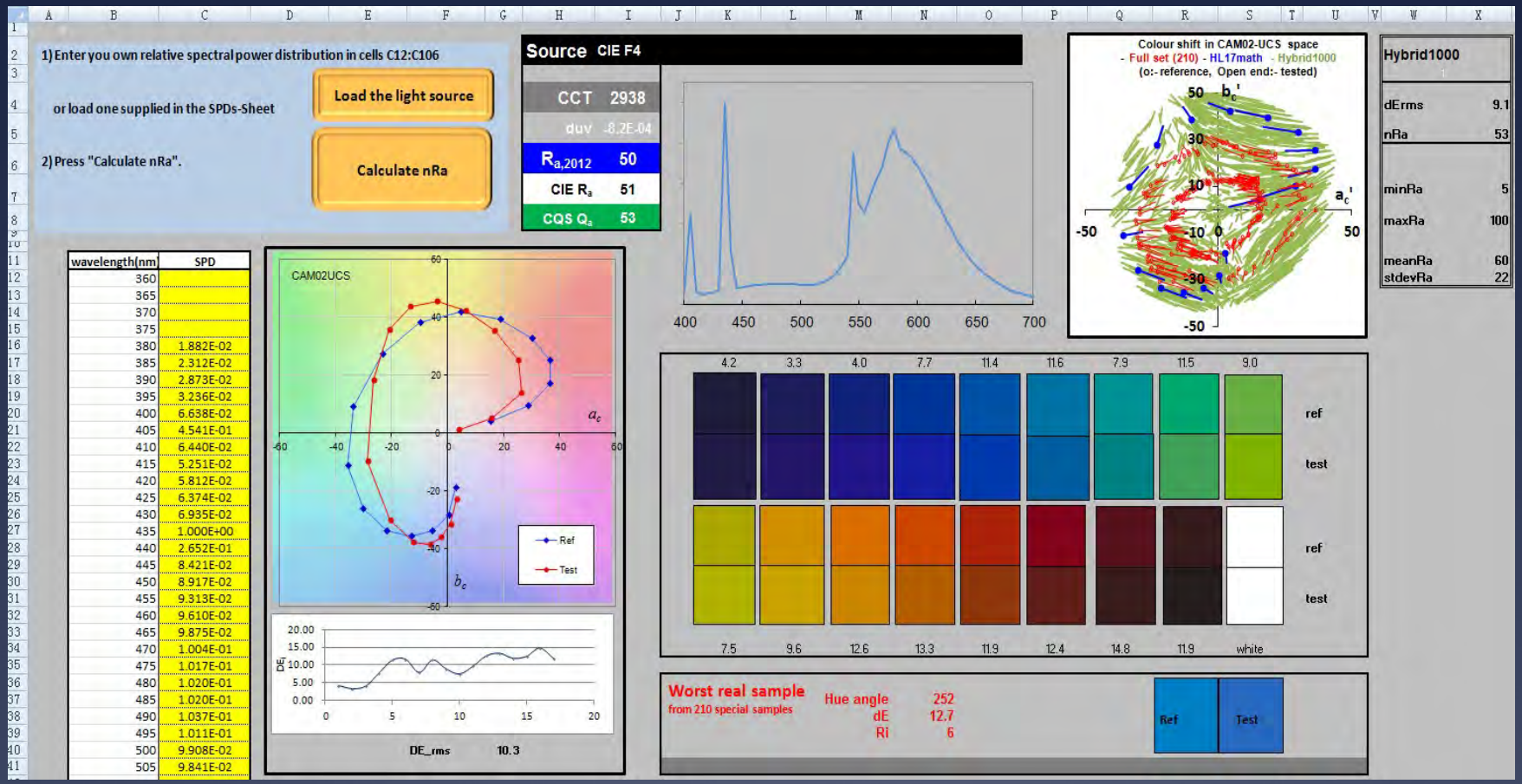
$$\Delta E' = \sqrt{\left(\Delta J'/K_L\right)^2 + \Delta a'^2 + \Delta b'^2}$$

