

Chromaticity Adrift: Understanding LED Color Stability

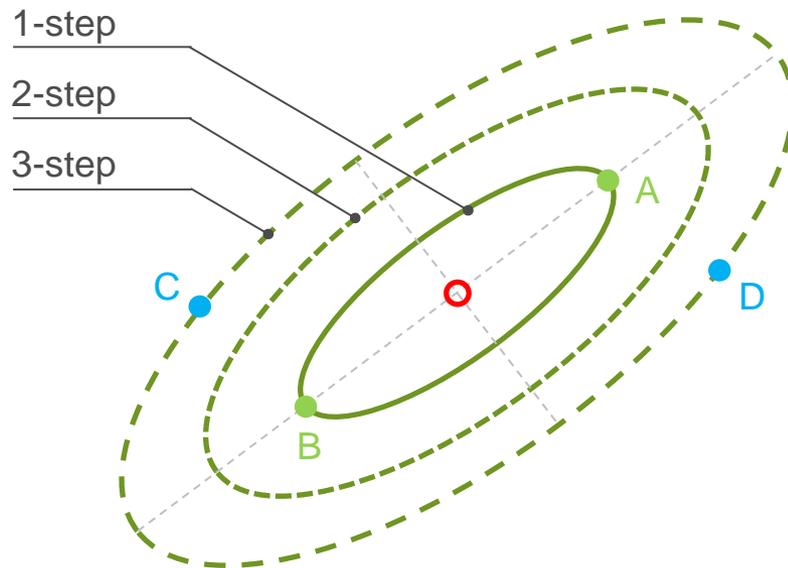
Lightfair

May 4–7, 2015

Michael Royer, PNNL

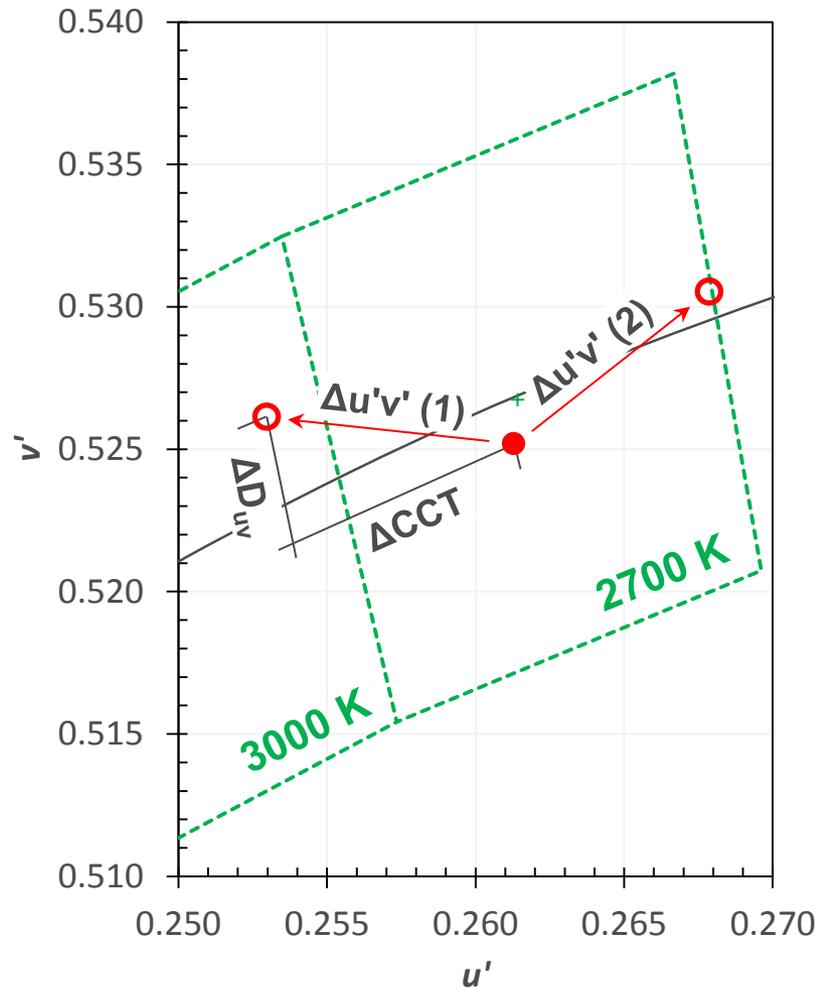
What metrics are used to describe color shift/color stability?

