Vision Experiment II on White Light Chromaticity for Lighting

– Duv range perceived most natural

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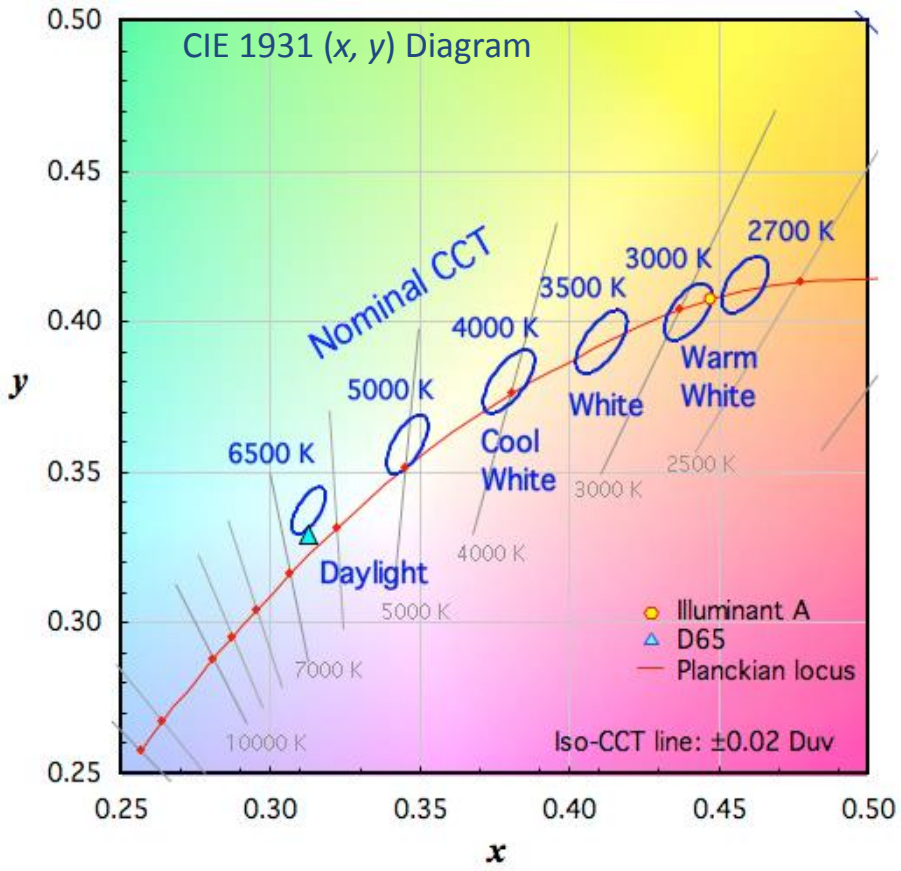
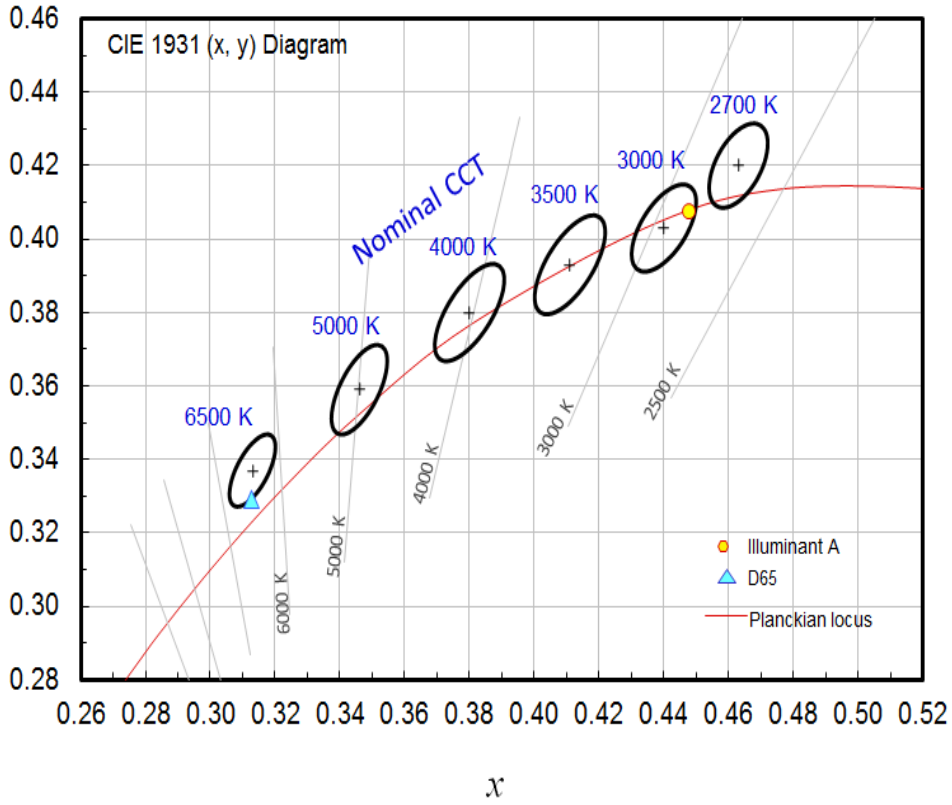
NIST Foreign Guest Researcher

Traditional White Light Chromaticity for Lighting

ANSI C78.376-2001 for fluorescent lamps



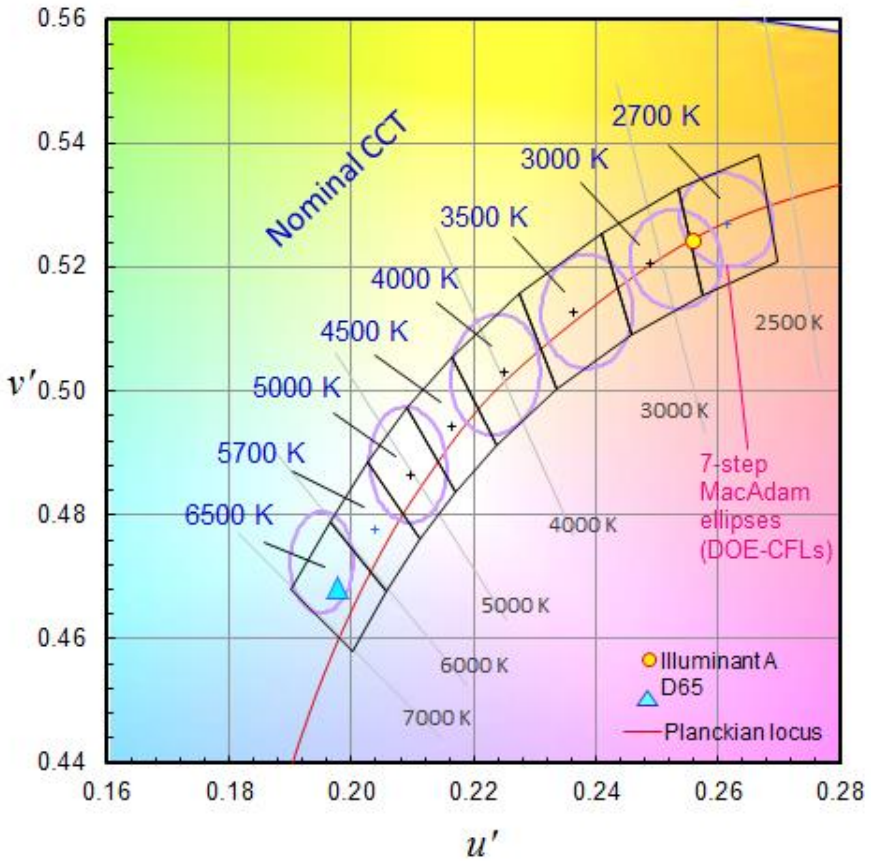
IEC 60081 for Fluorescent Lamps



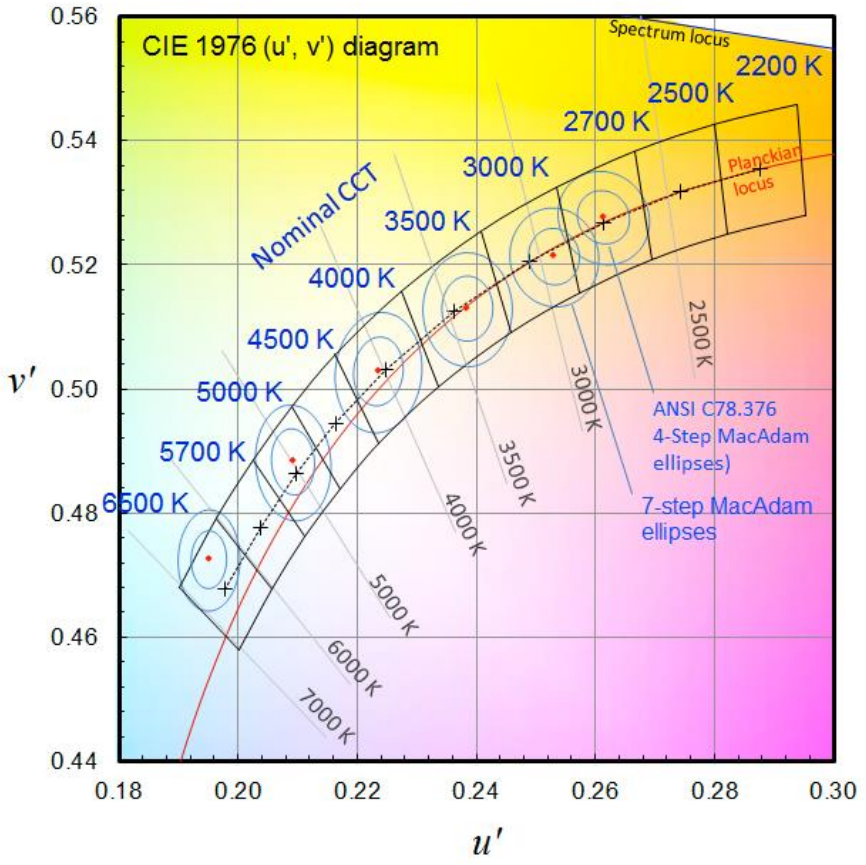
ANSI C78.377 (for Solid State Lighting Products)

Originally published 2008.

2011 version



2015 version

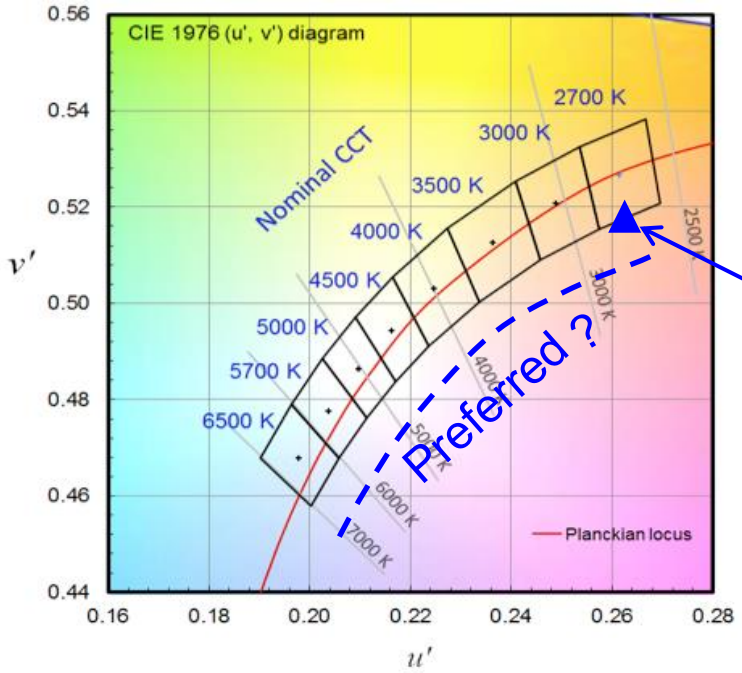


Used in Energy Star for SSL products.

