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Understanding TM-30 vs. CRI

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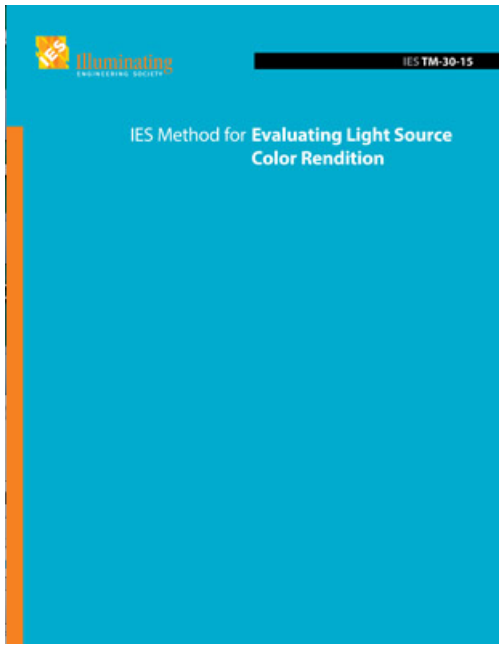
OUTLINE

1. Outline of TM-30
2. Analysis of TM-30 vs. CRI
   - Color space
   - Test color samples
   - Relation to color preference
3. Position statements
4. Conclusions

IES TM-30 IES Method for Evaluating Light Source Color Rendition



- ❑ Two-metric system
  - Fidelity index R_f
  - Gamut index R_g

  (CRI R_a: fidelity)

→ Color fidelity: Improvement of CRI R_a

→ Information related to preference

- ❑ 99 test samples

  (CRI: 8 samples)

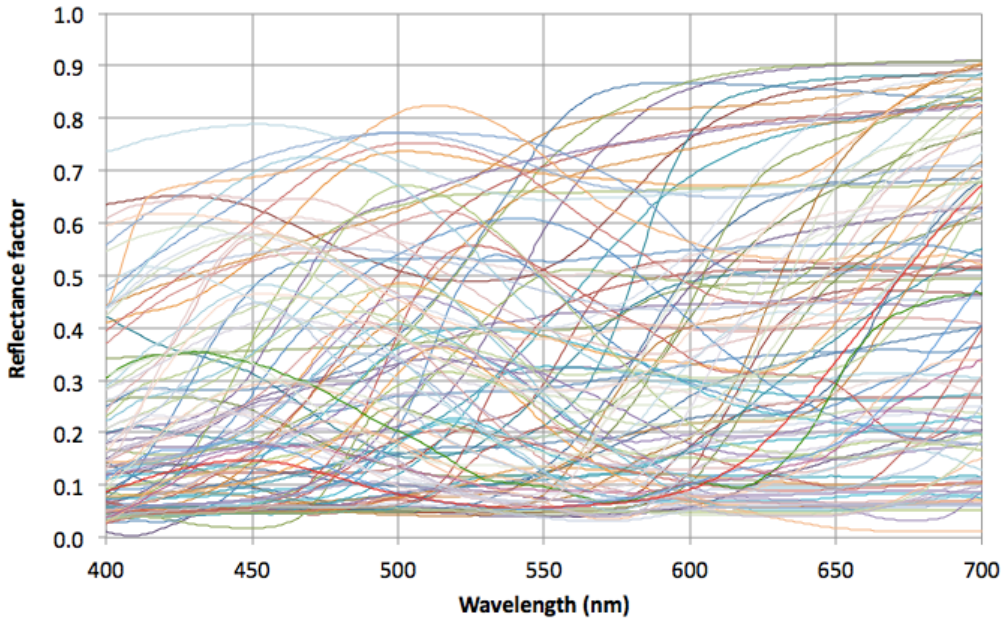
→ Works accurately for all colors of object and all kinds of spectra

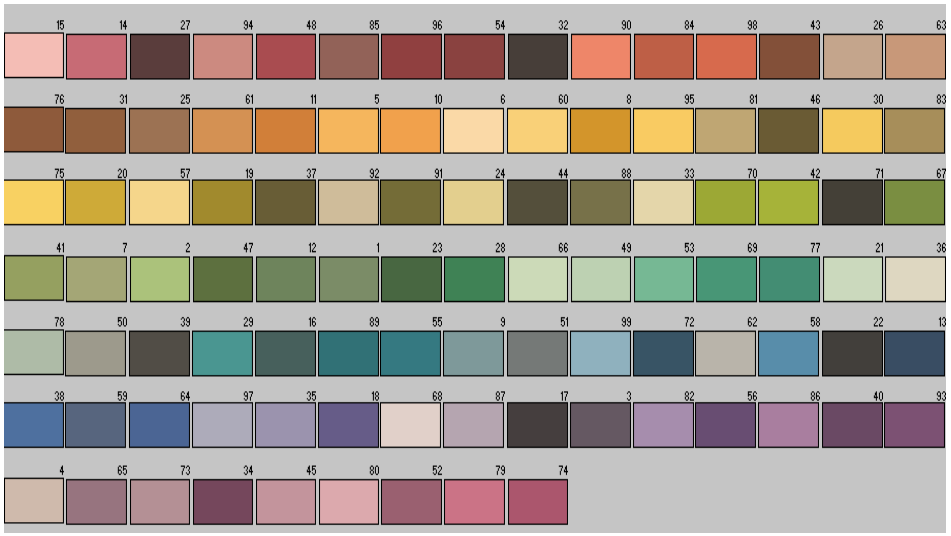
- ❑ Latest color space and chromatic adaptation formula

→ Provide details beyond R_f and R_g.

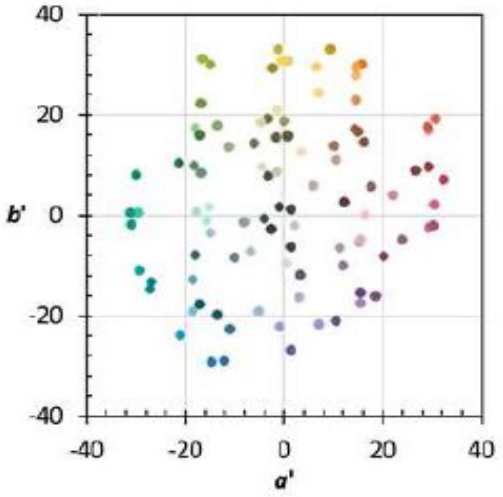
- ❑ Graphic tool

99 Test Samples



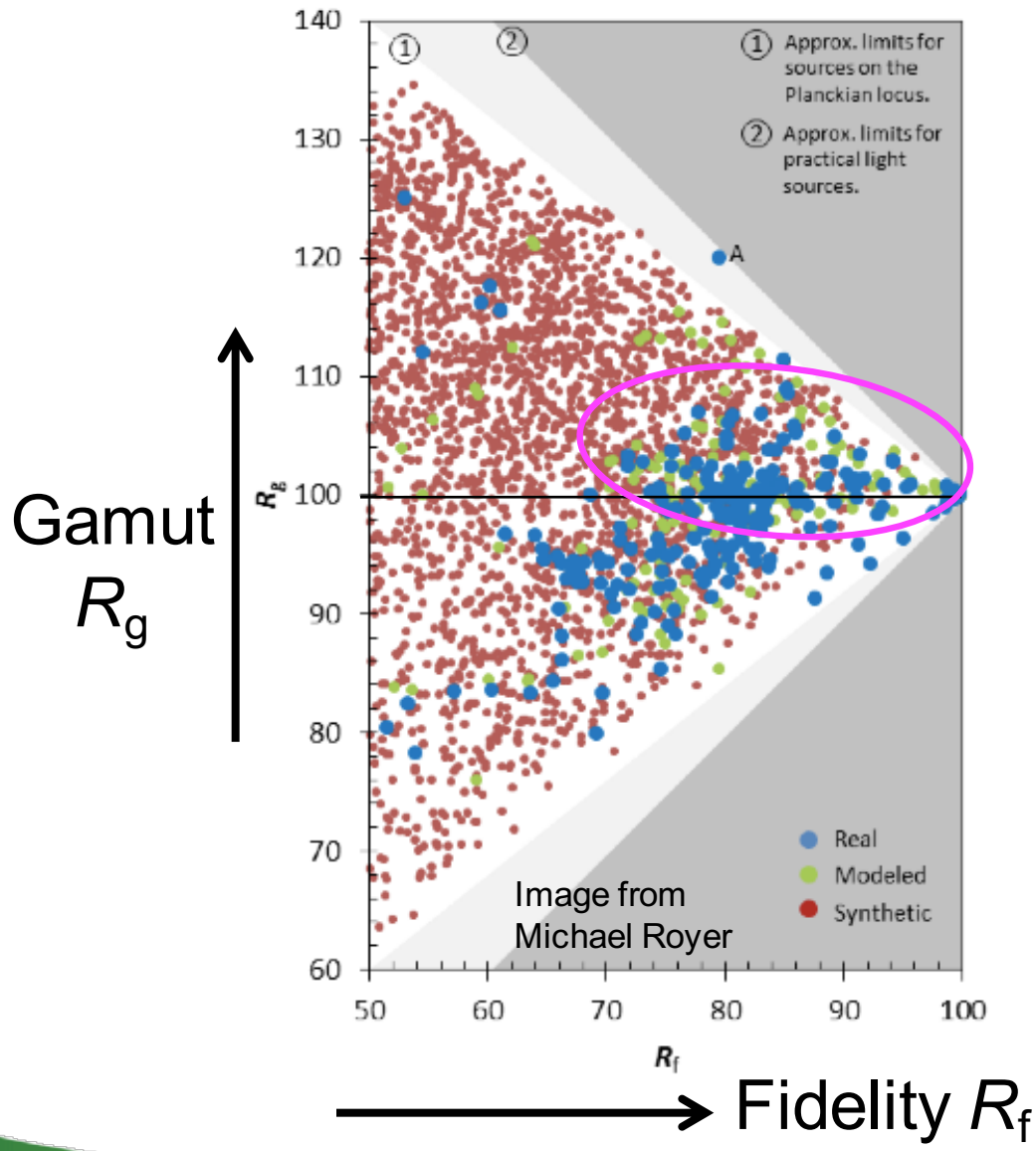


- Data of real objects taken from the U. Leeds database
- The samples are distributed evenly in the 3D object color space.



- More considerations

Concept of Two-Metric System



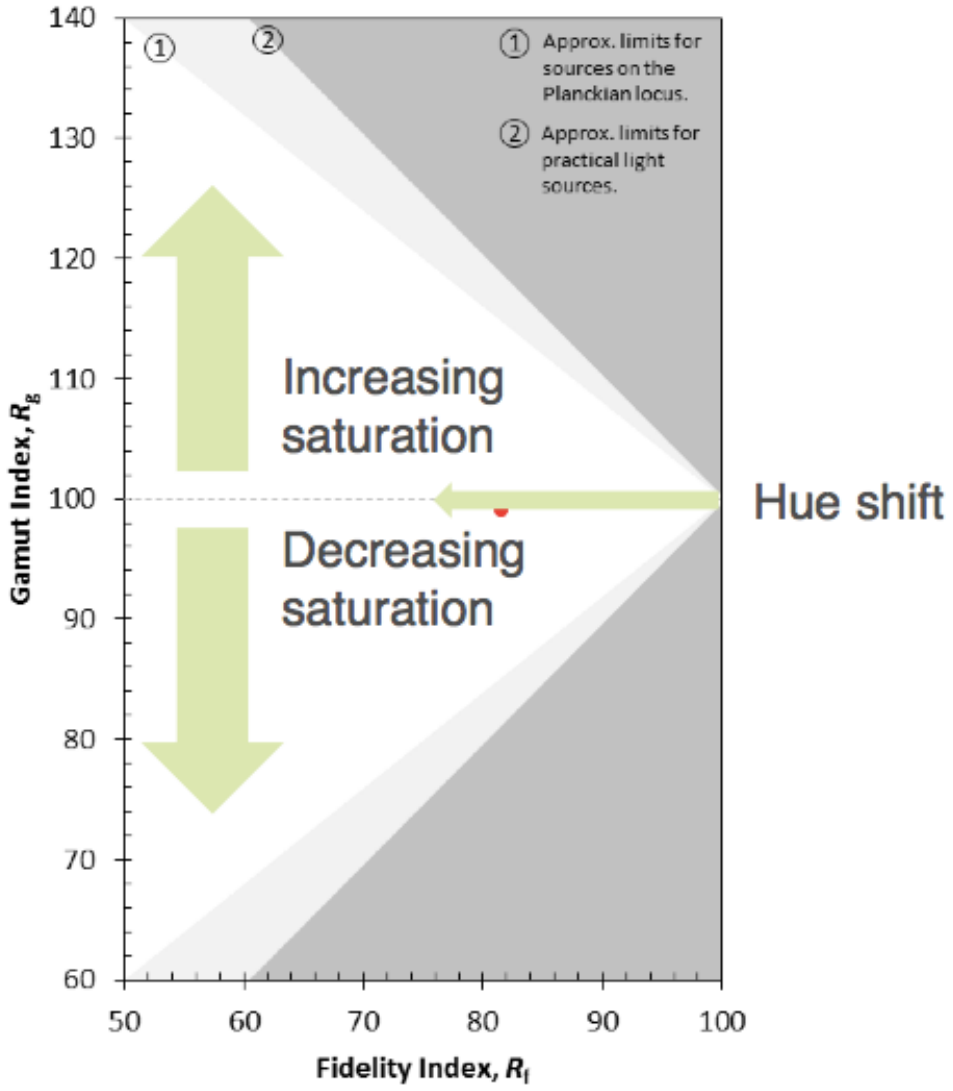
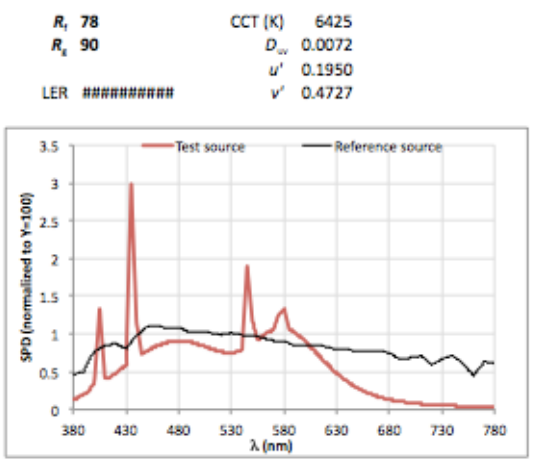
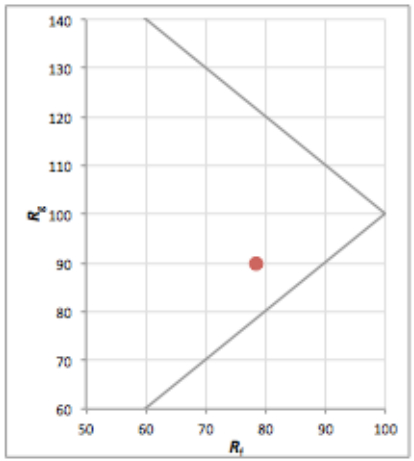


Image from Michael Royer.

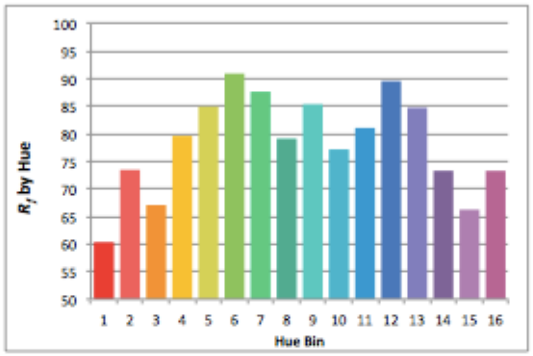
Graphic tools

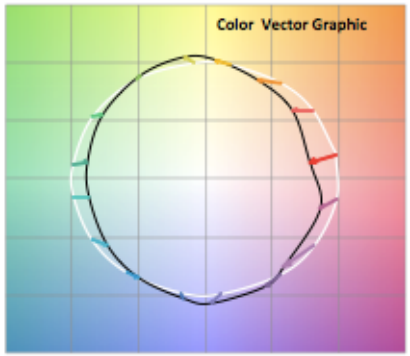




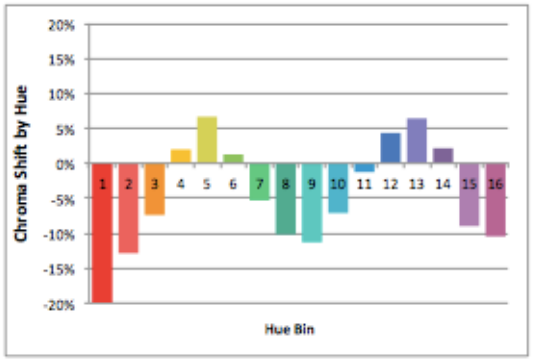
Calculation Tool distributed with TM-30 purchase.