$$J' = \frac{\left(1+100c_1\right)J}{1+c_1 J}$$

$$M' = \left(1/c_2\right)\ln\left(1+c_2 M\right)$$

$$a' = M'\cos(h), \quad b' = M'\sin(h)$$

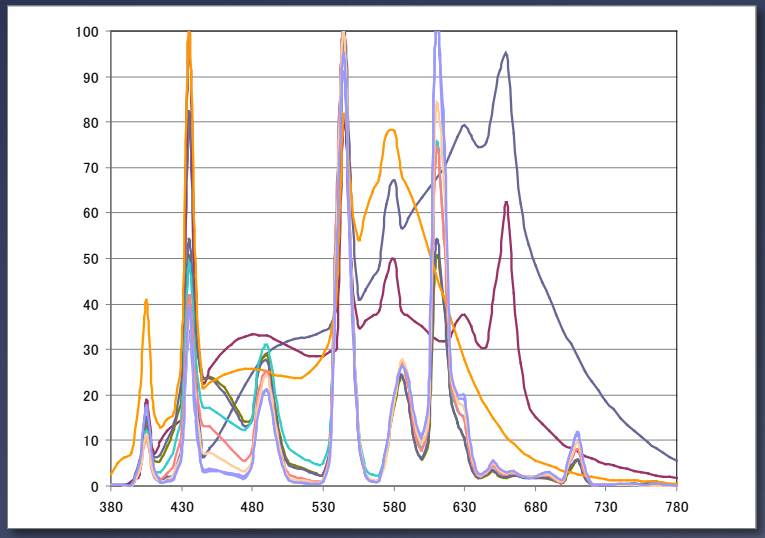
Practical examples



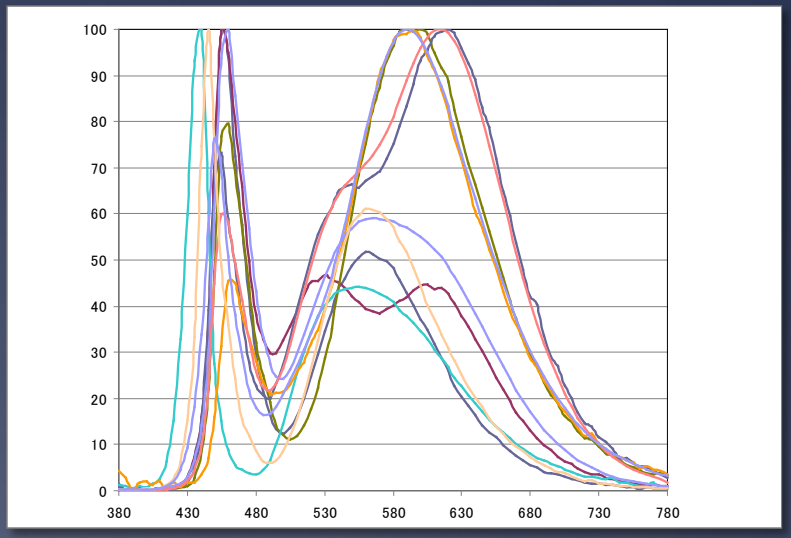
R. Luo, CIE TC1-90 Meeting, April 17, 2013

SPD (Spectral power distribution)