Chromaticity shift across Planckian Locus

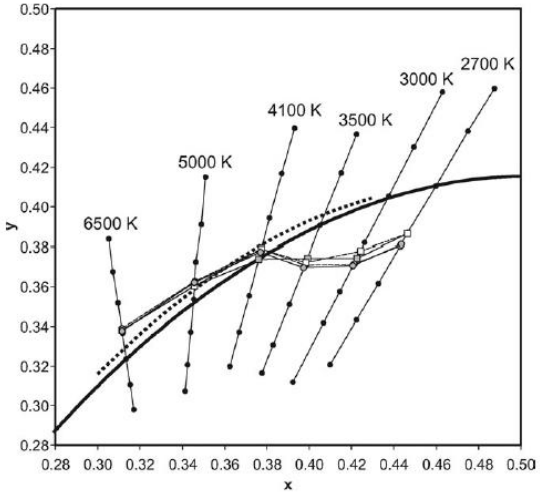
Anecdotes say …

- Lights below Planckian locus look better.



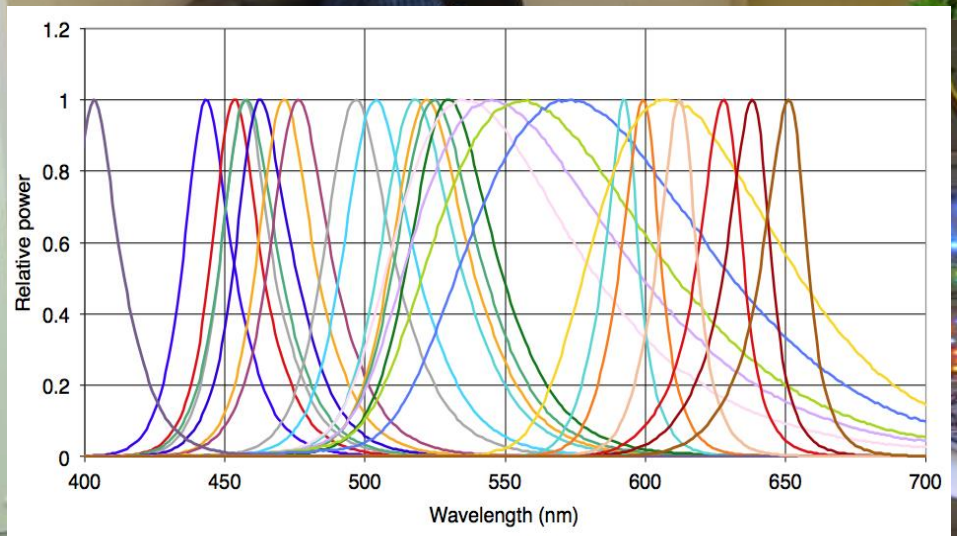
An example in neodymium lamp

Study by LRC on white perception



NIST Spectrally Tunable Lighting Facility

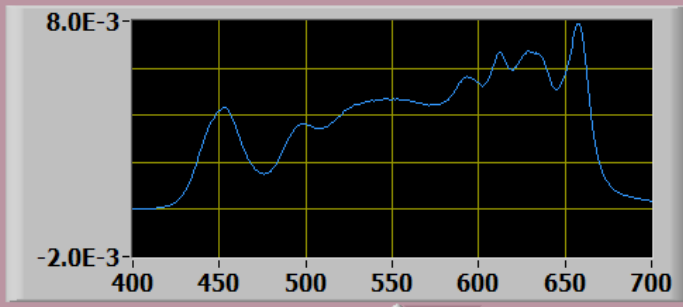
NIST Spectrally Tunable Lighting Facility



LCAS1.vi

File Edit Operate Tools Window Help

CAS SPECTRUM



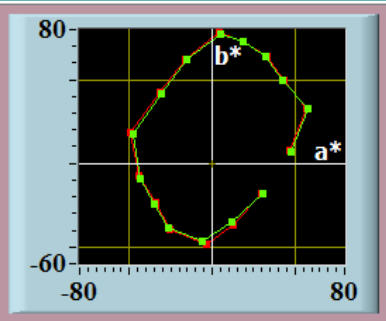
Single Continous

100 IntegrationTime

5 Accumulations

Save 5nm-Spectrum

CAS Color Metrics



1.67 S/P

CQS 2

97 99 93 96 99 96 97 10 98 98 10 98 98 98 97

Qa 97

CRI

99 99 95 96 99 98 98 97

Ra 97.7

x 0.4043

y 0.3903

u' 0.2352

v' 0.5109

CCT 3519

Duv -0.0000

W/m^2 1.09

lx 339.91

STLS MODE

1. Auto
2. File
3. * Manual

DATA FILE

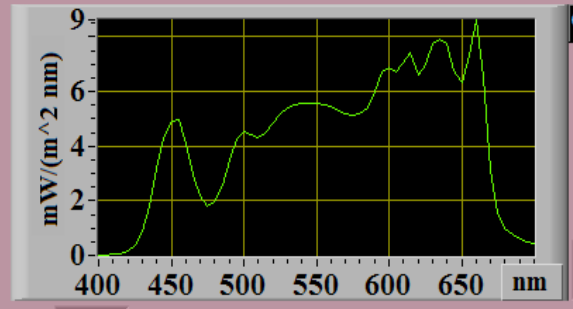
CCT	Duv	Lx	Comment
3595	-0.0038	401.1	B) Duv=-0.005 Ra=96
3580	0.0010	401.6	4. Duv=0.000 3500K
3595	-0.0038	401.1	A) Duv=-0.005 Ra=96
3580	0.0067	401.9	B) Duv=+0.005 Ra=97
3580	0.0118	402.2	5. Duv=+0.010 Ra=95

Output 1 0.5

Data File C:\22Sys\Duv

Save

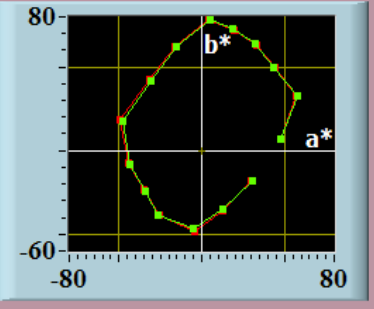
Comment 4. Duv=0.000 3500K



OUTPUT

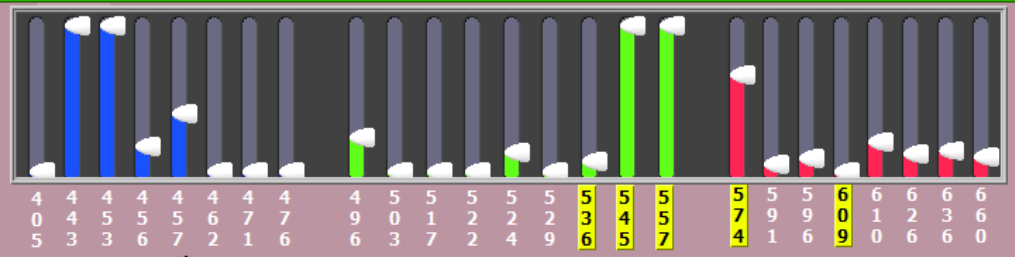
LER 309 lm/W

S/P 1.7



Ra 98 CRI 97 10(93 95 98 98 99 99 95 97 92 85 98 95

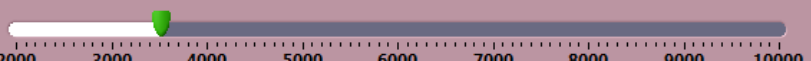
Qa 97 CQS 97 99 94 98 98 96 98 99 98 99 98 96 97 99 98



405 433 453 456 457 462 471 476 496 503 517 522 524 529 536 545 557 574 591 596 609 610 626 636 660

-1 +1

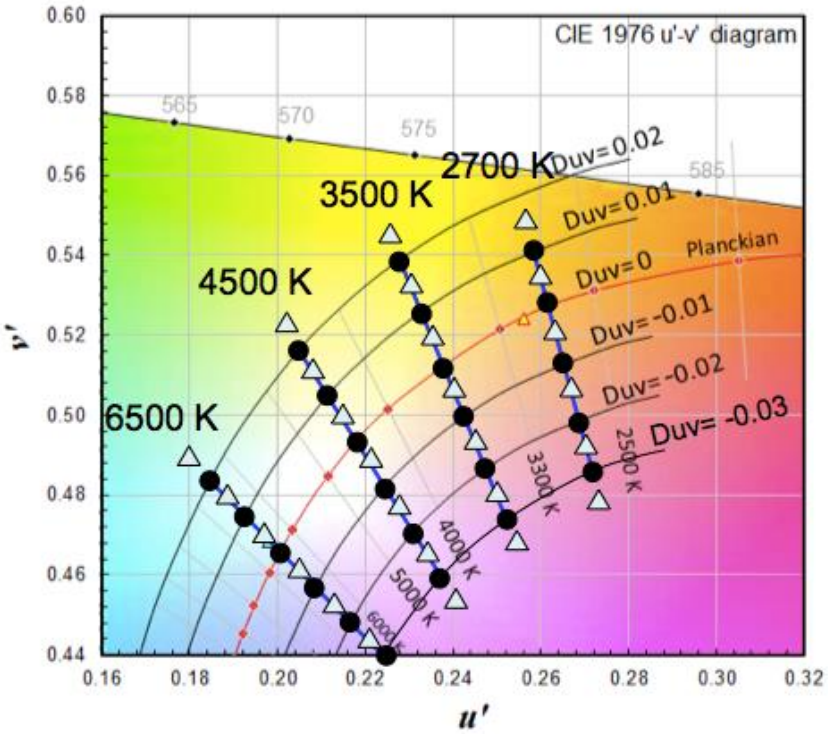
CCT 3520



Duv 0.0004

lx 325

2013 Vision Experiment at NIST on Preferred and Acceptable level of Duv

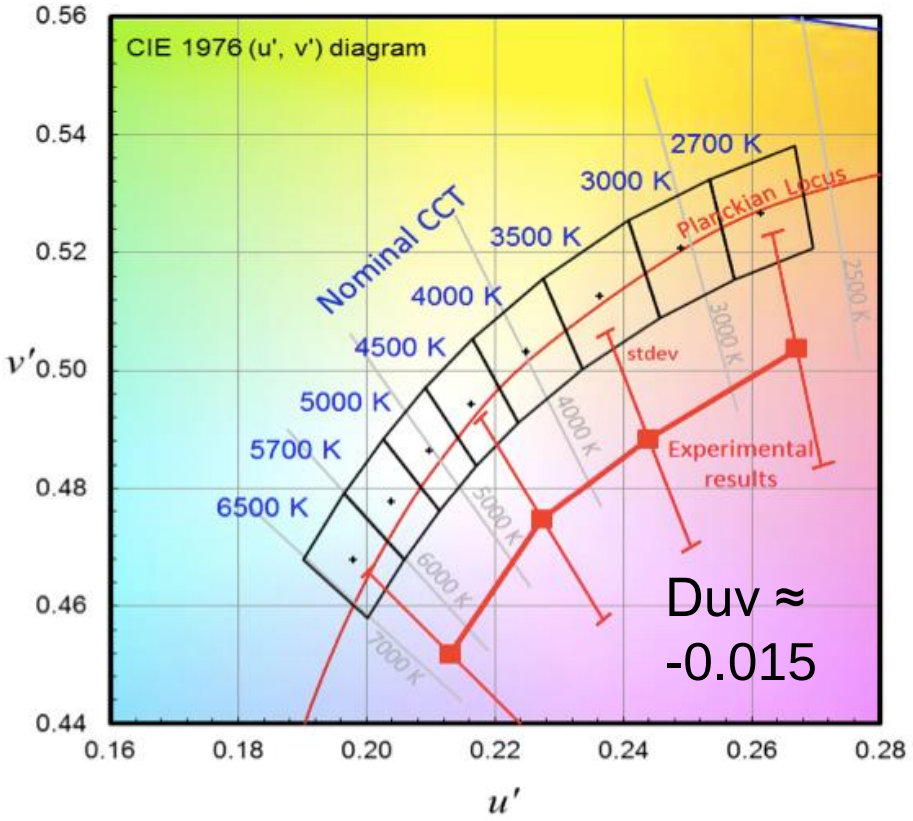


Experiments conducted at 4 CCTs, at 6 Duv points at each CCT, at total **23** points. **Total 50 spectra** used.