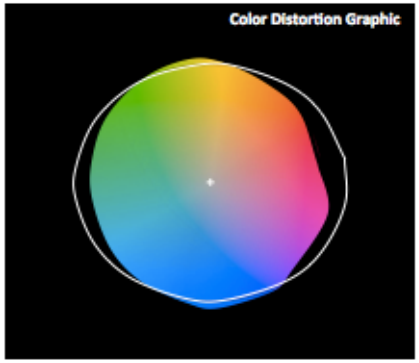
R_f-R_g Chart





Color Vector Graphic





Color Distortion Graphic

Comparison of CRI – CQS – TM-30

		CRI	CQS	TM-30
Score	Fidelity	Ra	Qf	Rf
	Gamut area		Qg	Rg
	General		Qa	
	for hue	R1-R14	Q1-Q14	Rfh,1 - Rfh,16
	Graphic		Saturation icon	Color Vector g.
Test Sample	Num. of samples	8	15	99
	Saturation	medium saturation	strong saturation	Various saturation
	Origin	Munsell samples	Munsell samples	Real objects data
	Color space	CIE 1964 W*U*V*	CIE LAB	CIECAM02
	Chromatic adaptation	von Kries	CMCCAT	CIE CAM02
	Scale	no limit	0-100	0-100
	Reference	Planck/Daylight	Planck/Daylight	Planck-Daylight

Scaling of CRI – CQS – TM-30

Scaling factor

TM-30 Rf

$$R'_f = 100 - 7.54\left(\frac{1}{99}\sum_{i=1}^{99}(\Delta E_{Jab,i})\right)$$

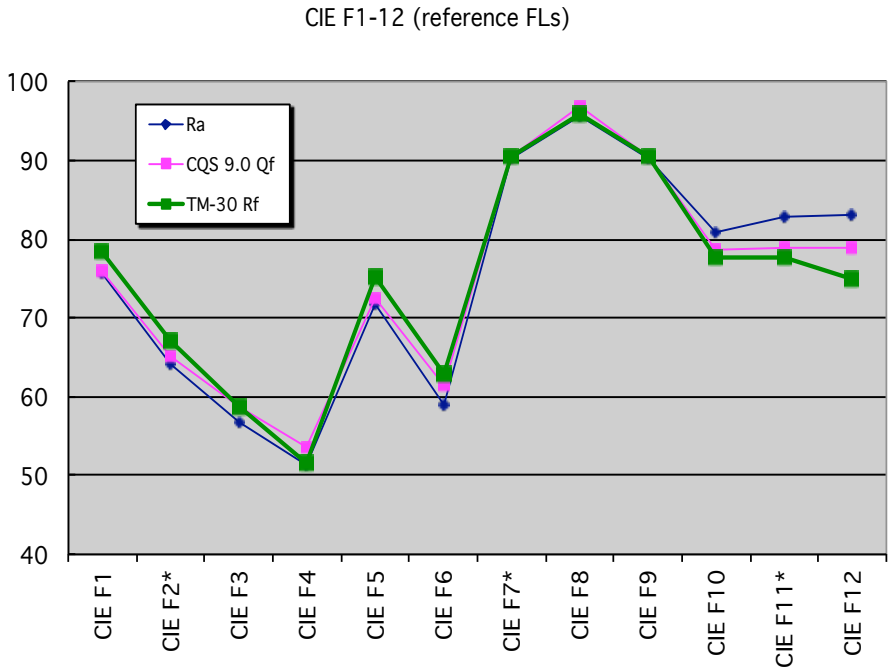
$$R_f = 10\ln\left(e^{R'_f/10} + 1\right)$$

The average score for CIE F1 to F12 is made equal.

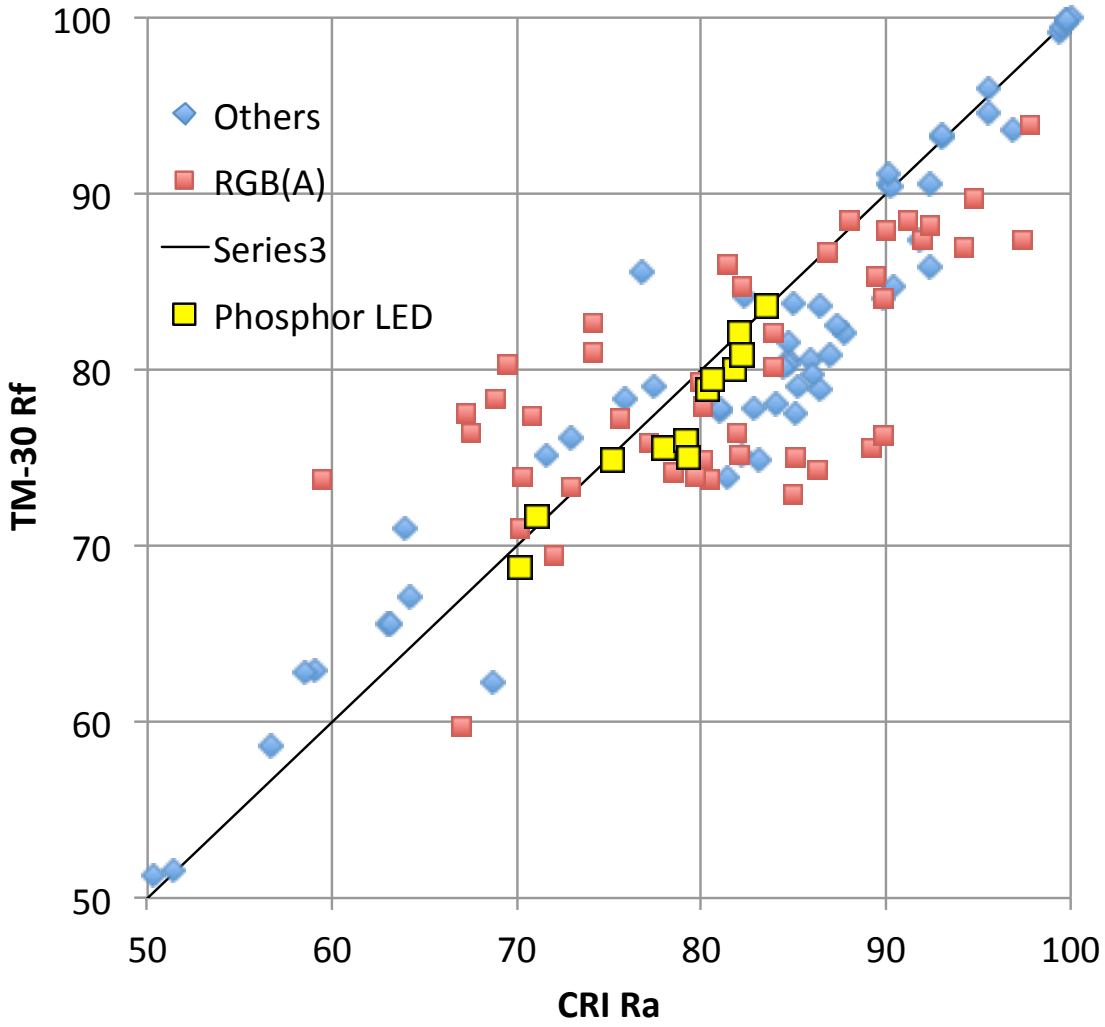
CRI $$\frac{1}{12}\sum_{i=1}^{12} R_{a,i} = 75.1$$

CQS $$\frac{1}{12}\sum_{i=1}^{12} Q_{f,i} = 75.1$$

TM-30 $$\frac{1}{12}\sum_{i=1}^{12} R_{f,i} = 75.1$$



Score differences for various sources



122 sources on CQS 9.0 sheet

Score differences > 5 points are significant.

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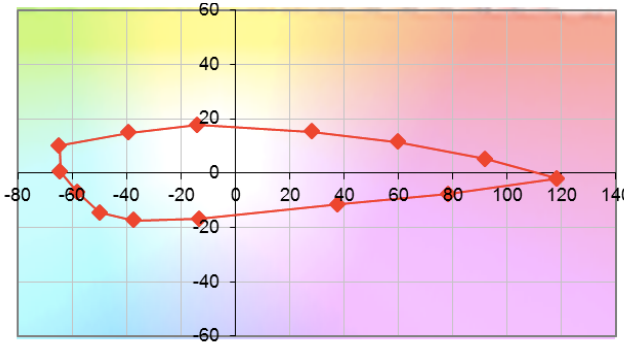
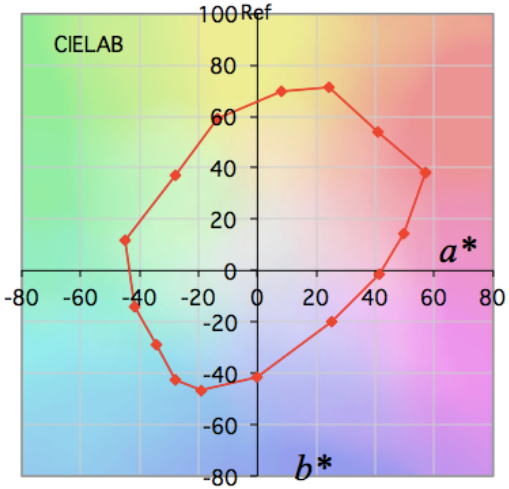
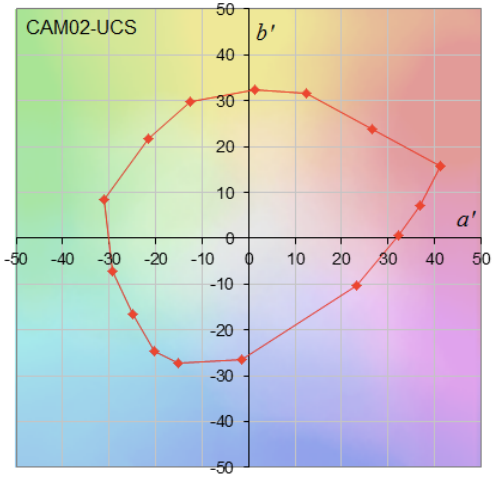
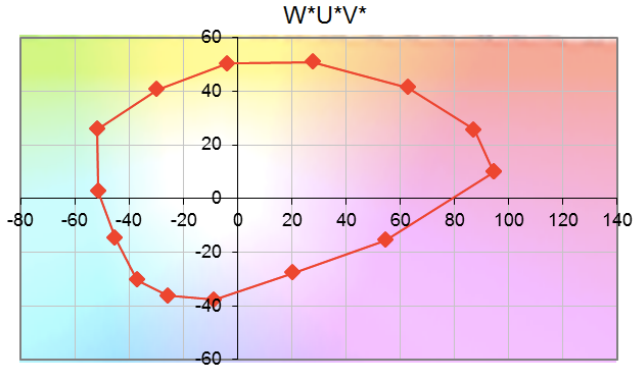
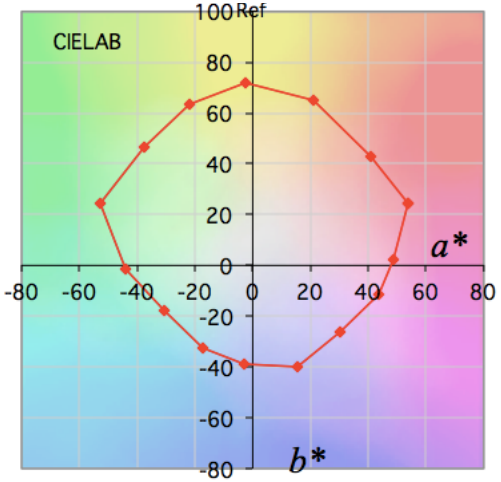
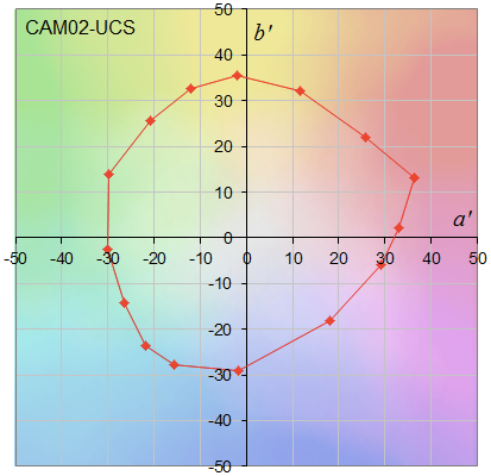
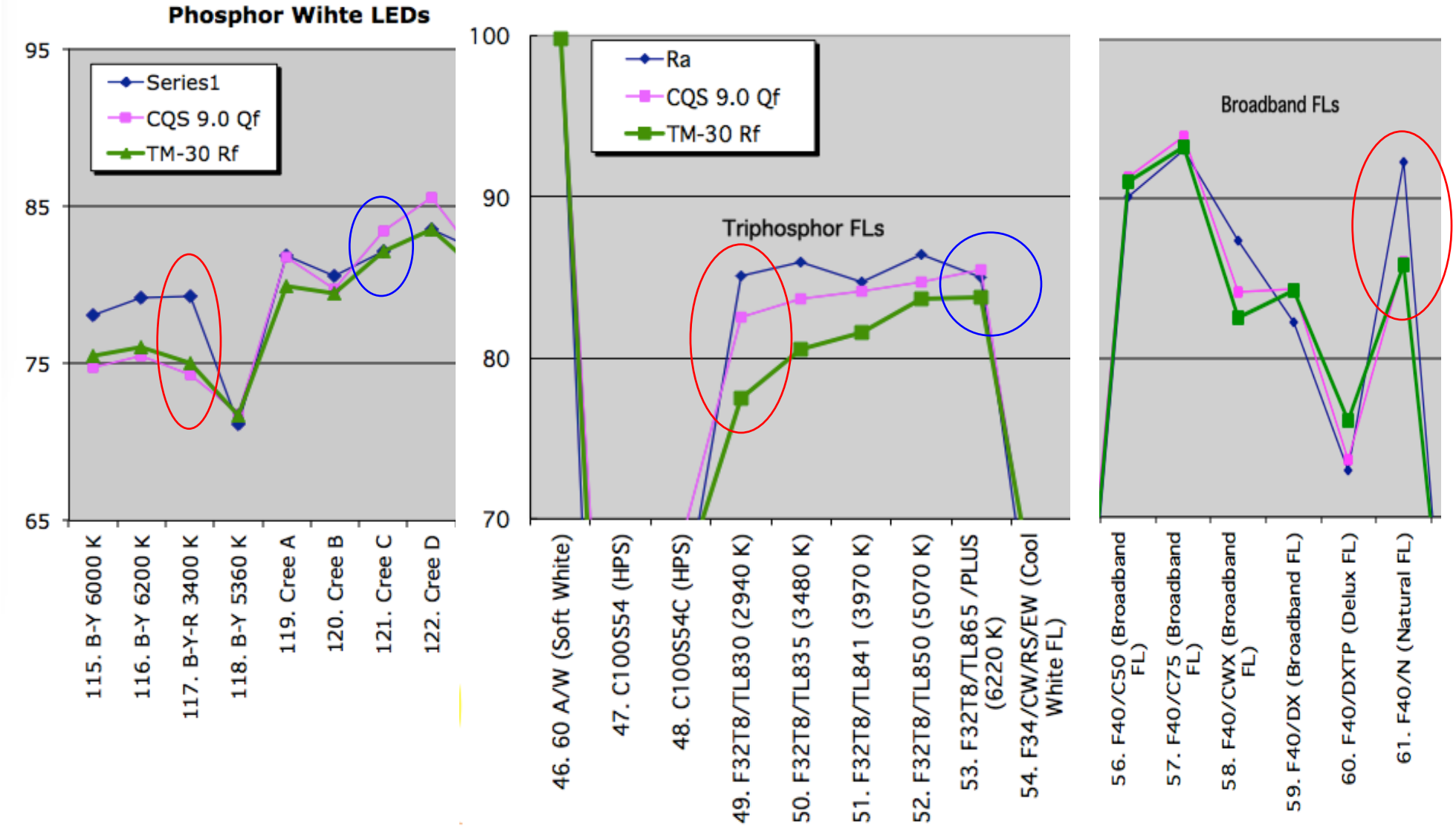
Color Space

Plots of 15 CQS samples.

	W*U*V* used in CRI	CIELAB Used in CQS	CAM02UCS used in TM-30
2700 K Planck			
D65 (6500 K)			

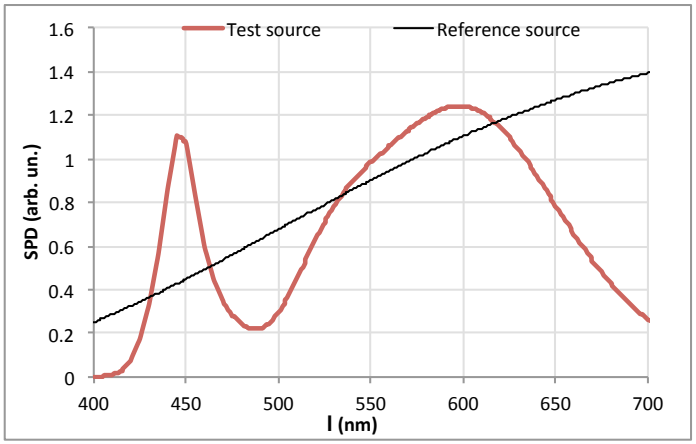
- High weights for red and green color shifts
- Low weights on yellow and blue region.
- R9 sensitive at low CCT.

