Color Quality Scale

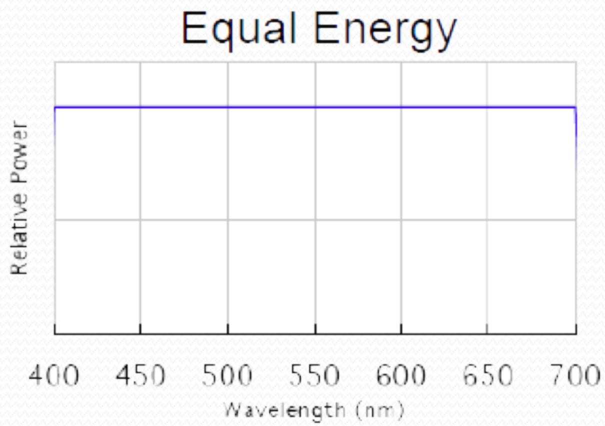
Measuring the color quality of light sources

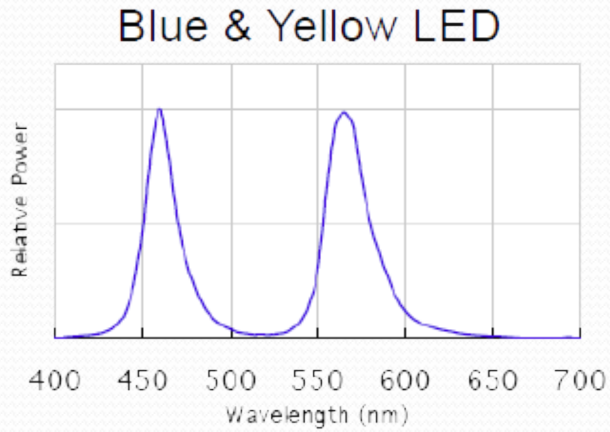
Marcel van der Steen, www.OliNo.org

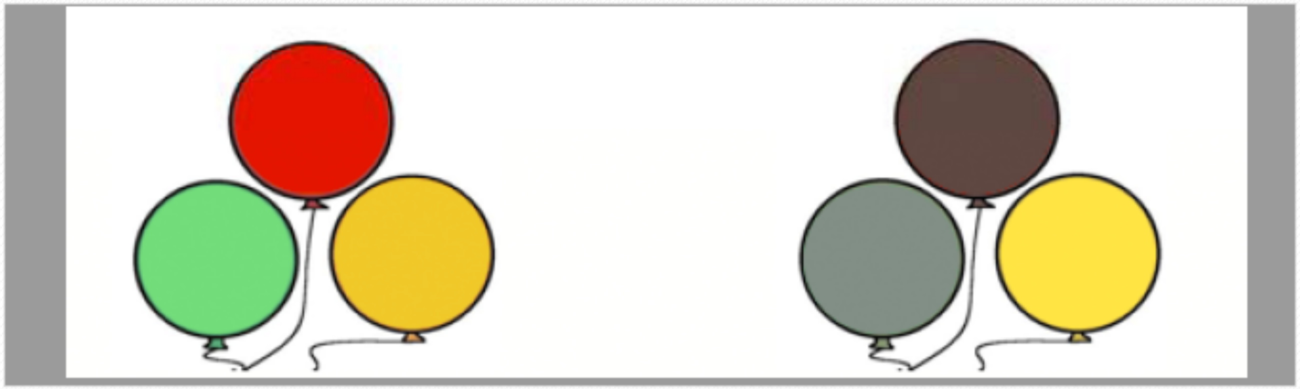
Materials used

- Toward an improved color rendering metric, W. Davis and Y. Ohno, 2005
- Presentation CQS Wendy Davis 2010
- Rationale of color quality scale, W. Davis and Y. Ohno, 2010
- Color Quality Scale Excel file v 9.0.3 Y. Ohno+notes 2011
- Presentation Color Perception and Lighting by Sophia Sotiropoulou 2013

Color Rendering

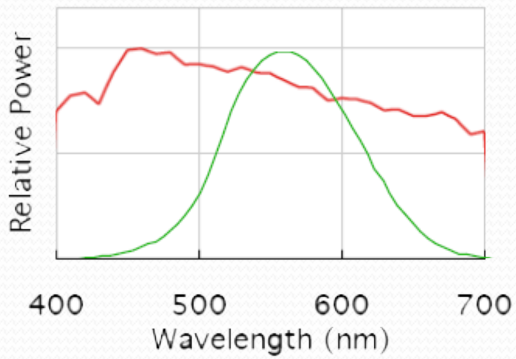




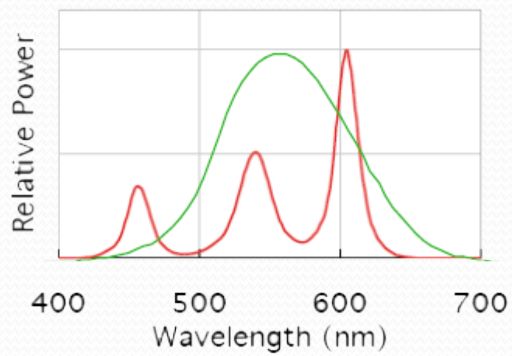


Good color rendering costs lm/W

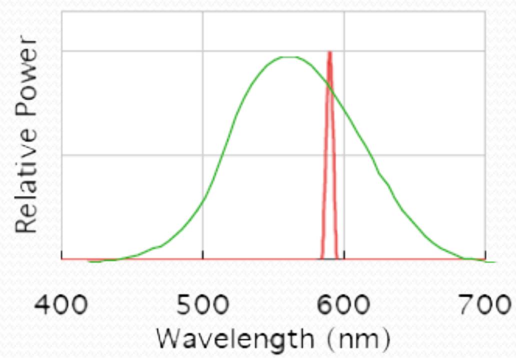
Daylight



White LED



Low pressure sodium lamp



Theoretical maximum

~250 lm/W	~ 400 lm/W	520 lm/W
Excellent color rendering	?? color rendering	No color rendering

