Presented at: National Archives and Records Administration
25th Annual Preservation Conference

Solid-State Lighting for Museums

Conserving energy, Conserving art

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The Getty Conservation Institute

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

Brooker Gallery, Field Museum, Chicago, Illinois

Smithsonian American Art Museum. Lighting and photography by Scott Rosenfeld

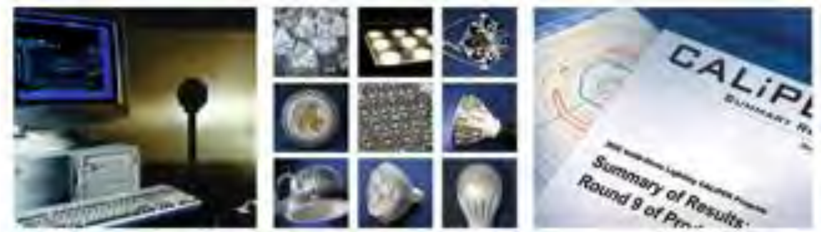
Talk Outline

- SSL lighting priorities for the Department of Energy
  - Testing products and non-biased reporting
  - Disseminating information
  - Demonstrations
- Sustainability goals for museums
- Comparison of LEDs with traditional incandescent lighting
- Tools and metrics for evaluating LED products
- Cost and payback of LEDs in museums
- How to get the best results from LEDs
- How do LEDs produce light
- Conservation risks or benefits to light-sensitive materials
  - Ishii et al., damage functions
- The GCI museum lighting experimental program

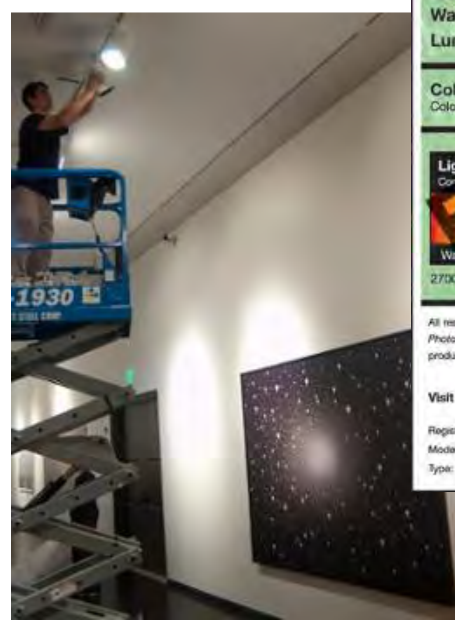
2012 the US will consume 10 Quads of electrical power on general illumination. From 2010 to 2030 it is estimated that a national SSL program could save 16 Quads in energy.

1 Quad is a Quadrillion BTUs
(36 million tons of coal)
(One trillion cubic feet of natural gas).

US Department of Energy Solid-State Lighting Program



- Development of product standards and specifications
- Testing of products (CALiPER)
- Development of fact sheets, product labeling, educational materials
- Product design competitions
- Gateway demonstrations



Sustainability Goals for Museums

- Reduce *energy* use

Energy (measured in kWh) = **Power** x **Time**

- Use lower wattage lamps/fixtu[illegible]
- Turn lighting OFF or dim i[illegible] [illegible]ot needed

- Minimize use [illegible] generated by fossil fuel plants
- Minimiz[illegible] [illegible]aterials in lighting and controls products
- R[illegible] [illegible]ution from mining, manufacturing, and tra[illegible]portation of lighting products
- Reduce materials sent to landfills (long life, durable)
- Recycle materials at the end of useful life

LEDs are efficient AND last a long time

Comparison of LED to Traditional Halogen Lighting

1. Luminous efficiency
2. Lifespan
3. Lumen maintenance
4. Uniformity of light beam
5. Color rendering
6. Color consistency and appearance over time
7. Evenness of intensity distribution
8. Cost
9. Conservation benefit (liability)

A comparison of light source efficiency

Description	Lamp Lumen Efficacy (lm/W)
60 W Tungsten incandescent	5 - 14
Tungsten halogen	15 - 26
Ideal blackbody radiator (4000K)	48
White LED	30 - 150
Compact fluorescent (9-26W)	35 - 70
T8 fluorescent, electronic ballast	80-100
Candle	0.3
3200 K theoretical limit	~520

Measuring LED Efficiency

IES LM-79 Report

- Light output (lumens and candelas)
- Distribution of light (beam size, beam edge, smoothness)
- Electrical power
- Efficacy lm/Watt

"Electrical and Photometric Measurements Of Solid-State Lighting Products"

DOE SSL CALiPER Report

Product Test Reference: CALiPER 09-49 MR16 Replacement

DOE TEST REPORT 09-49 – SUMMARY PAGE

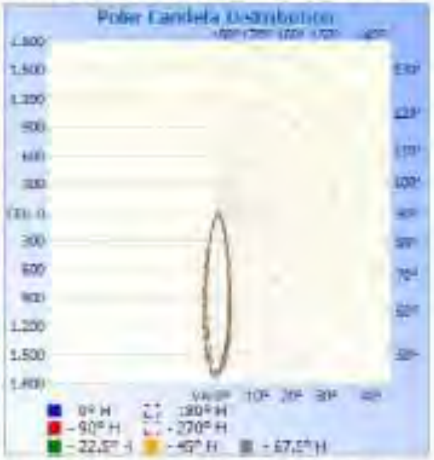
Product Category	MR16 Replacement
Product Description	CRS MR16 Replacement Lamp Narrow Beam P/N: 10-407-07
Date of Test(s) 09-49 A & B & C & D	June 11, 2009
Laboratory Performing Testing	OnSpeX
List of Tests Performed	Spectroradiometry & Goniophotometry following IESNA LM-79-08, Temperature

	09-49A	09-49B	09-49C	09-49D
Total Luminaire Light Output	302 lm	298 lm	287 lm	277 lm
Luminaire Efficacy	49.5 lm/W	48.6 lm/W	46.5 lm/W	45.5 lm/W
Luminaire Center Beam Candle Power	1705 cd	1670 cd	1669 cd	1572 cd
Luminaire Beam Angle	17.4 deg	17.6 deg	17.3 deg	17.4 deg

Product Photo

Photo source: www.crsmr16.com

Luminaire Candela Distribution Plot: 09-49-02A



Note: This testing is based on 12 V AC input. Readers should factor in additional transformer or system losses before comparing efficacy with products which use 120 V AC.

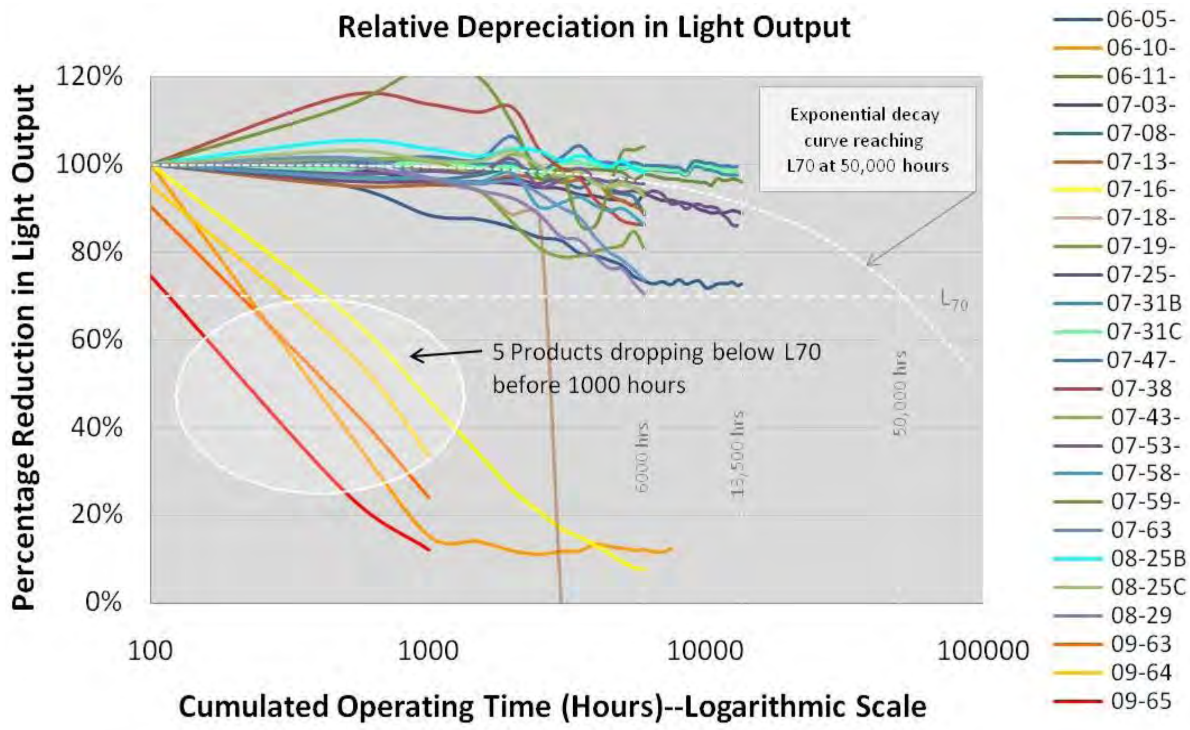
LED Lifespan and Lumen Maintenance

LM-80 Report

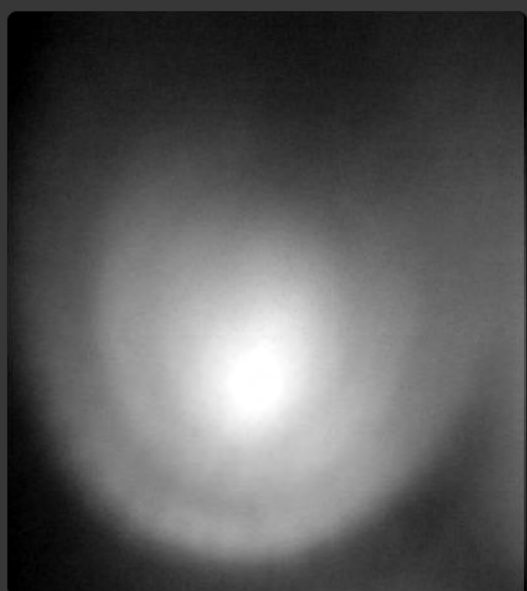
- Measurement protocol for LED chips, not fixtures or lamps
- Used in predicting “life,” measured at 70% light output
- Lumen maintenance

Life expectancy has been growing and is now commonly reported at 50,000 hrs.