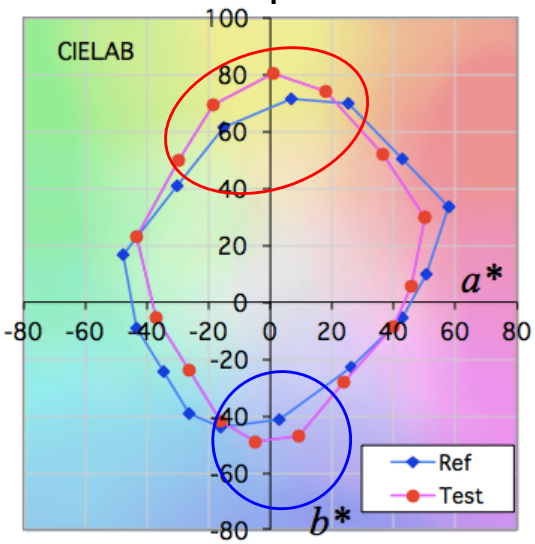
Examples of this effect



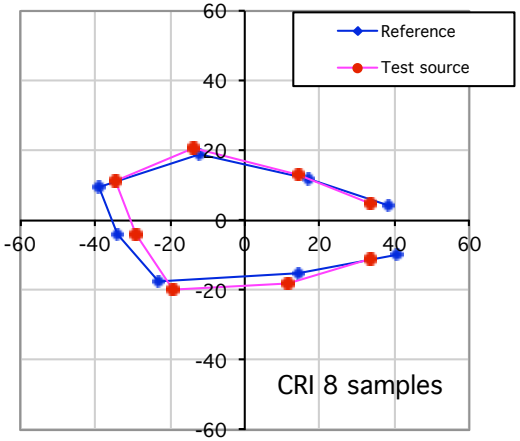
No. 117 White LED (3420 K)

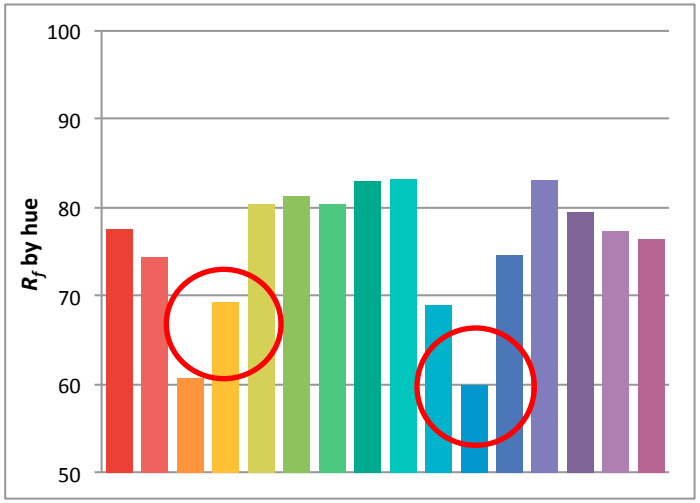
R_a=80
R_f=75

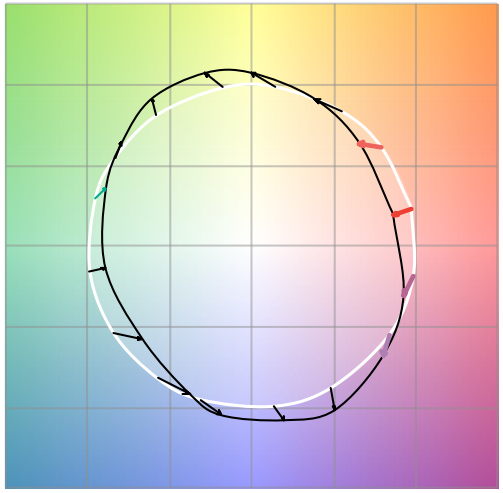


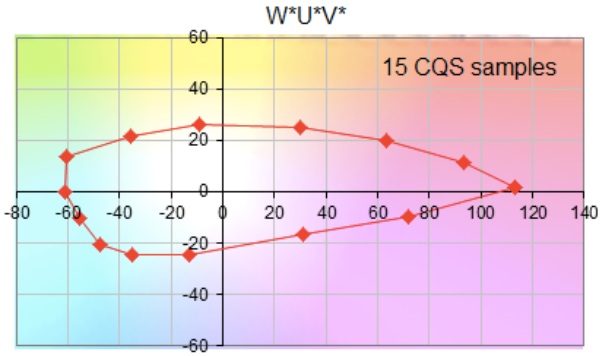


CRI samples on W*U*V*





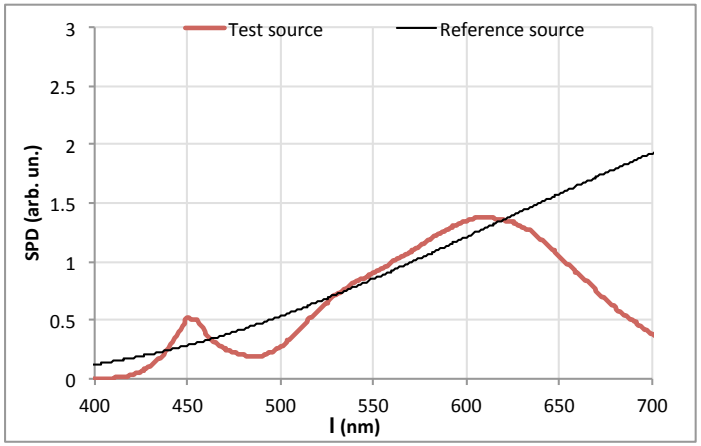


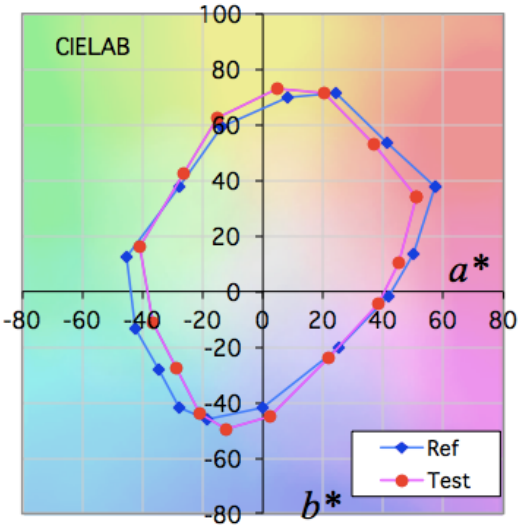


Yellow-blue shifts are large in this example, resulting in higher Ra value.

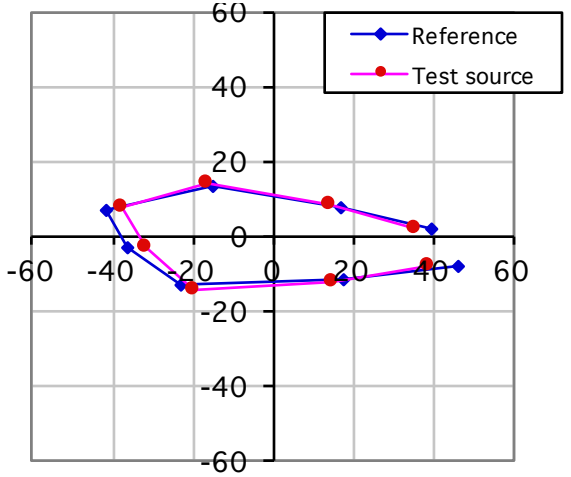
No. 121 White LED (2770 K)

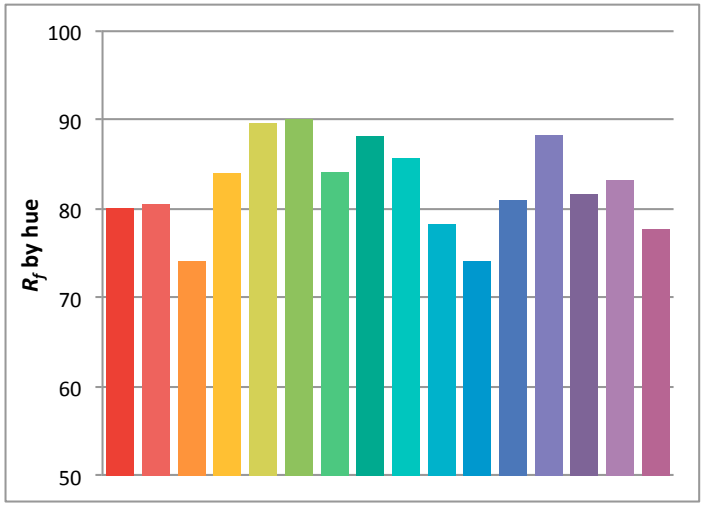
R_a=82
R_f=82

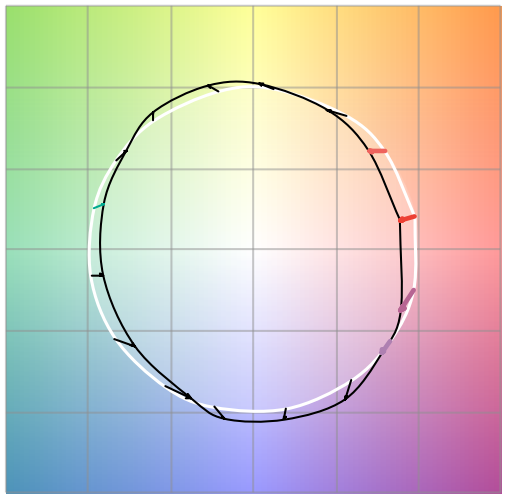


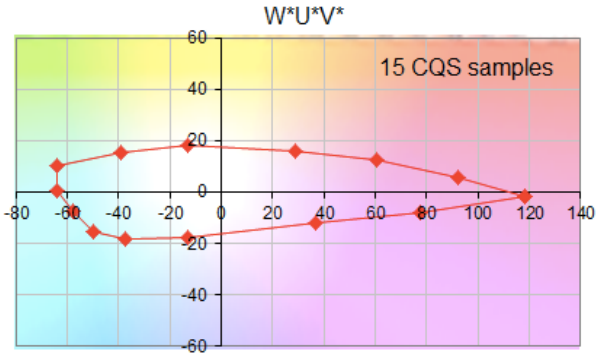


CRI 8 samples on W*U*V*





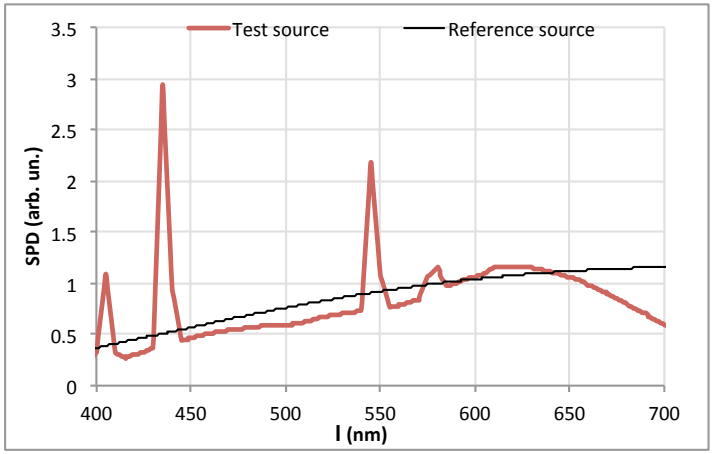


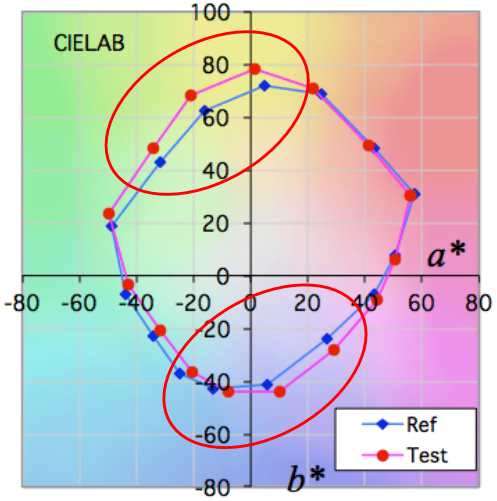


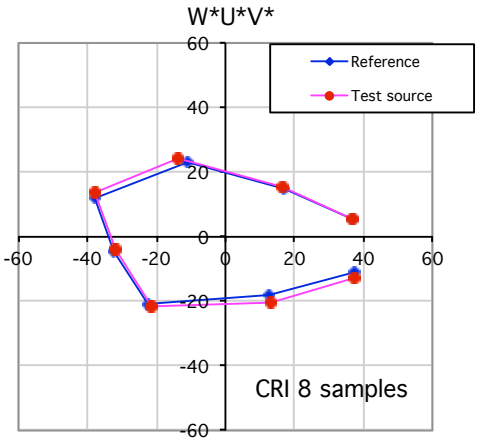
Yellow-blue shifts are small in this example, showing little advantage in CRI score.

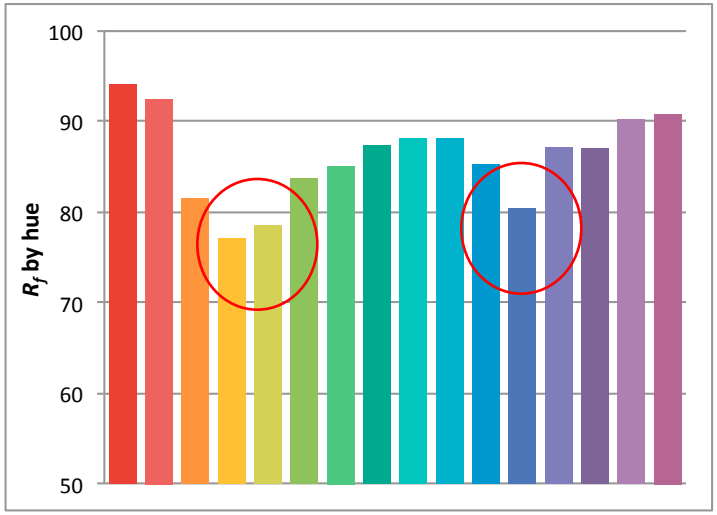
No. 61 Natural FL (3900 K)