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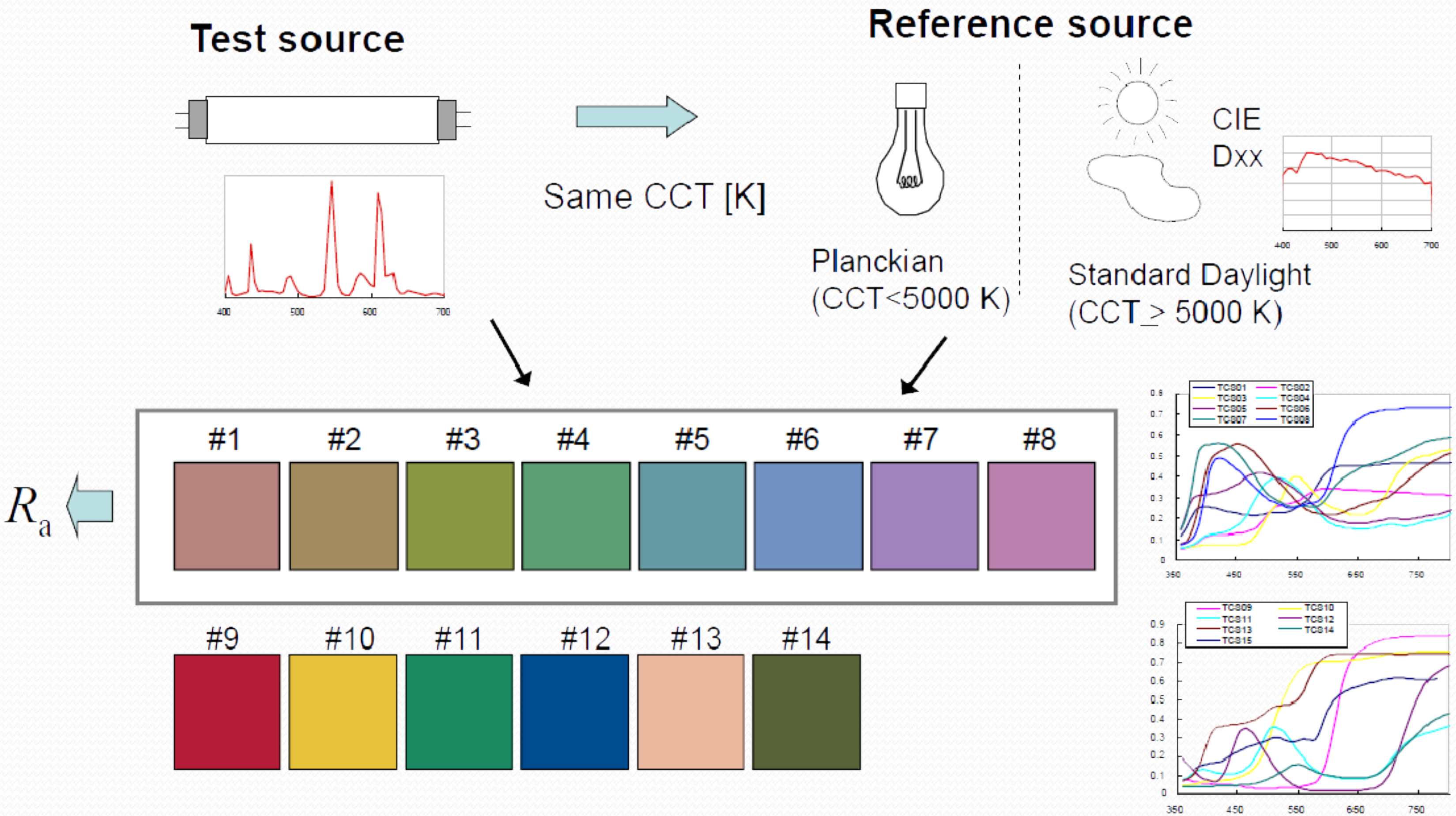
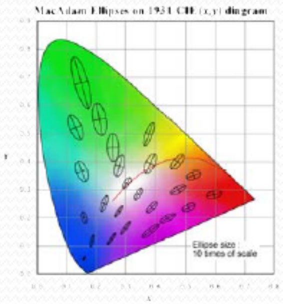
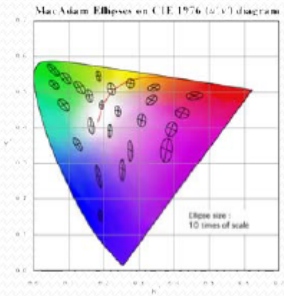
Color rendering index (CRI)



Measuring color differences



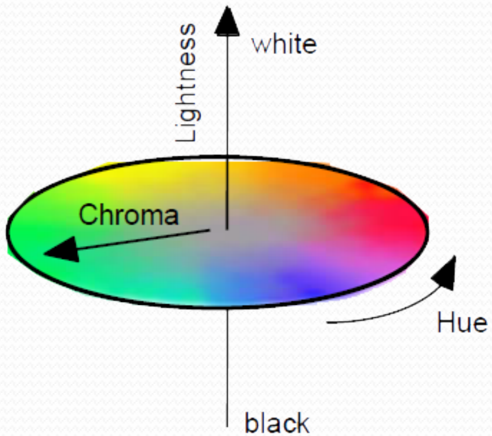


Two-dimensional diagrams

Only for light color

No black, grey, or brown

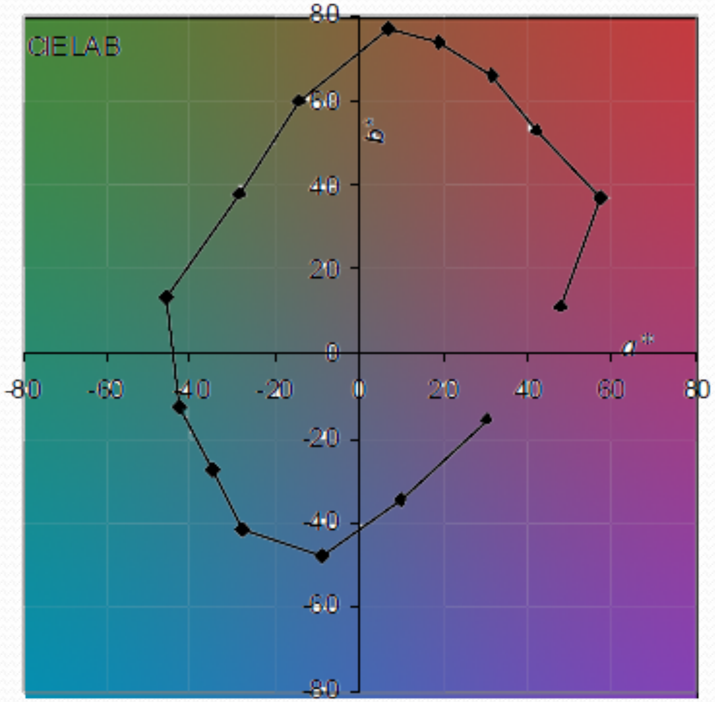
Three attributes of color are hue, chroma (saturation), and lightness, and are expressed in a three dimensional space.

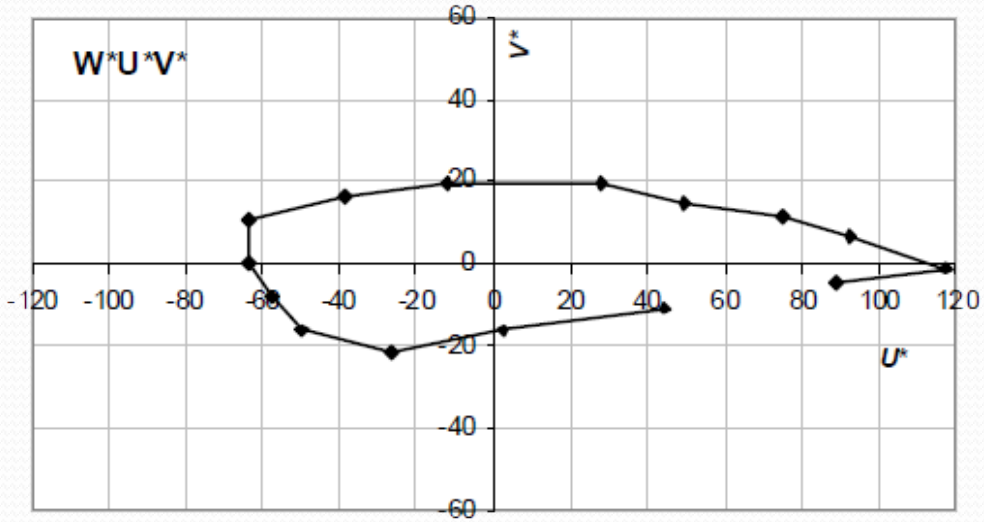


To allow accurate specification of object colors and color differences, CIE recommended CIELAB and CIELUV in 1976.

Color spaces for meas. difference

15 reflective CQS samples in CIE 1976 L*a*b* and CIE 1964 W*U*V* color spaces





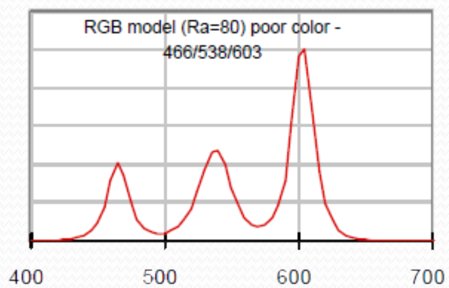
CIE 1964: color differences extremely exaggerated in red and suppressed in yellow and blue regions.