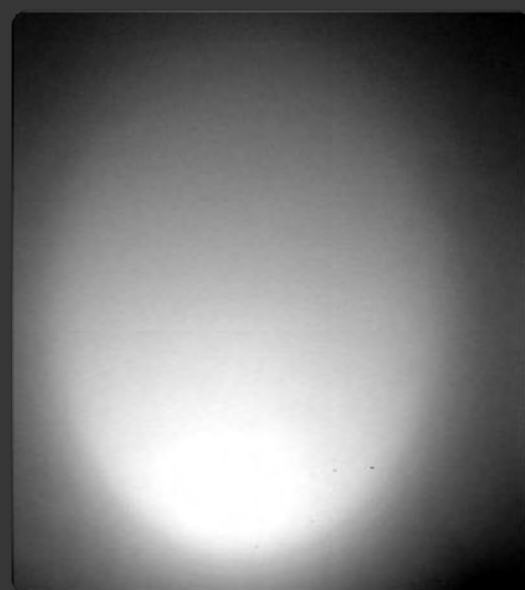
11 hrs/day for 312 days/yr = 14.6 years



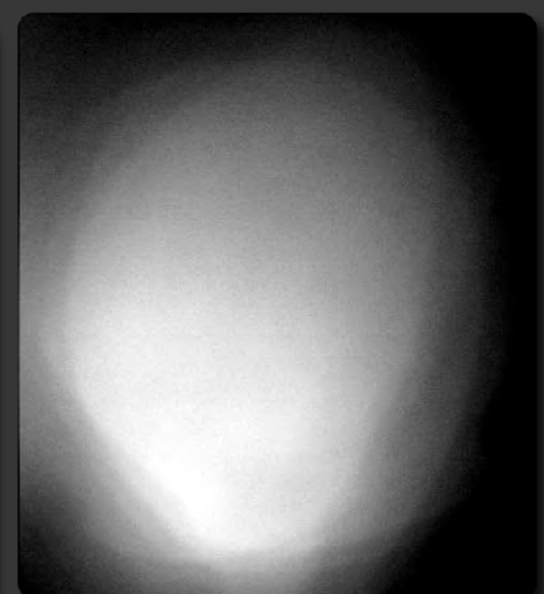
Evenness of intensity distribution



Typical Halogen



Xicato, Cree, CRS



LED Array

Color Rendering

CRI 80

CRI 90

Courtesy of Xicato

Color appearance

IES LM-79 report

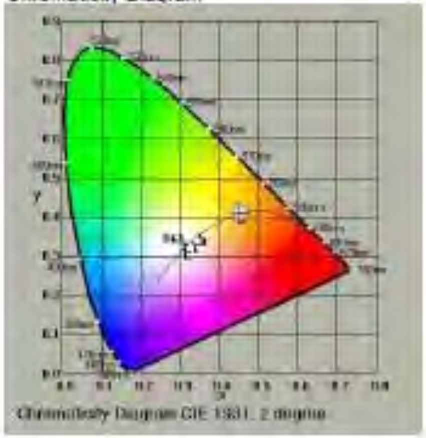
Color characteristics

- Chromaticity
- CCT
- CRI
- Duv
- SPD

Measured Photometric Quantities – Test Results: Color Metrics

Test Identifier: CALiPER 09-49-01A

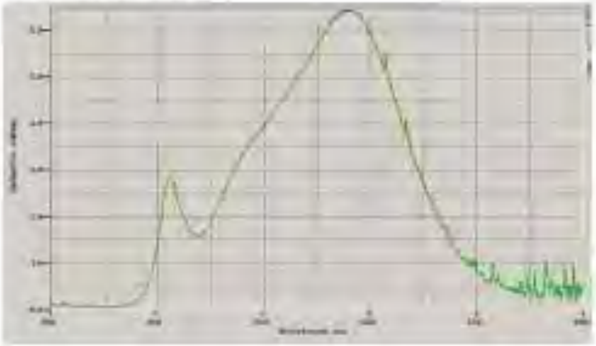
Chromaticity Diagram



Correlated Color Temperature-CCT (K)[1]	2830
Duv	0.001
Chromaticity Coordinates x	0.4517
Chromaticity Coordinates y	0.4122
Chromaticity Coordinates u'	0.2565
Chromaticity Coordinates v'	0.5267
CRI[2]	93.5

Spectral Power Distribution Curve

CALiPER 09-49-01A



[1] Specifications for the chromaticity of solid state lighting products are defined in ANSI_NEMA_ANSLG C78.377-2008.

[2] Readers are urged to be aware of the complexities of assessing color quality and the limitations of CRI with regard to SSL technologies. Alternative metrics are under development. In the meantime, qualitative visual assessment by human observers may provide additional insight regarding the suitability of color quality of a luminaire for a given application. See: Protzman, J. Brent and Kevin W. Houser. October 2006. LEDs for General Illumination: The State of the Science. Leukos. Vol. 3, No. 2, pp. 121-142. Narendran N, Deng L. 2002. Color rendering properties of LED light sources. Proc. of SPIE: Solid State Lighting II.

Smithsonian American Art Museum. Lighting and photography by Scott Rosenfeld

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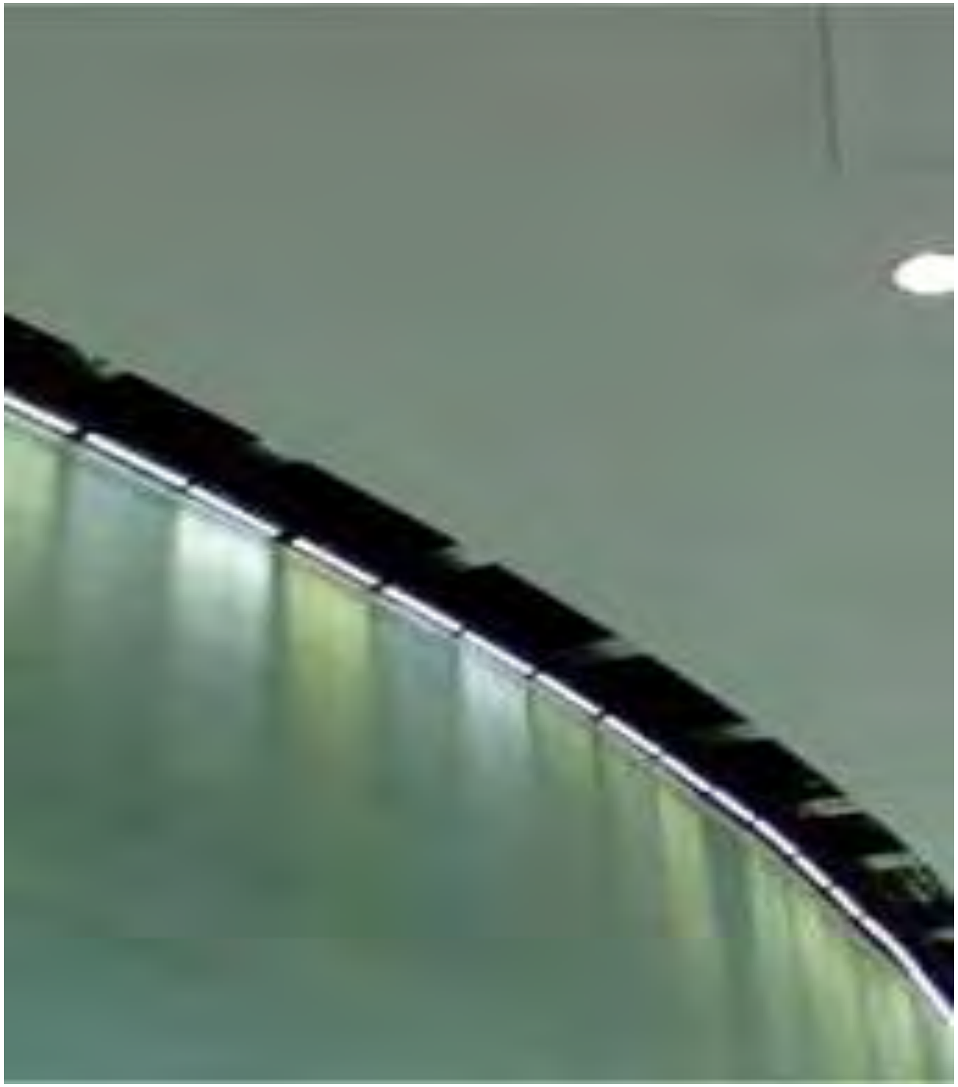
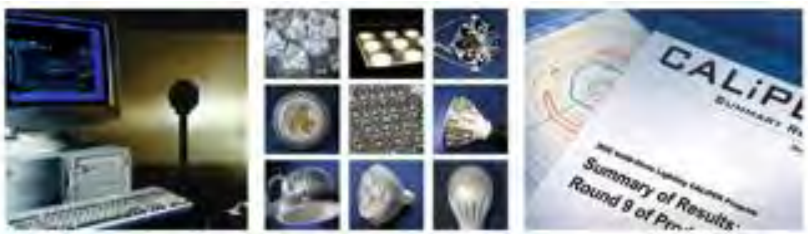
Color Consistency