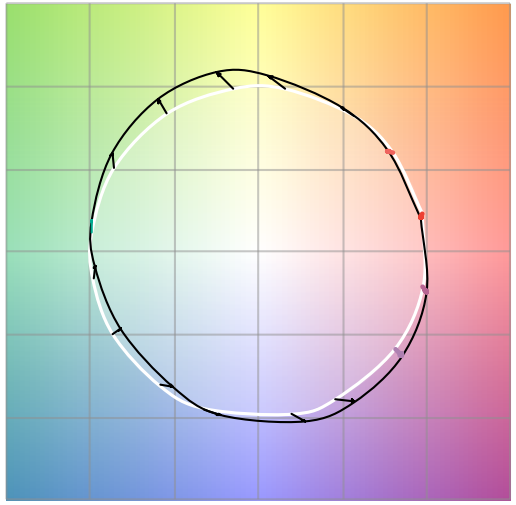
R_a=92
R_f=86

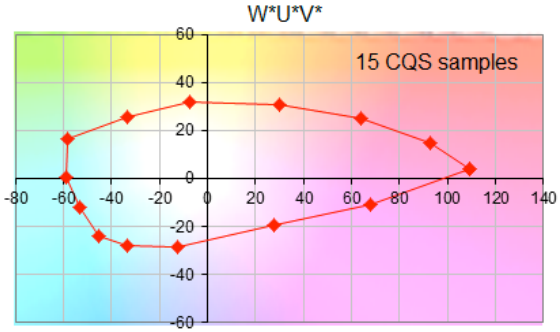






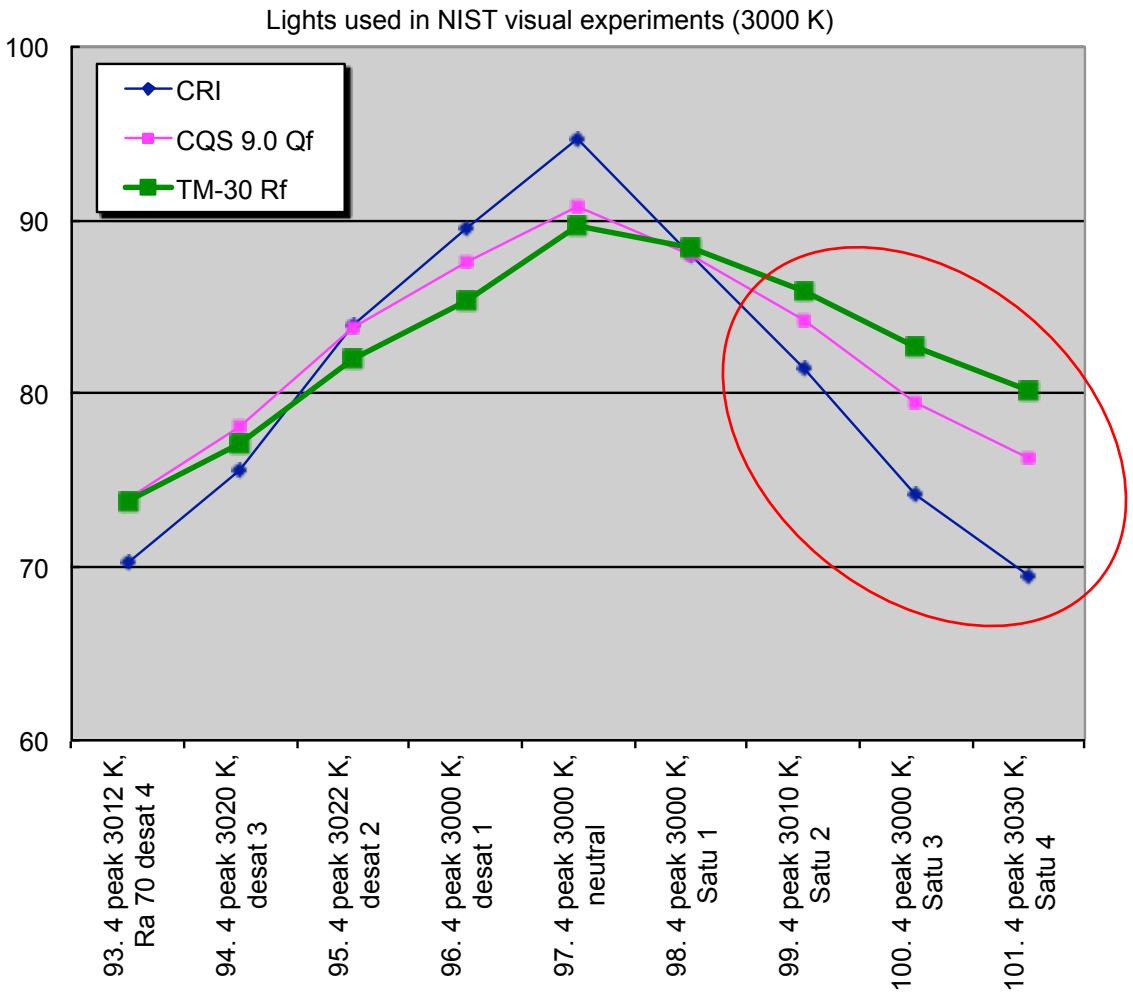


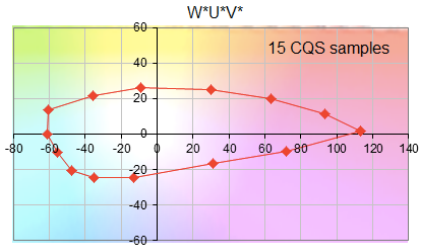


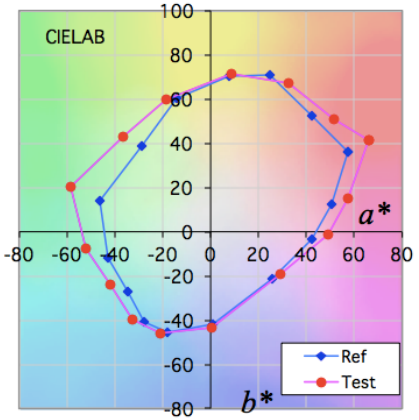


Yellow-blue shifts are large in this example, resulting in higher Ra value.

The other effect of color space
(for saturated lights)



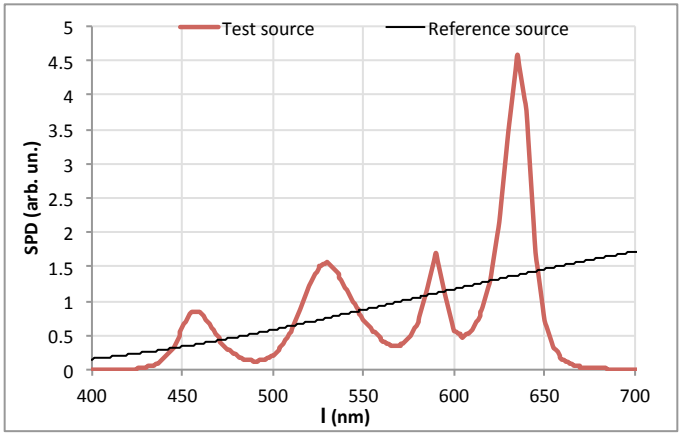


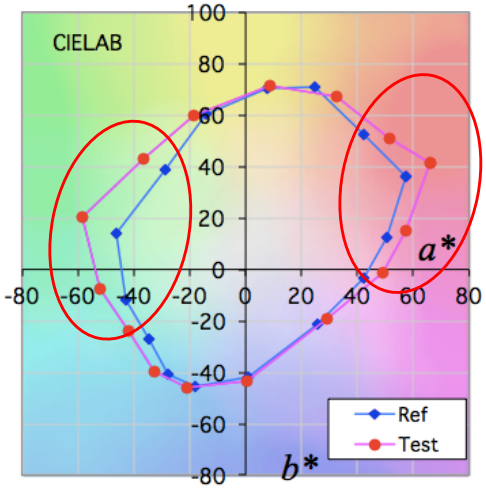


CRI R_a value goes down sharply as red-green saturation increases.

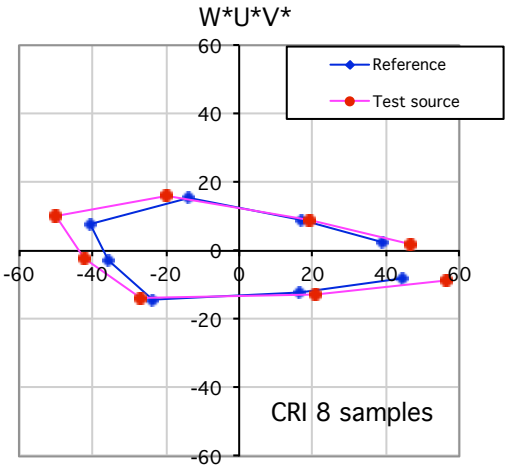
No. 101 Saturated-4
(3000 K)

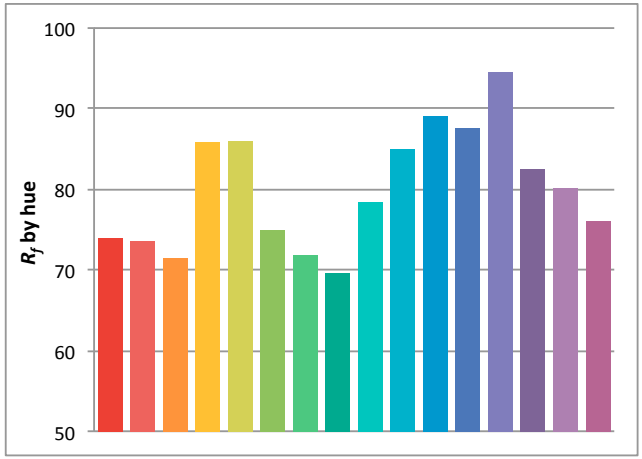
R_a=69
R_f=80

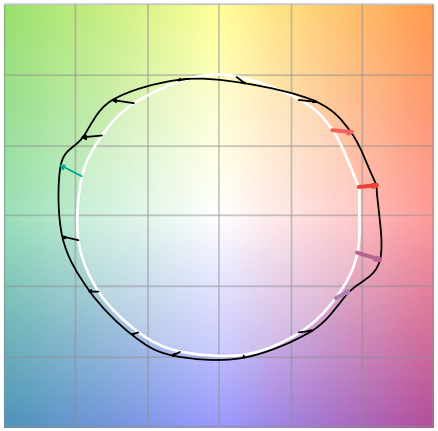


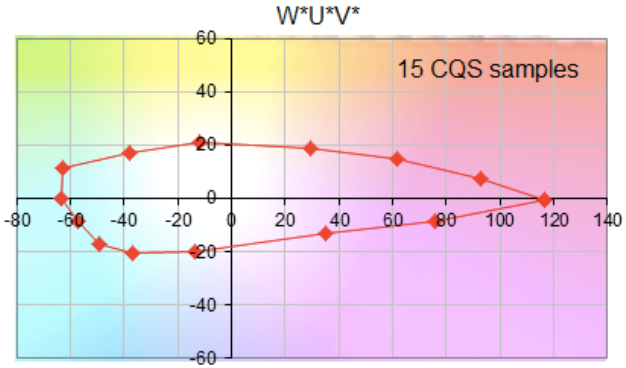


CRI 8 samples
on W*U*V*







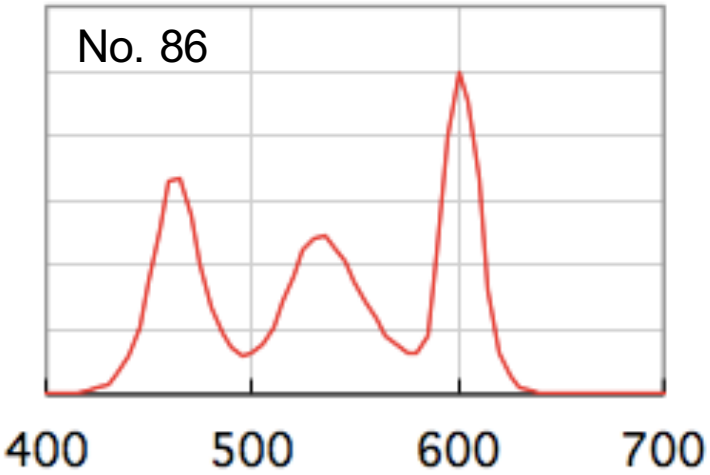


- Oversaturation is at heavily weighted red-green region.
- Ra values tend to go lower.

Test Sample problem

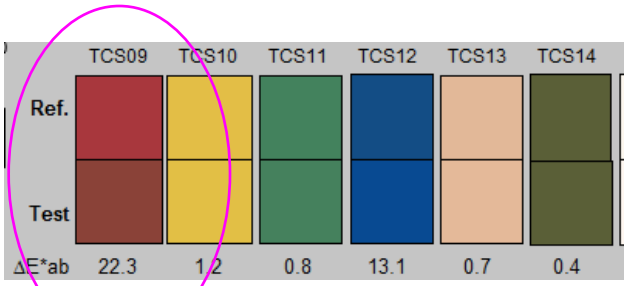
– CRI allows very poor red rendering

An example



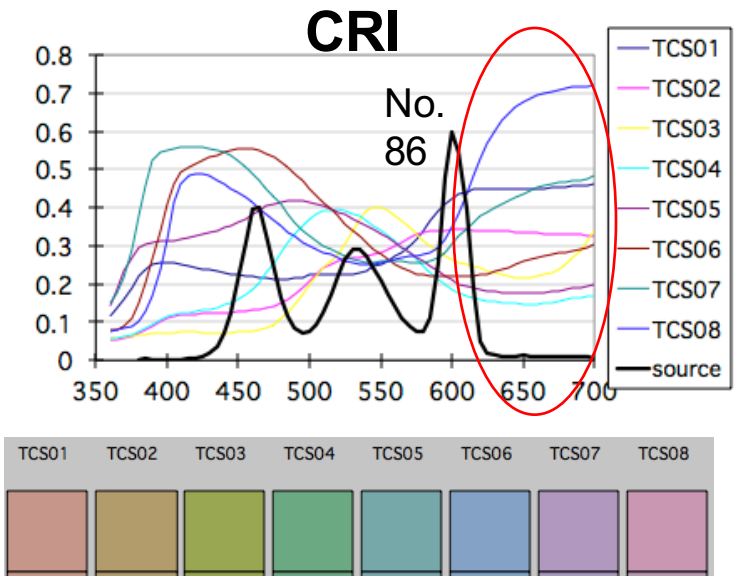
R_a= 82

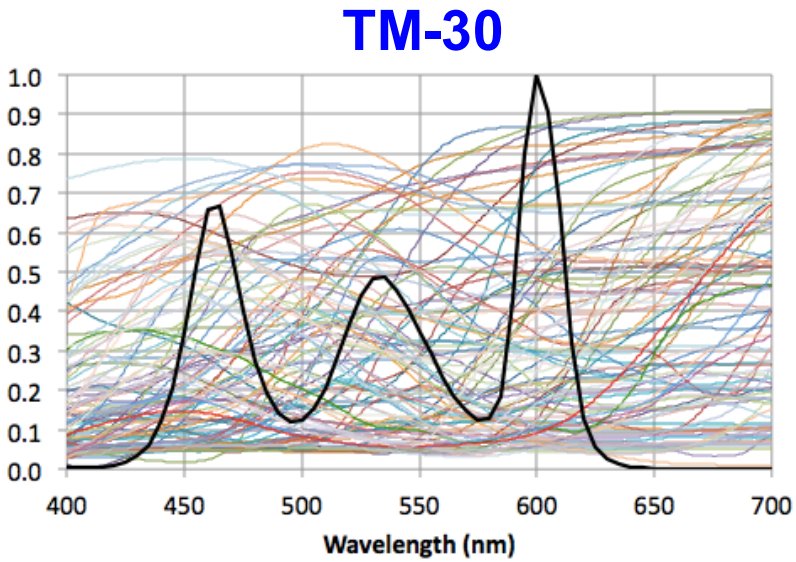
R_f= 76

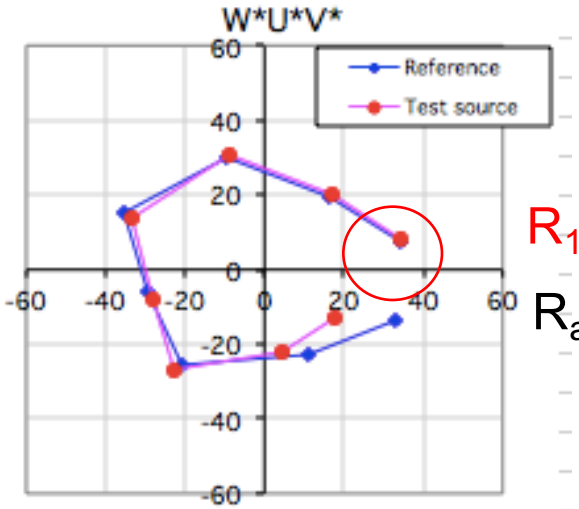


R_9= -97

Spectral sensitivity of test samples



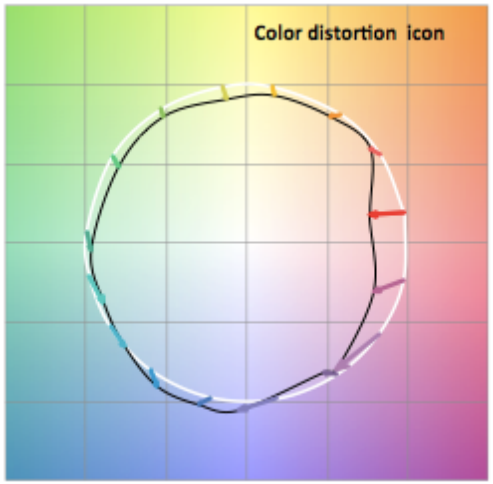




R_1=93

R_a=82

CRI fails to catch the problem with saturated red objects.



R_1=54

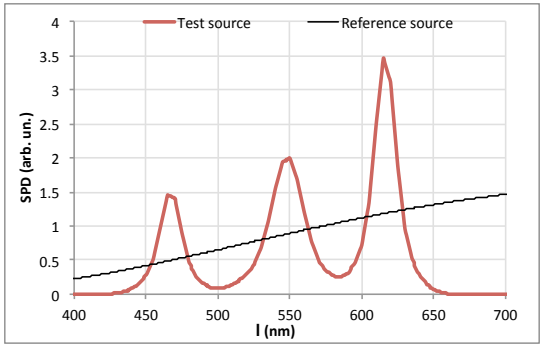
R_f=76

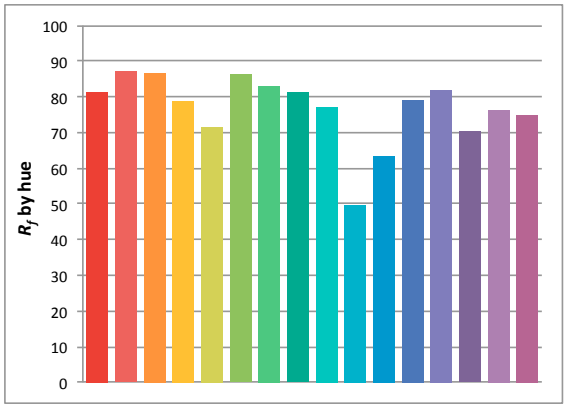
TM-30 and CQS catches this problem and reflect in score.