Color rendering index (CRI)

- The CRI was designed to evaluate fluorescent lamps
- The CRI was intended to measure the ‘naturalness’ of objects’ colors, not preference
- Reflective samples (1st eight) chosen to represent “average” saturation of objects, not fully saturated
- Has had no substantive changes in 35 years
  - Narrowband LED spectra showed the characterizing limits of CRI
  - LEDs’ CRI result does not correspond to its: 1) level of being visually appealing, 2) naturalness, 3) ability to discriminate between colors

Problems with the CRI

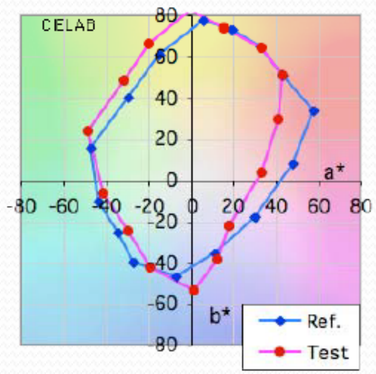
High scores do not guarantee good saturated colors

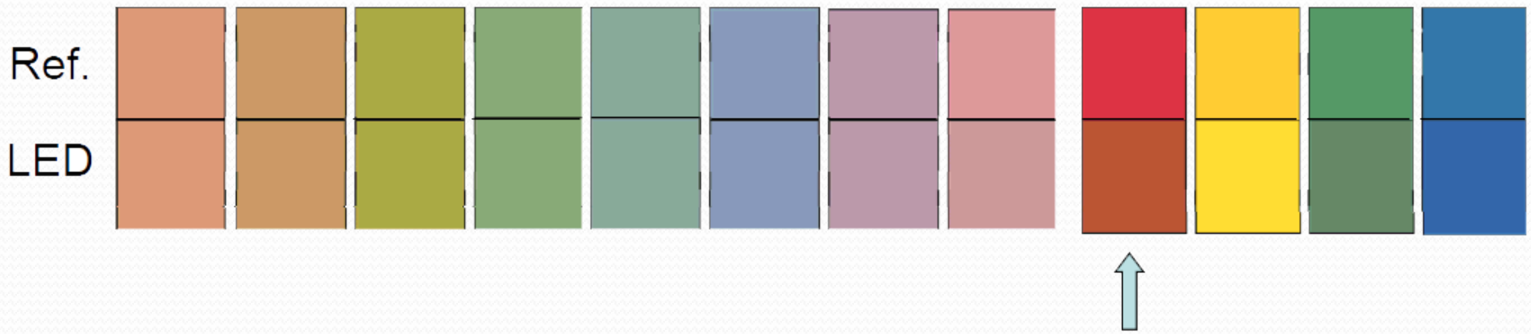


3-LED Model

Peaks at:
457, 540, & 605 nm

CRI =80



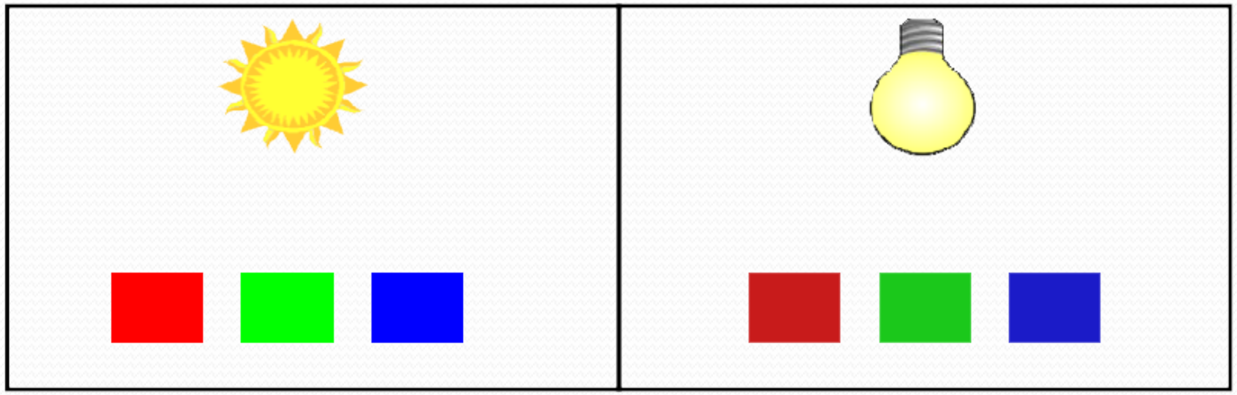


Products are optimized for metrics.
Inadequate metrics can lead to bad products.

Saturation and Naturalness

Hunt Effect

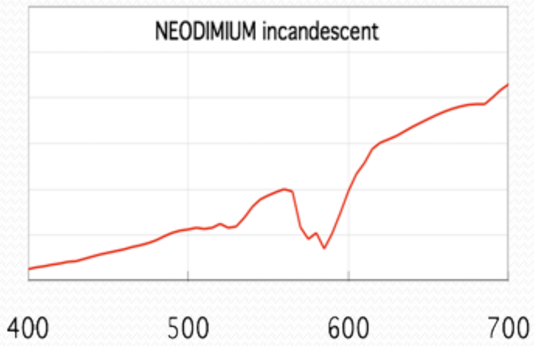
Colorfulness / saturation
increases with luminance



If we want objects to appear most natural in perceived color, we may want artificial sources to enhance their saturation.

Problems with the CRI

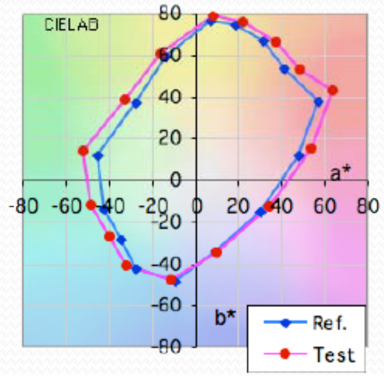
CRI penalizes light sources having enhanced color contrast

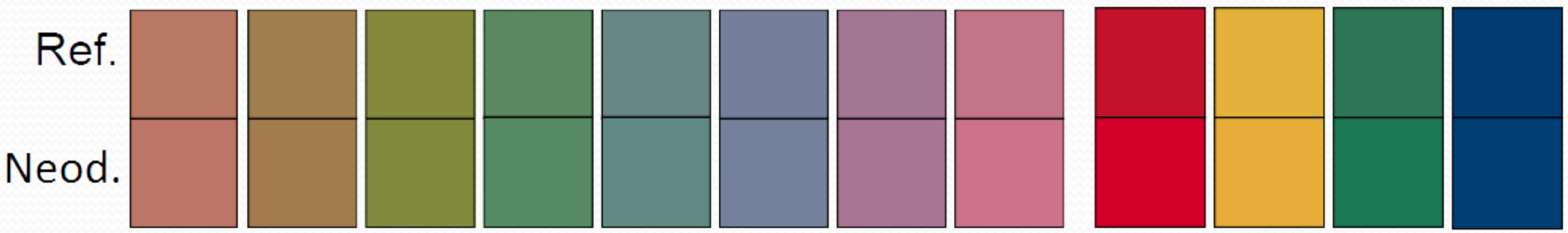


Neodymium incandescent lamp

CRI = 77

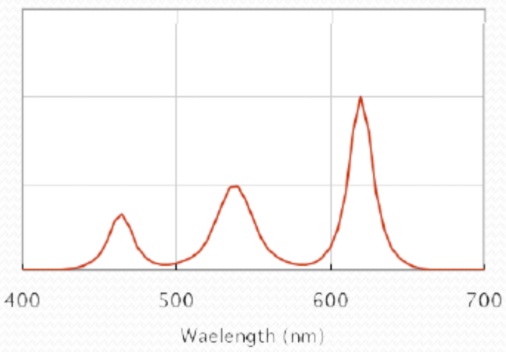
(Normal incandescent lamp CRI=100)