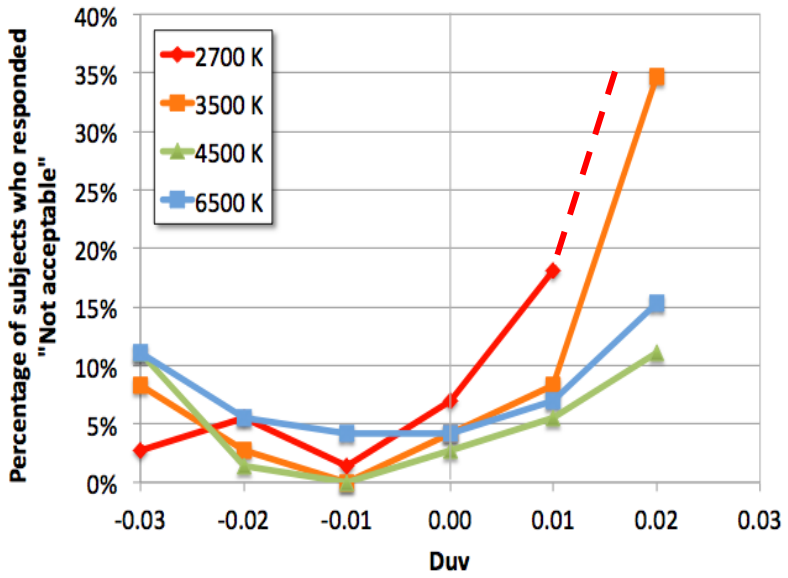
- 18 subjects participated.
- Subject was **fully adapted** to the illumination (chromatic adaptation).
- Subjects viewed **fruits, vegetables**, his/her **skin tone** and **the whole room.**
- Selected lights that looked "**more natural**".

Results of 2013 Experiment

Average crossover points of Duv



Percentage of "Not acceptable"



Y. Ohno and M. Fein, Vision Experiment on Acceptable and Preferred White Light Chromaticity for Lighting, CIE x029:2014, pp. 192 – 199 (2014)

Discussion by M Wei & Kevin Houser

What Is the Cause of Apparent Preference for Sources with Chromaticity below the Blackbody Locus?

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Published online: 18 Apr 2015.

Leukos, April 2015 http://dx.doi.org/10.1080/15502724.2015.1029131

"We infer that the preference expressed by participants in the studies by Dikel and others [2014] and Ohno and Fein [2014] may not be solely related to chromaticity."

"aspects of color rendition (that is, color fidelity and relative gamut) may also influence preference."

Preferred Chromaticity of Color-Tunable LED Lighting

Erhan E. Dikel, Gregory J. Burns, Jennifer A. Veitch, Sandra Mancini & Guy R. Newsham

To cite this article: Erhan E. Dikel, Gregory J. Burns, Jennifer A. Veitch, Sandra Mancini & Guy R. Newsham (2014) Preferred Chromaticity of Color-Tunable LED Lighting, LEUKOS, 10:2, 101-115, DOI: 10.1080/15502724.2013.855614

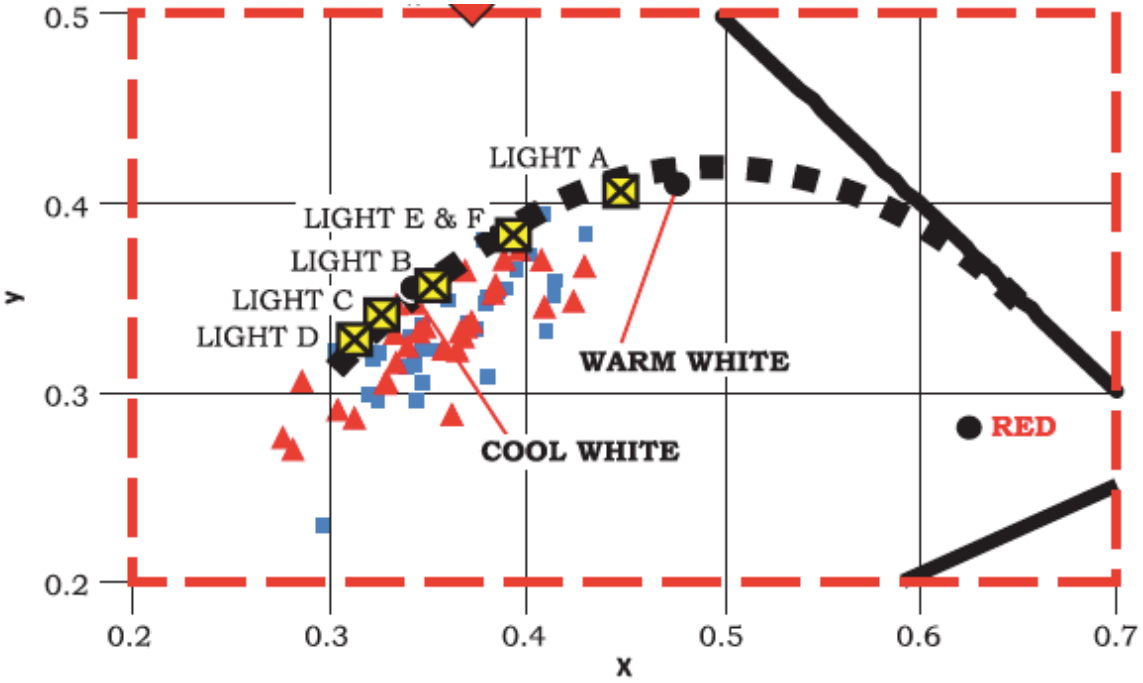
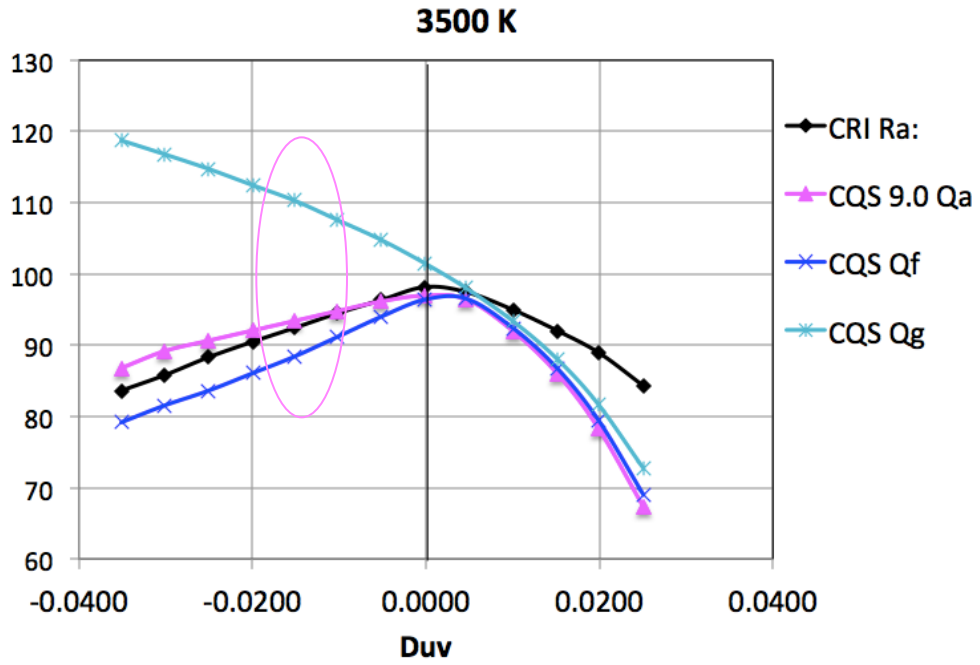
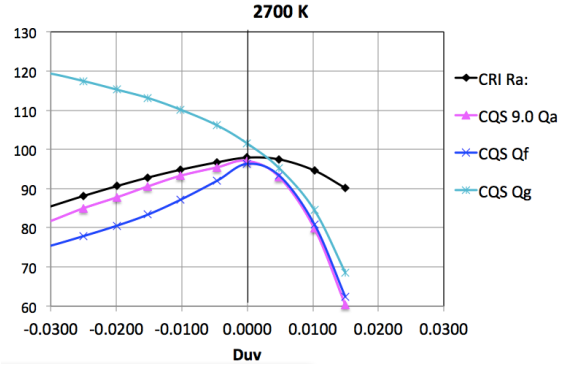
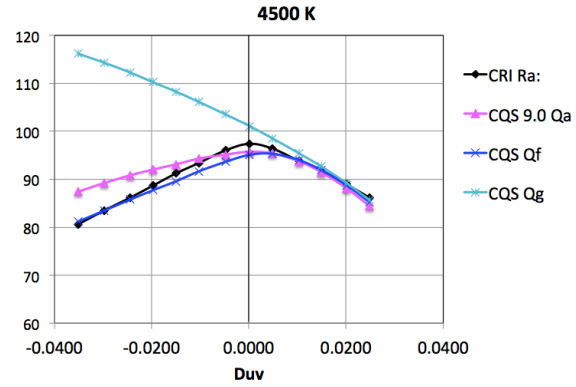


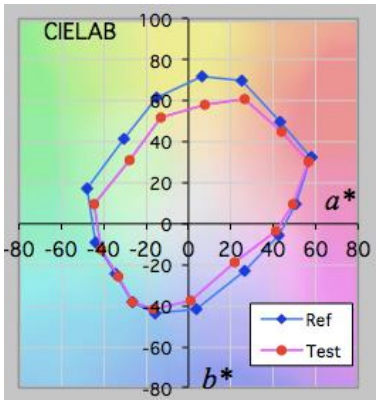
Fig. 8 LED choices and presets plotted on the 1931 CIE chromaticity diagram. Top panel: Full chart, where the yellow dotted lines mark the boundary of possible conditions with these five channels. Bottom panel: Close-up of area near the blackbody curve.