MacAdam Ellipses



- Experimentally-derived indicators of human color vision tolerances at various chromaticities
- Based on the observations of one highly-trained observer in a very specific scenario/apparatus; results cannot be translated to every installation
- Sometimes referred to as SDCM (standard deviation of color matching)
- Can be reported in multiples (e.g., 3-step ellipse)
- Do not convey the direction of shift/difference

What metrics are used to describe color shift/color stability?

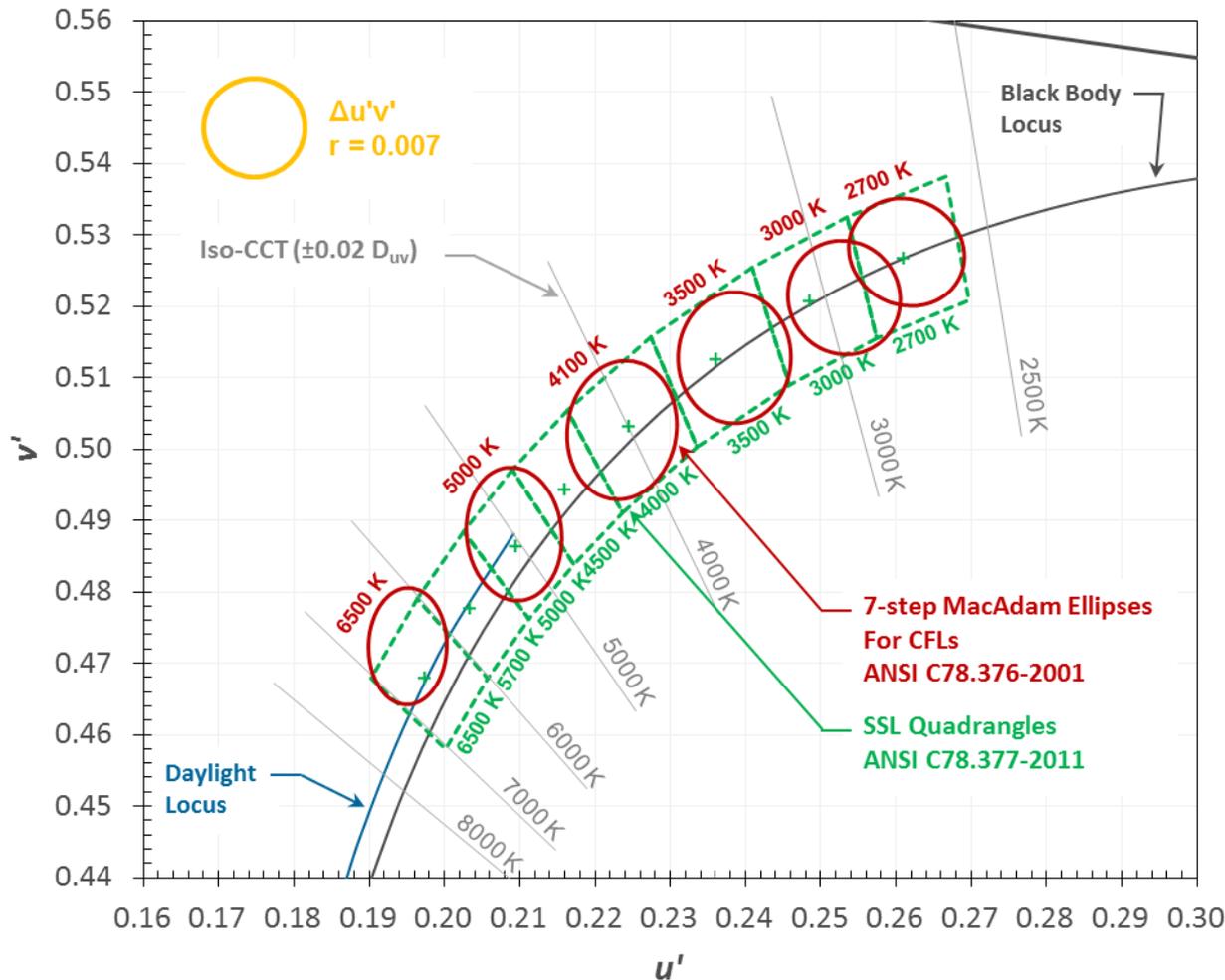


$\Delta u'v'$

- $\Delta u'v'$ is the Euclidian distance between two sets of chromaticity coordinates in the CIE 1976 UCS chromaticity diagram.
- As with MacAdam Ellipses, $\Delta u'v'$ does not convey the direction of a shift
- $\Delta u'v'$ does not convey whether or not a difference is noticeable

What metrics are used to describe color shift/color stability?