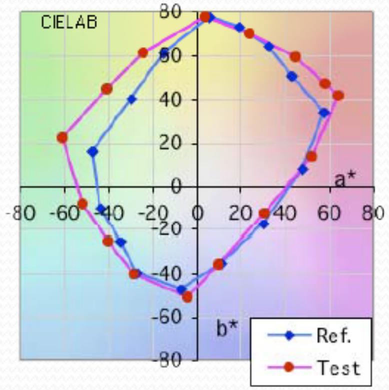
Problems with the CRI

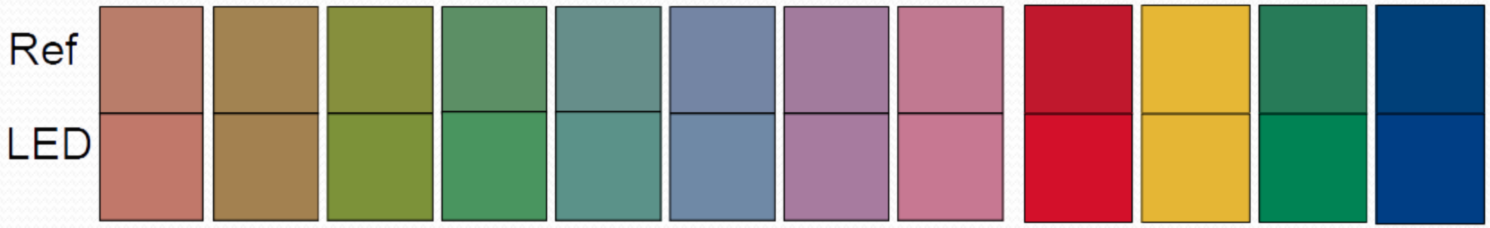
RGB white LEDs can have the same effects



3-LED Model
Peaks at:
464, 538, 620 nm

CRI = 63



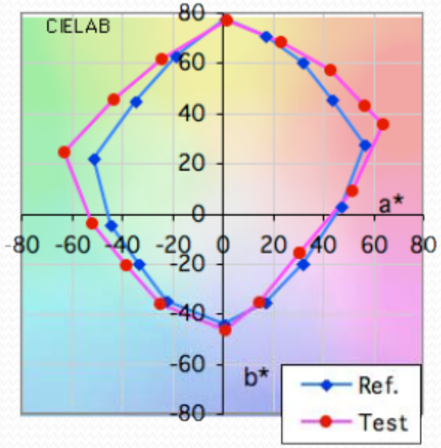


Products are optimized for metrics.
Outdated metrics can impede development of new technologies.

Color quality scale (CQS)

<u>To replace the CRI</u>

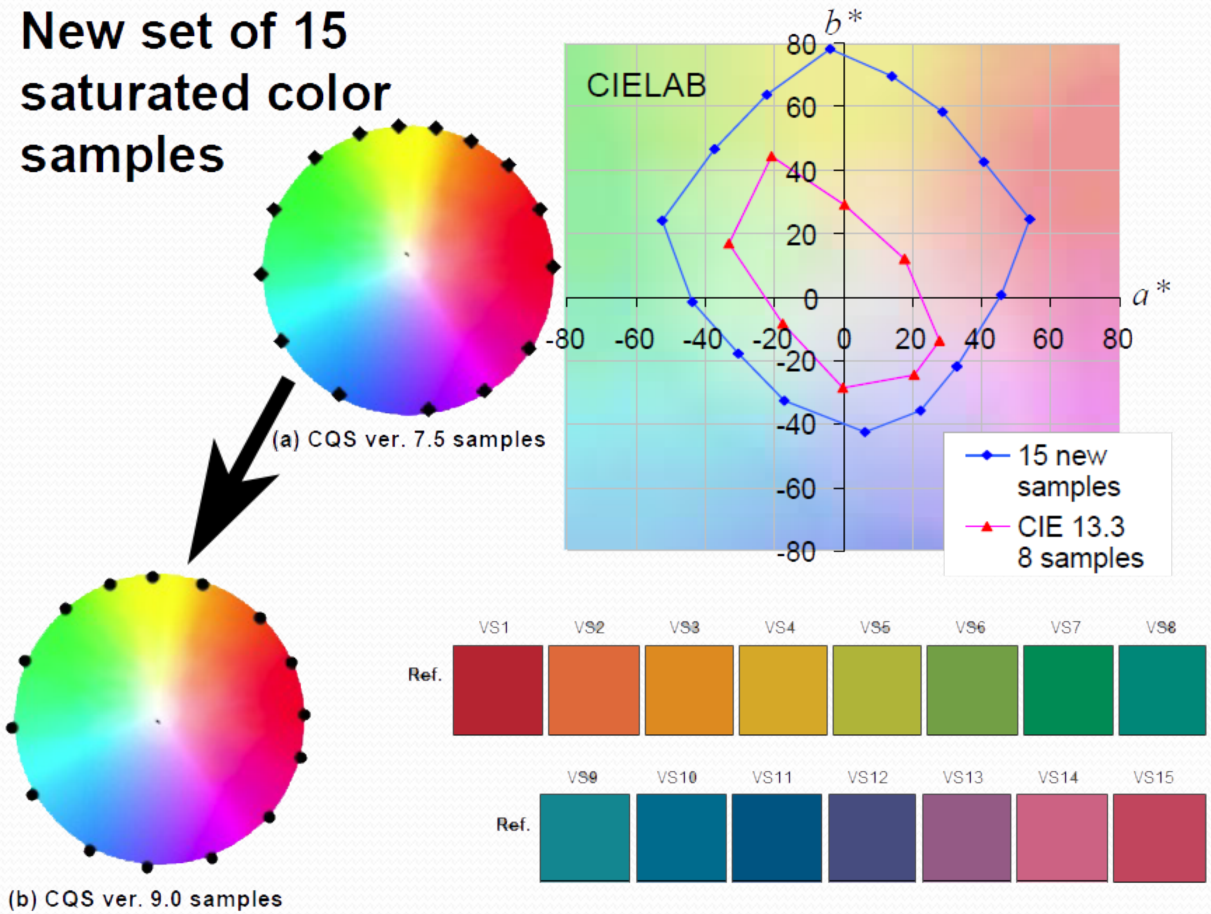
- Fix the problems of the CRI
- Replace outdated formulae in CRI
- Works for all light sources
- Considers not only color fidelity but also color preference and other aspects of color quality
- Initially developed with colorimetric simulations
- Being tested with vision science experiments



Color quality scale (CQS)

Inspiration taken from CRI	Primary deviations from CRI
•Uniform object color space to calculate color differences •Test sample method •Reference source, matched in CCT •Single number output	•Name •Different reflective samples partly new set since v9 2011 •Updated object color space & chromatic adaptation transform •Saturation factor •~~CCT factor~~ remv'd since v9 2011 •RMS combining of color differences •0-100 scale •New scaling factor

Reflective sample set



Root mean square

The CRI makes it possible for a lamp to score quite well, even when it renders one or two samples very poorly. This situation is more likely with SPDs having narrowband peaks, such as LEDs.