Color rendering characteristics at different Duv levels

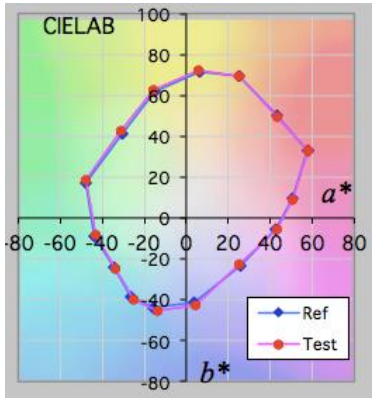




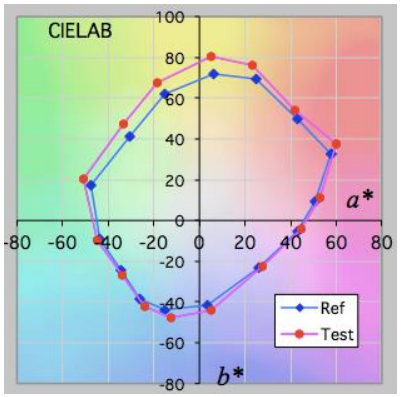




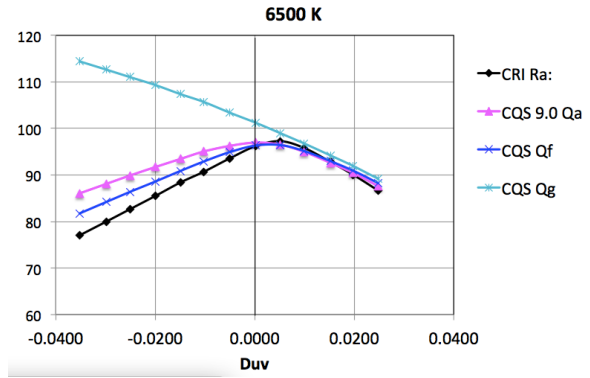
Duv=0.02



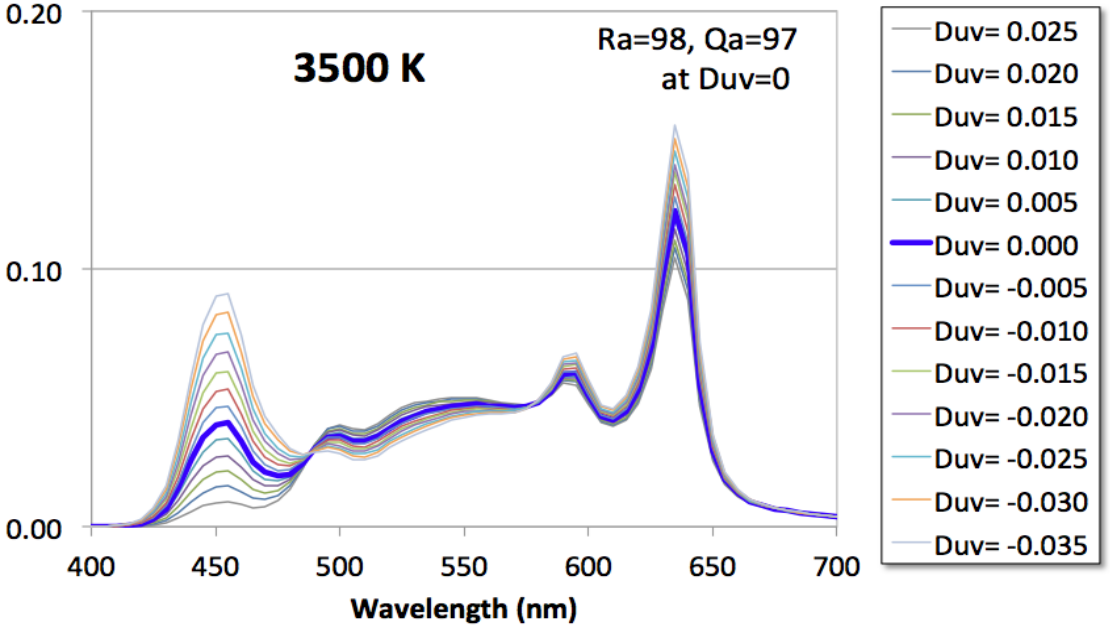
Duv=0

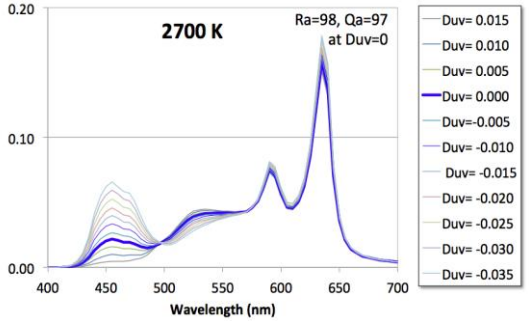


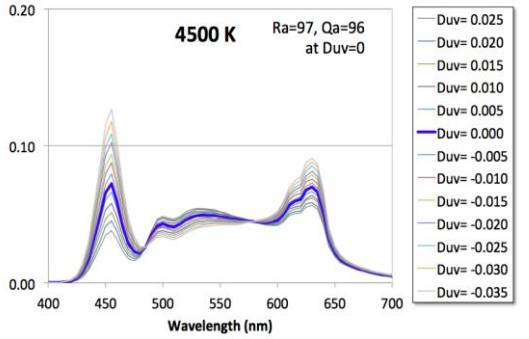
Duv= - 0.03

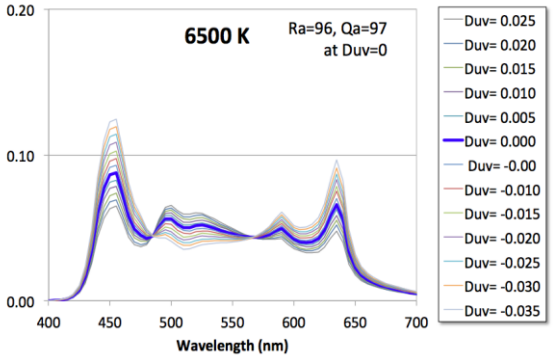


Light spectra

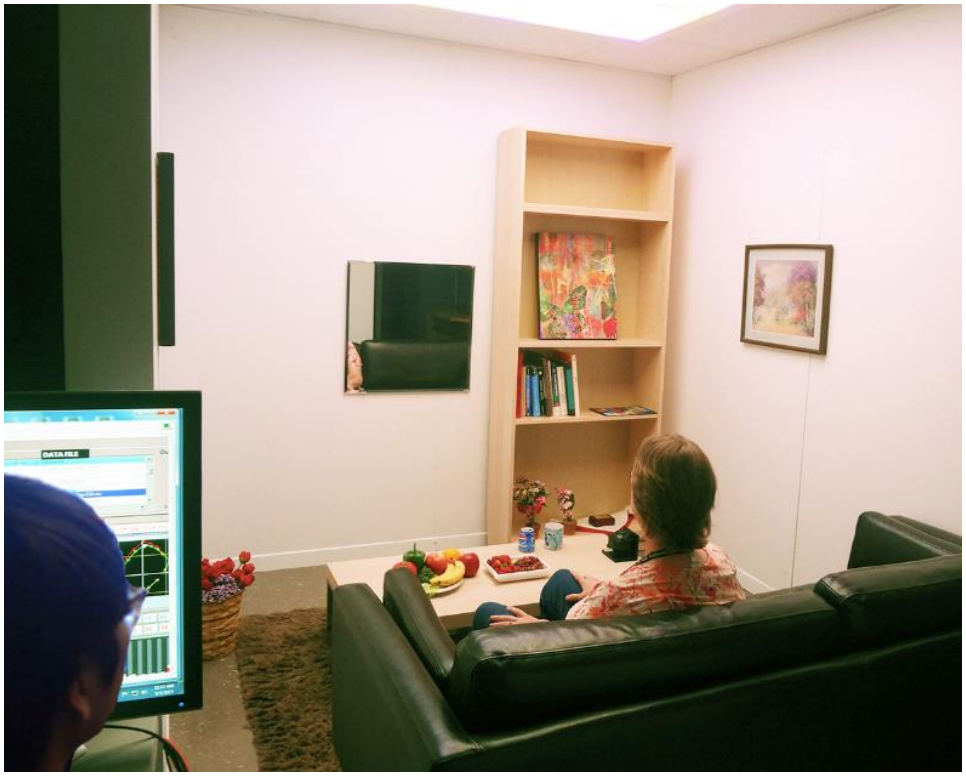








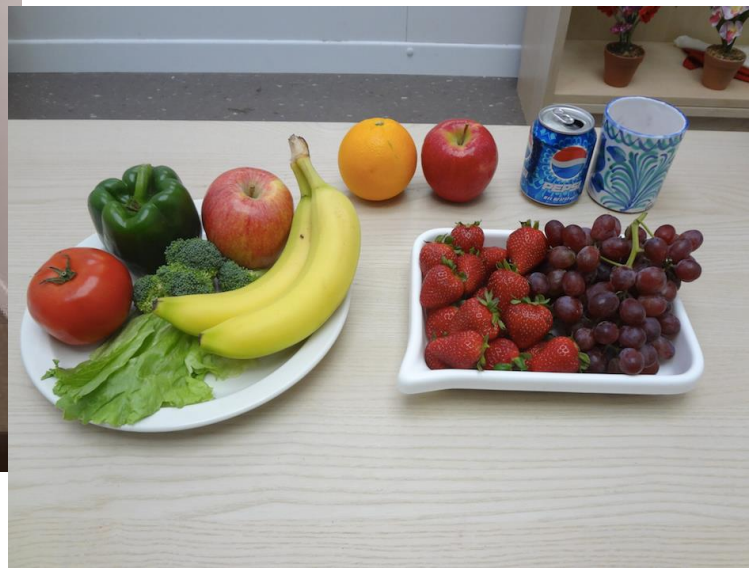
2015 Experiment at NIST



The same conditions as 2013:

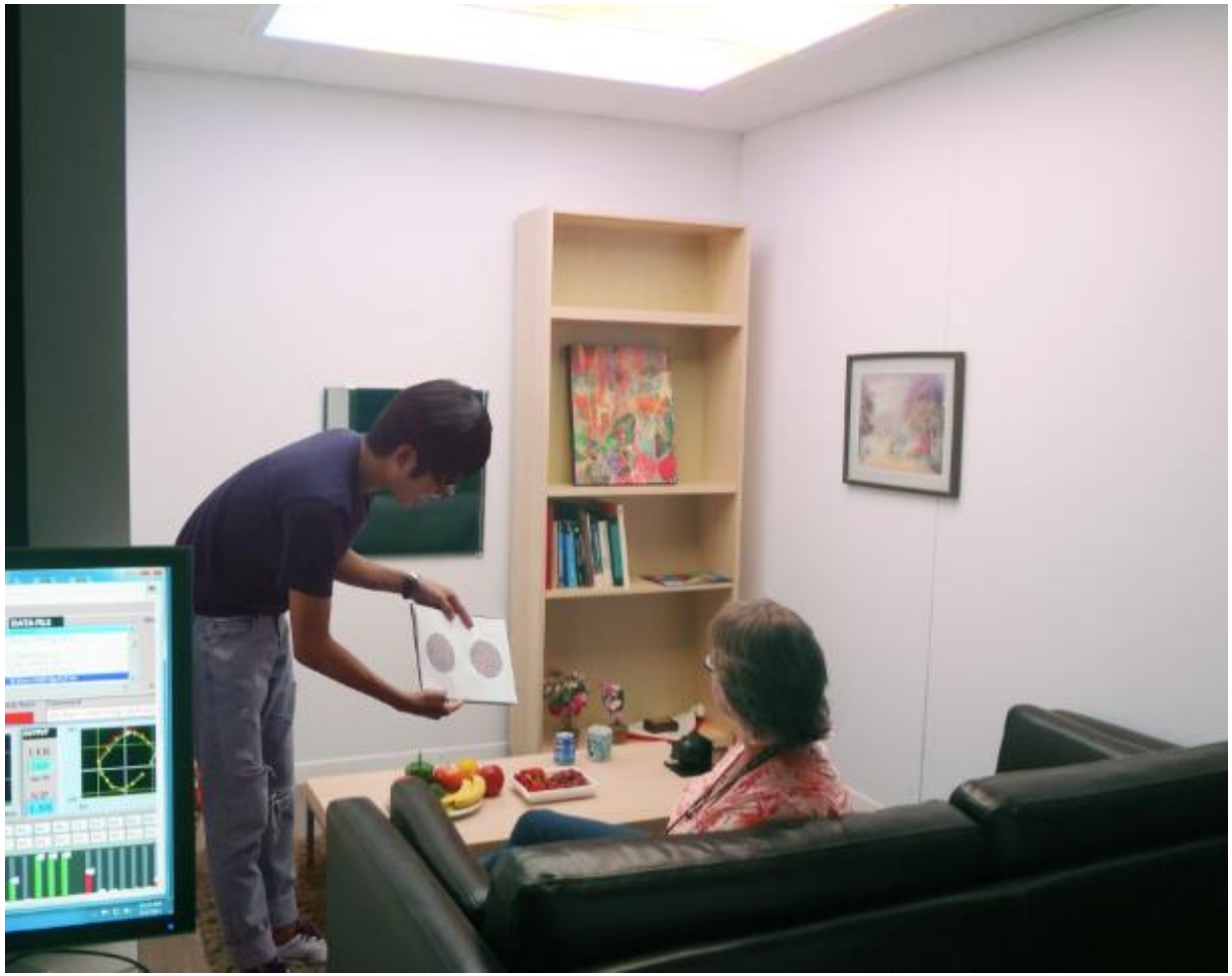
- 4 CCTs: 2700 K, 3500 K, 4500 K, 6500 K
  Duv range: -0.03 to 0.02
- Spectra were similar broadband but adjusted to remove the effects of gamut and chroma saturation.
- 21 subjects (19 to 68 years old) participated.