Color Appearance over Time



Color consistency

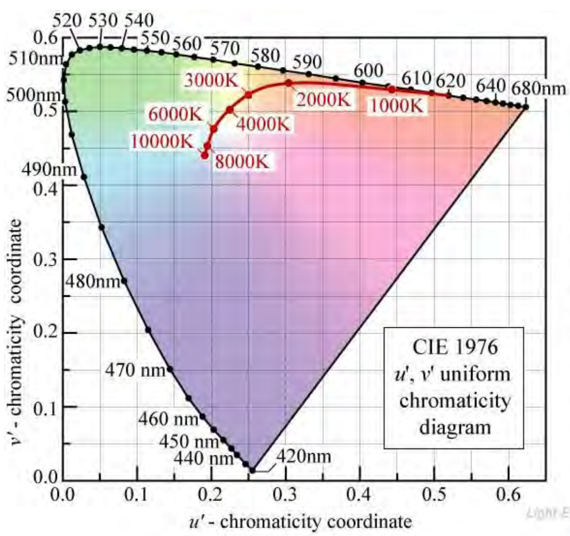
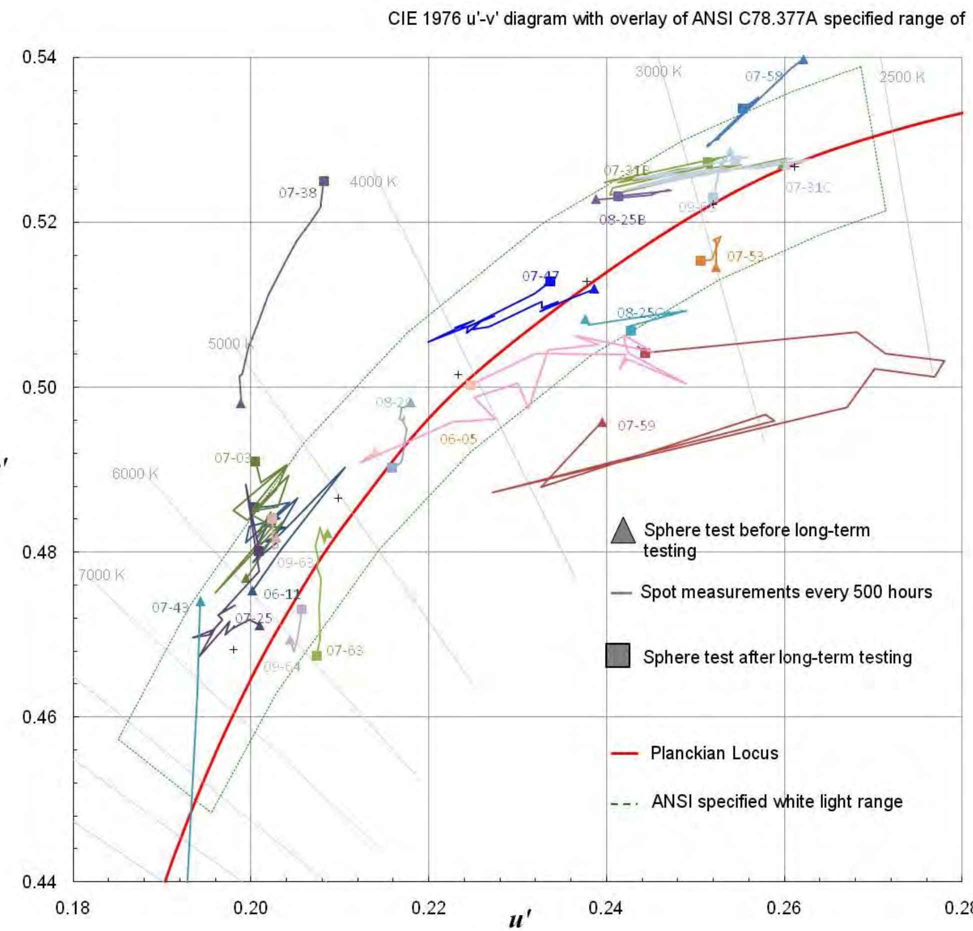


Fig. 18.4. CIE 1976 (u', v') uniform chromaticity diagram calculated using the CIE 1931 2° standard observer and planckian locus.

E. F. Schubert
Light-Emitting Diodes (Cambridge Univ. Press)
www.LightEmittingDiodes.org



LED Cost and Payback

Quality LEDs can reduce lighting power by 75%

+

1W lighting power savings = 1/3W A/C load savings

Payback will be less than 4 years if

- Lights are on 8+ hours/day
- Cost of relamping labor is high (>$25/hr)
- Power cost is >13c/kWh
- Cost of LED replacement lamp is $60 or less

Examine Life Cycle Cost, not just Initial Cost

Case Study: Brooker Gallery, Field Museum

Source	Lamp Type	Lamp Type	Lamp Type	Output W	Energy Savings
Halogen	8 (PAR36)	23 (PAR38)	1 (MR16)	894	
LED	14 (70 mm)	12 (90 mm)		335	63%

Case Study: Brooker Gallery, Field Museum

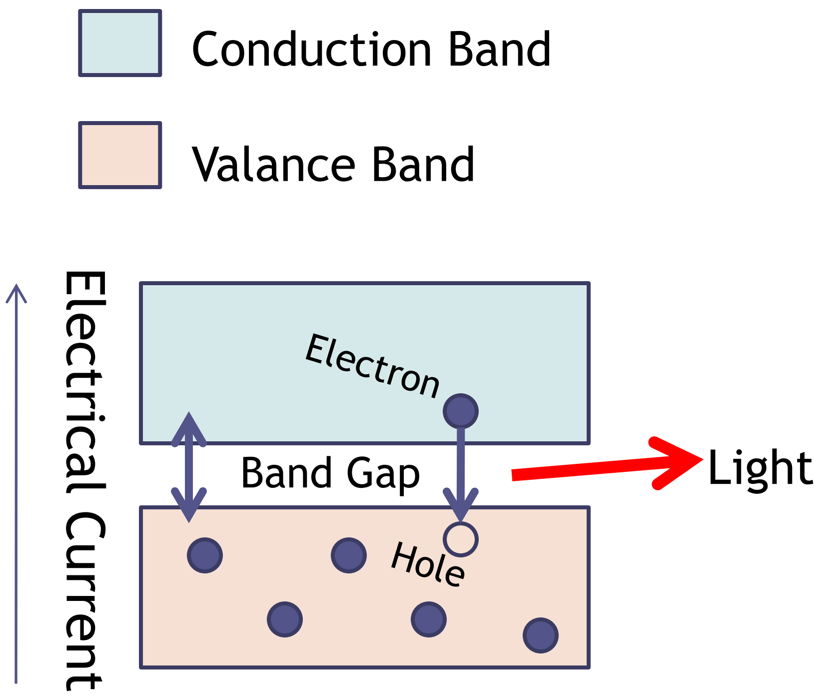
	Halogen	LED
Total Initial Cost	$7,645.00	$ 8,216.00
Annual Hours of Operation	2912	2912
Operating Power of Lighting System	836	335
Annual Ltg. Electric Operating Cost	$292.13	$116.99
Payback from Lighting alone (Years)	-----	3.26
Payback from Lighting + HVAC (Years)	-----	2.38
Lifespan (50,000 hrs/2912) Years		17.17

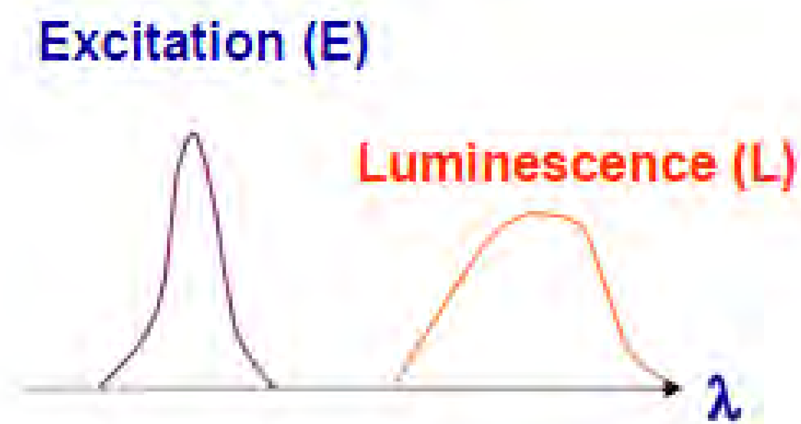
How to get best results using LEDs

- See it before you specify it. See two or three installed.
- Require LM-79 testing for information on performance
- Evaluate lumens and LPW and beam spread
- Check DOE CALiPER website for impartial test data
- Use on non-dimming circuits….. or, test out LED, driver, transformer, dimmer, and loading of dimmer and transformer to be sure they all work together for smooth dimming
- Specify products from companies you know or whom you trust, or that have a documented support history
- Get a written warranty that includes light output and color variation performance, labor included