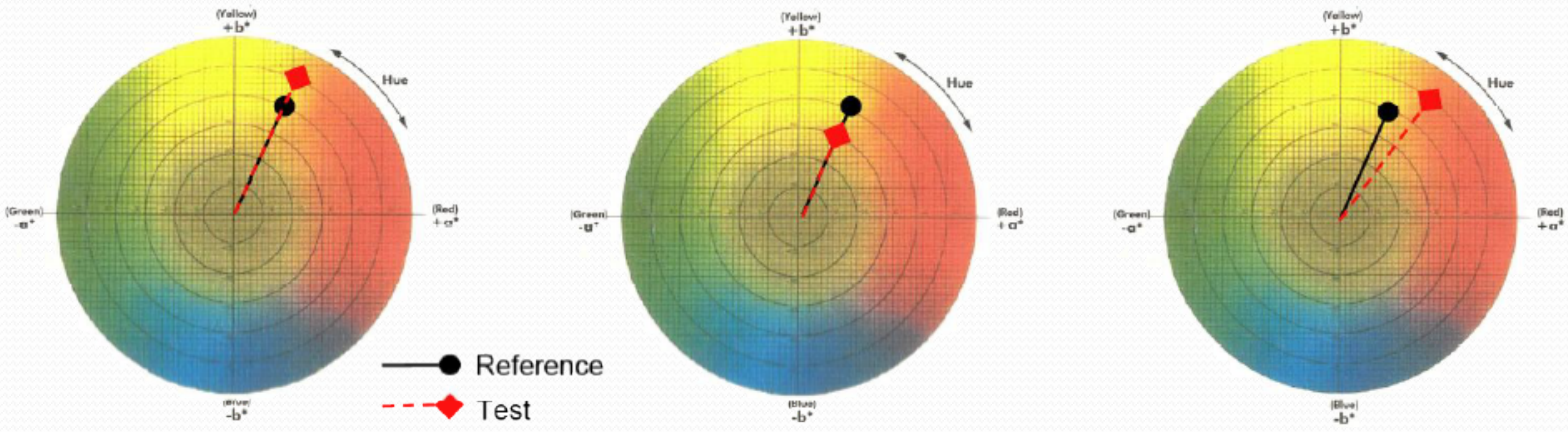
RMS (Root Mean Square) color difference of 15 samples:

$$\Delta E_{\mathrm{RMS}} = \sqrt{\frac{1}{15}\sum_{i=1}^{15} \Delta E_i^{\,2}}$$

Example

	Case A ΔE	Case B ΔE
TS1	3	1
TS2	3	1
TS3	3	1
TS4	3	1
TS5	3	1
TS6	3	1
TS7	3	1
TS8	3	1
TS9	3	1
TS10	3	1
TS11	3	1
TS12	3	1
TS13	3	1
TS14	3	16
TS15	3	16
Ra(mean)	91	91
Ra(RMS)	91	82

Saturation factor



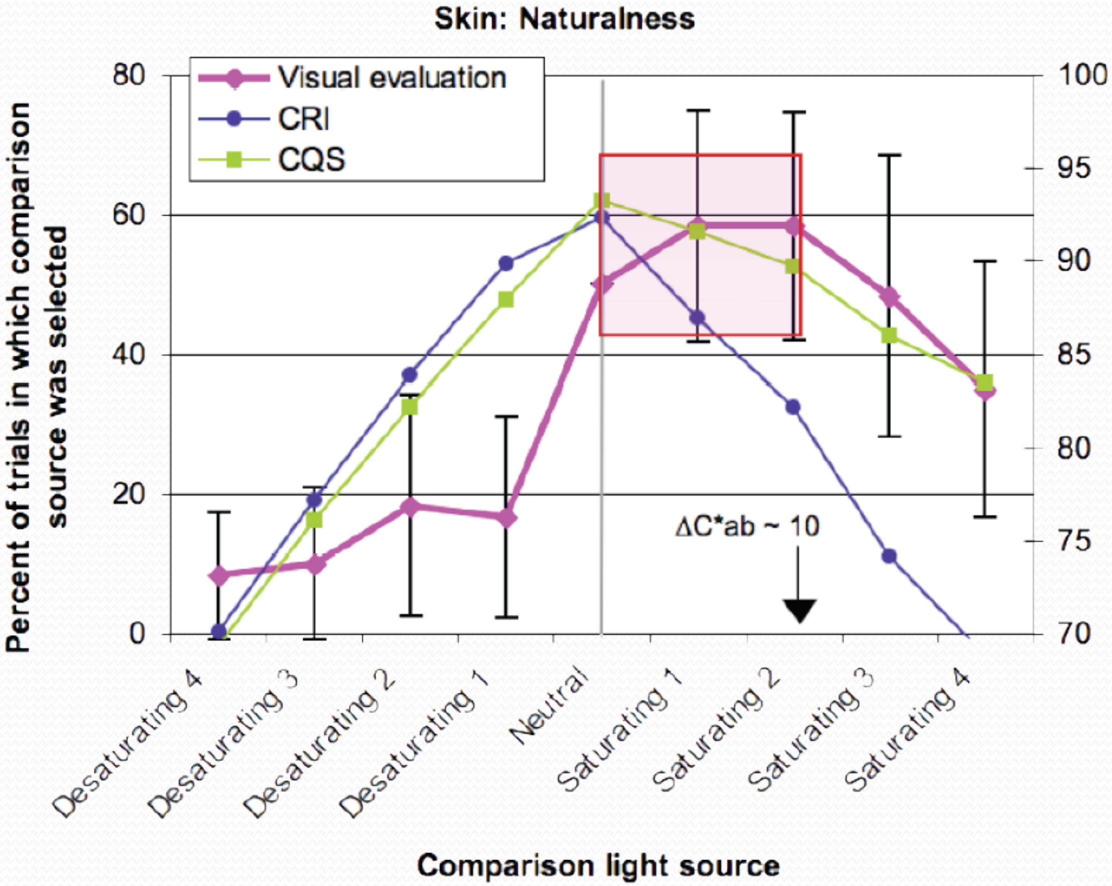
A B C

A: not penalized for increase of chroma (however there is a limit since v9, see next page)

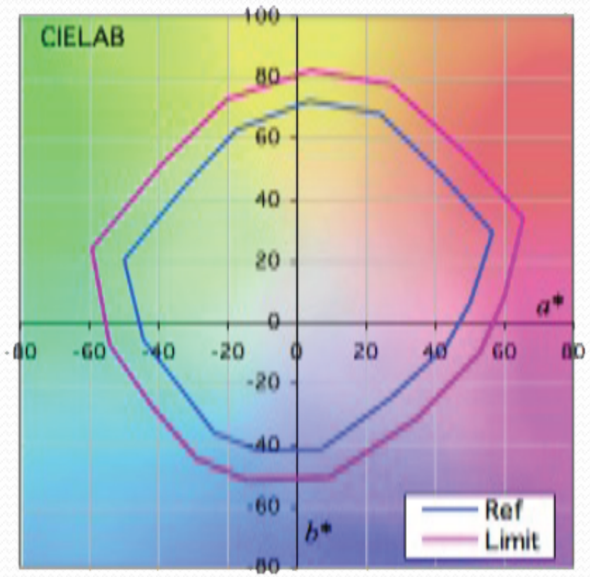
B: penalized for decrease of chroma

C: penalized for hue shift, but not for increase of chroma (however a limit, see next page)