Experimental Setting



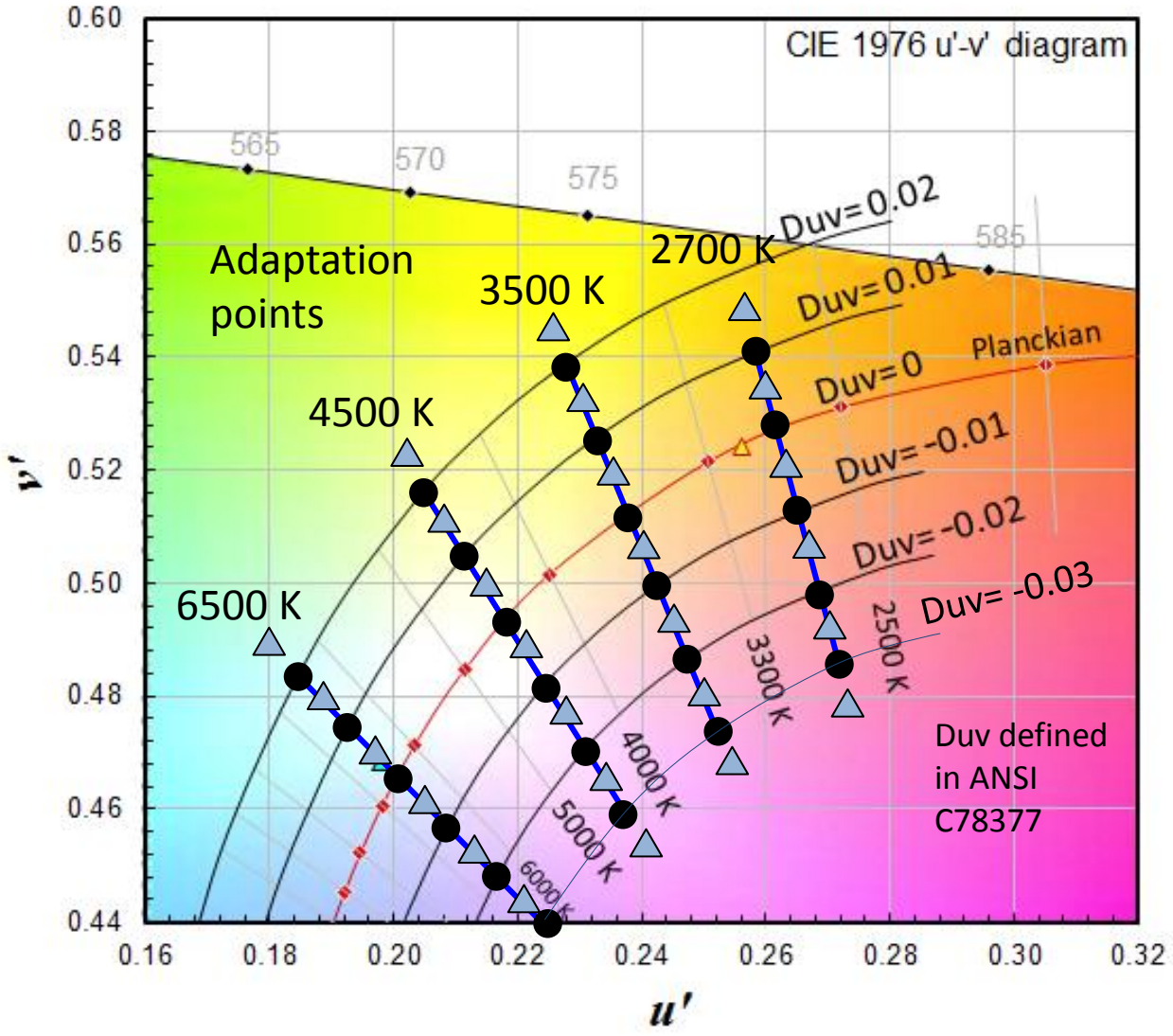
- Room was set with neutral white walls.
- Illuminance ~300 lx on the table (variations within ±1 %).
- Subjects viewed **fruits/vegetables** on the table, his/her face **skin tone** in mirror and the **whole room**.

Preparation for each subject



- Ishihara Test for normal color vision
- Explanations on experiment
- Instructions
- Trial run

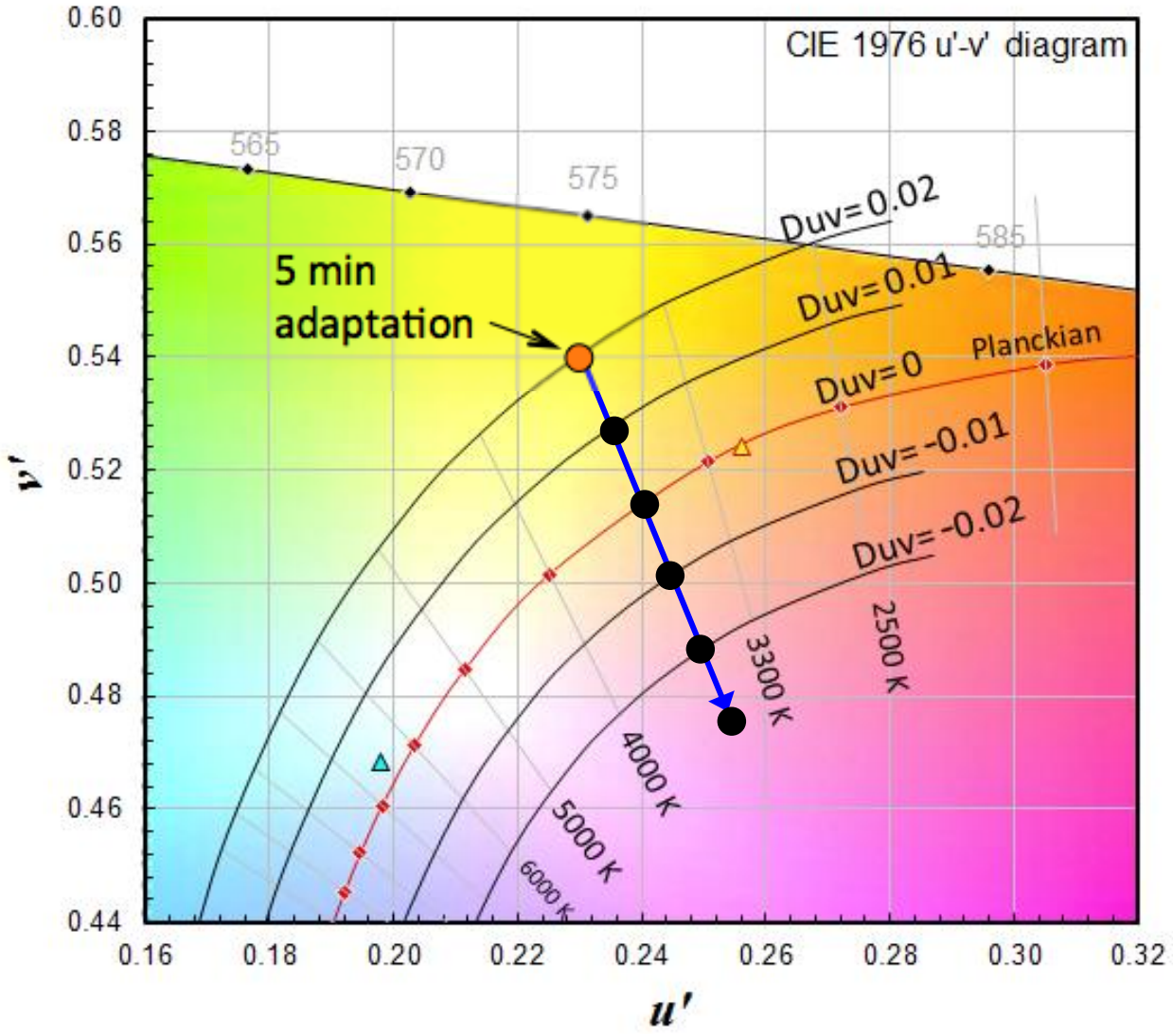
Experimental Design



Experiments prepared for 4 CCTs, at 6 Duv points at each CCT, at total **23** points.

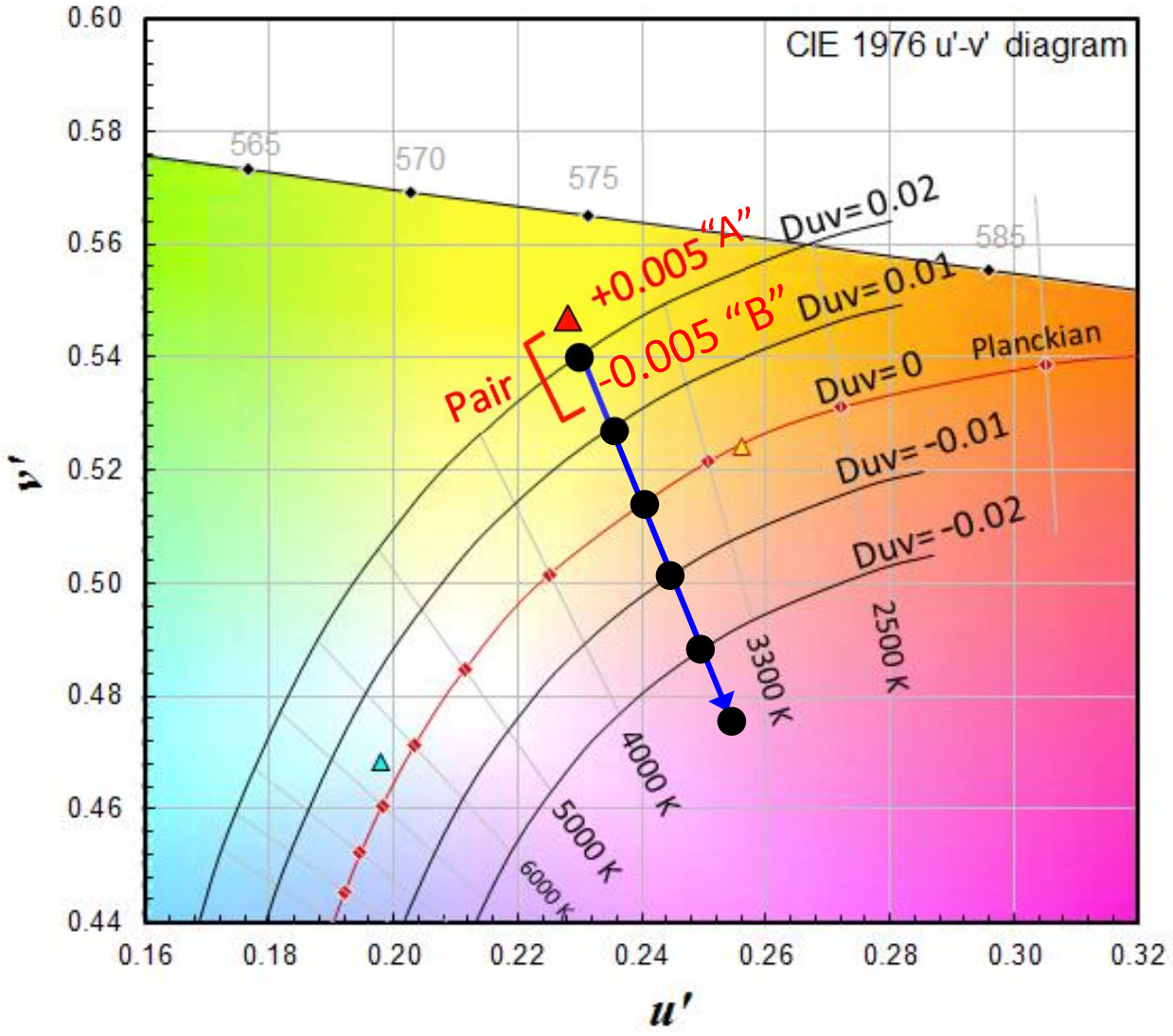
Spectra prepared for the 23 points plus points in between and outside, total **50** points.

Experimental Procedures



"Is this light acceptable or not?"