$\Delta u'v'$ and MacAdam Ellipses



- MacAdam ellipses are approximately circles in the 1976 (u' , v') chromaticity diagram
- A 1-step ellipse is approximately equal to a $\Delta u'v'$ of 0.001
- ANSI definitions of white light allow for fairly large tolerances (~14-step difference from edge to edge)

When does color shift become noticeable?

The million dollar question...

It depends.

Viewer

Field of View

Surface Characteristics

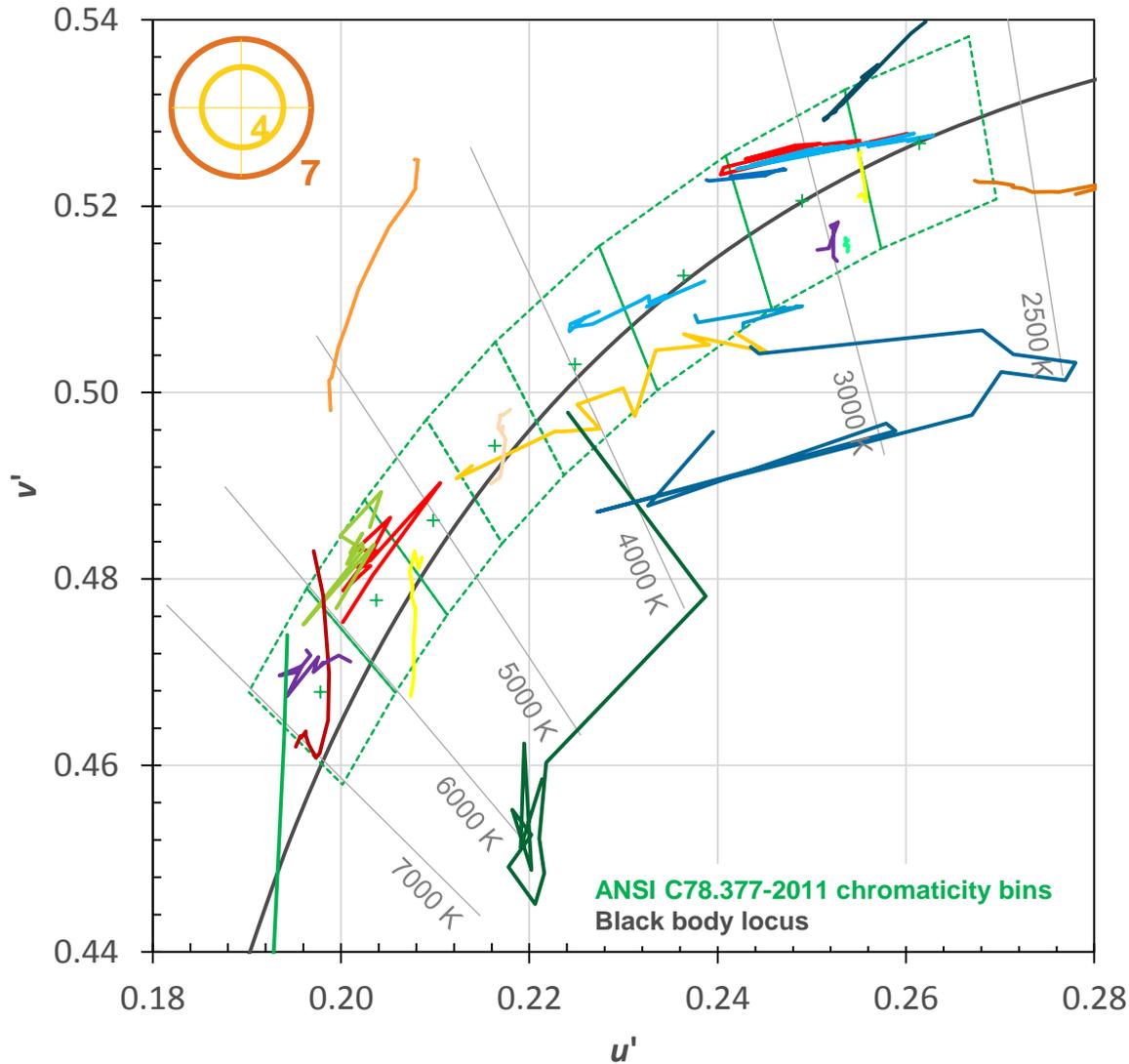
Proximity

Time

In MacAdam's experimental setup, a just noticeable difference was determined to be three times the standard deviation of color matching (or a 3-step ellipse) for a given observer. However, a 1-step ellipse is often called a *MacAdam unit of color difference*.

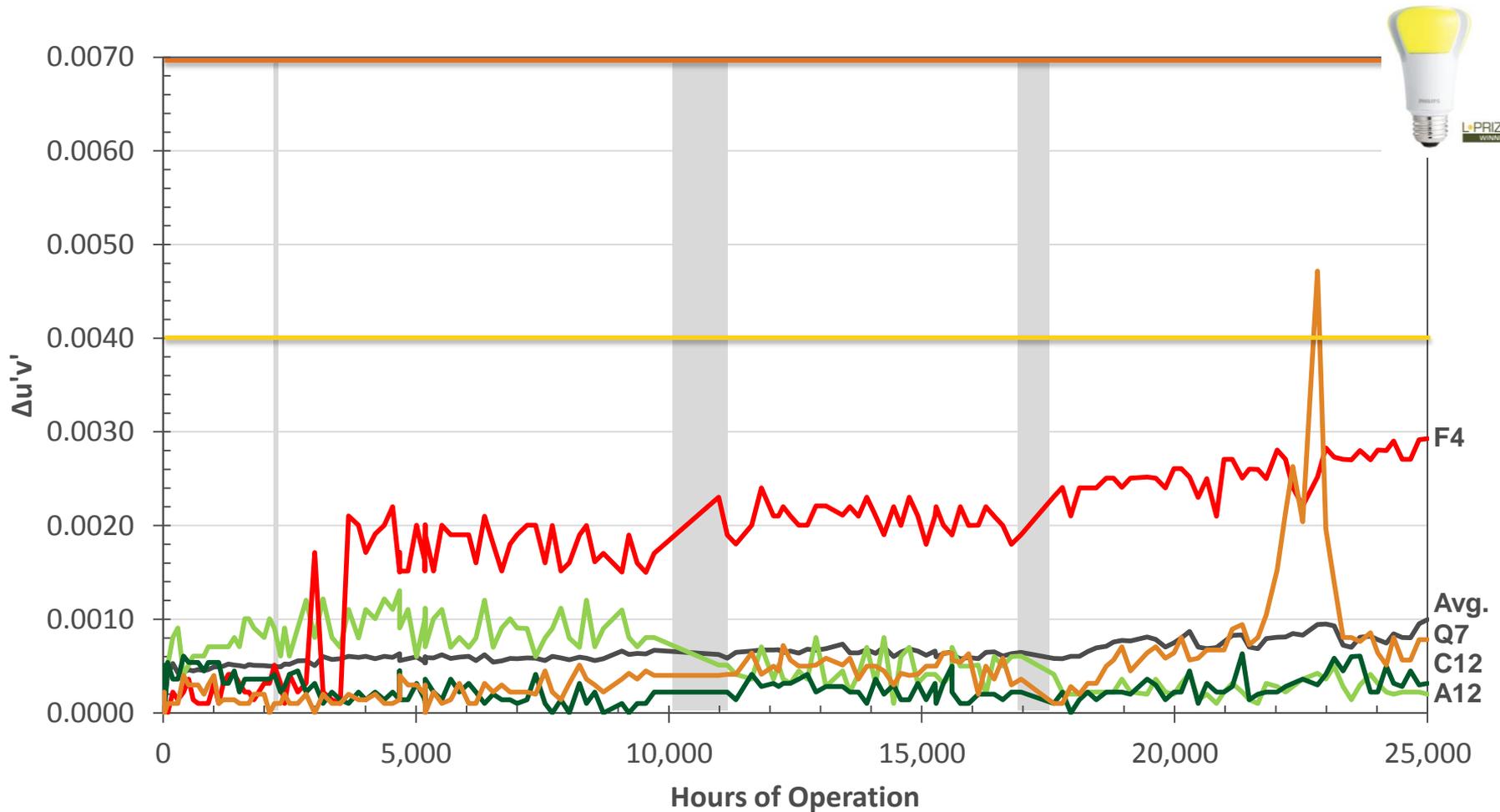
Is color shift a problem for LEDs?