- Check for EPA EnergyStar ® rating

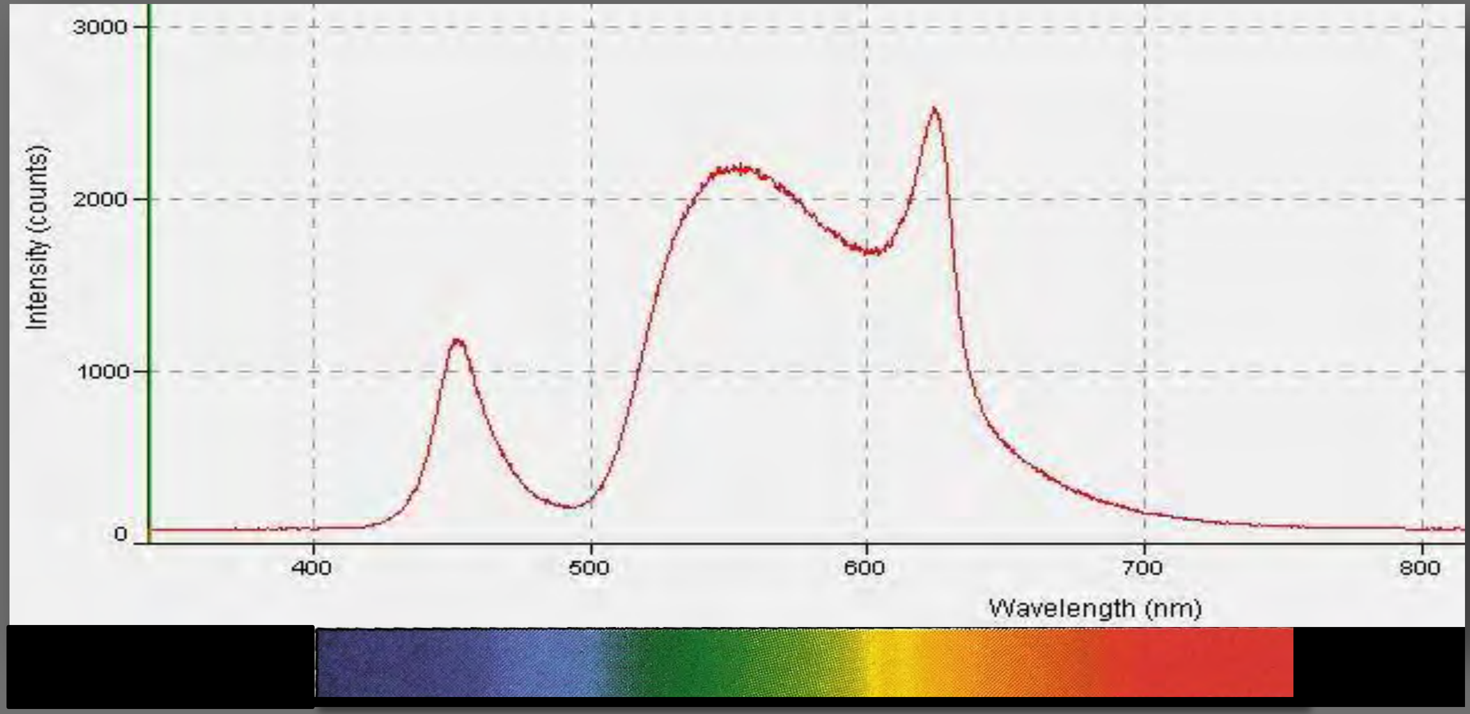
Light is emitted from a semiconductor (LED) by a process called electroluminesence.



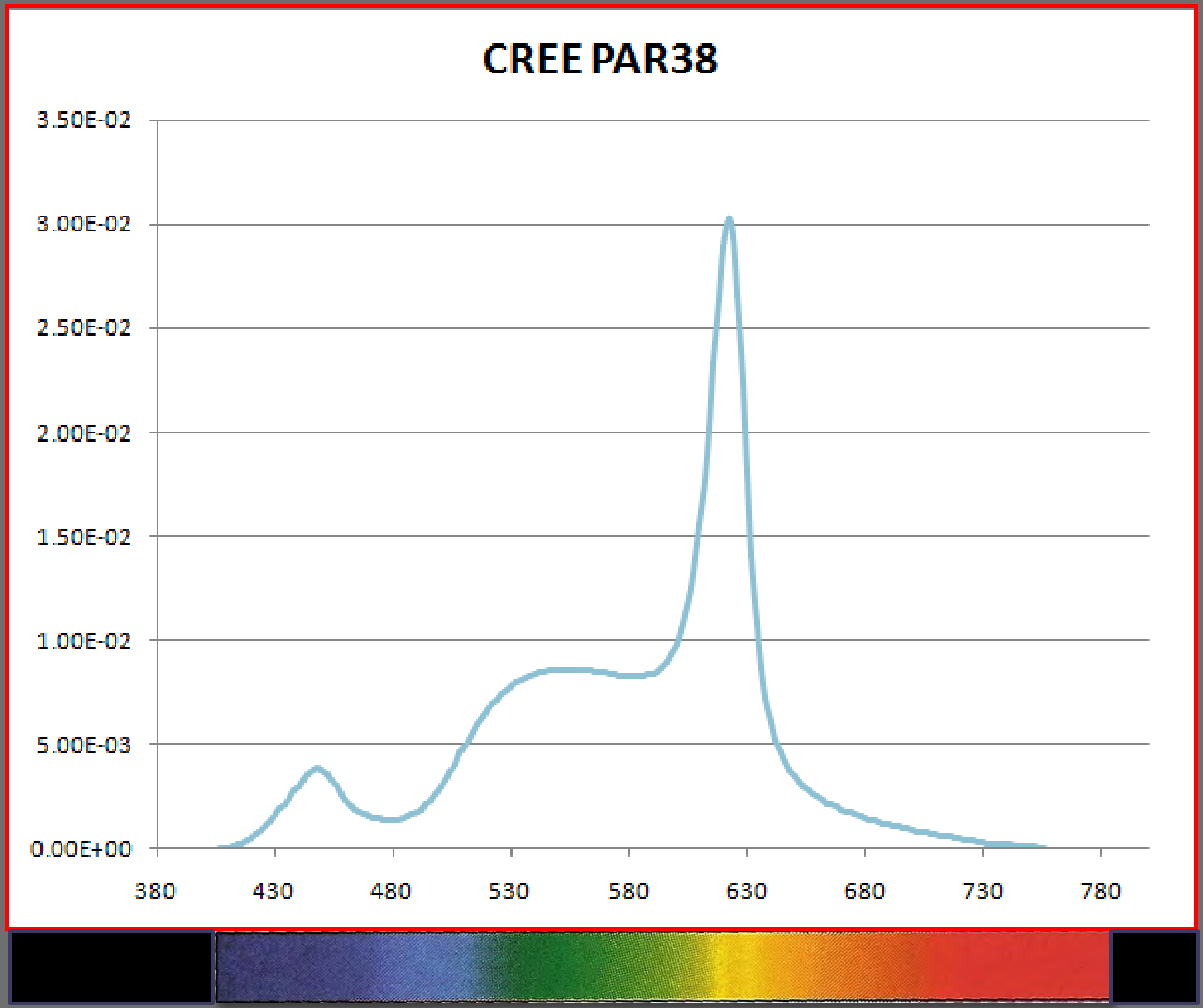


Xicato
CRS Electronics
Solais
Cree
Optiled
Philips

A few LED spectra for your viewing pleasure.



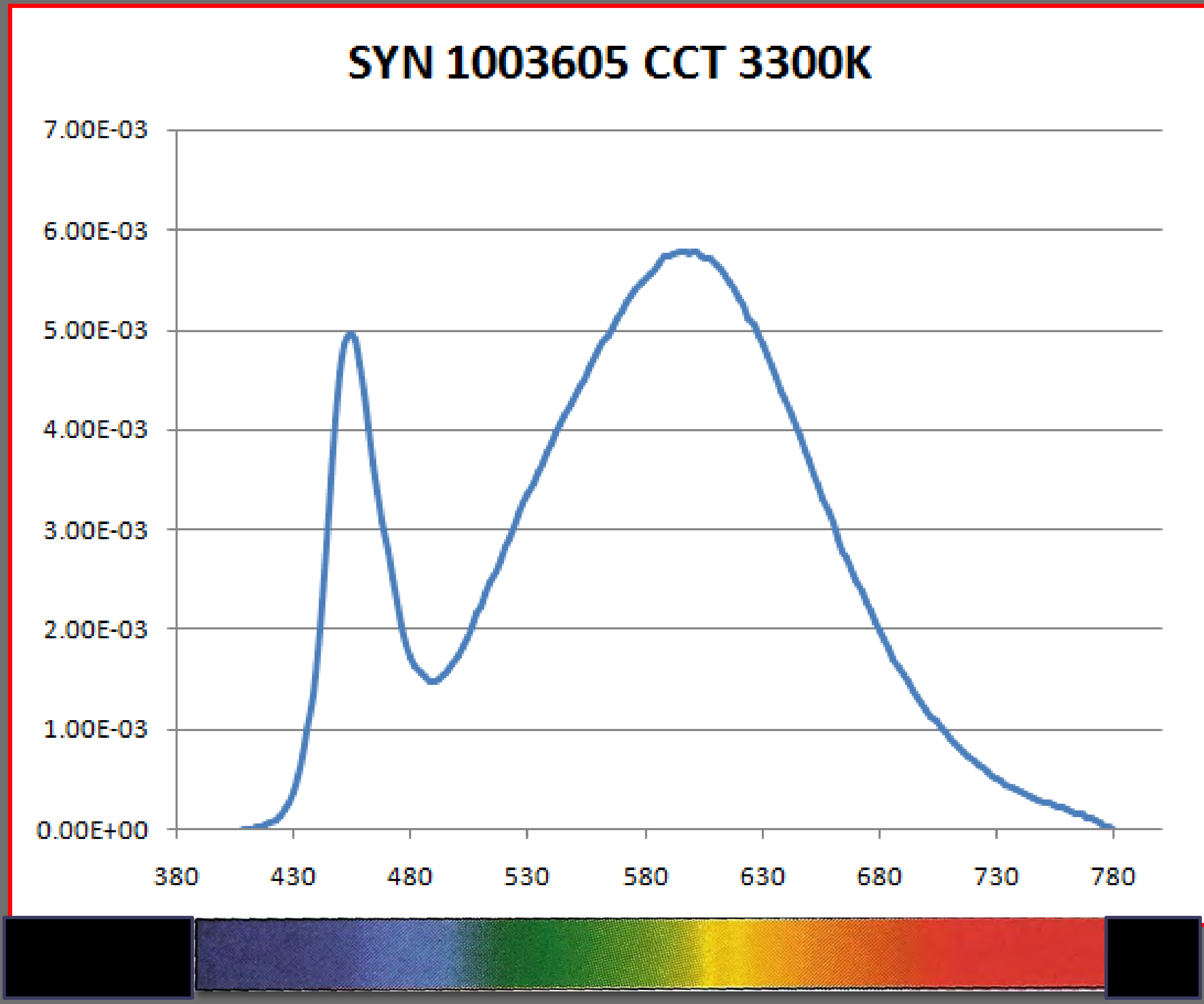
CCT~3000K
CRI ~ Poor



CRI = 93

CCT = 2700K

Δuv = 0.002



SYN 1003605 CCT 3300K
7.00E-03
6.00E-03
5.00E-03
4.00E-03
3.00E-03
2.00E-03
1.00E-03
0.00E+00
380
430
480
530
580
630
680
730
780