Color Sample problem (2)
– CRI anomaly / TM-30 spectral feature

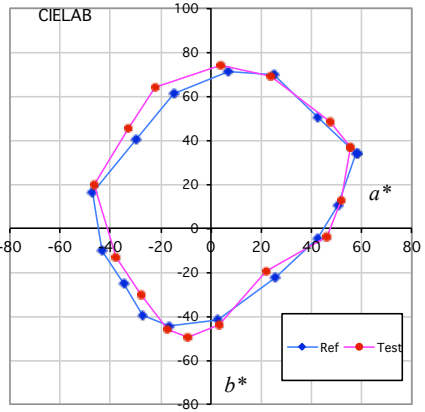
No. 72
(3300 K)

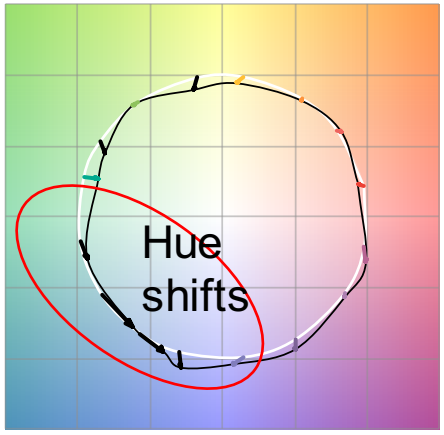
R_a=90
R_f=76
(Q_f=80)



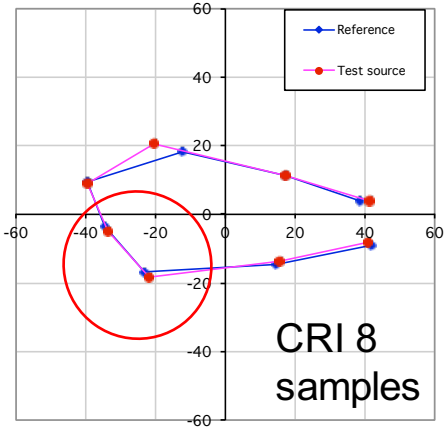


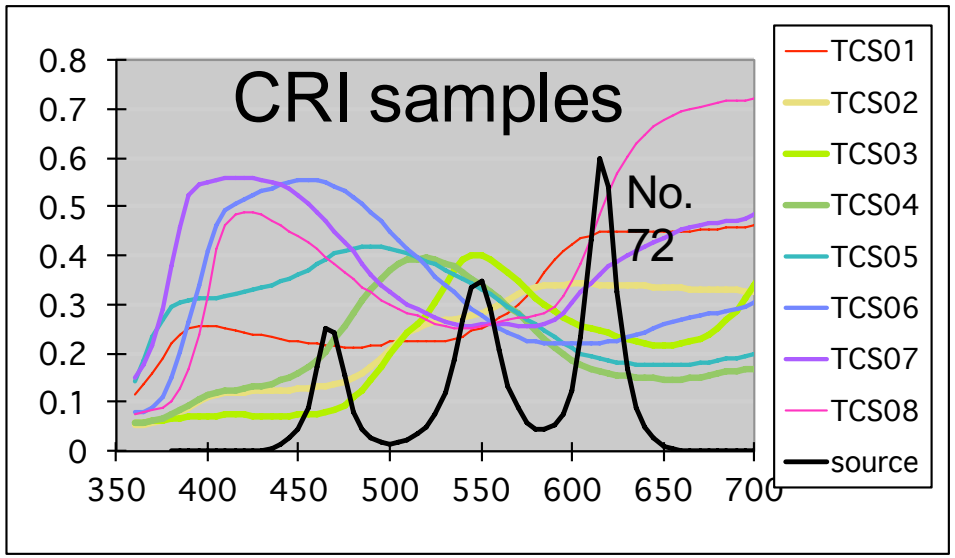
CQS samples
on CIELAB

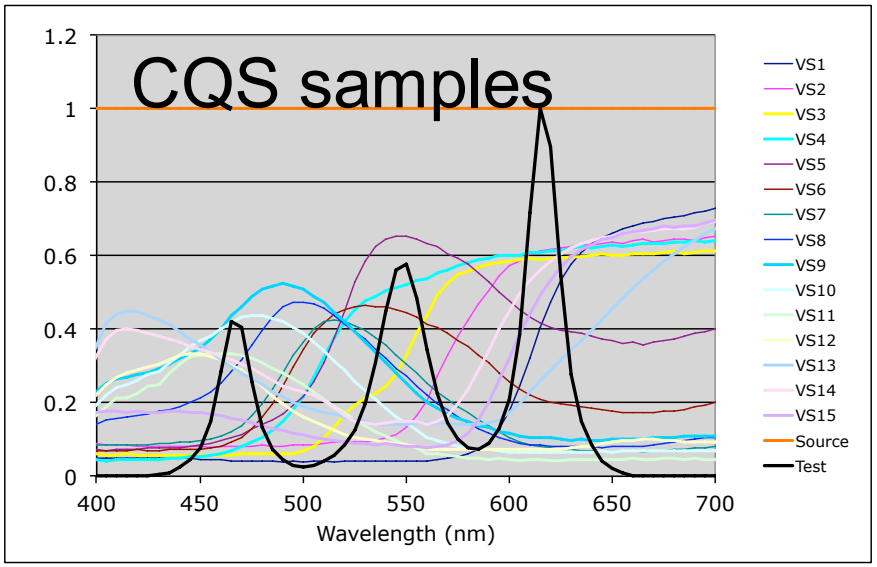


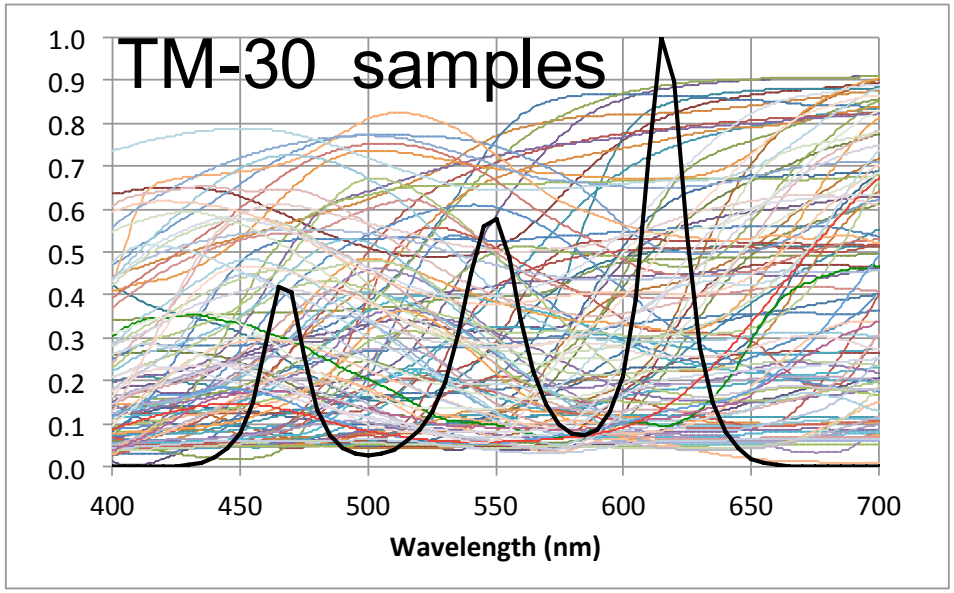


CRI samples
on W*U*V*

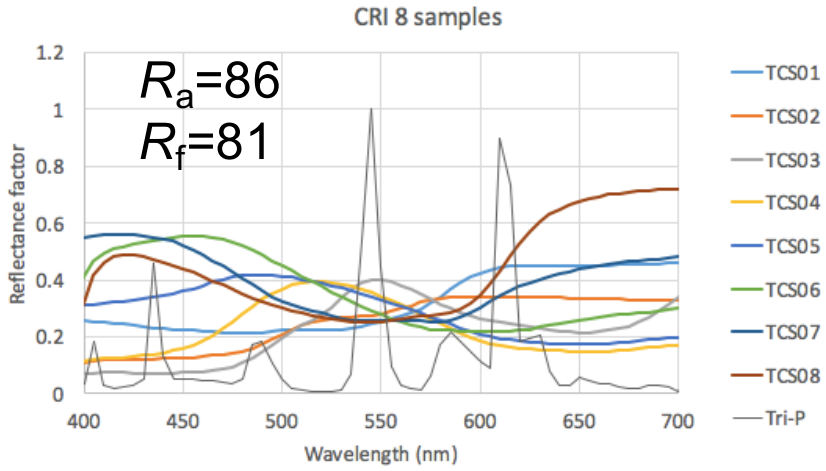


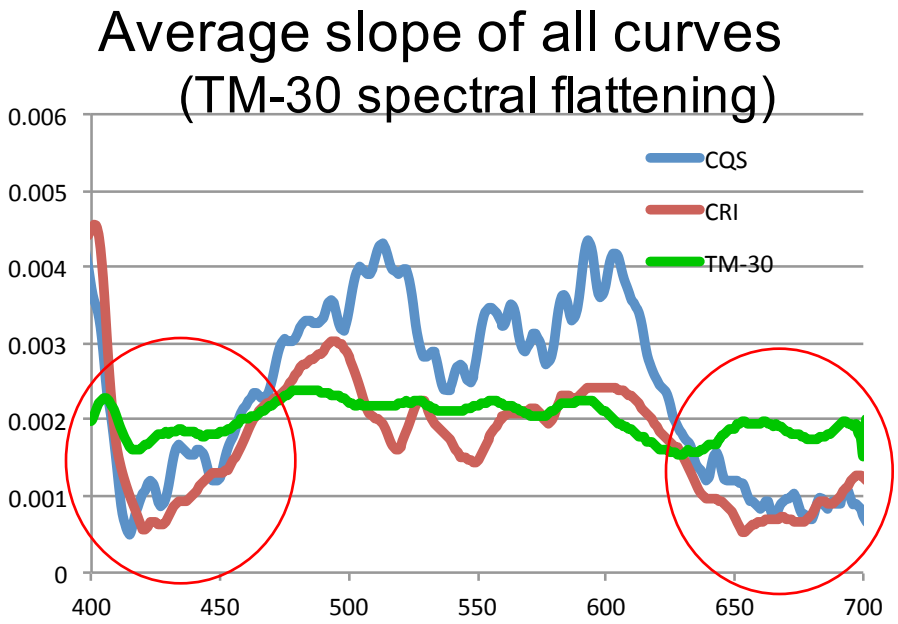


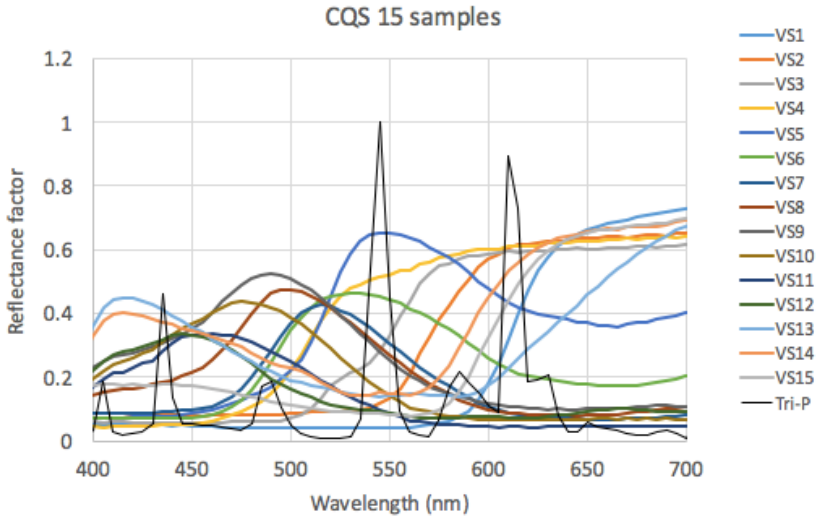


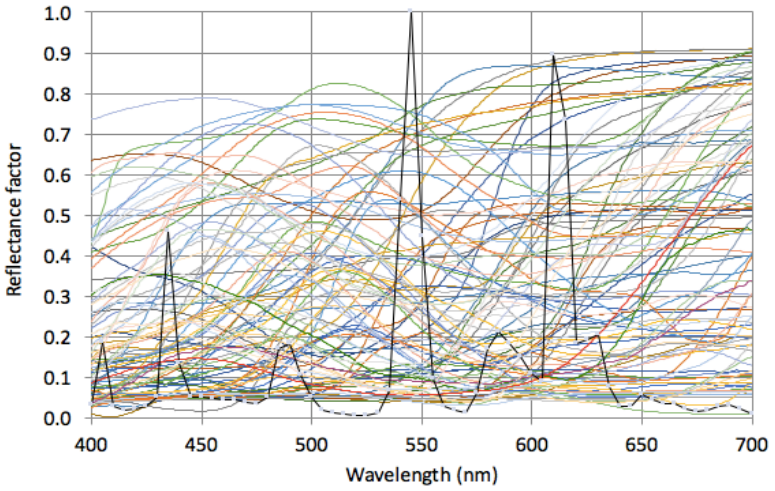


- The CRI 8 sample curves have some tendency.
- The set of 8 samples allows some combinations of peaks that yield unreasonably high score (anomaly)
- This tends to occur with narrowband sources.
- It is difficult to occur with 99 samples.









- CRI sample slope falls at both ends, while TM-30 is made flat.
- This feature of TM-30 allows fair evaluation of all colors (including strong purple), while it tends to require broader spectra.

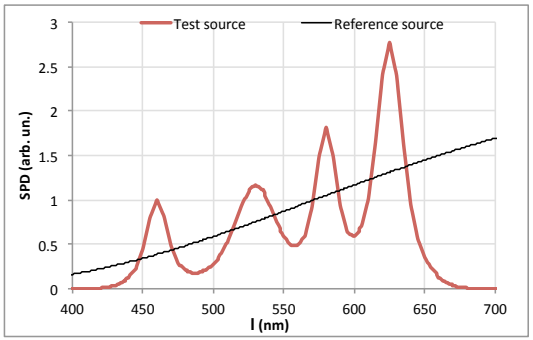
Color Sample problem (3)
– CRI anomaly / TM-30 spectral feature

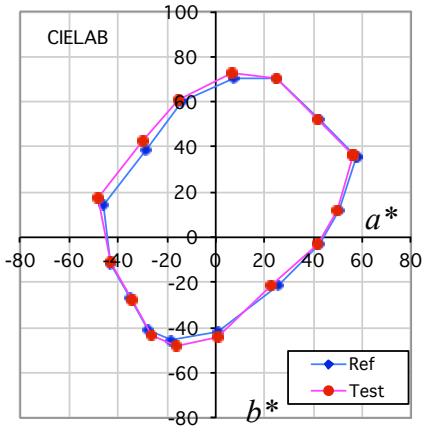
No. 19
(3300 K)

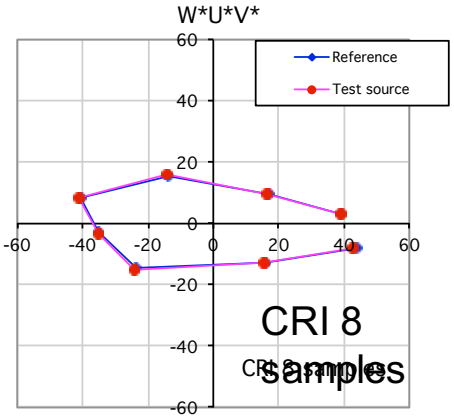
R_a=97
R_f=87
(Q_f=93)