FL

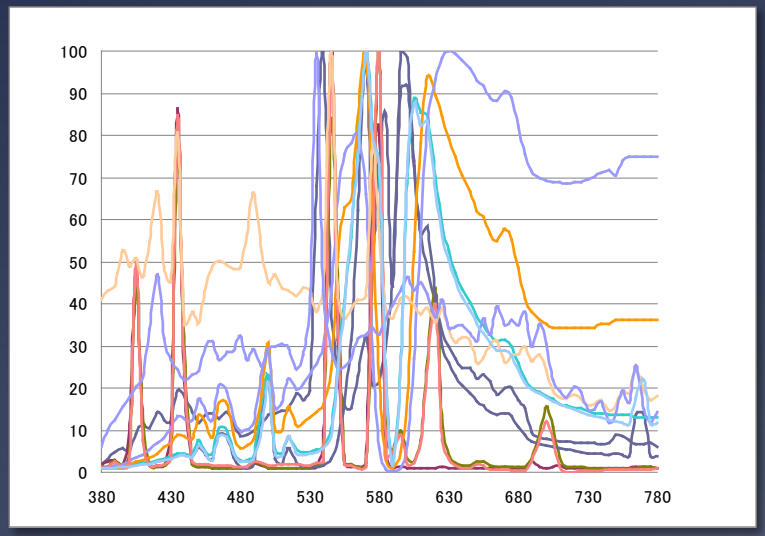


LED

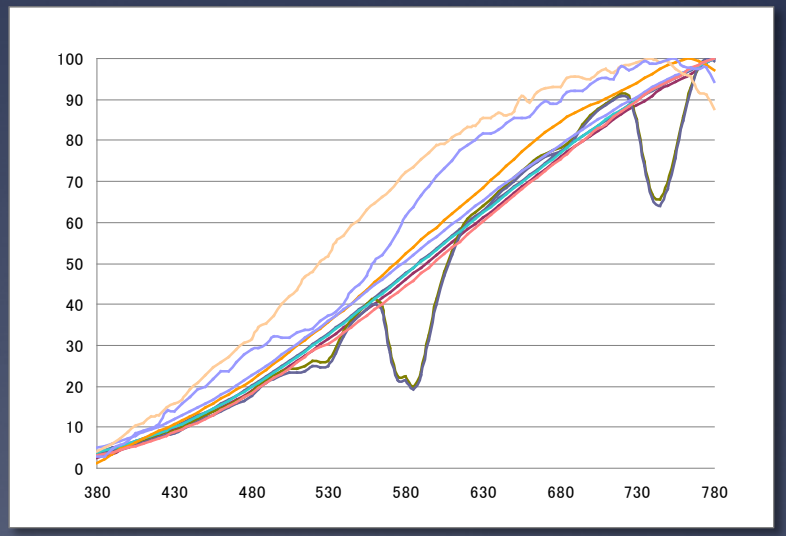


SPD (Spectral power distribution)