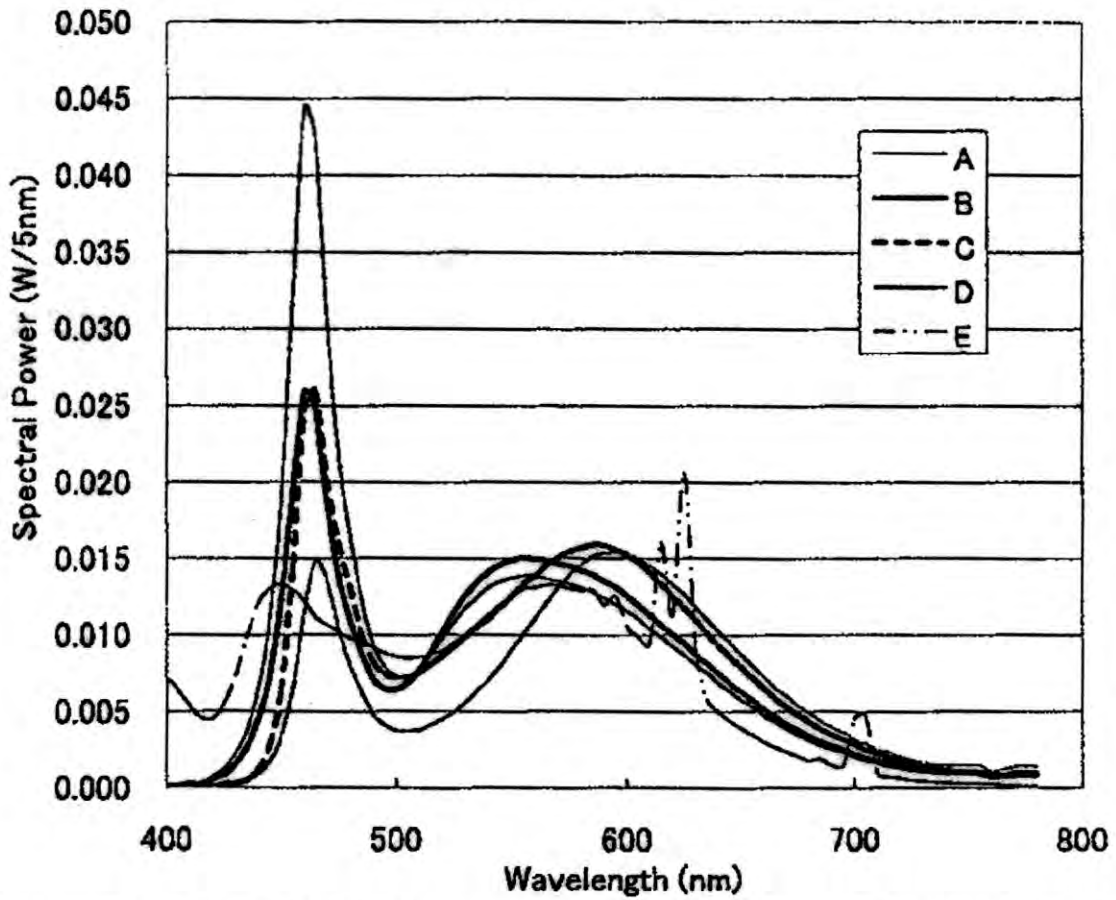
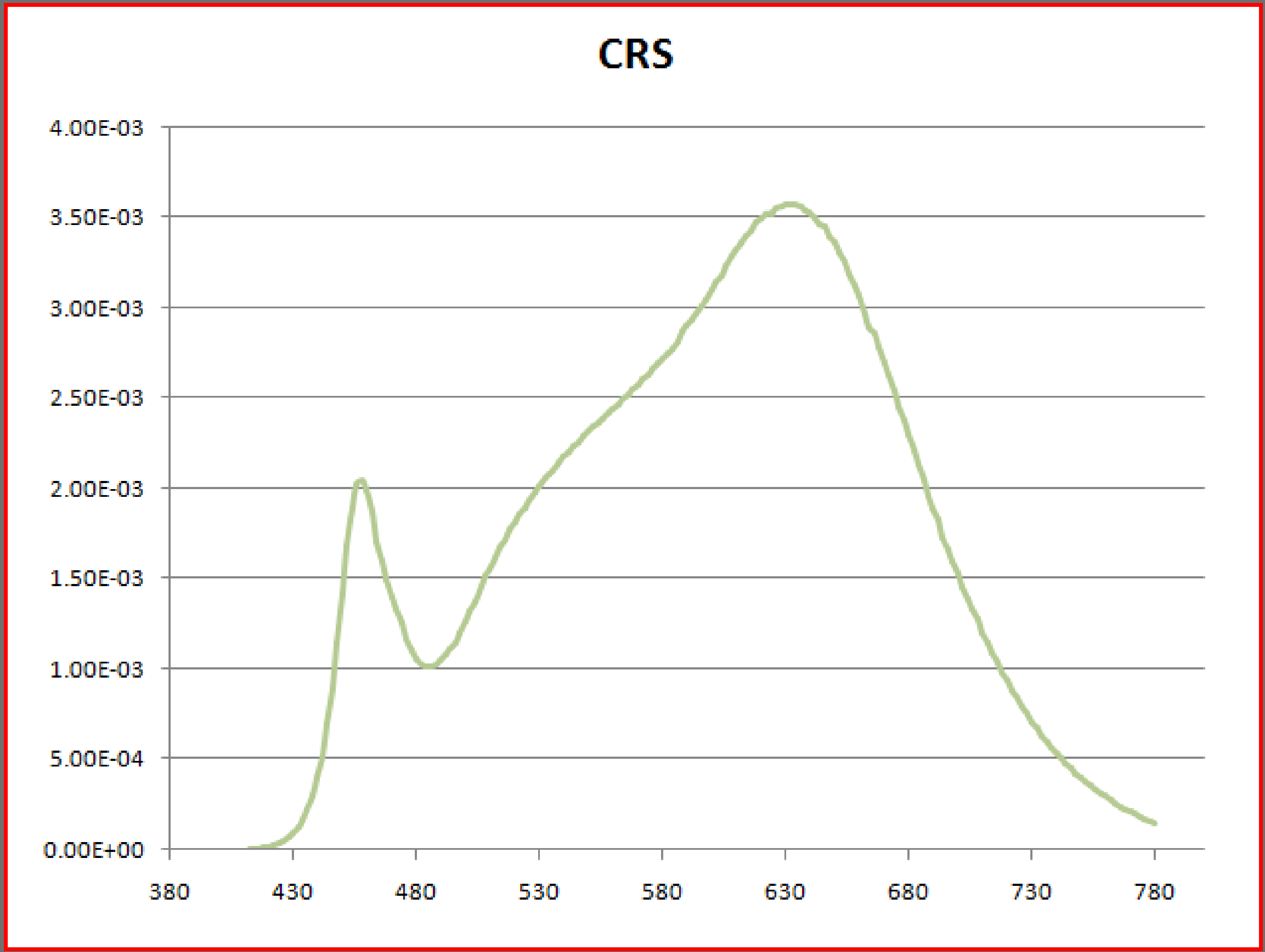
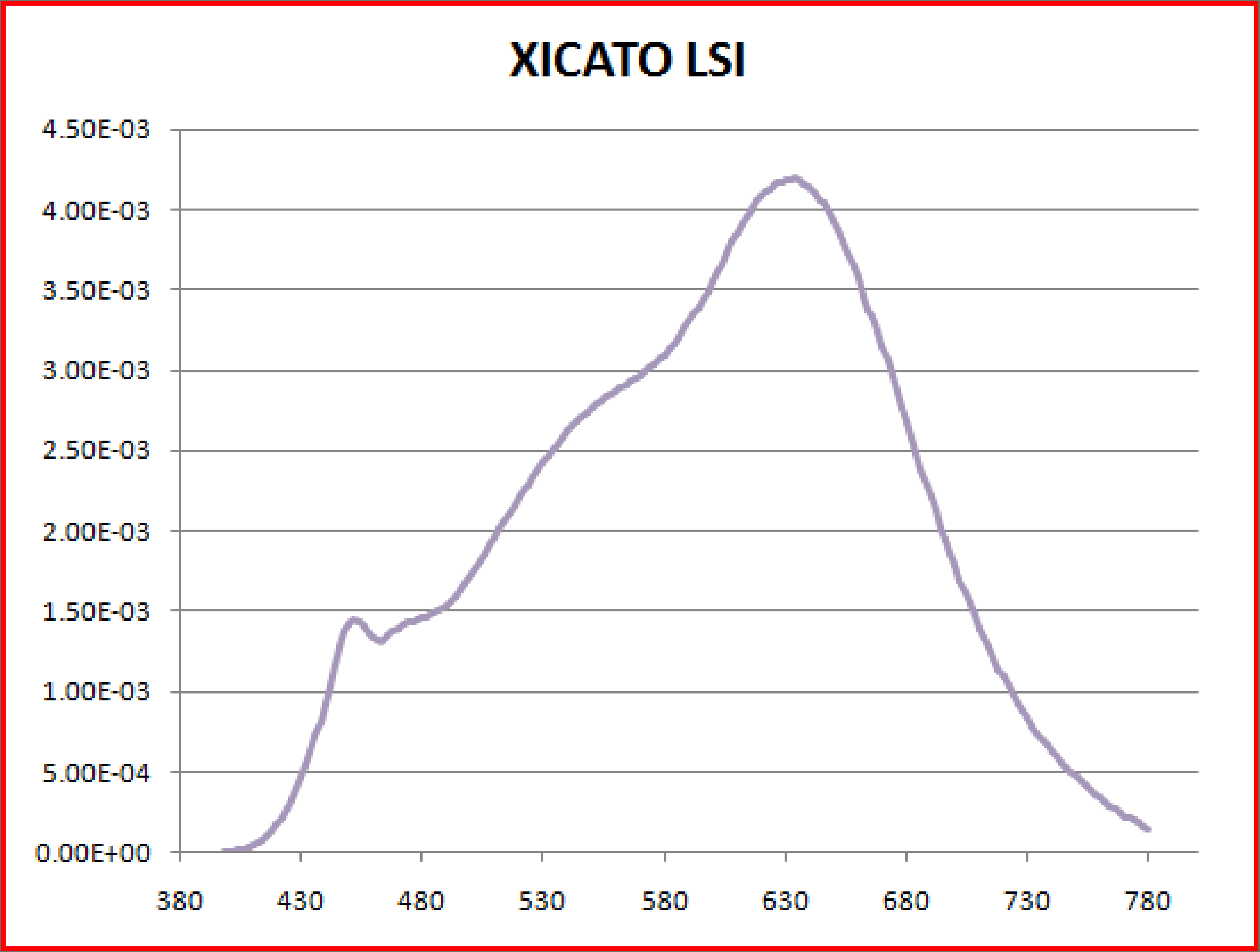
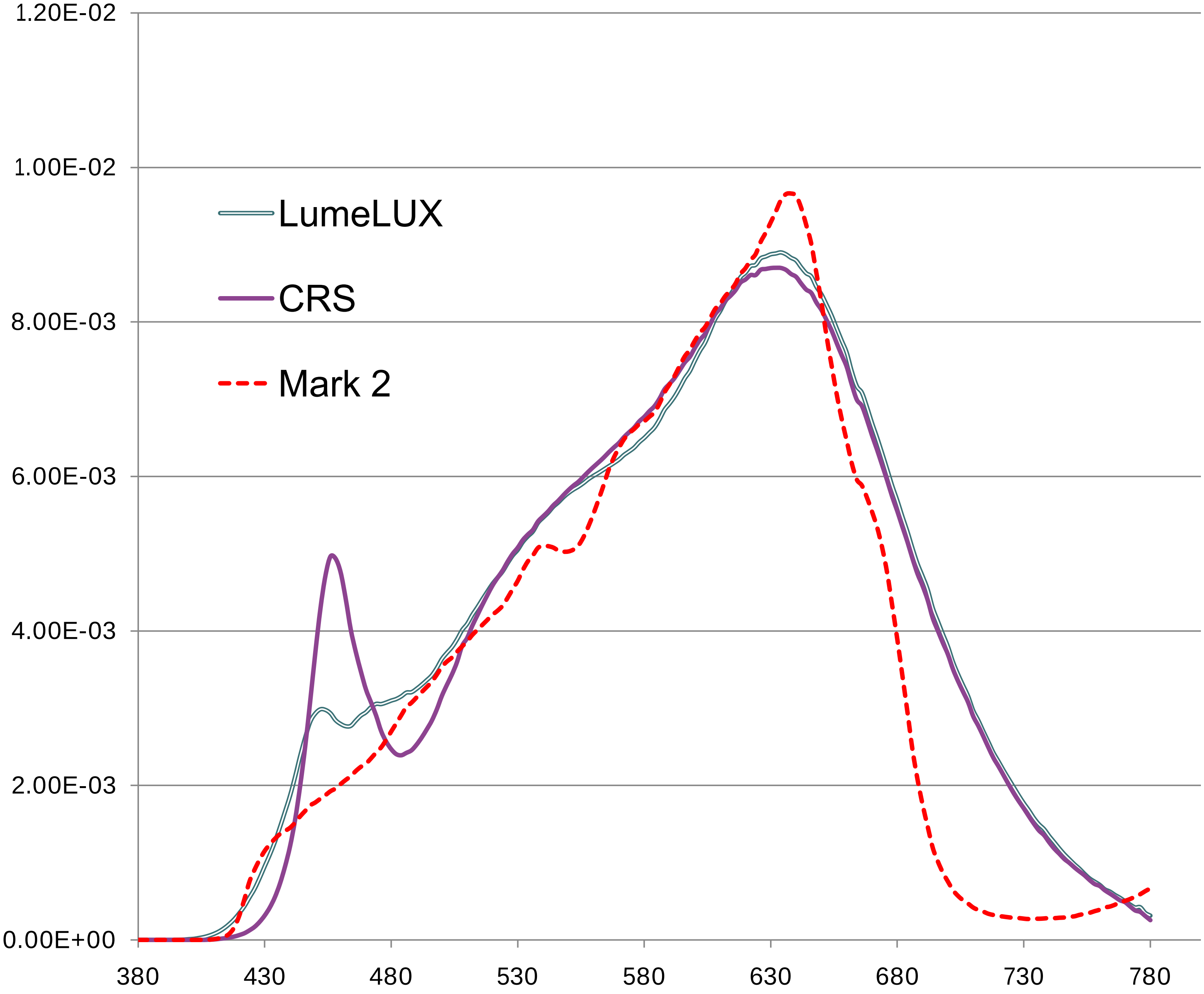