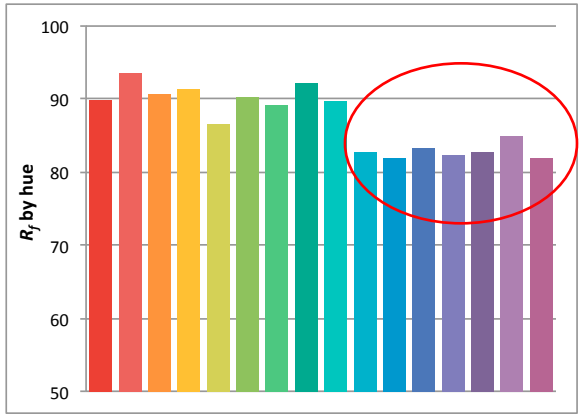
CQS samples
on CIELAB

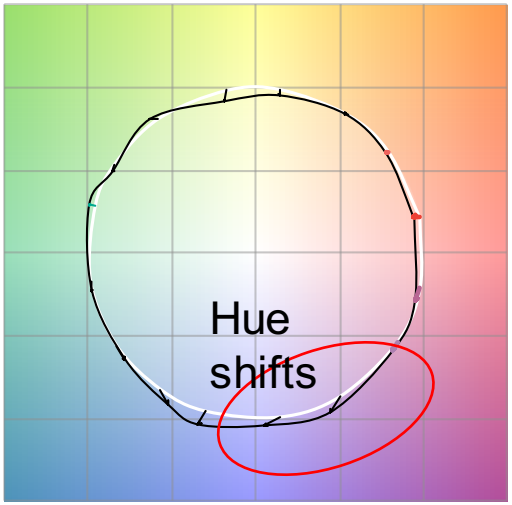
CRI samples
on W*U*V*

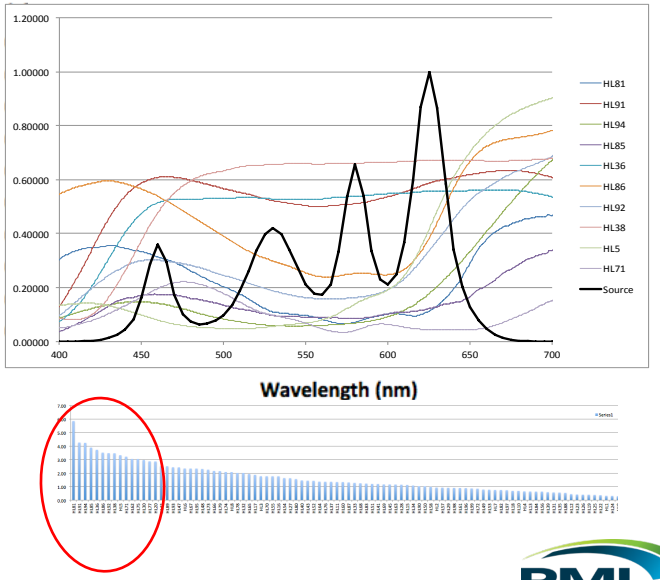








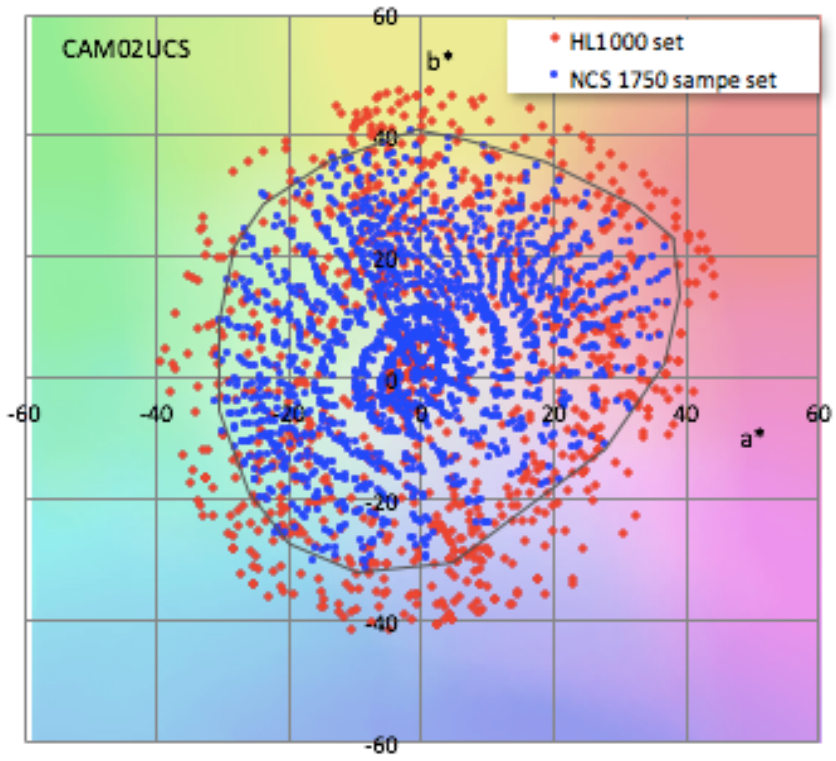




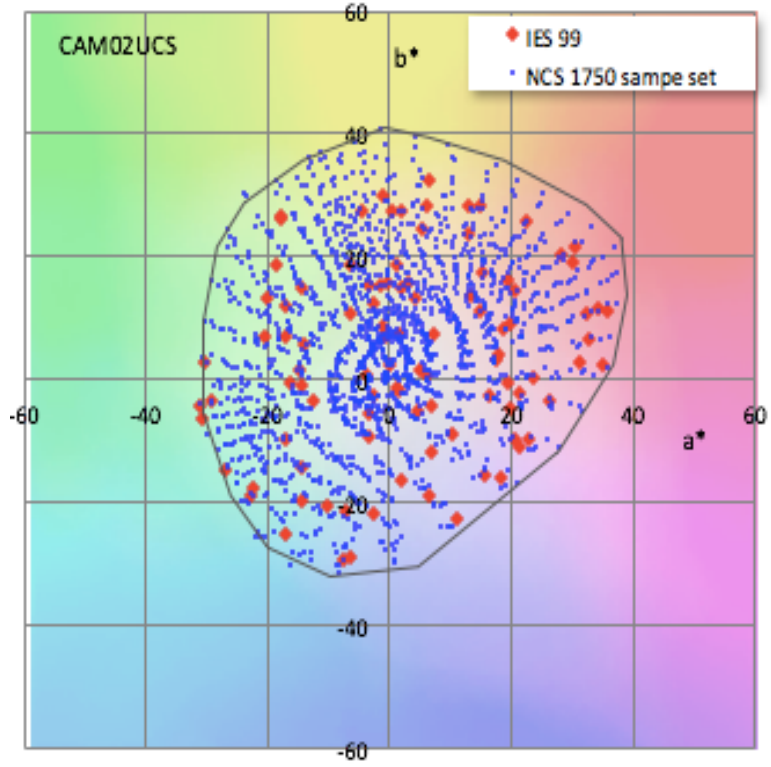
Sample gamut of TM-30 reduced

to the size of the NCS sample set

HL1000 from U. Leads
(red dots)



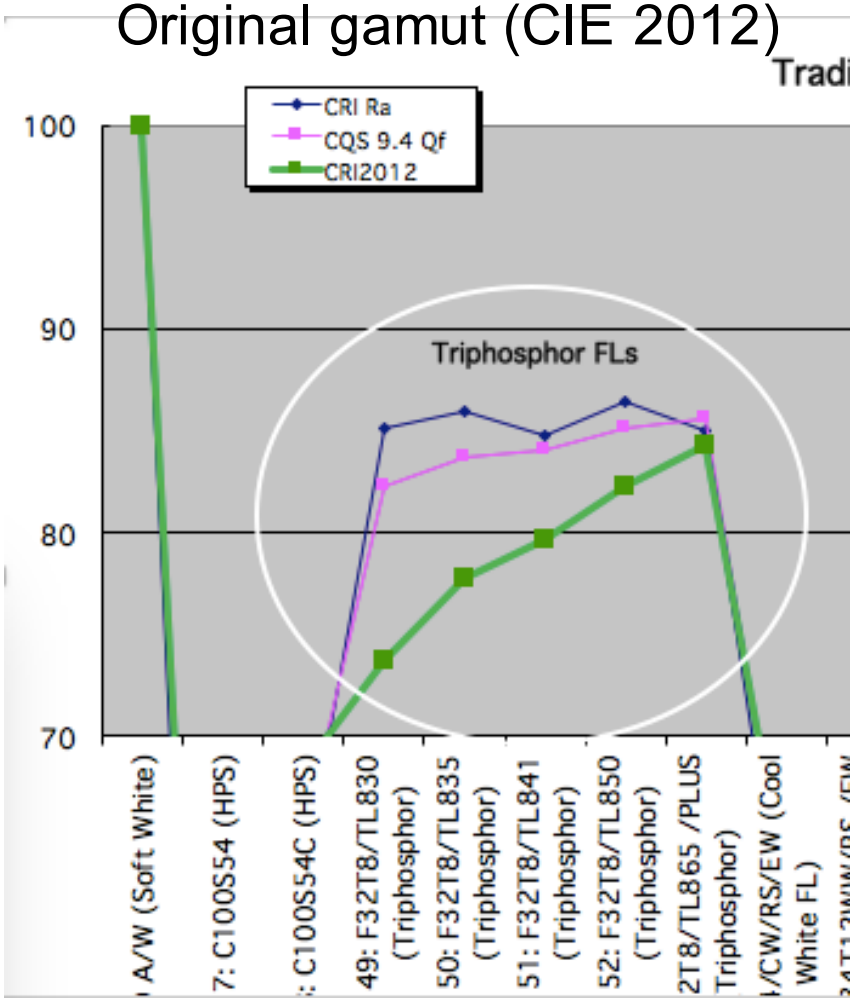
Red:TM-30 99 samples
(red dots)



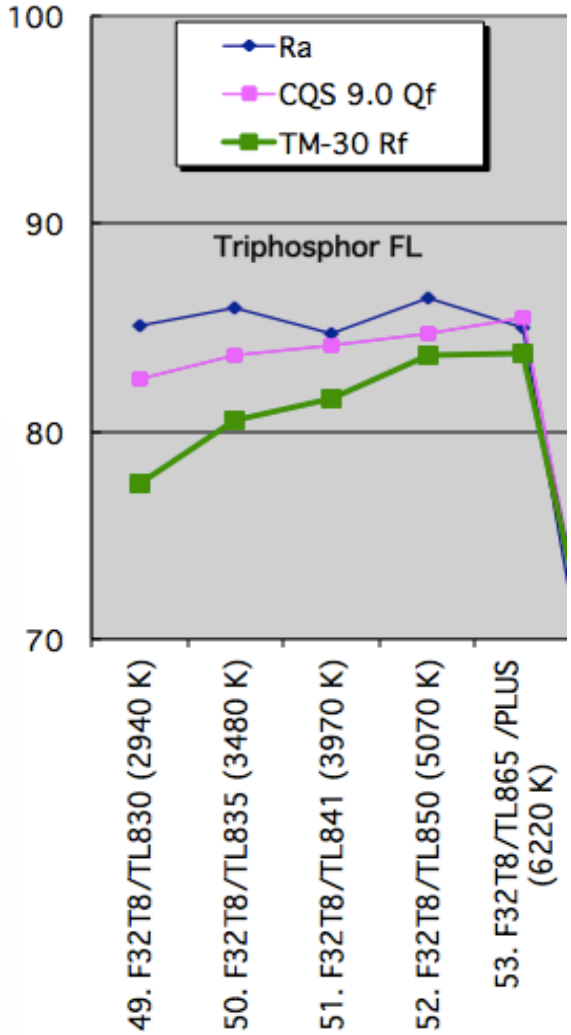
This is from consideration that such extremely color-saturated objects are not common in our daily life.

The effect of gamut reduction

Original gamut (CIE 2012)



After gamut reduced (TM-30)



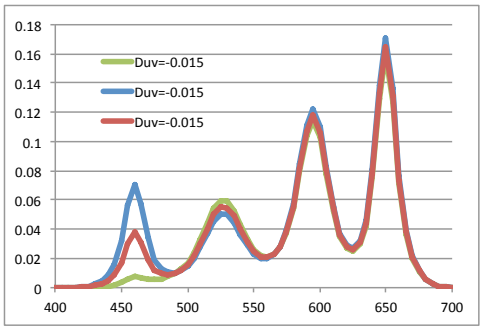
Current version of TM-30

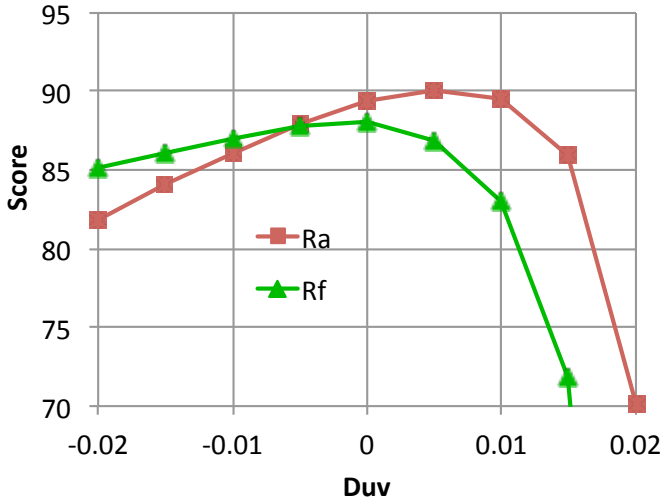
This version required more broader band to obtain the same score.

CRI R_a response to Duv shift

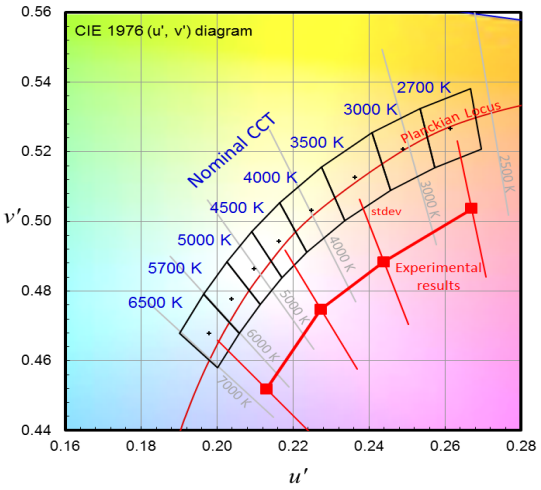
- Poor performance of von Kries chromatic adaptation transform

2700 K



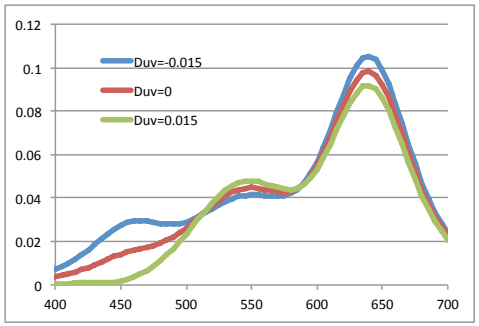


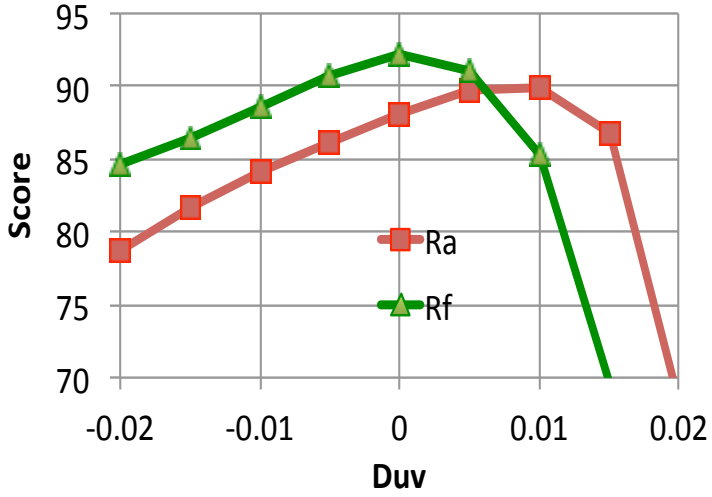
NIST vision experiment in 2013



Ohno, Y., Fein, M., Vision Experiment on Acceptable and Preferred White Light Chromaticity for Lighting, CIE x039:2014, pp. 192-199 (2014).