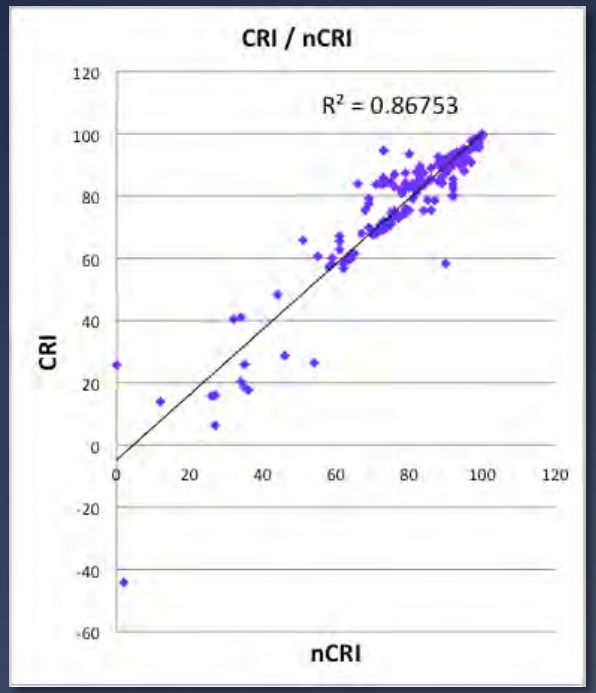
HID

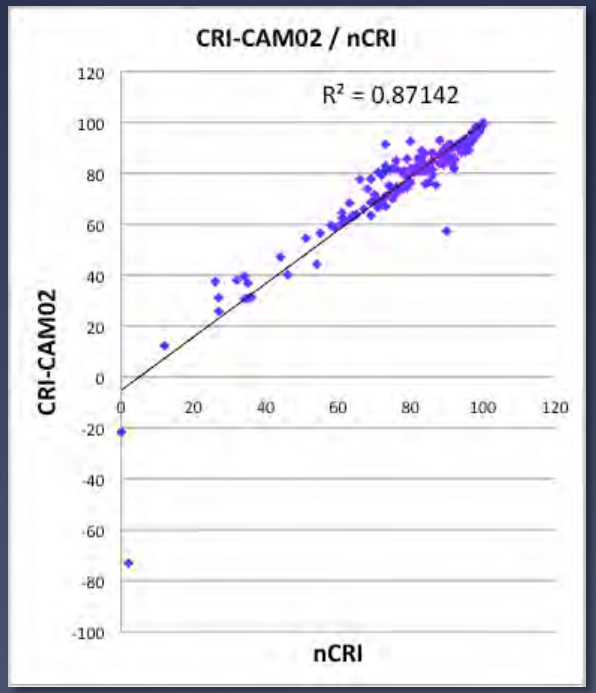


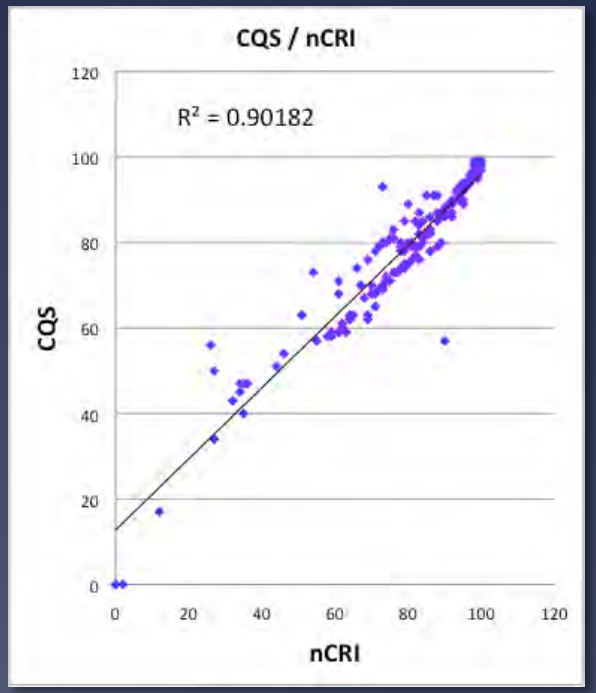