Figure 1 Spectral irradiance distribution of five white LED lamps



CRI = 96
CCT = 3000K
Δuv = -0.0015

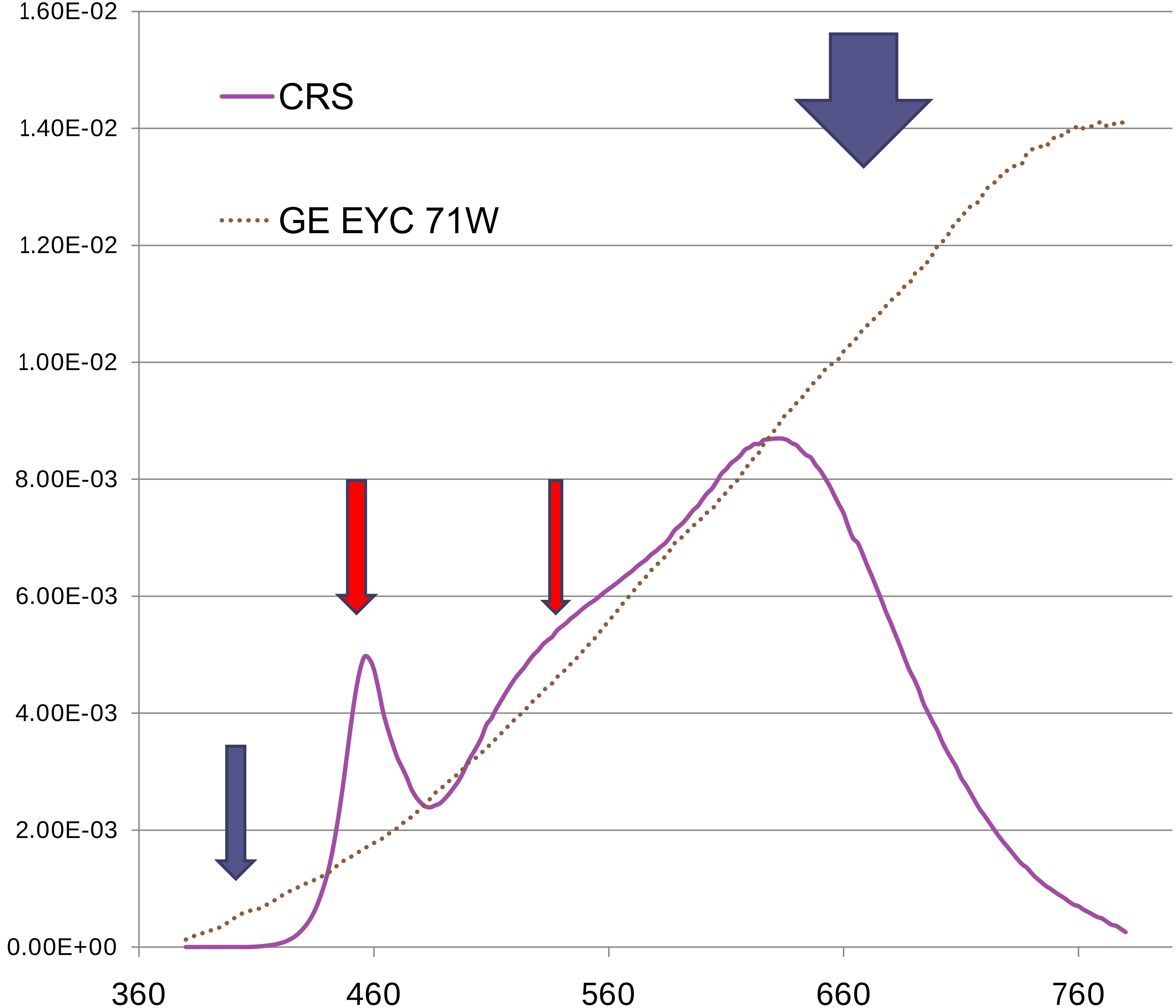

XICATO LSI
4.50E-03
4.00E-03
3.50E-03
3.00E-03
2.50E-03
2.00E-03
1.50E-03
1.00E-03
5.00E-04
0.00E+00
380
430
480
530
580
630
680
730
780



1.20E-02
1.00E-02
8.00E-03
6.00E-03
4.00E-03
2.00E-03
0.00E+00
380
430
480
530
580
630
680
730
780
LumeLUX
CRS
Mark 2