Experimental Procedures

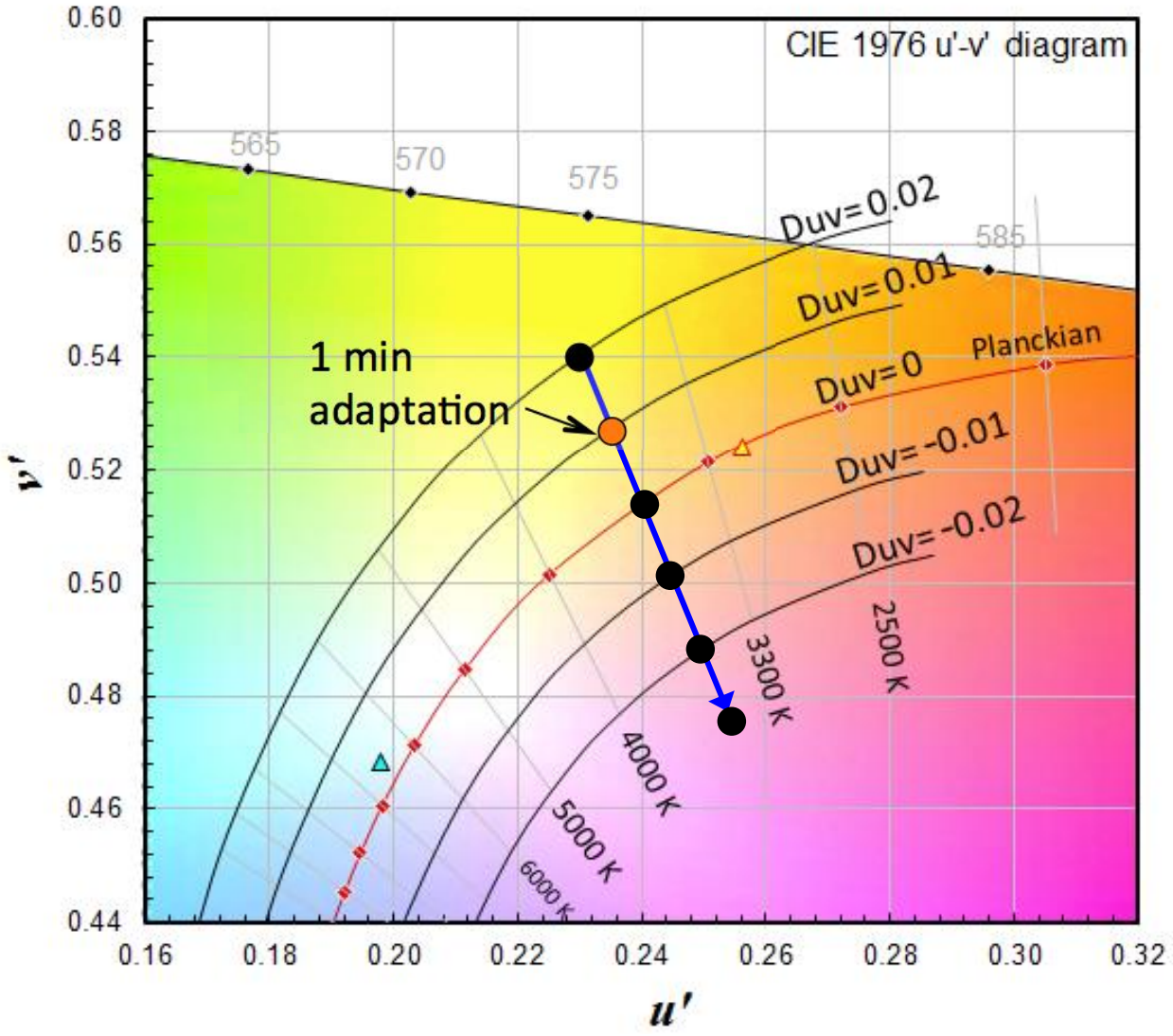


Pair of lights presented alternately.

Question: "Which light looks more natural?"

Subject answers A or B.

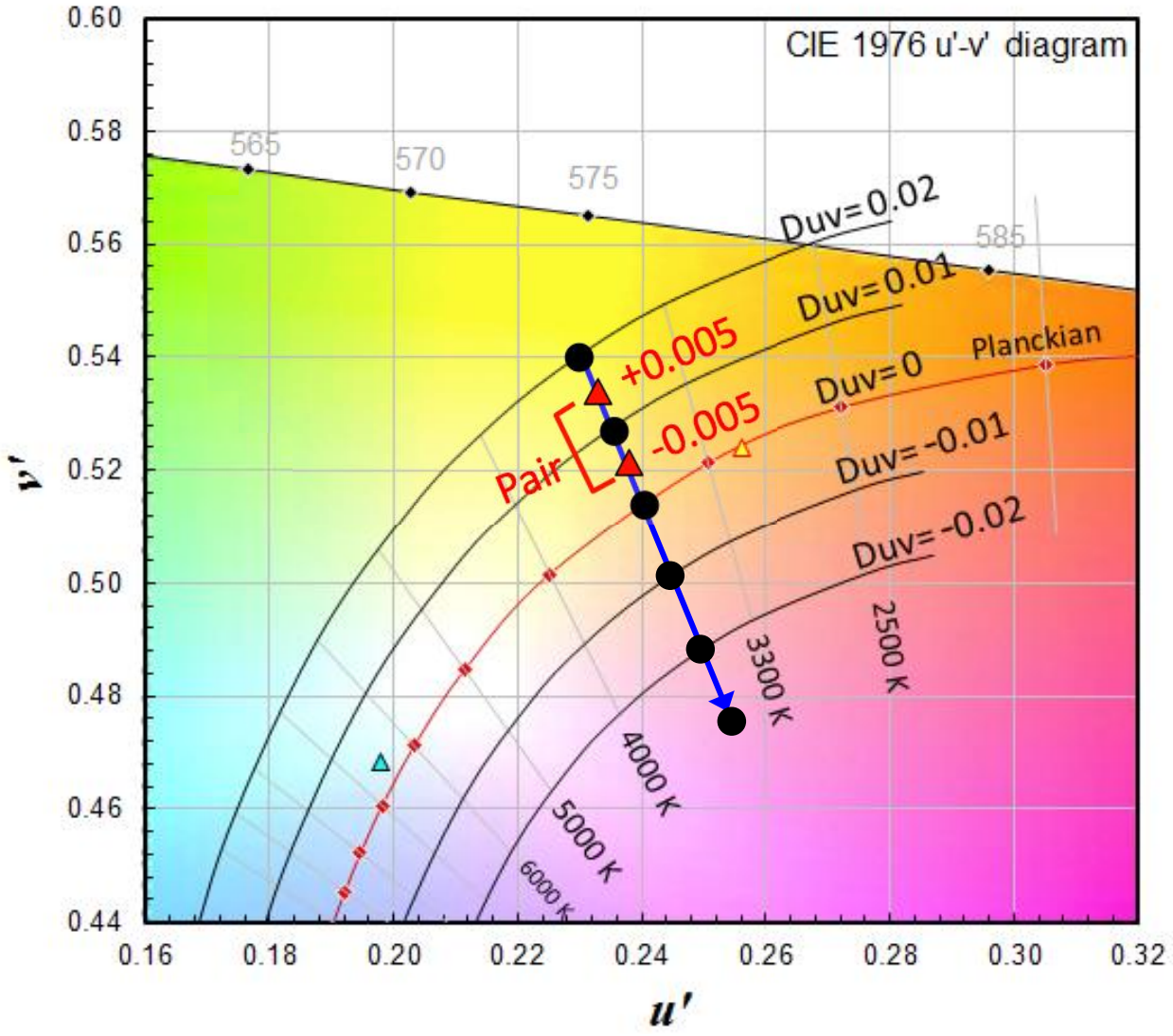
Experimental Procedures



Next point

"Is this light acceptable or not?"

Experimental Procedures



Pair of lights presented alternately.

Question: "Which light looks more natural?"

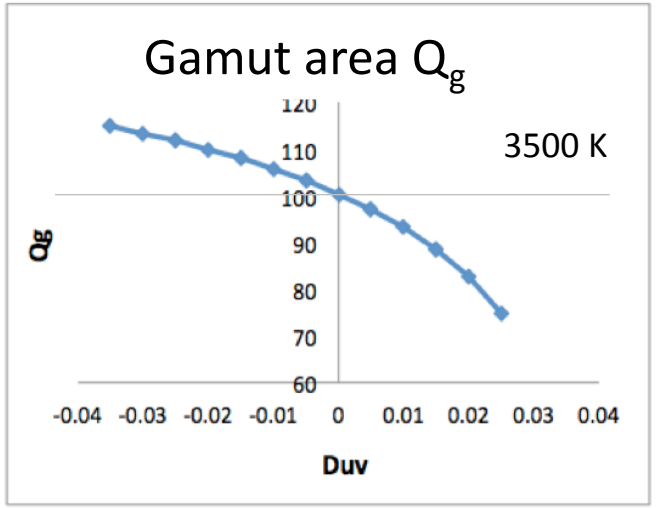
Subject answers A or B.