Incandescent lamps



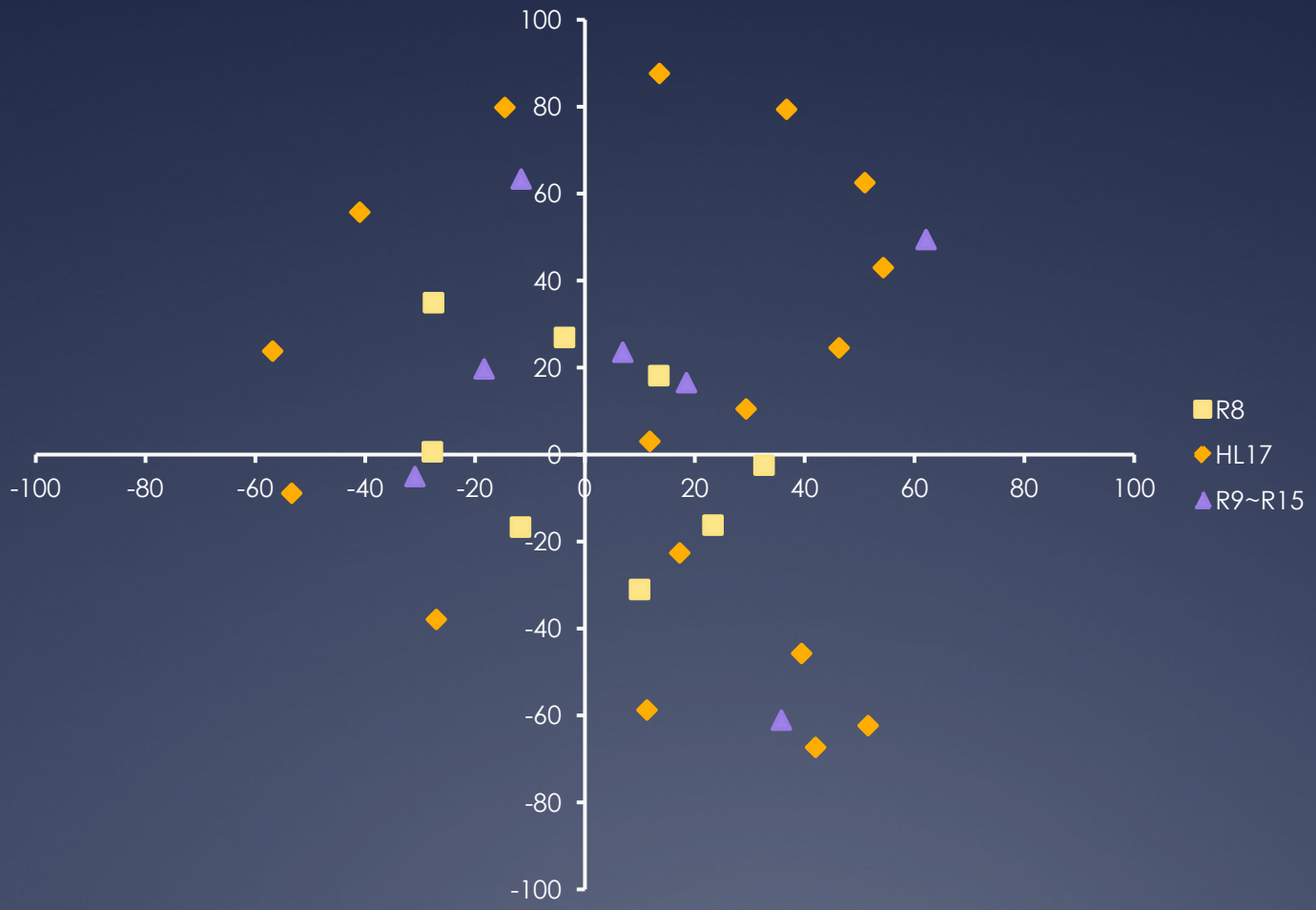
Correlation between nCRI and other color rendering indices (all light sources)