Xicato LED Light Engine Installed

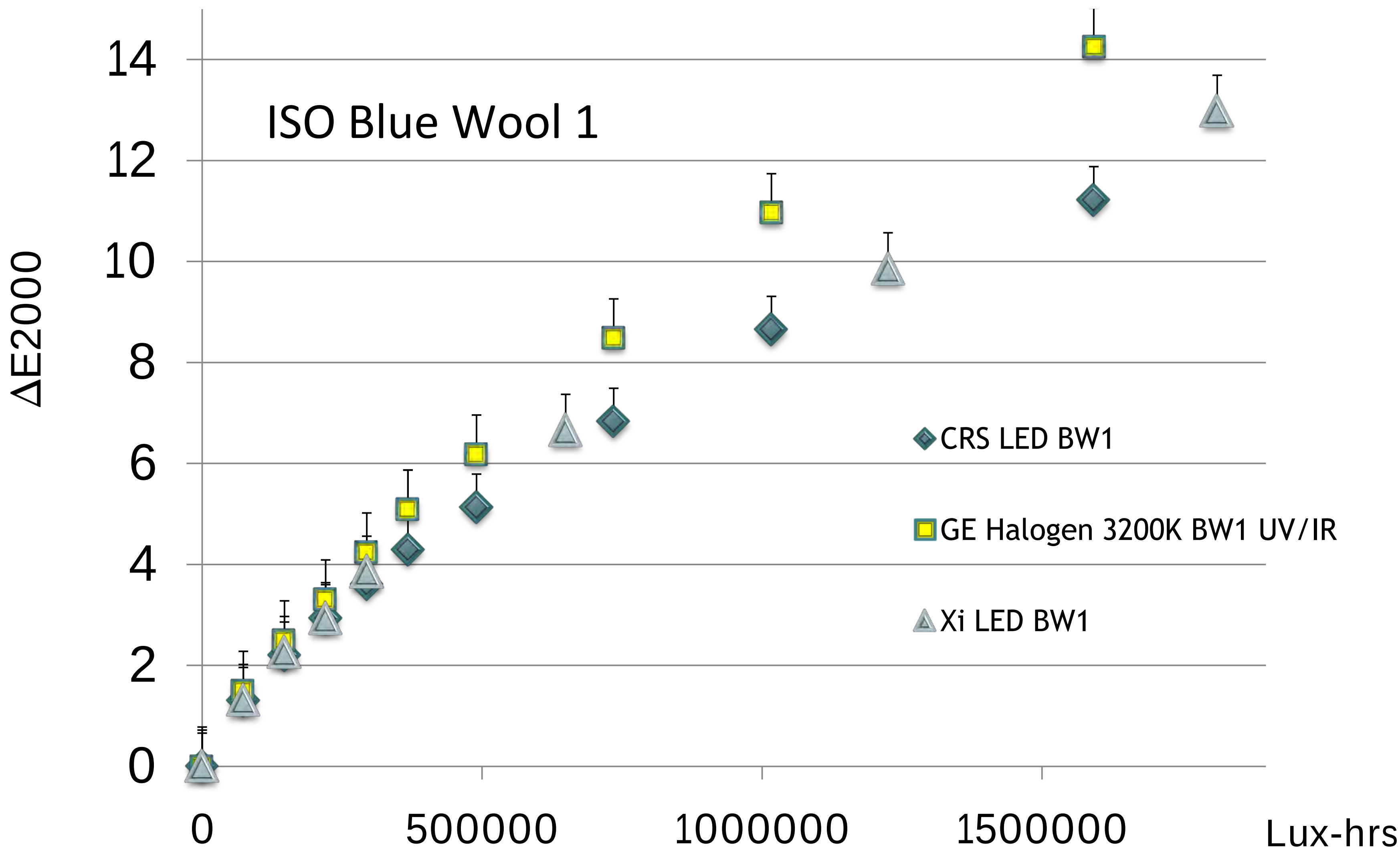
GE MR16 Halogen Installed



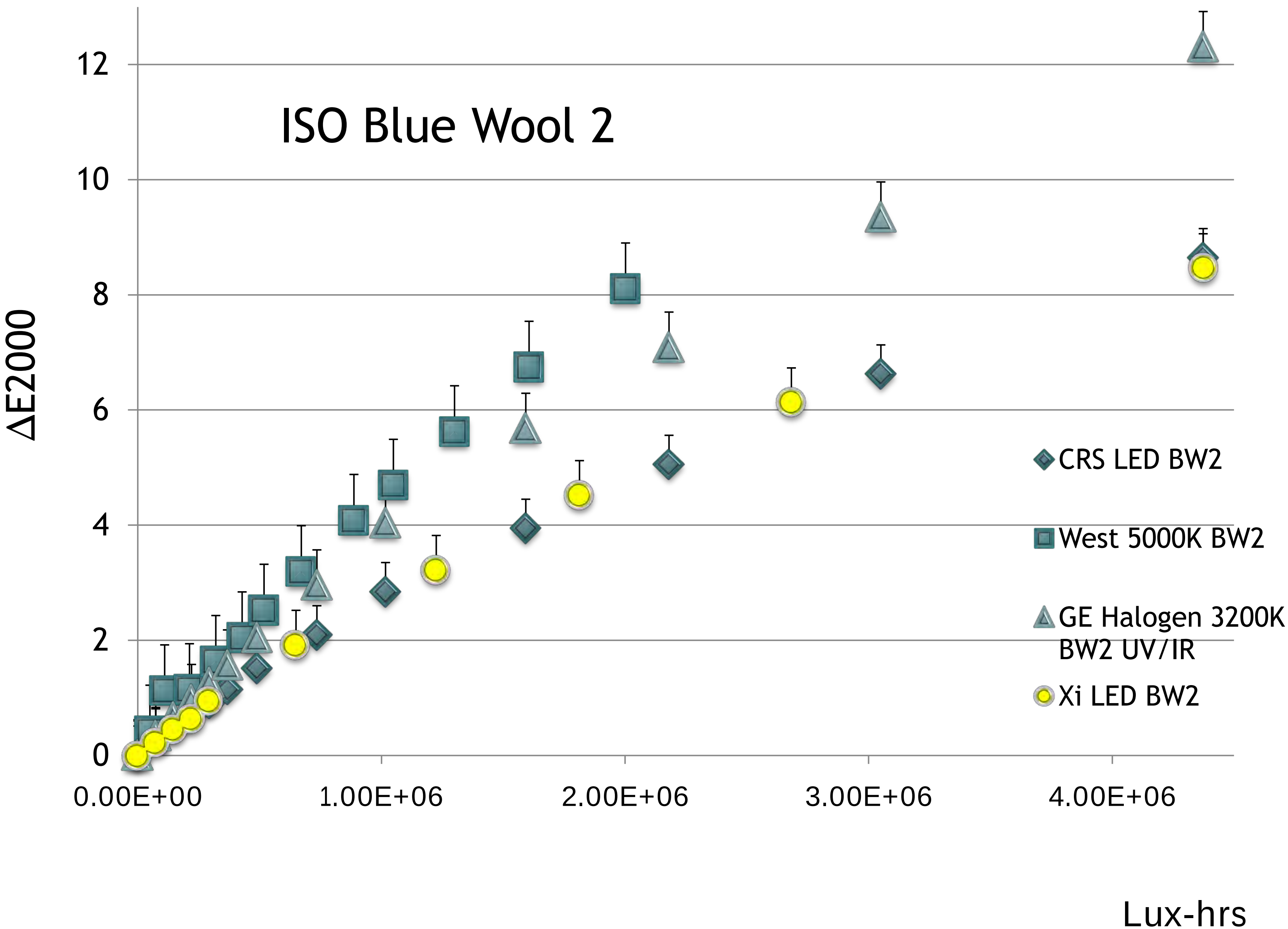
1.60E-02
1.40E-02
1.20E-02
1.00E-02
8.00E-03
6.00E-03
4.00E-03
2.00E-03
0.00E+00
360
460
560
660
760
CRS
GE EYC 71W