Saturation factor since v9.0



Max tolerable increase in chroma is +10



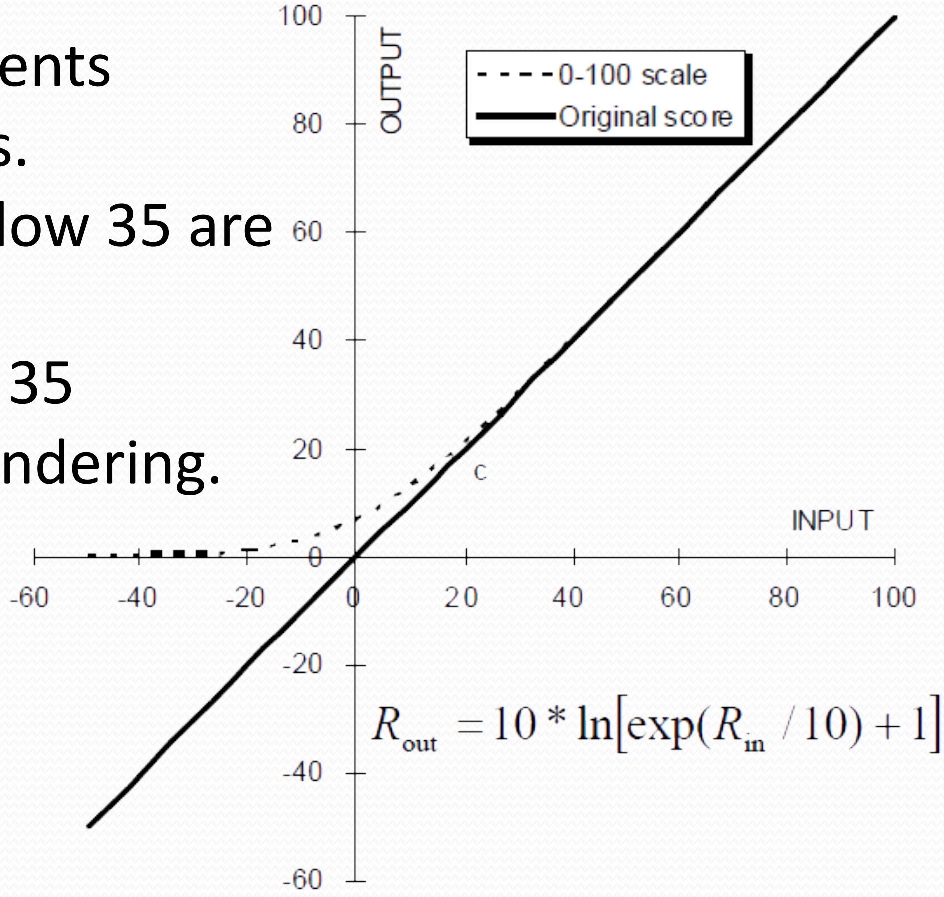
Saturation factor example

Color-desaturating light (R_a=82, Q_a=74)

Color-enhancing light (R_a=71, Q_a=83)

New scaling factor

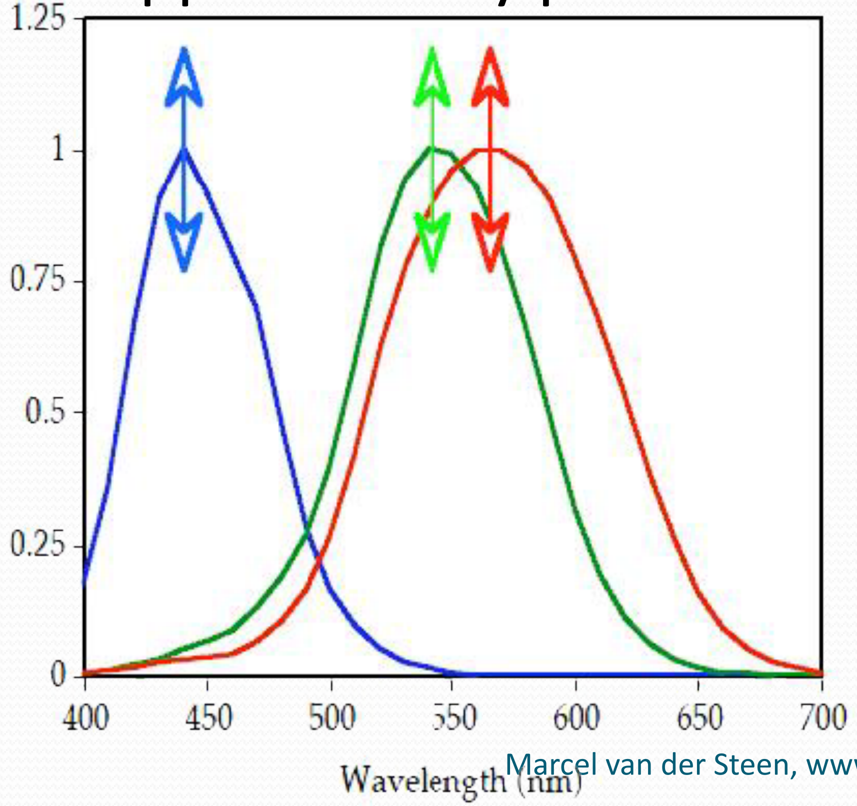
- The CQS prevents negative values.
- CRI values below 35 are affected.
- Values below 35 indicate bad rendering.



$$R_{out} = 10 * \ln\left[\exp(R_{in} / 10) + 1\right]$$

Chromatic adaptation (correction)

- Chromatic adaptation is the ability of the human visual system to discount the color of the illumination and to approximately preserve the appearance of an object

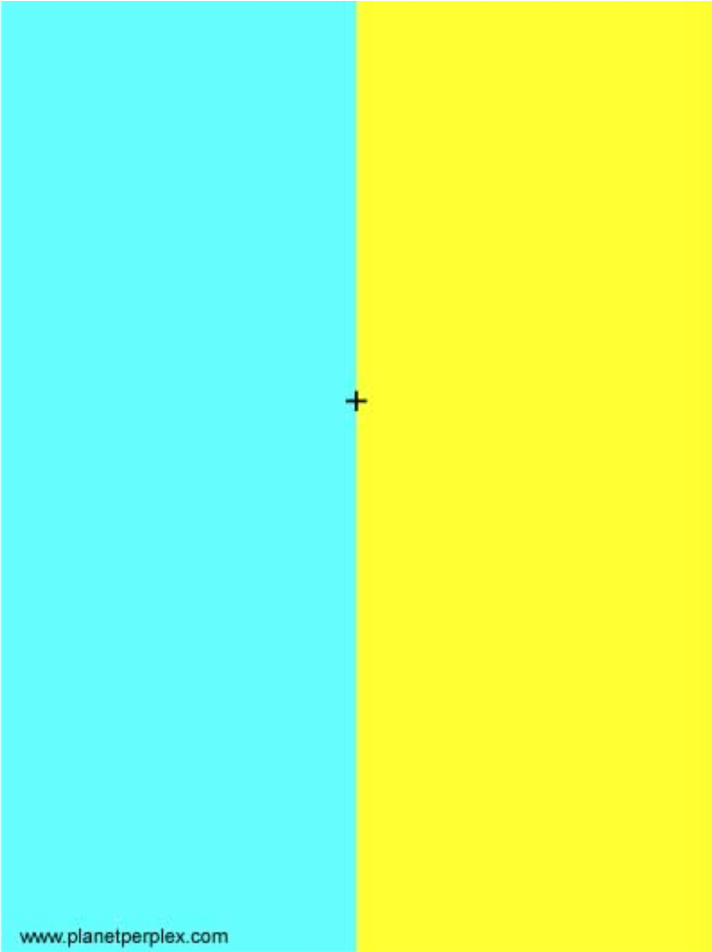


(e.g. white sheet of paper under different illuminants)

CQS uses a newer Chromatic Adaptation Transform (CMCCAT2000) than CRI does.

It can be explained as independent sensitivity regulation of the three cone responses.

Chromatic adaptation



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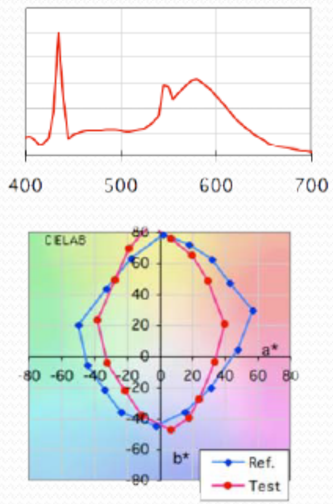
CCT factor – and removal

- Light with low CCT (say < 2500K) and even CRI=100, cannot render well blue tones.
  - One cannot distinguish black and blue socks with halogen light as there is little blue in it
- To correct for this, the max CQS value should be less than 100 for low CCTs.
- A proposal was in v7.5 but removed in v9.0 due to some opposition of industry people and the lack of experimental validation. This factor could come back later.