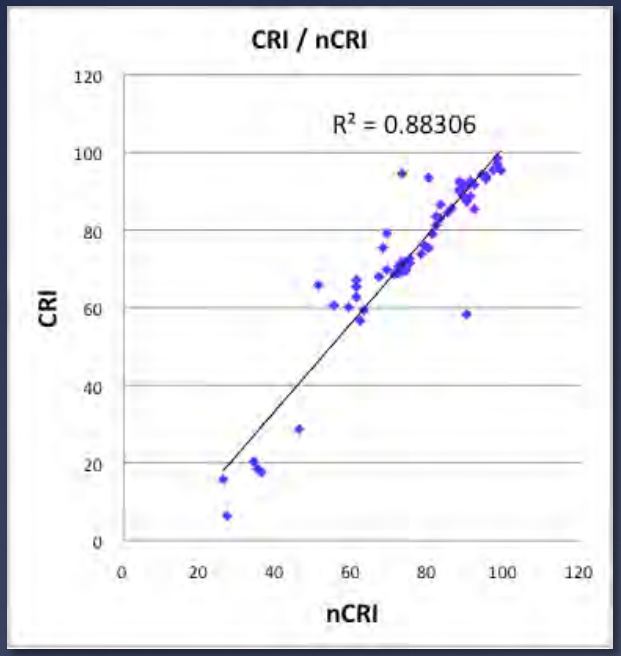


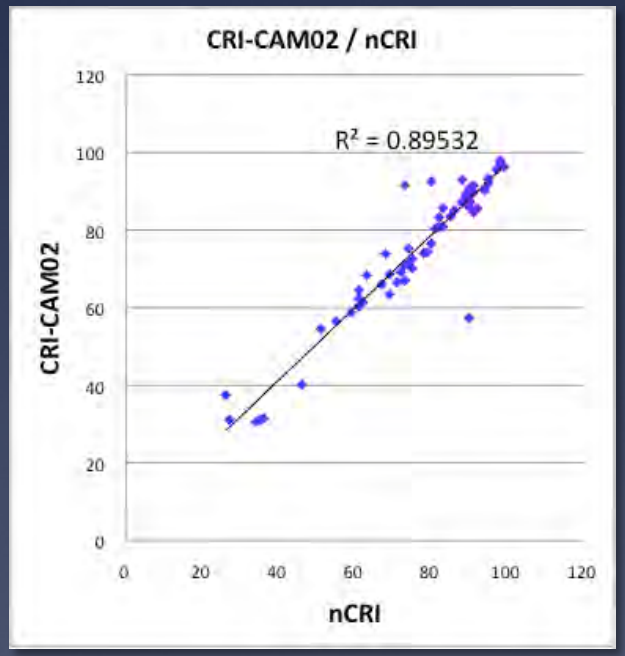


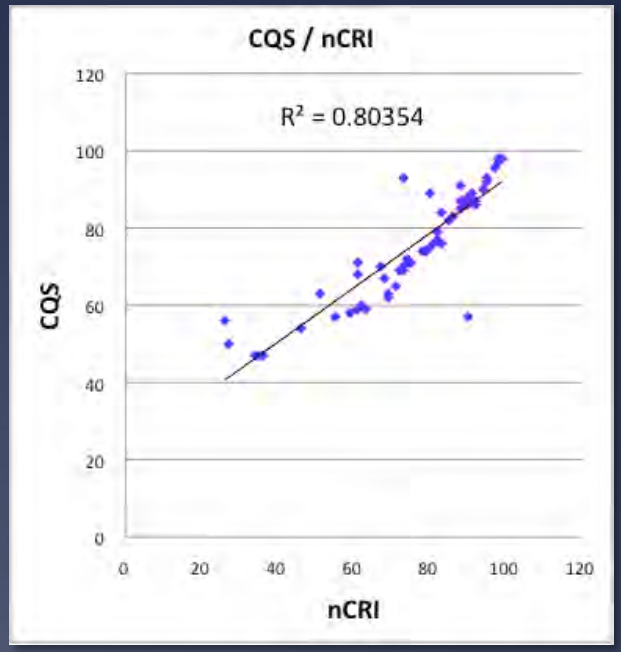
(a*, b*) coordinates of test color samples



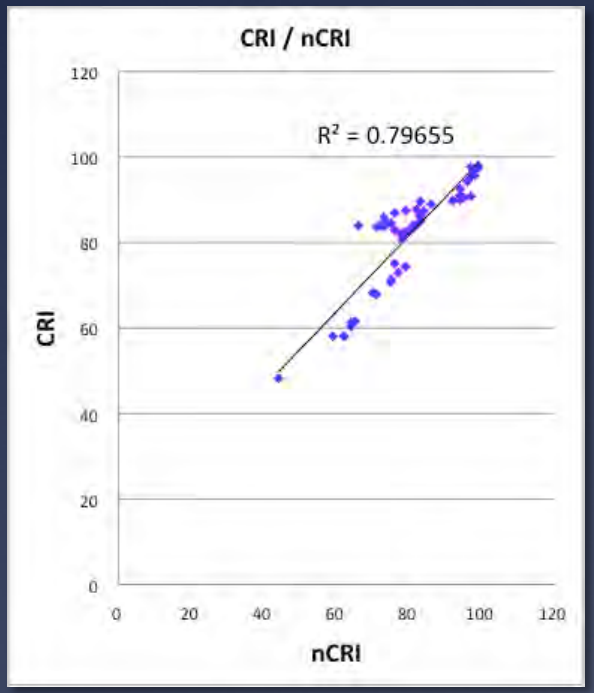
Correlation between nCRI and other color rendering indices (LED)