2700 K



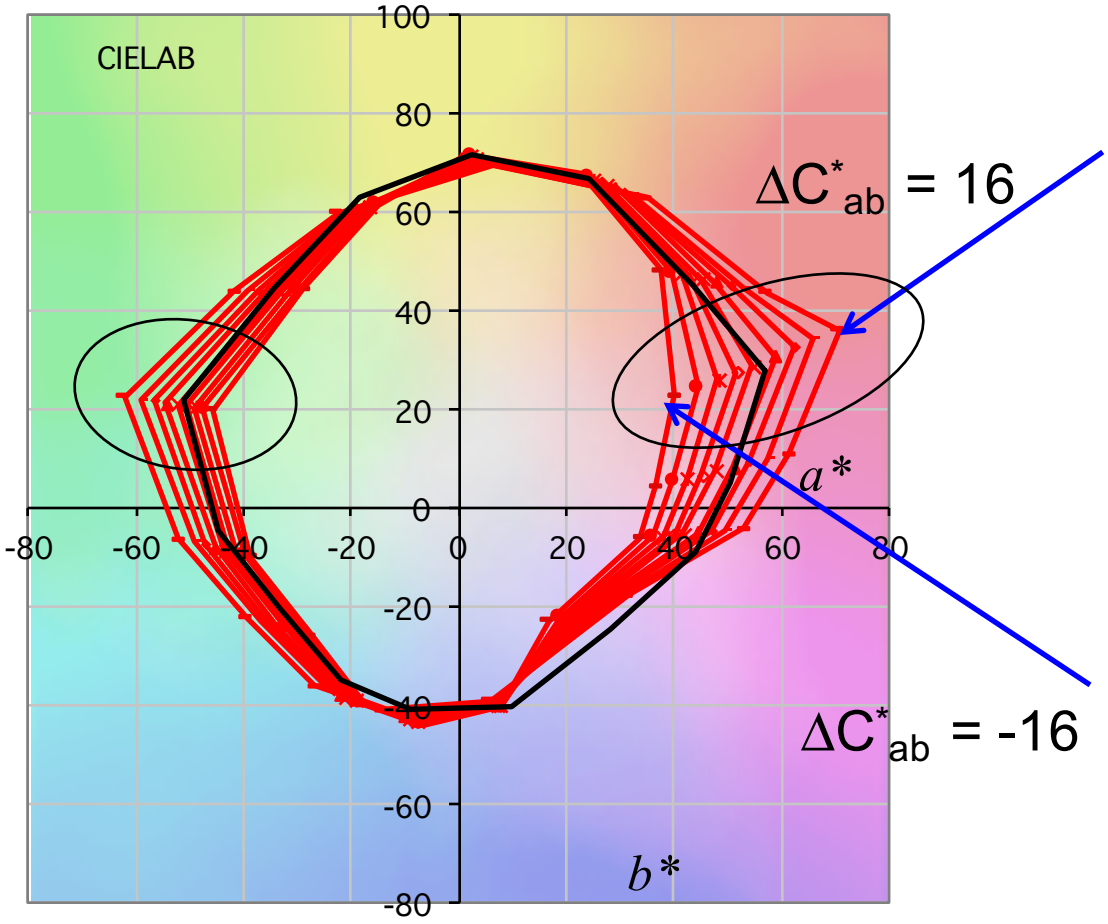


Relation to Color Preference

– CRI penalizes good preferred lights

2014 Vision Experiment at NIST on preferred chroma saturation level

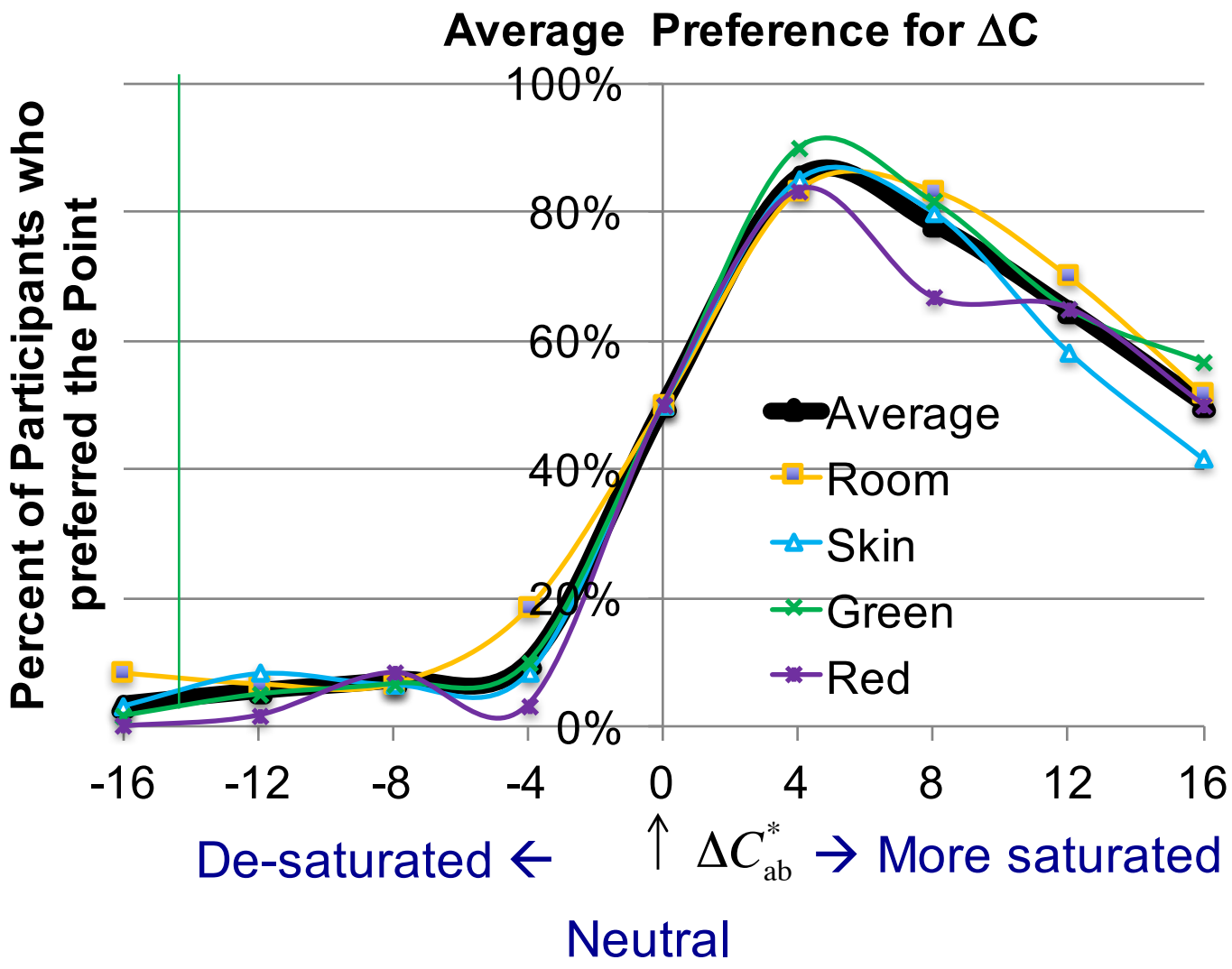
- 20 subjects
- 3 CCTs (2700, 3500, 5000 K), D_{uv}= 0
- 3500 K, D_{uv}= -0.015



Most saturated

Most de-saturated

Results



(1) Entire room

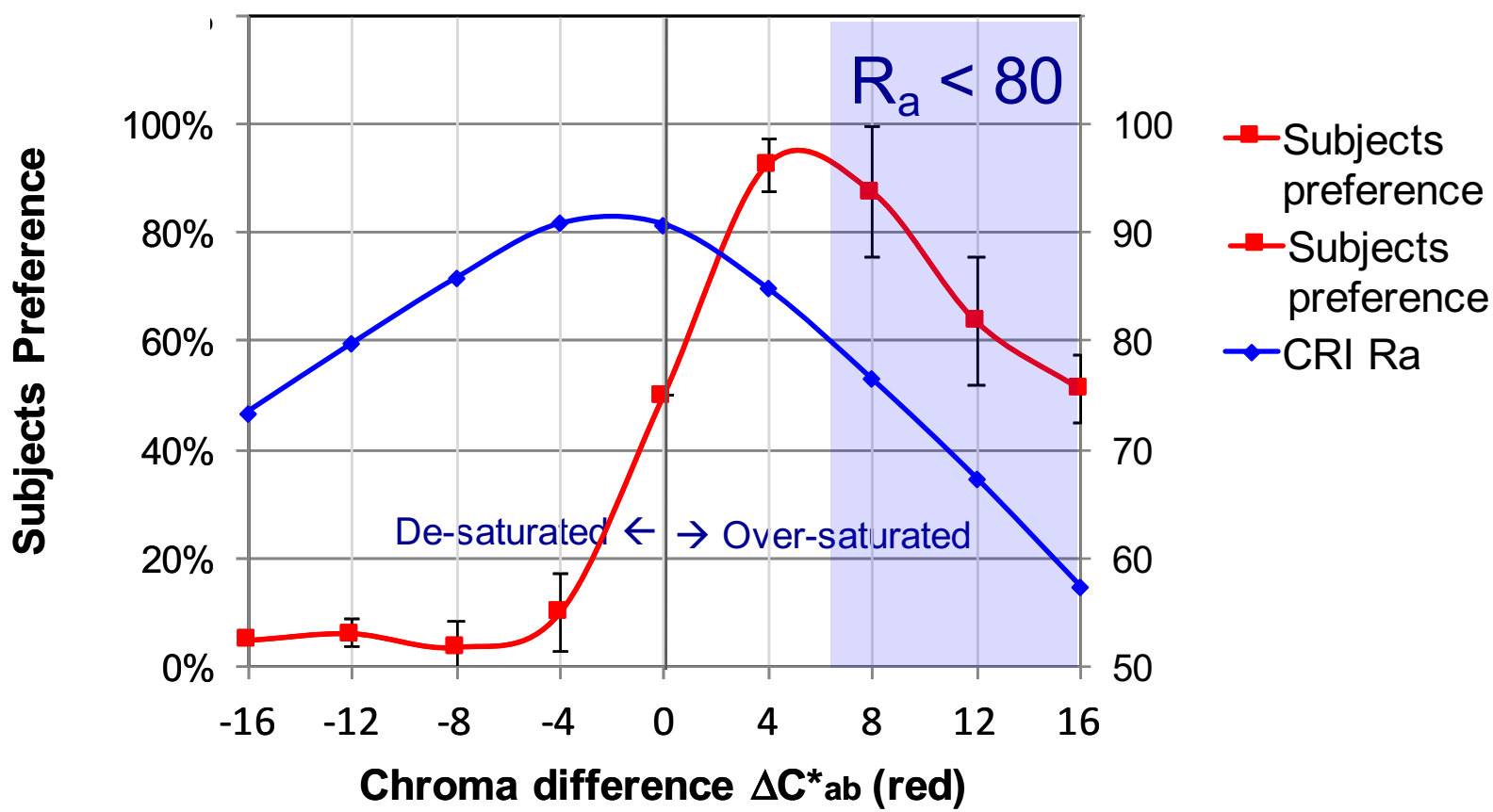
(2) Skin tone of subject

(3) Red fruits/vegetables

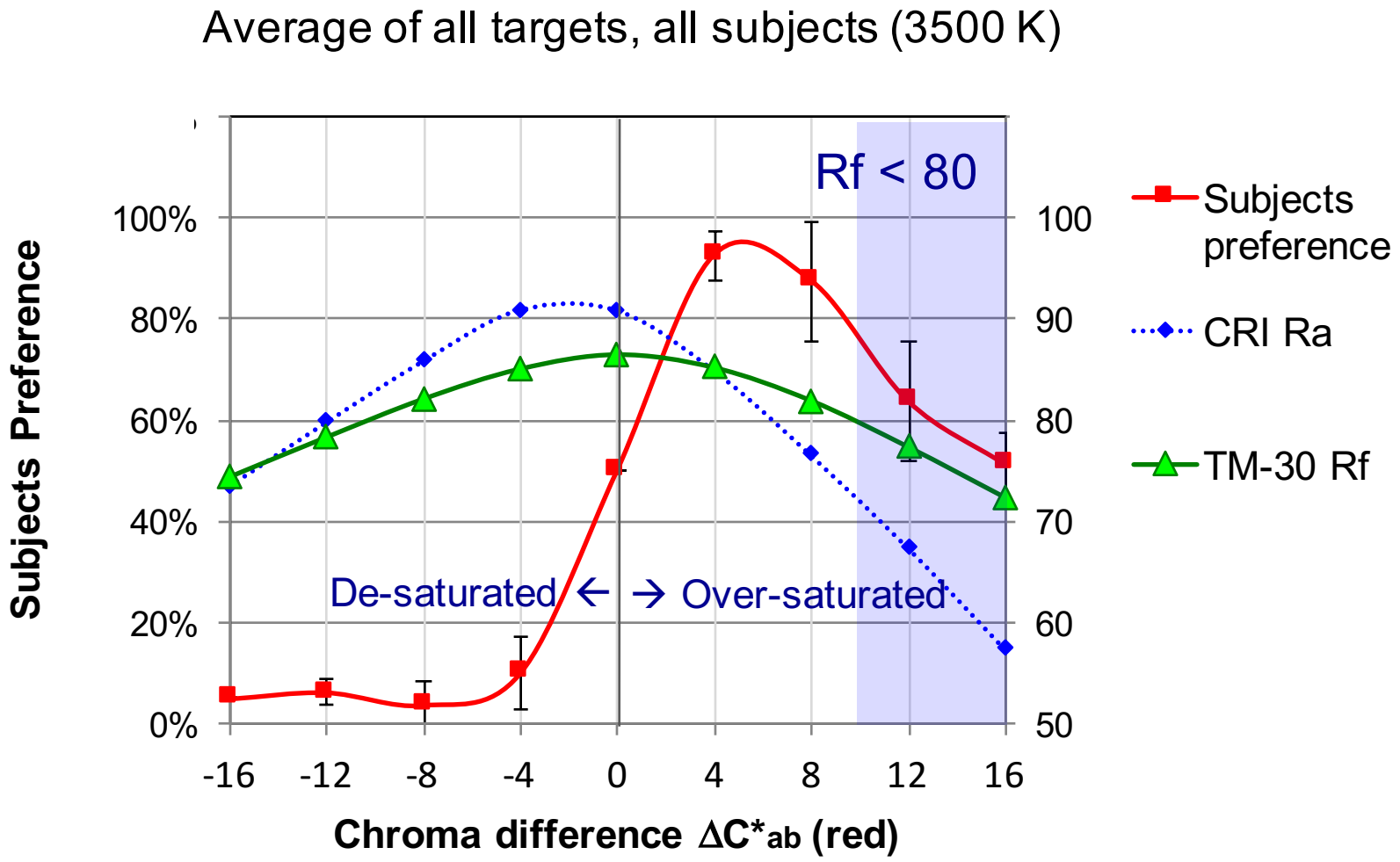
(4) Green fruits/vegetables

Reference: Y. Ohno, M. Fein, C. Miller, Vision Experiment on Chroma Saturation for Color Quality Preference, CIE 216 :2015, pp. 60 – 69 (2015)

Average of all targets, all subjects (3500 K)

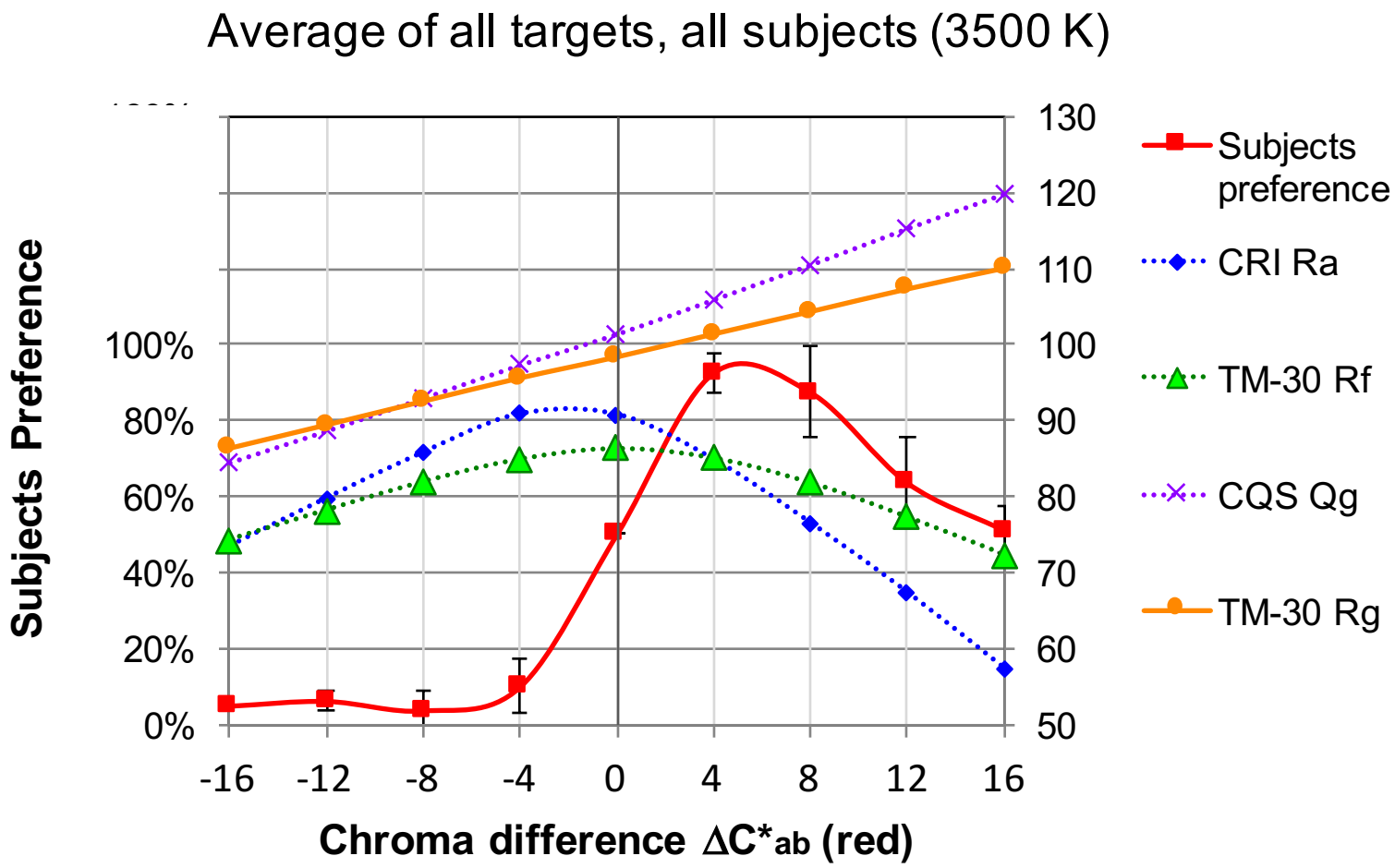


CRI penalizes or exclude many preferred light sources.