CCT [K]	Mult.Fctr.
1000	0.19
1500	0.64
2000	0.87
2500	0.96
2856	0.98
3000	0.99
3500 and up	1.00

Some results of the CQS

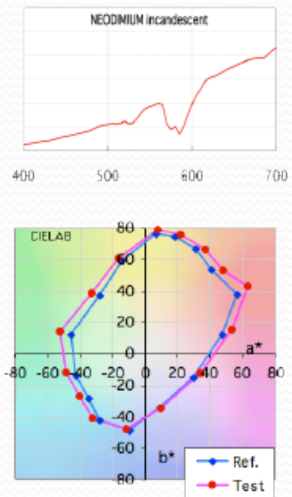
Cool White Fluorescent



CRI =63

CQS=64

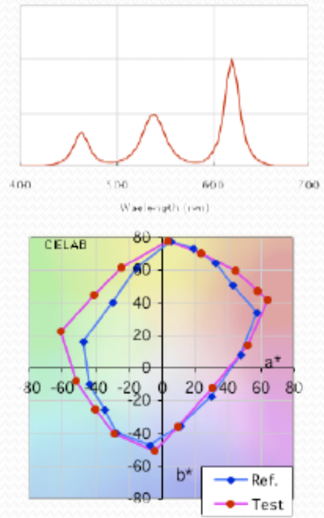
Neodymium Incandescent



CRI =77

CQS=88

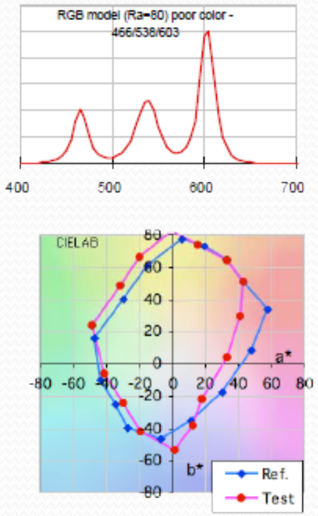
RGB (enhanced)
(464/538/620 nm)



CRI =63

CQS=80

RGB (poor red)
(457/540/605 nm)

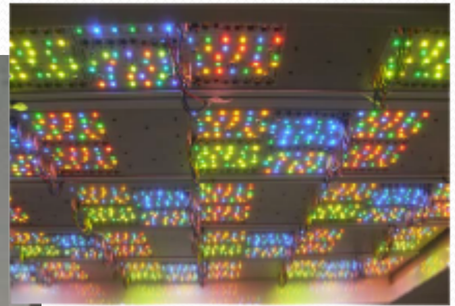


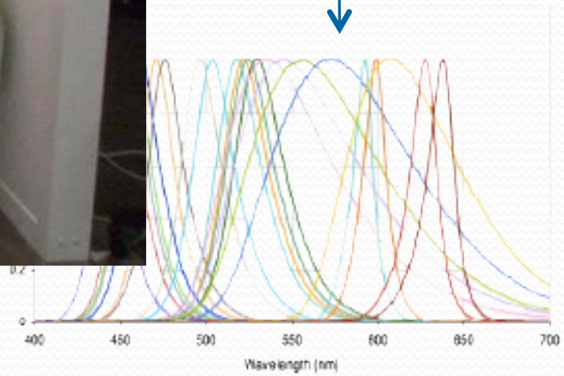
CRI =80

CQS=74

Consistency of scores is maintained for fluorescent lamps

Evaluation room at NIST

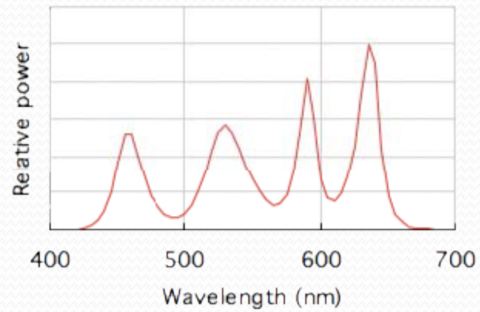




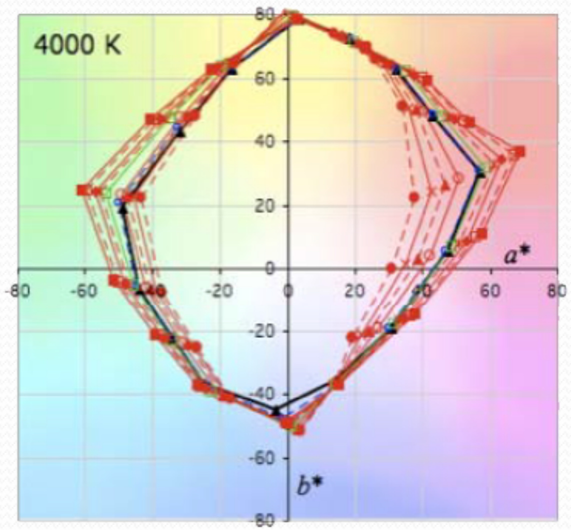
Experimental spectra

Lights tested

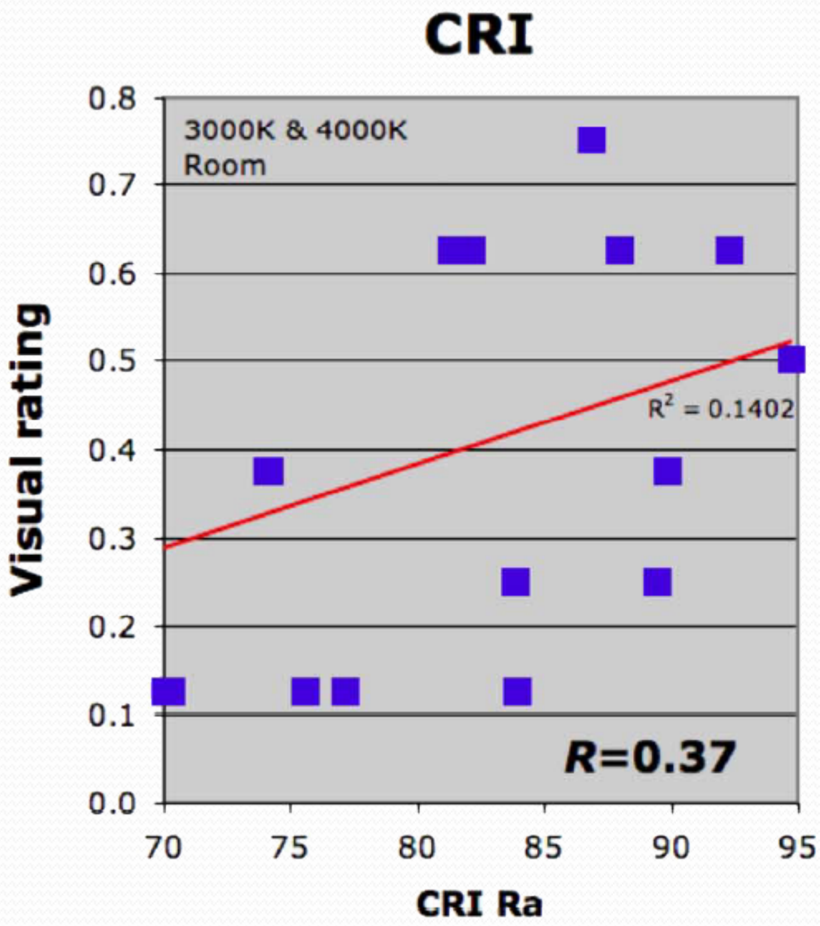
CCT: 4000 K (800 lx), Duv=0.000
3000 K (300 lx), Duv=0.000