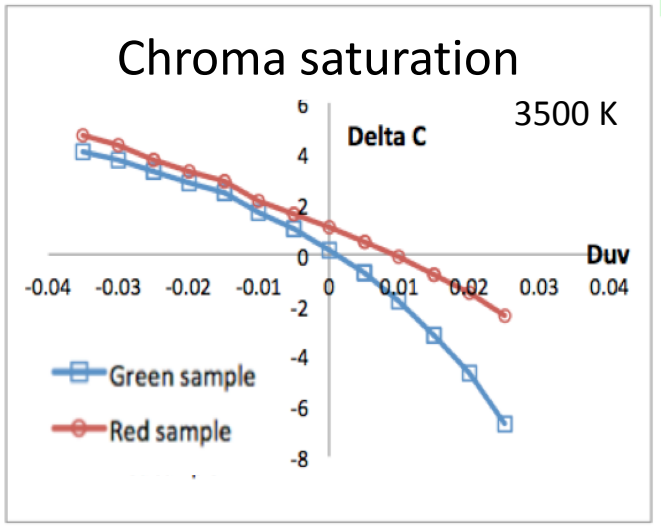
Which light looks more natural? A

Which light looks more natural? B

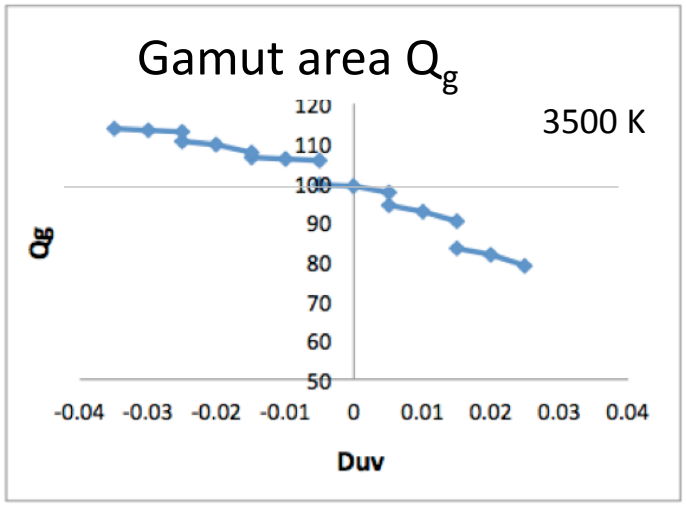
Adjustment of Spectra in each pair

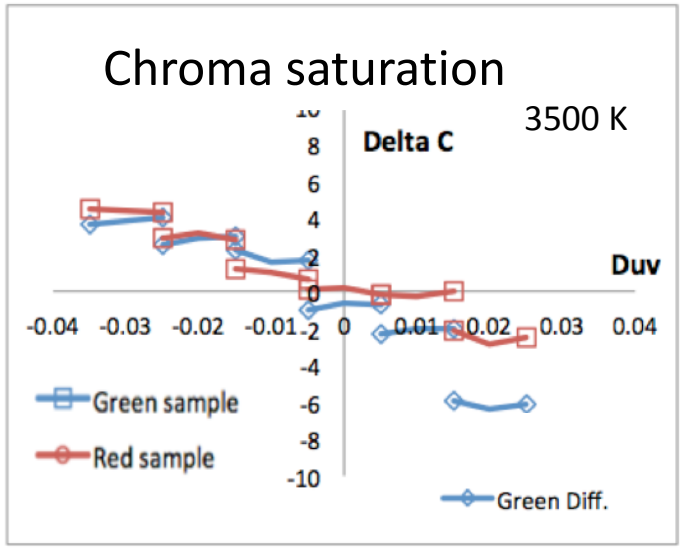
2013



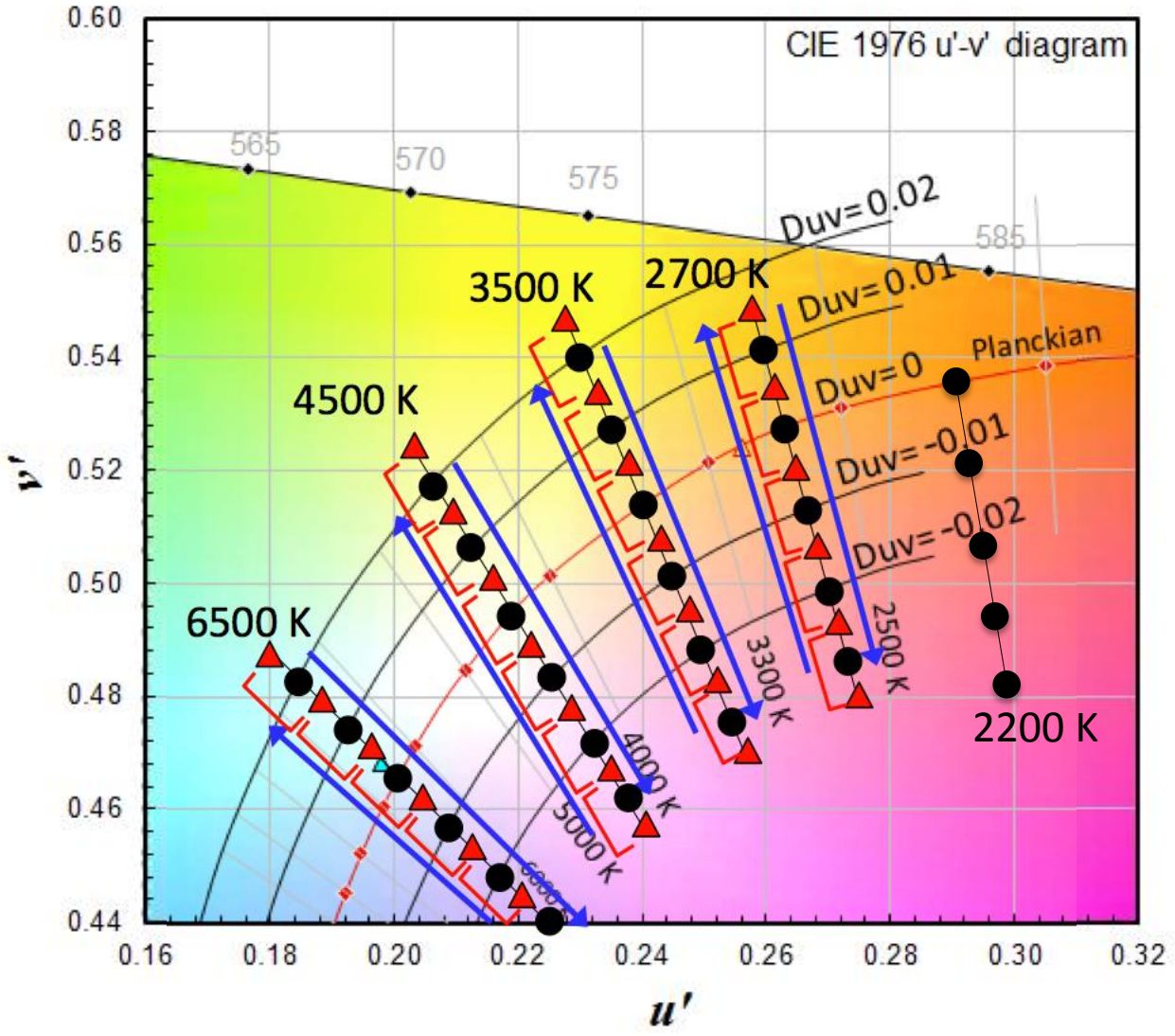


2015





Experimental Procedures



- 6 Duv points each run
- 2 directions (runs)
- 4 CCTs

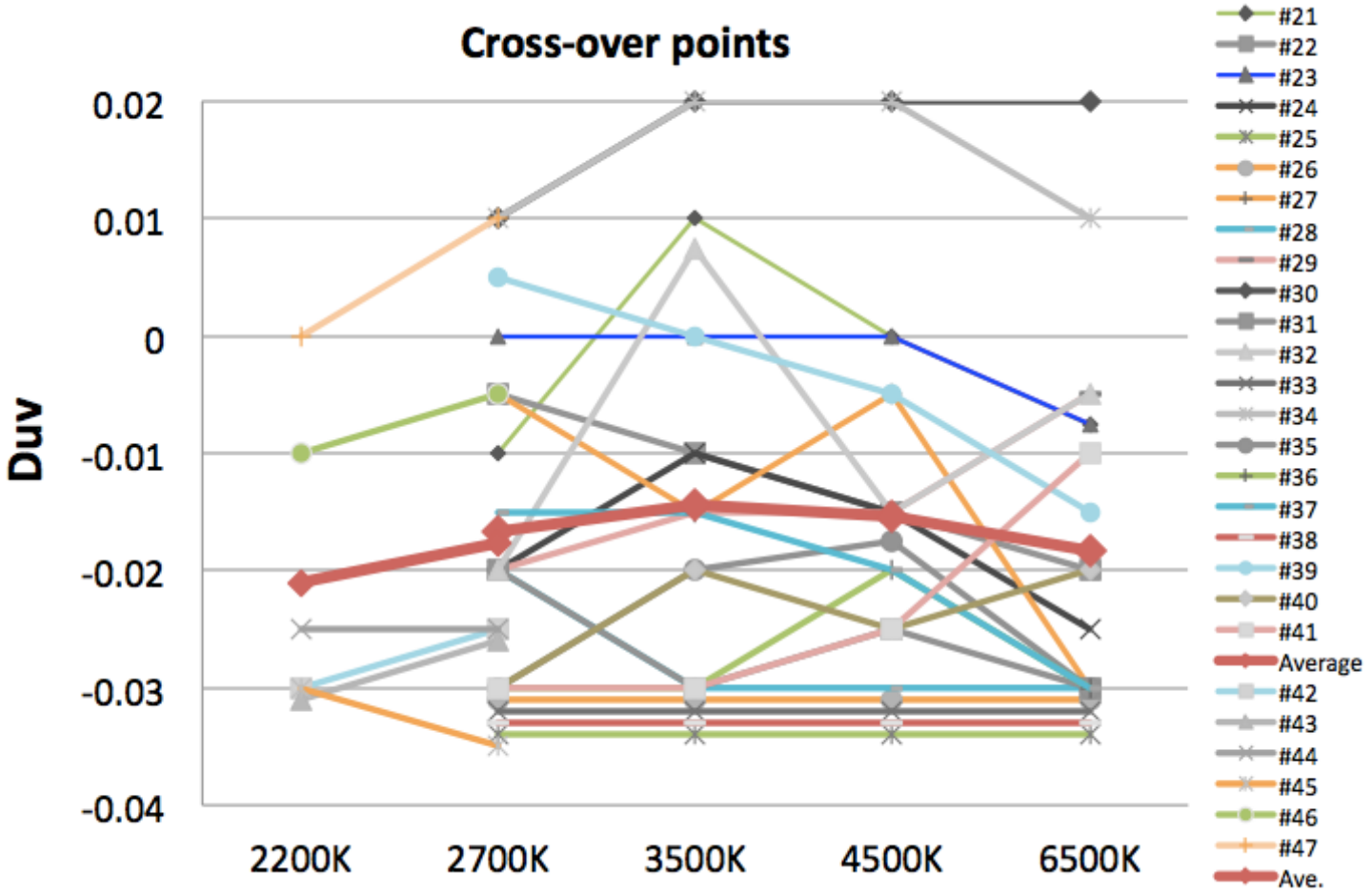
Total **8 runs**, **48 comparisons** of pairs of light per subject.

Took ~ 2 h per subject.

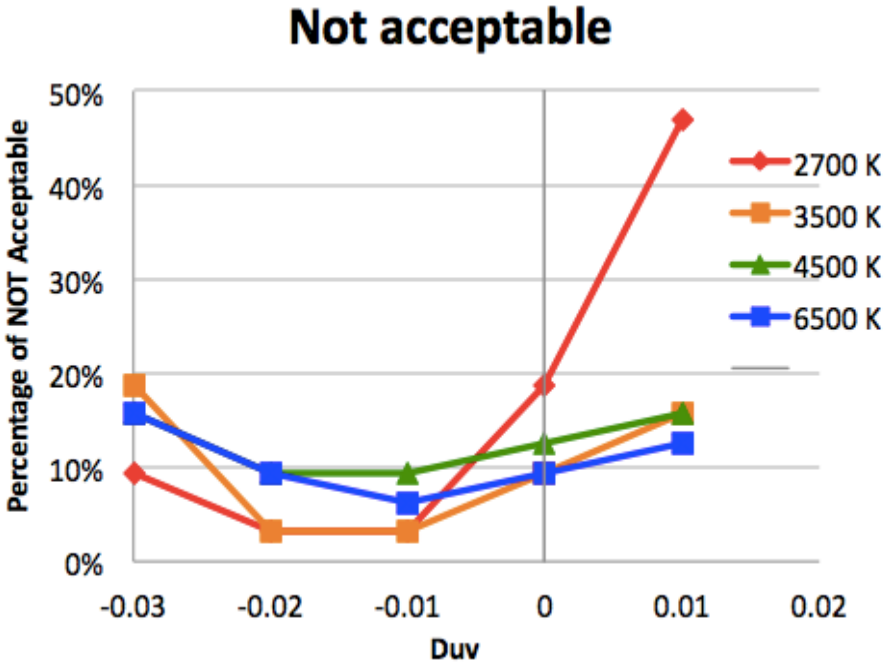
- Whole experiments not repeated in 2015.

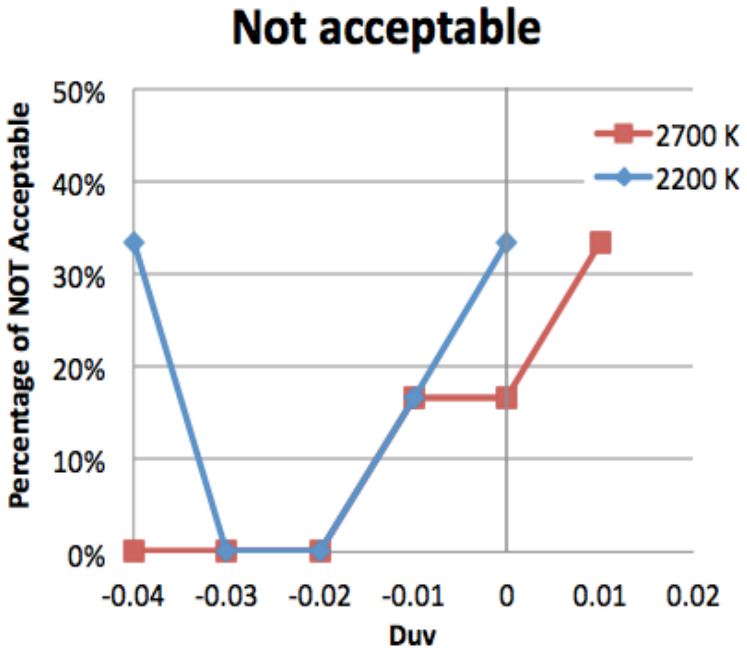
- 2200 K for six subjects added. (no control of saturation)

Individual Results



Results for “Is this light acceptable?”