Problem is less in TM-30 R_f.

Gamut index R_g

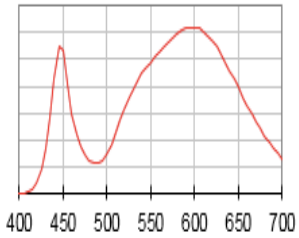


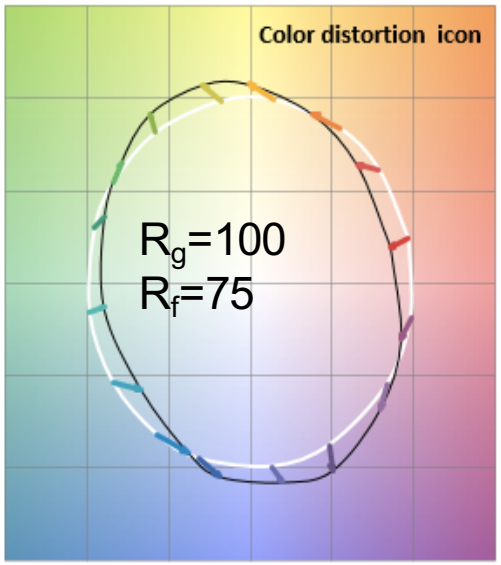
R_g is not proportional to preference, but it can tell if light is de-saturating or saturating (preferred side).

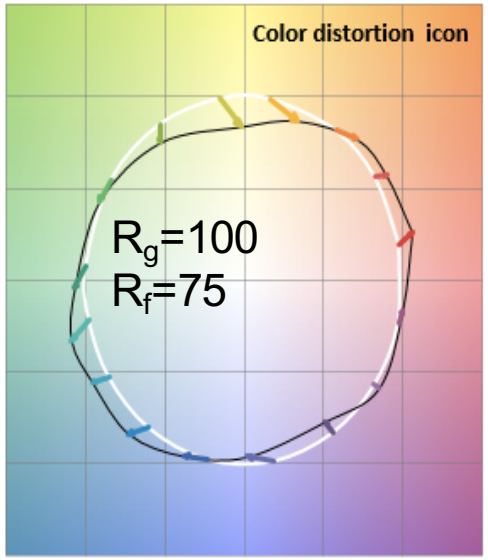
Limitation of R_g

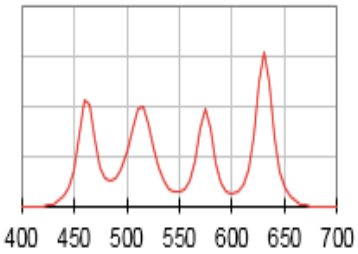
- ave. of all hues

R_g equal but different shapes









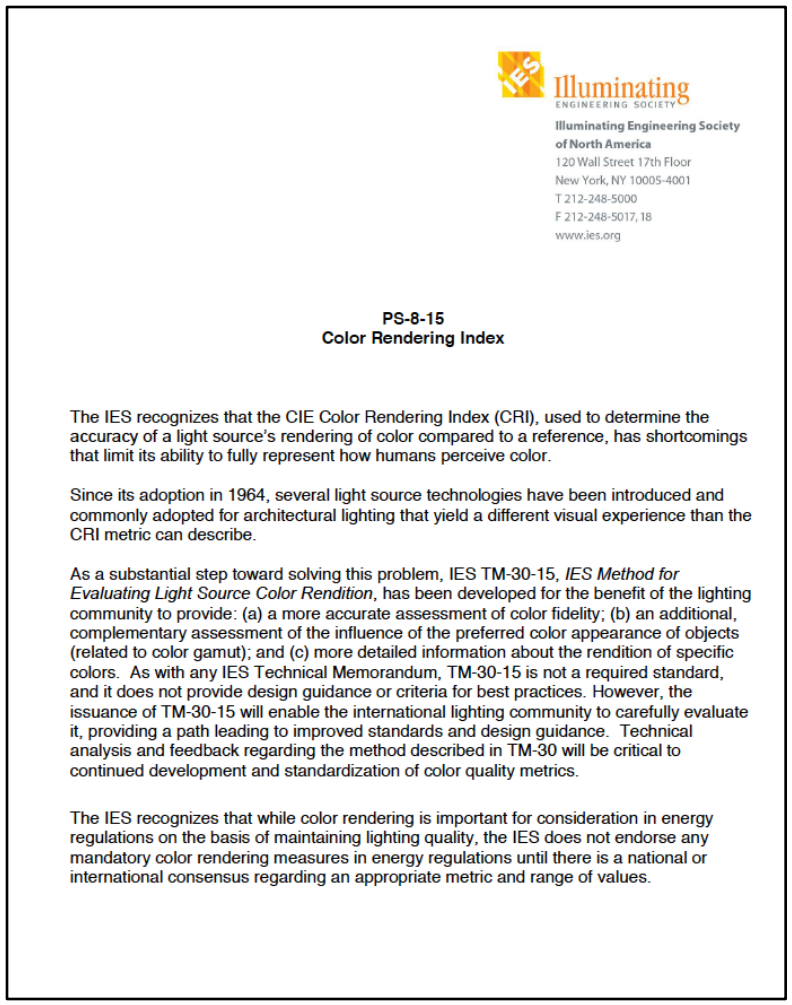
- Perceived rendering of these two lights is very different.
- Gamut area is not sufficient to address color preference.

OUTLINE

1. Outline of TM-30
2. Analysis of CRI and TM-30
   - Color space
   - Test color samples
   - Relation to color preference
3. Position statements
4. Conclusions

IES Position statement on CRI – 2015

Issued Sep. 2015



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www.ies.org

PS-8-15
Color Rendering Index

The IES recognizes that the CIE Color Rendering Index (CRI), used to determine the accuracy of a light source's rendering of color compared to a reference, has shortcomings that limit its ability to fully represent how humans perceive color.

Since its adoption in 1964, several light source technologies have been introduced and commonly adopted for architectural lighting that yield a different visual experience than the CRI metric can describe.

As a substantial step toward solving this problem, IES TM-30-15, *IES Method for Evaluating Light Source Color Rendition*, has been developed for the benefit of the lighting community to provide: (a) a more accurate assessment of color fidelity; (b) an additional, complementary assessment of the influence of the preferred color appearance of objects (related to color gamut); and (c) more detailed information about the rendition of specific colors. As with any IES Technical Memorandum, TM-30-15 is not a required standard, and it does not provide design guidance or criteria for best practices. However, the issuance of TM-30-15 will enable the international lighting community to carefully evaluate it, providing a path leading to improved standards and design guidance. Technical analysis and feedback regarding the method described in TM-30 will be critical to continued development and standardization of color quality metrics.

The IES recognizes that while color rendering is important for consideration in energy regulations on the basis of maintaining lighting quality, the IES does not endorse any mandatory color rendering measures in energy regulations until there is a national or international consensus regarding an appropriate metric and range of values.

- IES recognize that CIE CRI has shortcomings, especially with new lighting technologies. TM-30 was developed to solve this problem.

- "TM-30-15 is not a required standard, and it does not provide design guidance or criteria for best practices."

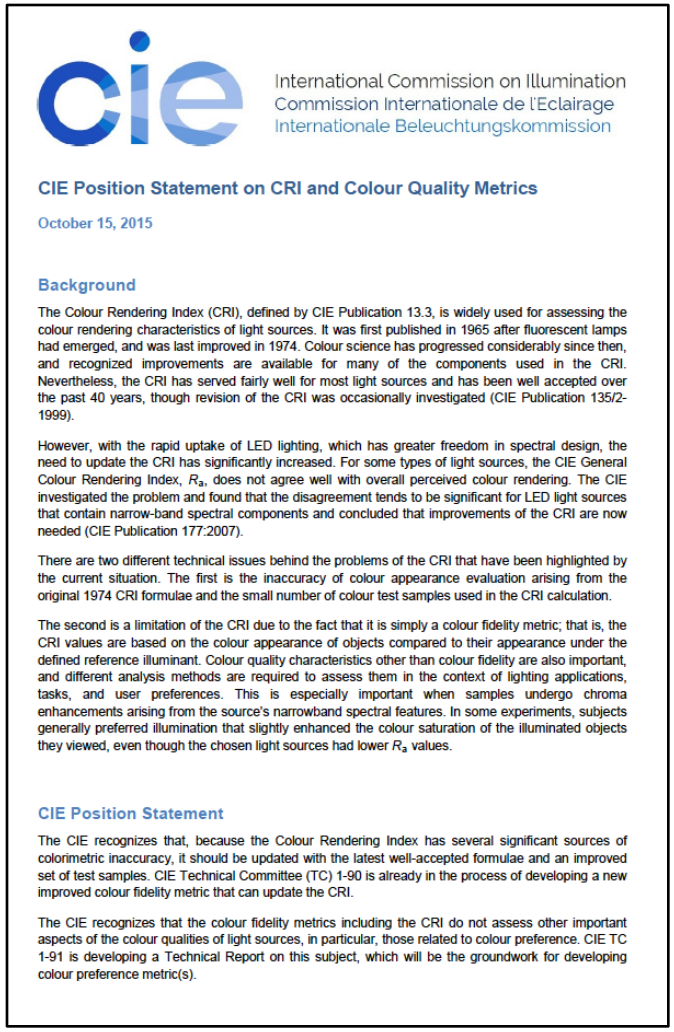
- "the issuance of TM-30-15 will enable the international lighting community to carefully evaluate it, providing a path leading to improved standards and design guidance."

Link: https://www.ies.org/PDF/PositionStatements/PS-8-15.pdf

CIE Position statement

on CRI and Color Quality Metrics

Issued Oct. 2015.



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

CIE Position Statement on CRI and Colour Quality Metrics

October 15, 2015

Background

The Colour Rendering Index (CRI), defined by CIE Publication 13.3, is widely used for assessing the colour rendering characteristics of light sources. It was first published in 1965 after fluorescent lamps had emerged, and was last improved in 1974. Colour science has progressed considerably since then, and recognized improvements are available for many of the components used in the CRI. Nevertheless, the CRI has served fairly well for most light sources and has been well accepted over the past 40 years, though revision of the CRI was occasionally investigated (CIE Publication 135/2-1999).

However, with the rapid uptake of LED lighting, which has greater freedom in spectral design, the need to update the CRI has significantly increased. For some types of light sources, the CIE General Colour Rendering Index, R_a, does not agree well with overall perceived colour rendering. The CIE investigated the problem and found that the disagreement tends to be significant for LED light sources that contain narrow-band spectral components and concluded that improvements of the CRI are now needed (CIE Publication 177:2007).

There are two different technical issues behind the problems of the CRI that have been highlighted by the current situation. The first is the inaccuracy of colour appearance evaluation arising from the original 1974 CRI formulae and the small number of colour test samples used in the CRI calculation.

The second is a limitation of the CRI due to the fact that it is simply a colour fidelity metric; that is, the CRI values are based on the colour appearance of objects compared to their appearance under the defined reference illuminant. Colour quality characteristics other than colour fidelity are also important, and different analysis methods are required to assess them in the context of lighting applications, tasks, and user preferences. This is especially important when samples undergo chroma enhancements arising from the source's narrowband spectral features. In some experiments, subjects generally preferred illumination that slightly enhanced the colour saturation of the illuminated objects they viewed, even though the chosen light sources had lower R_a values.

CIE Position Statement

The CIE recognizes that, because the Colour Rendering Index has several significant sources of colorimetric inaccuracy, it should be updated with the latest well-accepted formulae and an improved set of test samples. CIE Technical Committee (TC) 1-90 is already in the process of developing a new improved colour fidelity metric that can update the CRI.

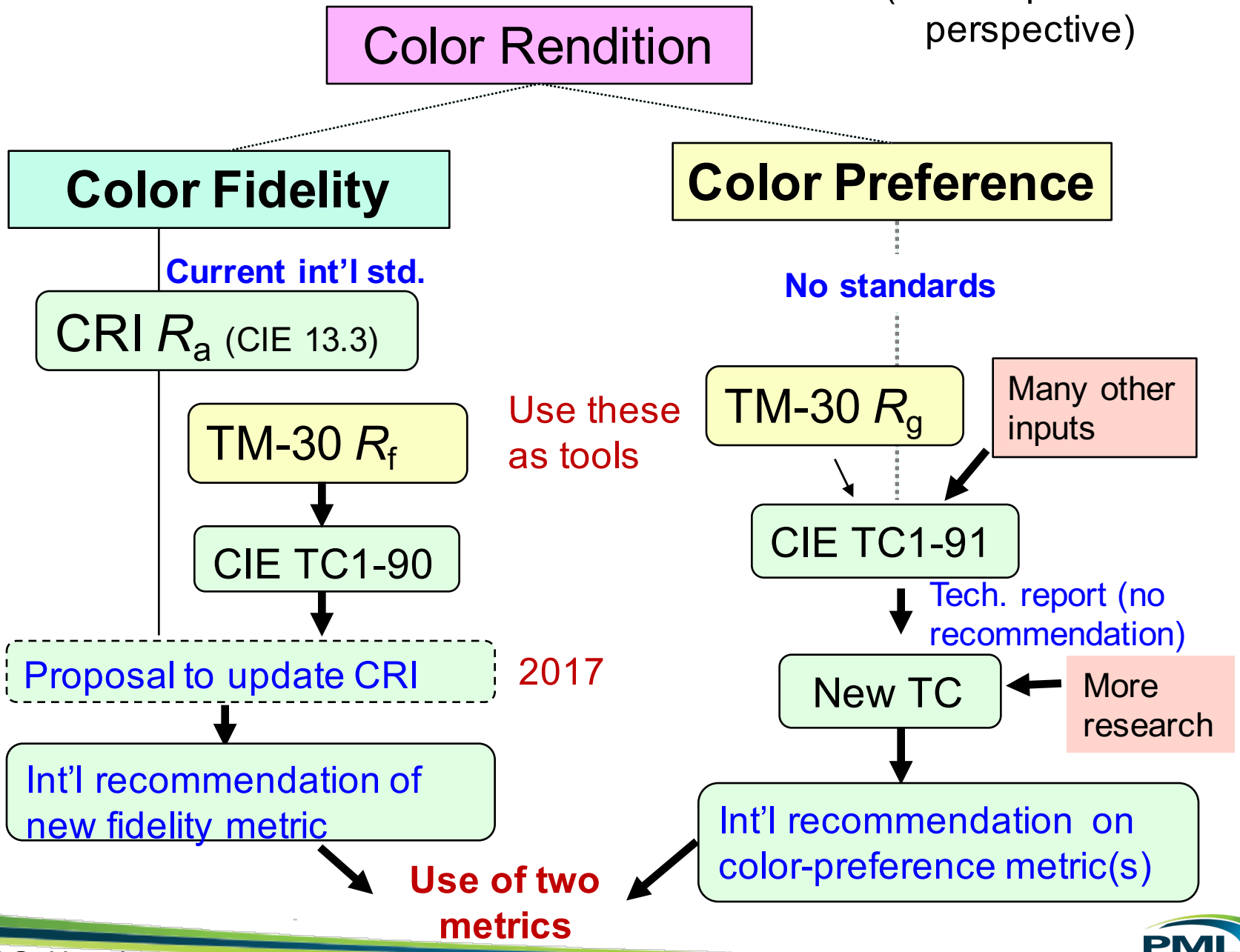
The CIE recognizes that the colour fidelity metrics including the CRI do not assess other important aspects of the colour qualities of light sources, in particular, those related to colour preference. CIE TC 1-91 is developing a Technical Report on this subject, which will be the groundwork for developing colour preference metric(s).

Link: http://www.cie.co.at/index.php?i_ca_id=981

- CRI has several significant sources of colorimetric inaccuracy. CRI needs to be updated. CIE TC1-90 is developing a new color fidelity metric.
- CIE supports the study of the recently published IES TM-30. TC1-90 accepted TC-30 R_f metric as basis for the TC's first draft.
- An orderly transition is needed when a new metric is to be introduced.
- Both TC reports to be completed by end of 2016.
- The colour fidelity metrics including the CRI do not assess other important aspects of the colour qualities of light sources, in particular, those related to colour preference. CIE TC 1-91 is developing a Technical Report on this subject.

Future perspective

(Ohno's personal perspective)



Summary

- TM-30 R_f provides a more (scientifically) accurate color fidelity metric for “all colors” of object.
- CRI scores can be biased due to only one type of test sample used (Munsell samples). → TM-30 R_f avoids bias by using test samples from real objects database.
- CRI score can have anomaly due to only eight samples.
  → TM-30 R_f avoids anomaly (by using varieties of 99 test samples.)
- However, we do not expect that R_f will correlate with visual impression of lit scenes better than R_a (due to inherent limitation of the fidelity metric).
- Color fidelity is only one aspect of color quality. A preference-related metric(s) is in urgent need.

THANK YOU for your attention.