Error Bars = 2 x SD + MCDM*

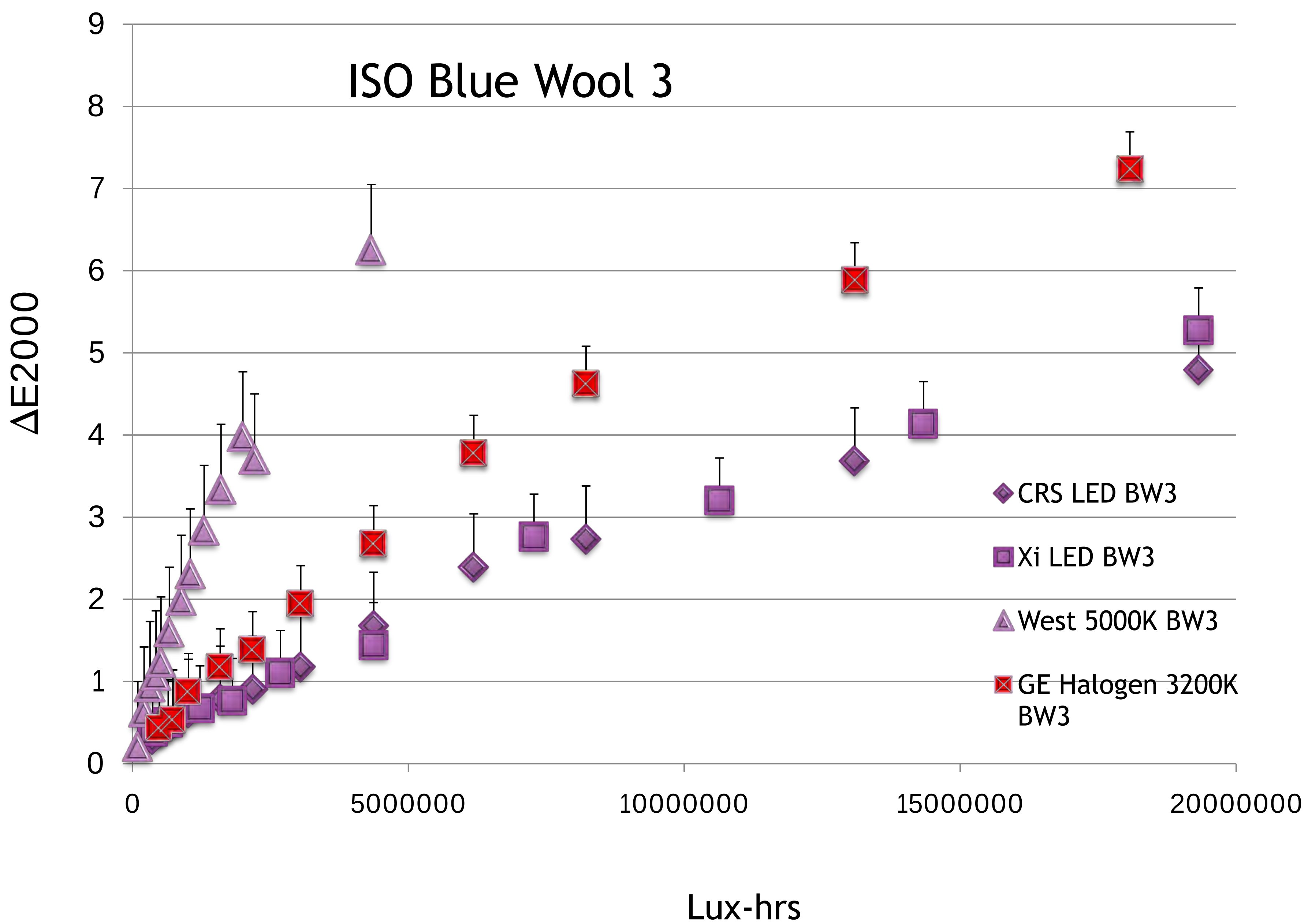
•Berns, R.S. (2000), *Billmeyer and Saltzman's Principles on Color Technology*, Third Edition, pages 97-98.
•Nadal, M. E., et al.(2010), "Statistical Methods for Analyzing Color Difference Distributions", Color: R&A

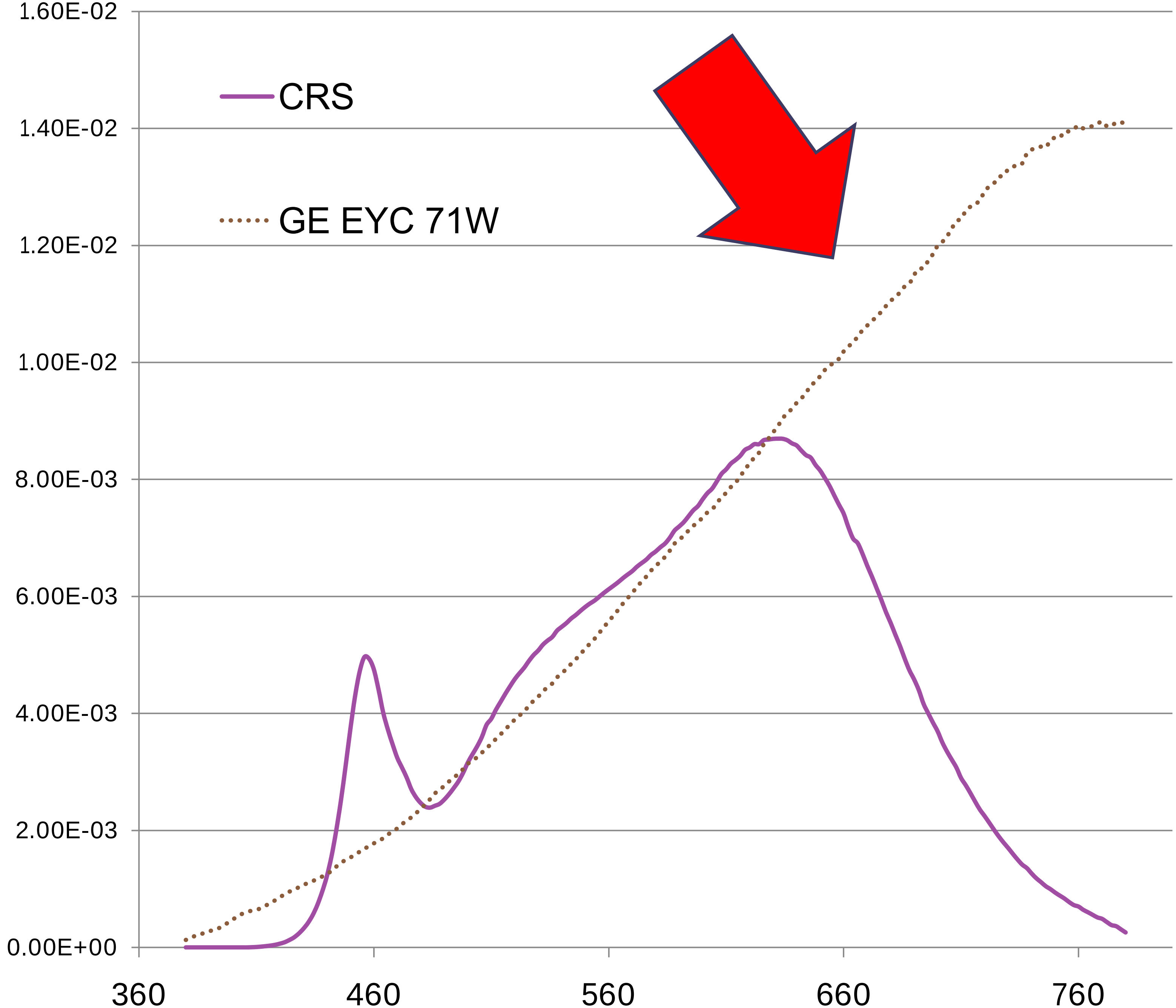


Error Bars = 2 x SD + MCDM



Error Bars = 2 x SD + MCDM




CRS
GE EYC 71W
1.60E-02
1.40E-02
1.20E-02
1.00E-02
8.00E-03
6.00E-03
4.00E-03
2.00E-03
0.00E+00
360
460
560
660
760

			ROUND 2			
Code	**Name**	**Type**	**Substrate**	**Color**	**Origin**	**Use**
Ukon *	Ukon	Japanese Dye	Silk	Yellow	Curcuma linga	Textiles
Zakuro *	Zakuro	Japanese Dye	Silk	Yellow	Punica granatum	Textiles
Kihada *	Kihada	Japanese Dye	Silk	Yellow	Phellodendron	Textiles
Weld *	Weld	European Dye	Silk	Yellow	Reseda luteola	Textiles
Old Fustic *	Old Fustic	European Dye	Silk	Yellow	Chlorophora	Textiles
Onion *	Onion Skin	European Dye	Silk	Yellow	Allium cepa	Textiles
Annatto *	Annatto	European Dye	Silk	Yellow	Bixa Orellana	Textiles
Safflower *	Safflower	Japanese Dye	Silk	Red	Carathamus	Textiles
Sappan *	Sappan wood	Japanese Dye	Silk	Red	Caesalpinia	Textiles
45430 **	Erythrosine B	Modern	Paper	Brown-Red	Synthetic	Autochrome
45440 **	Rose Bengal	Modern	Paper	Red	Synthetic	Autochrome
19140 **	Tartrazine	Modern	Paper	Yellow	Synthetic	Autochrome
42051 **	Patent Blue	Modern	Paper	Dark Blue	Synthetic	Autochrome
42555 **	Crystal Violet	Modern	Paper	Violet	Synthetic	Autochrome
42025 **	Rhoduline	Modern	Paper	Turquiose	Synthetic	Autochrome

* Courtesy of Masako Saito, Kyoritsu Women's University, Tokyo, Japan.
Ishii et al., Color Degradation of Textiles with Natural Dyes and if the Blue Scale Standards Exposed to White LED Lamps: Evaluation of White LED Lamps for Effectiveness as Museum Lighting". J. Light & Vis., Vol. 32, No. 4, 2008

**Courtesy of Luisa Casella.

Thank you

- Color
  - What the heck is D_{UV}?
  - Look for negative D_{UV} (i.e. below black body curve) to avoid green appearance

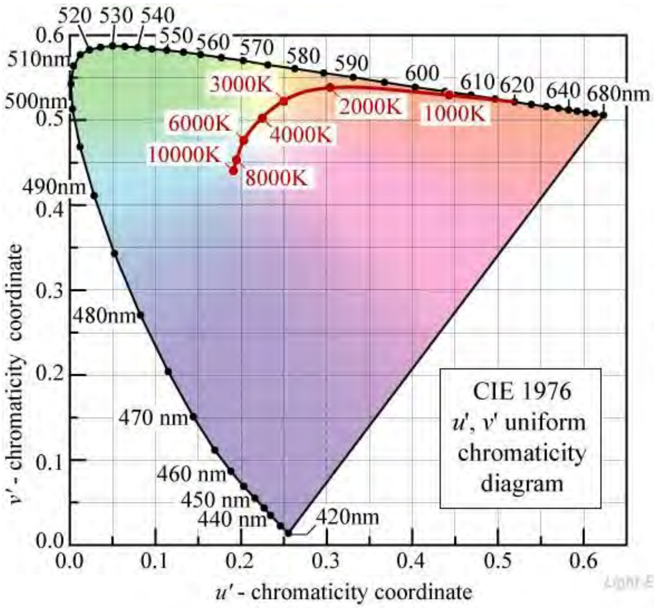


Fig. 18.4. CIE 1976 (u', v') uniform chromaticity diagram calculated using the CIE 1931 2° standard observer and planckian locus.

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