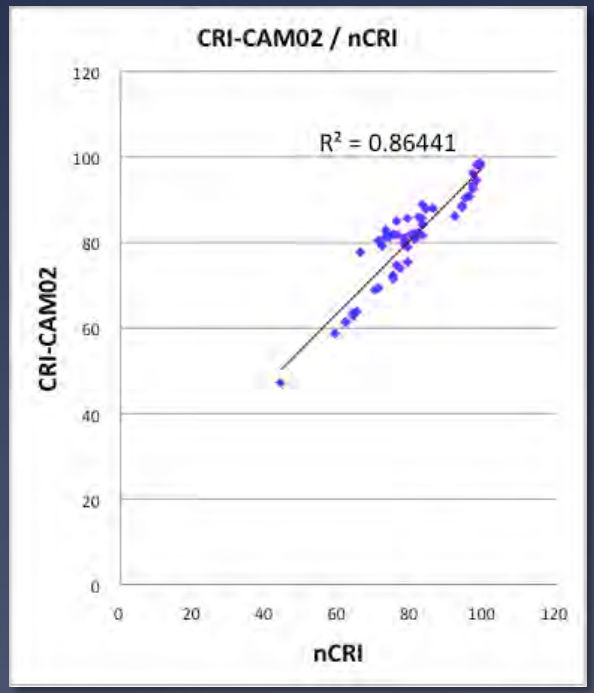


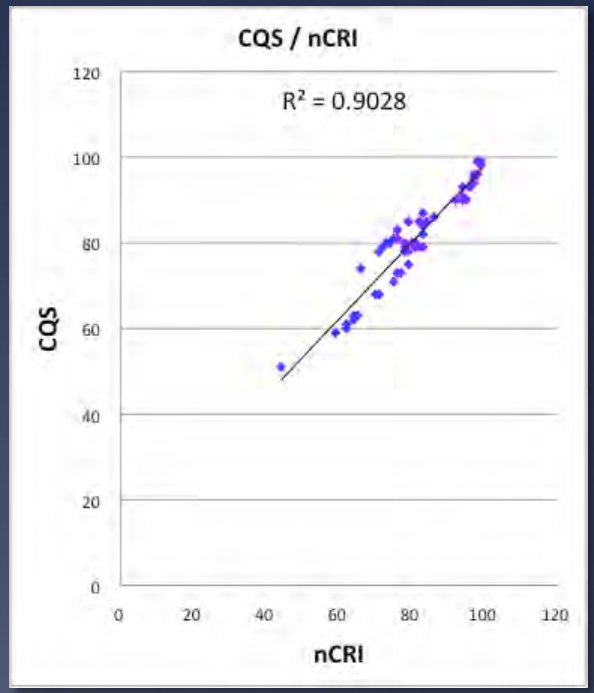




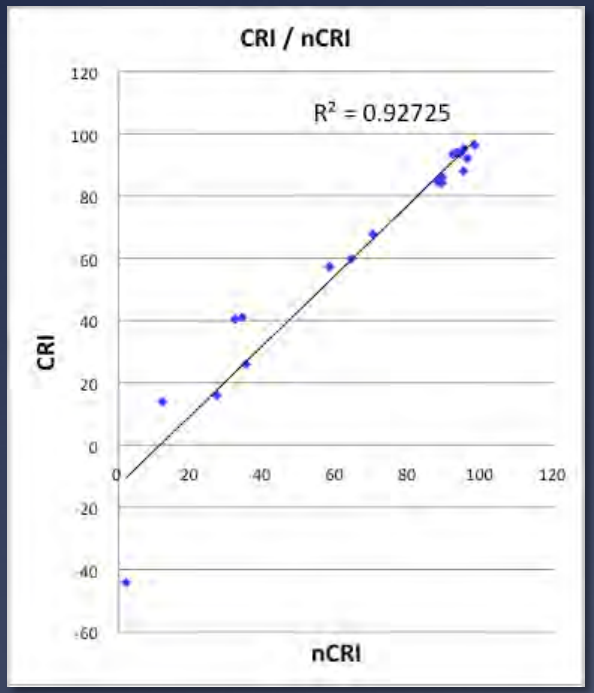
Correlation between nCRI and other color rendering indices (FL)