CALiPER
c. 2008



Is color shift a problem for LEDs?

L Prize
LED A19 c. 2009



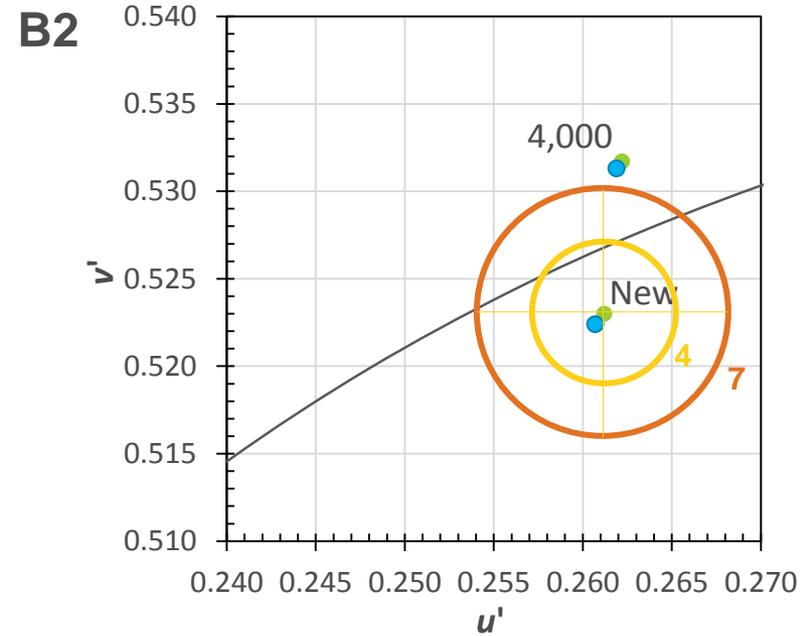
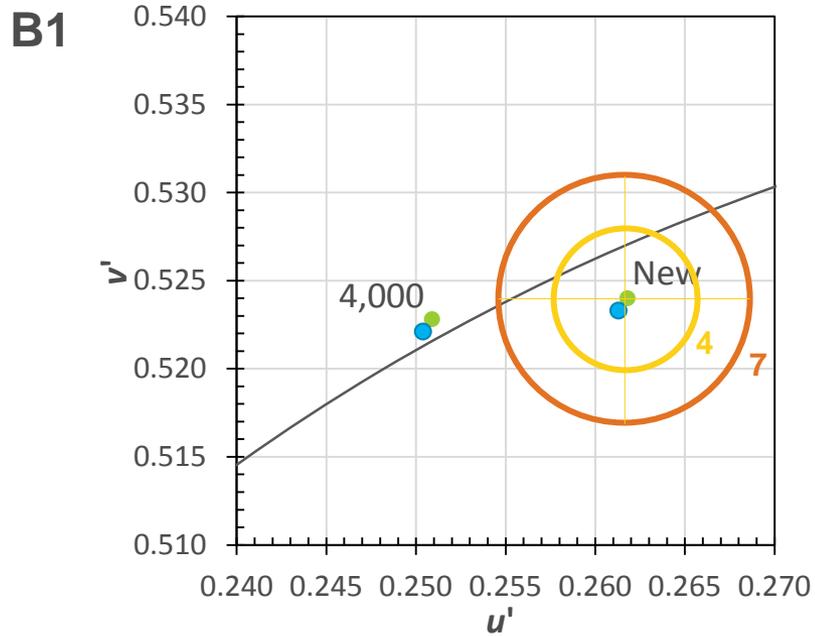


JULIUS WALTERS AND SAM ROSE GALLERY

Image Courtesy of Scott Rosenfeld, Smithsonian American Art Museum

Is color shift a problem for LEDs?