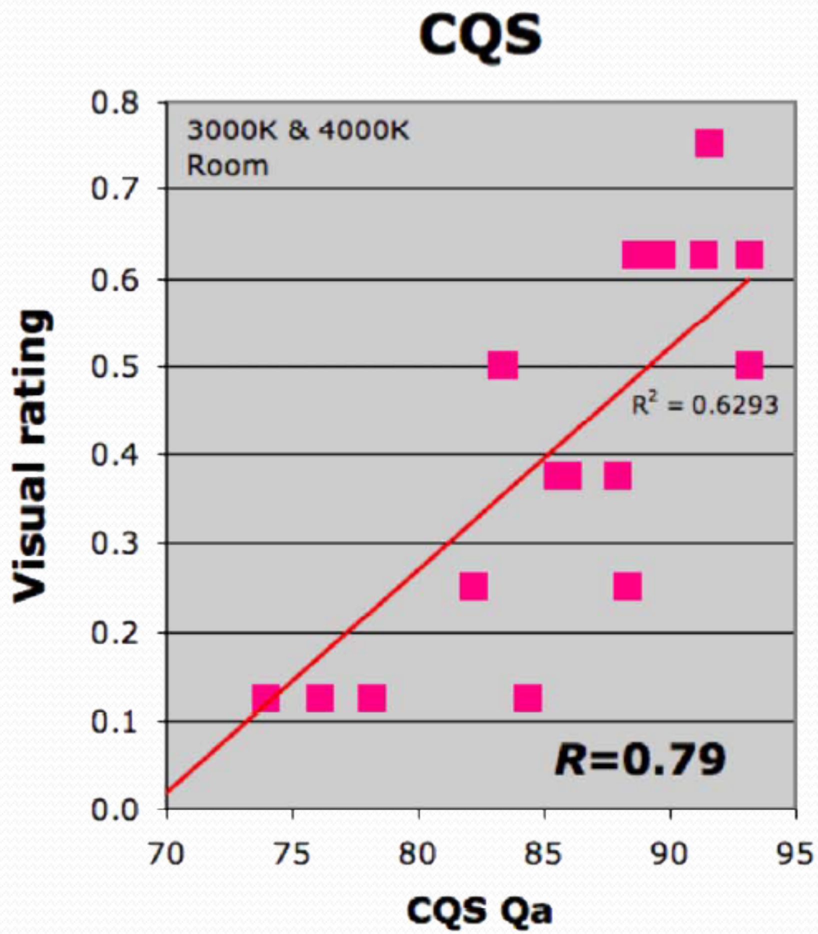


	4000 K	3000 K
Reference: broadband	Ra=98	Ra=97
4 peak (RGBA) Desaturating-4	Ra=70	Ra=70
4 peak (RGBA) Desaturating-3	Ra=77	Ra=76
4 peak (RGBA) Desaturating-2	Ra=84	Ra=84
4 peak (RGBA) Desaturating-1	Ra=90	Ra=90
4 peak (RGBA) Neutral	Ra=92	Ra=95
4 peak (RGBA) Saturating-1	Ra=87	Ra=88
4 peak (RGBA) Saturating-2	Ra=82	Ra=81
4 peak (RGBA) Saturating-3	Ra=74	Ra=74
4 peak (RGBA) Saturating-4	Ra=69	Ra=69

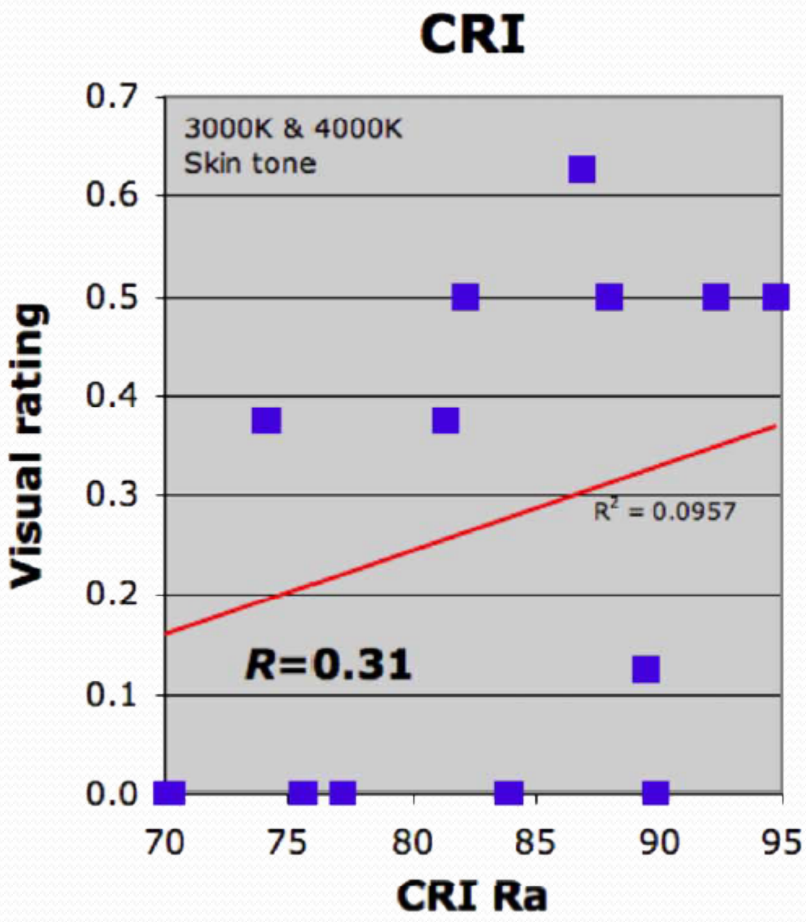


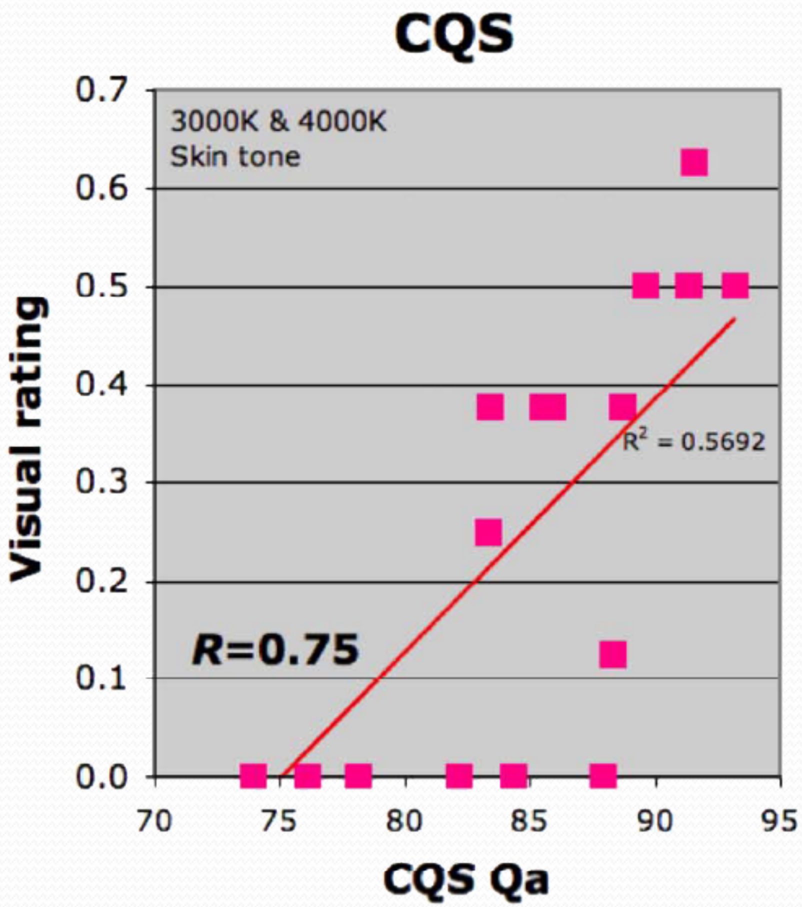
Results: Room evaluation





Results: Skin evaluation





CQS available

- The CQS v9.0 will from mid Feb be an addition to OliNo lamp measurements
- Some changes may occur as the metric is not adopted yet (scaling factor)?
- The metric has many improved elements over the CRI

More Info: www.OliNo.org