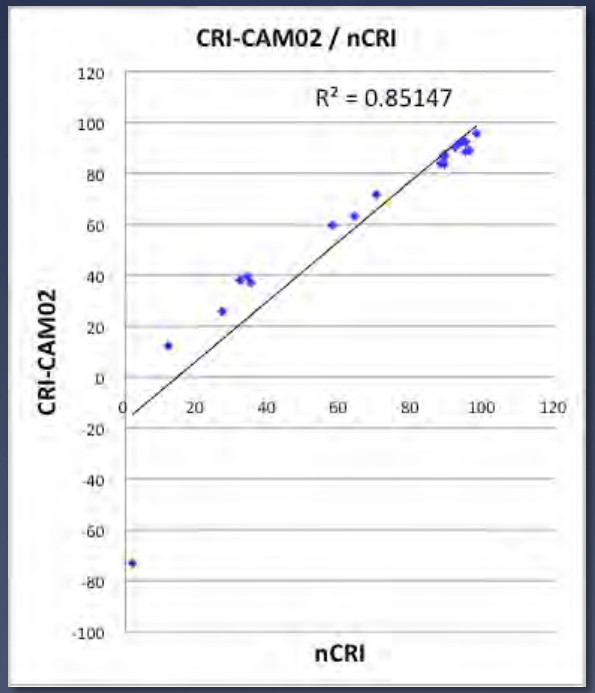


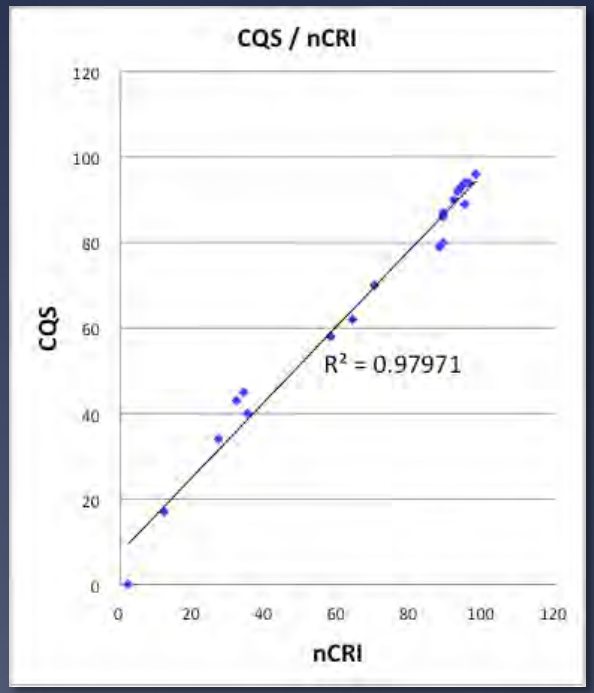




Correlation between nCRI and other color rendering indices (HID)







Work Plan

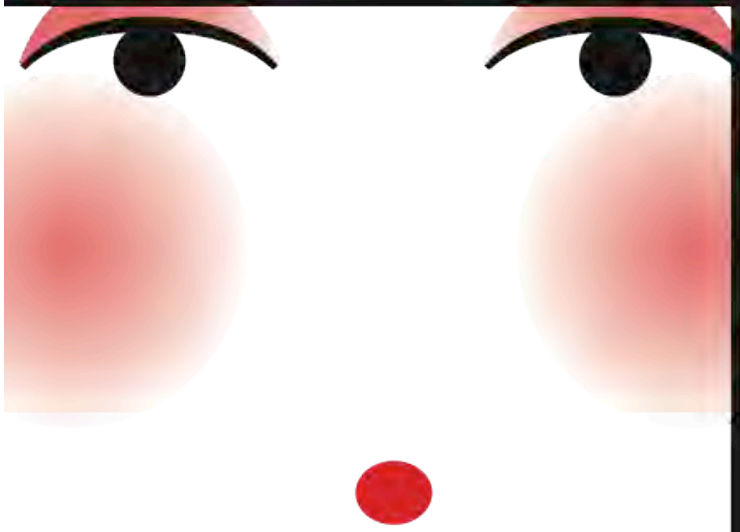
1. To gather reliable experimental data assessing colour fidelity. Div.1 Meeting 2014
2. To analyze the data by proposed colour fidelity indices. End of 2014
3. To write a report to propose the new CIE CRI. Middle of 2015

TC1-91: New Methods for Evaluating the Colour Quality of White-Light Sources

- Color quality index (CQS)
- Memory color rendering index (MCRI)
- Feeling of contrast index (FCI)
- Categorical color rendering index (CCRI)
- more
- To be discussed

AIC 2015 TOKYO

Color and Image 色と像



Date: 19 – 22 May 2015

Venue: Ochanomizu sola city Convention Center, Tokyo, Japan

Welcome to Tokyo

http://www.aic2015.org