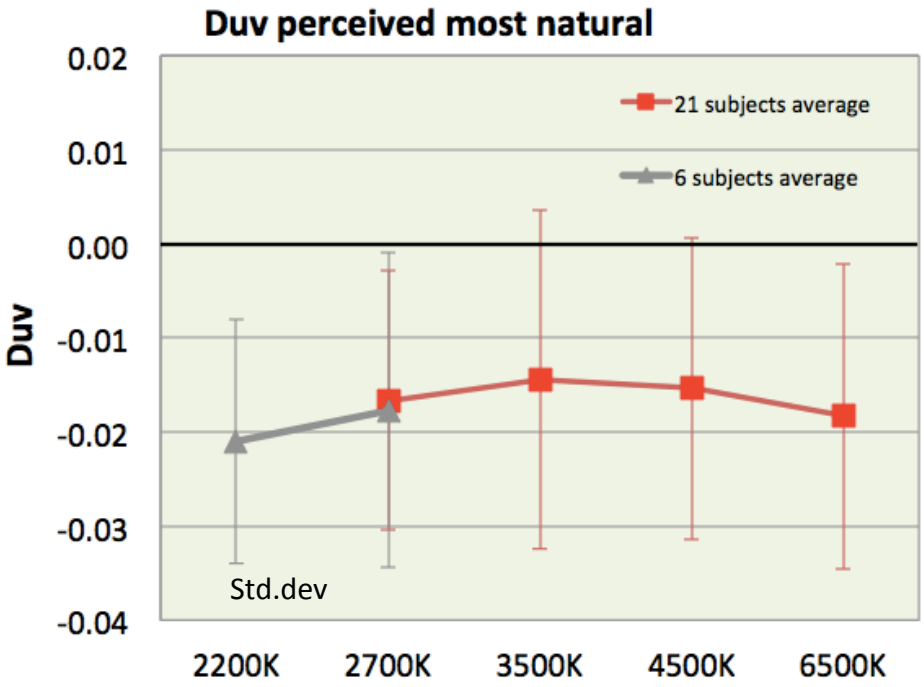




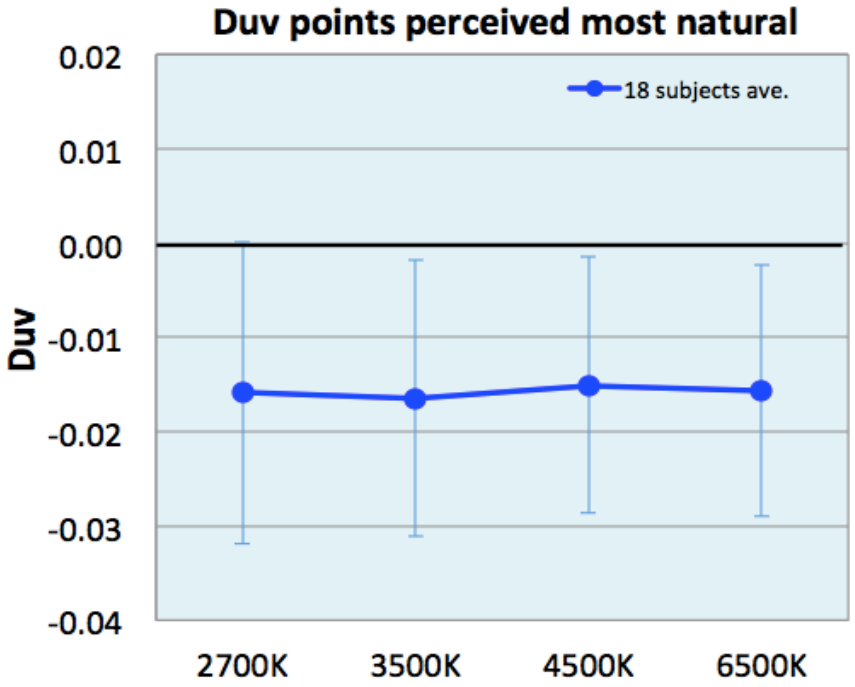
(6 subjects)

Average Results of 2015 Experiment

2015 results



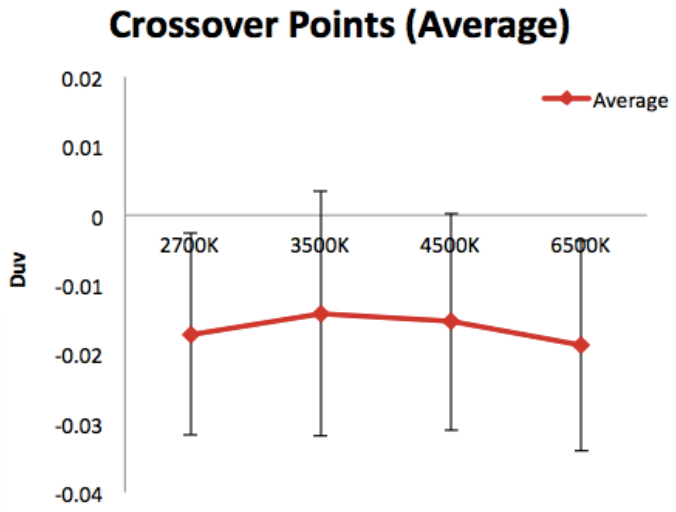
2013 results

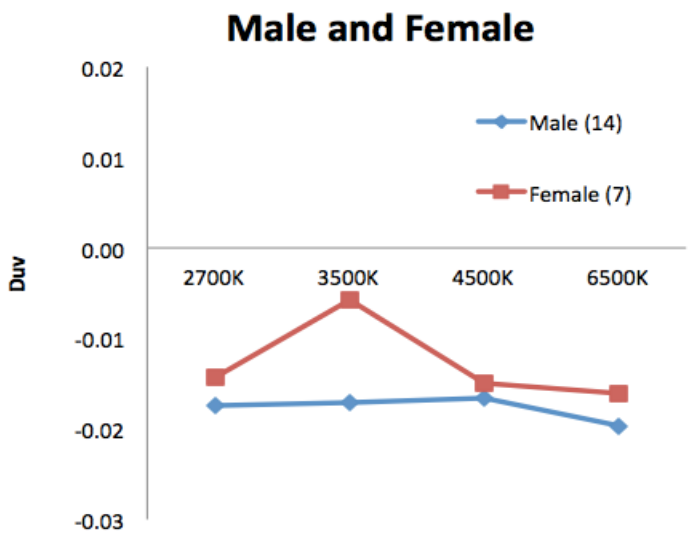


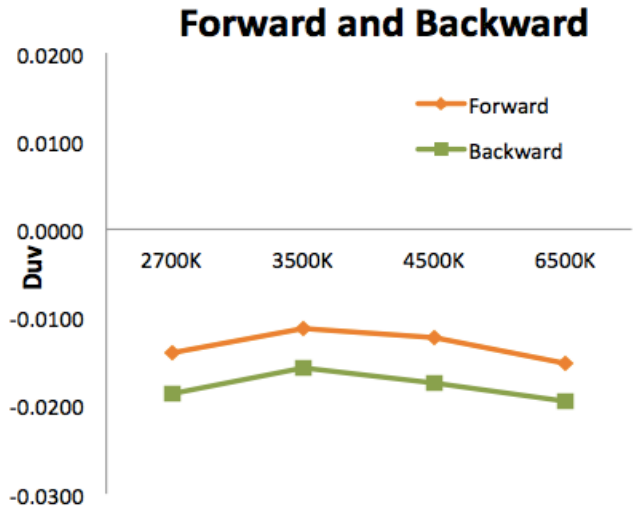
No significant differences found.

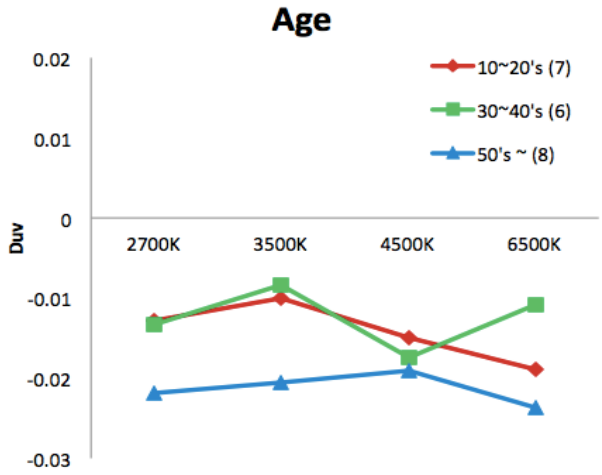
[In preparation] Y. Ohno and S. Oh, Vision Experiment II on Preferred White Light Chromaticity for Lighting, CIE 2016, Melbourne, March 2016 (abstract submitted)

Average Results



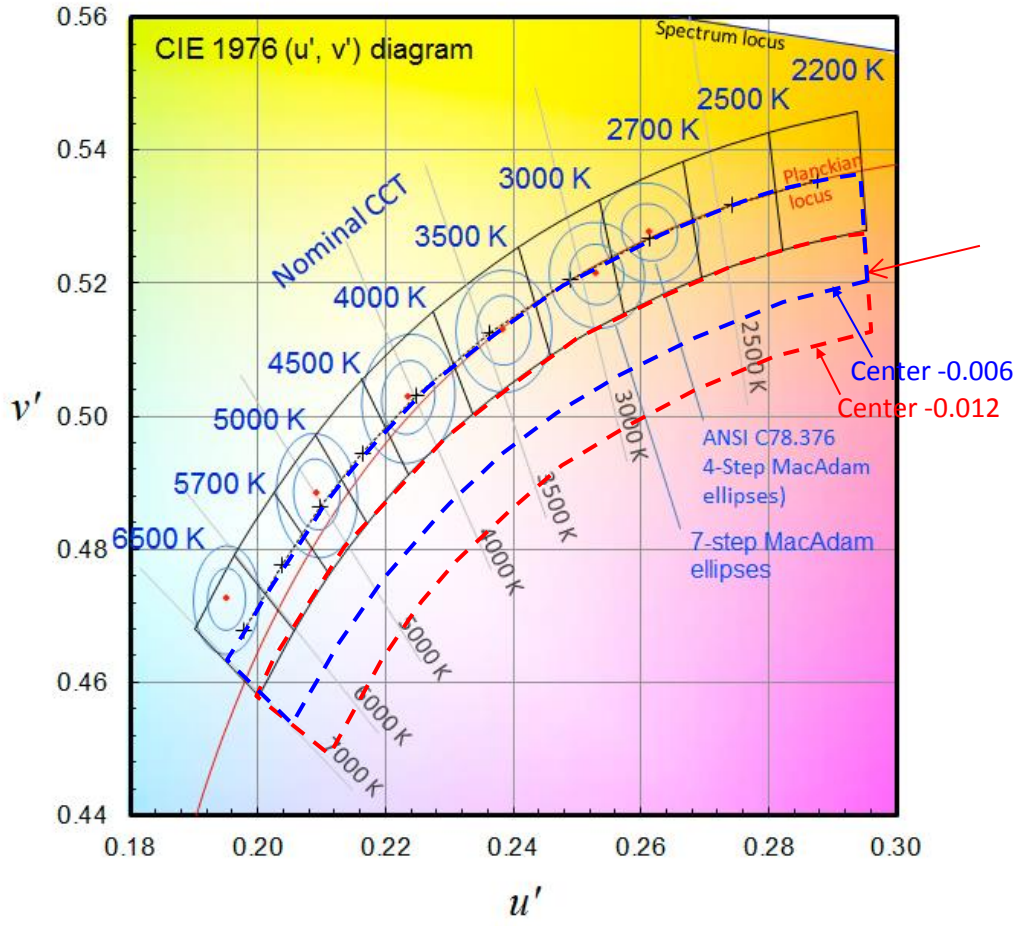






A proposal being prepared in ANSI C78.377 WG

Current specification



- DOE regulation on SSL products (mandatory) coming.

Possible addition
"Preference-based specification"

Flexible Duv spec.
Center Duv (2200-3000 K)
-0.003
-0.006
-0.009
-0.012

Conclusions

- In response to Wei and Houser study, the 2015 results showed that the preference to negative Duv is caused by **the effect of chromaticity shift** not due to the associated gamut area change.
- However, it is considered that **chroma increase** in negative Duv (which occurs in general cases) may also affect (enhance) the preference in the same direction.
- It is verified that the preference for negative Duv is **consistent over all CCT ranges** (2200 to 6500 K).
- Further experiments or observations with **real application scenes** are desired.
- Additional specification is considered in ANSI C78.377.

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THANK YOU FOR YOUR ATTENTION. Contact: ohno@nist.gov