GATEWAY Smithsonian
LED PAR38 c. 2011



● Bare Lamp ● Bare Lamp with Secondary Optics Removed

The image shows three bright, circular lamps arranged horizontally, illuminating a color calibration chart. The chart is a dark board with various colored squares. The lamps are labeled with their age and the lux level they provide at a distance of 1.26 meters.

NEW LAMP
4600 lux @ 1.26m

5750 HOUR LAMP
5000 lux @ 1.26m

6600 HOUR LAMP
4600 lux @ 1.26m



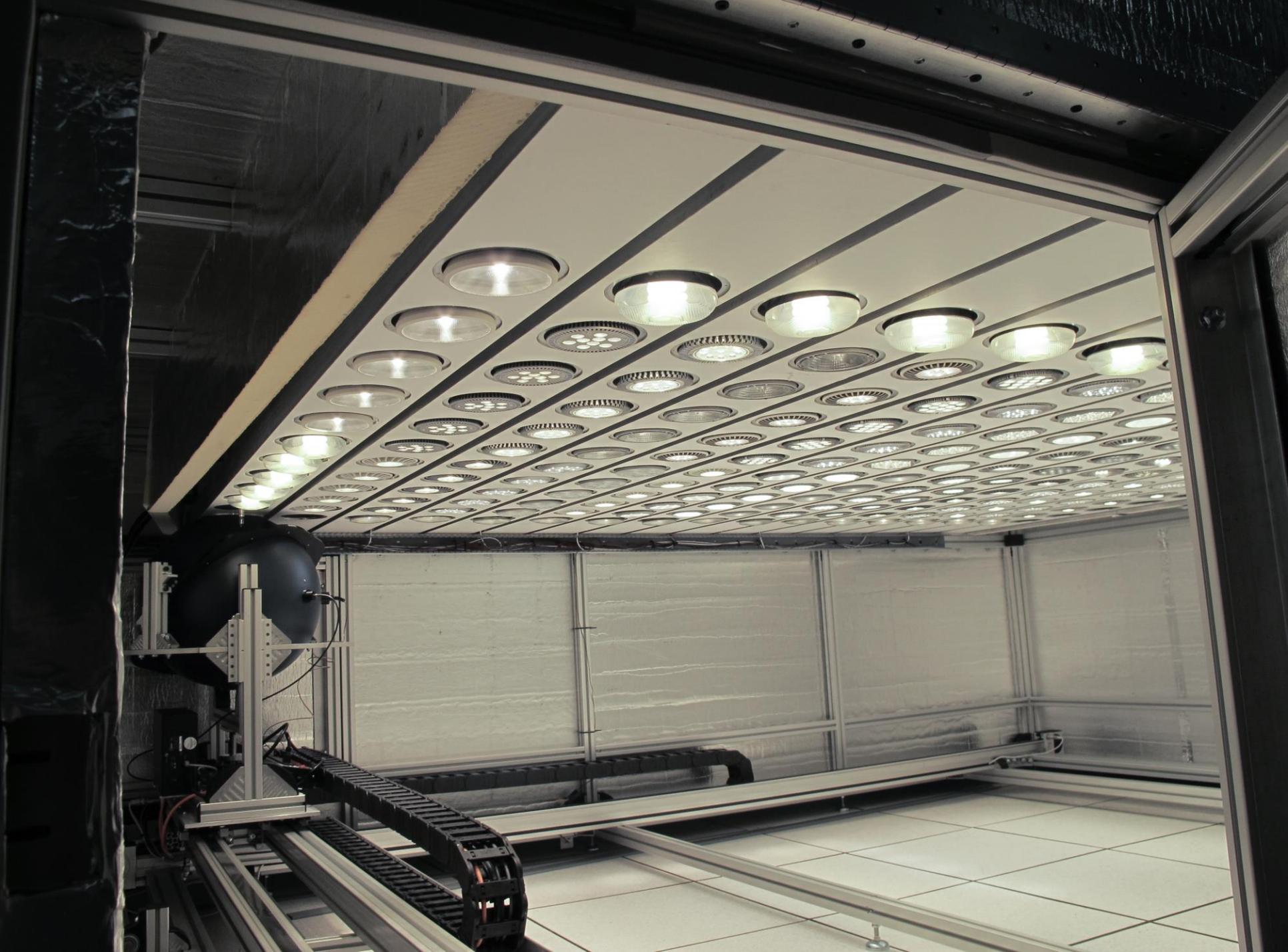
NEW LAMP
1400 lux @ 1.26m

6600 hour lamp
1300 lux @ 1.26m

Is color shift a problem for LEDs?

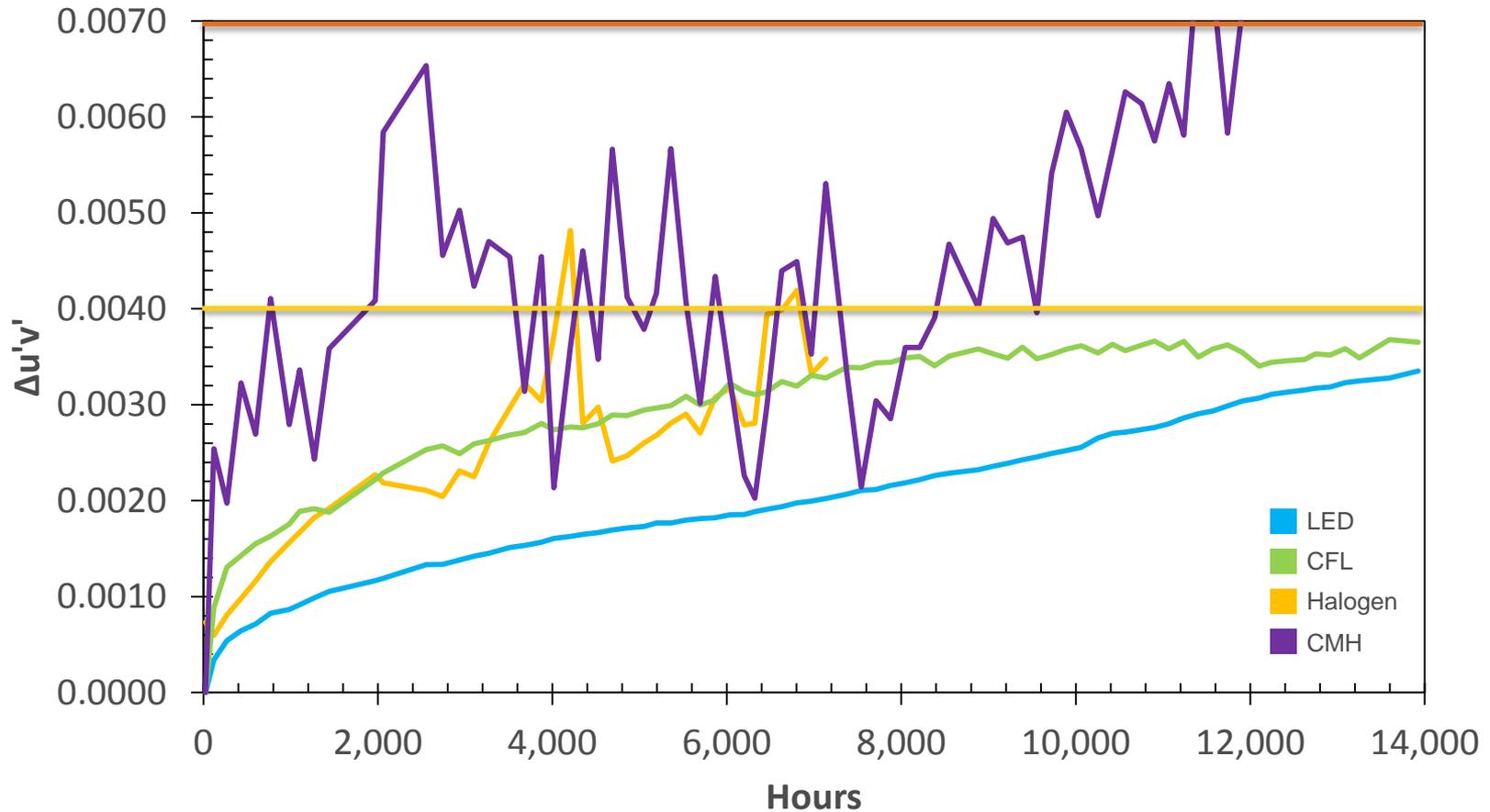


http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/2013_gateway_color-maintenance.pdf



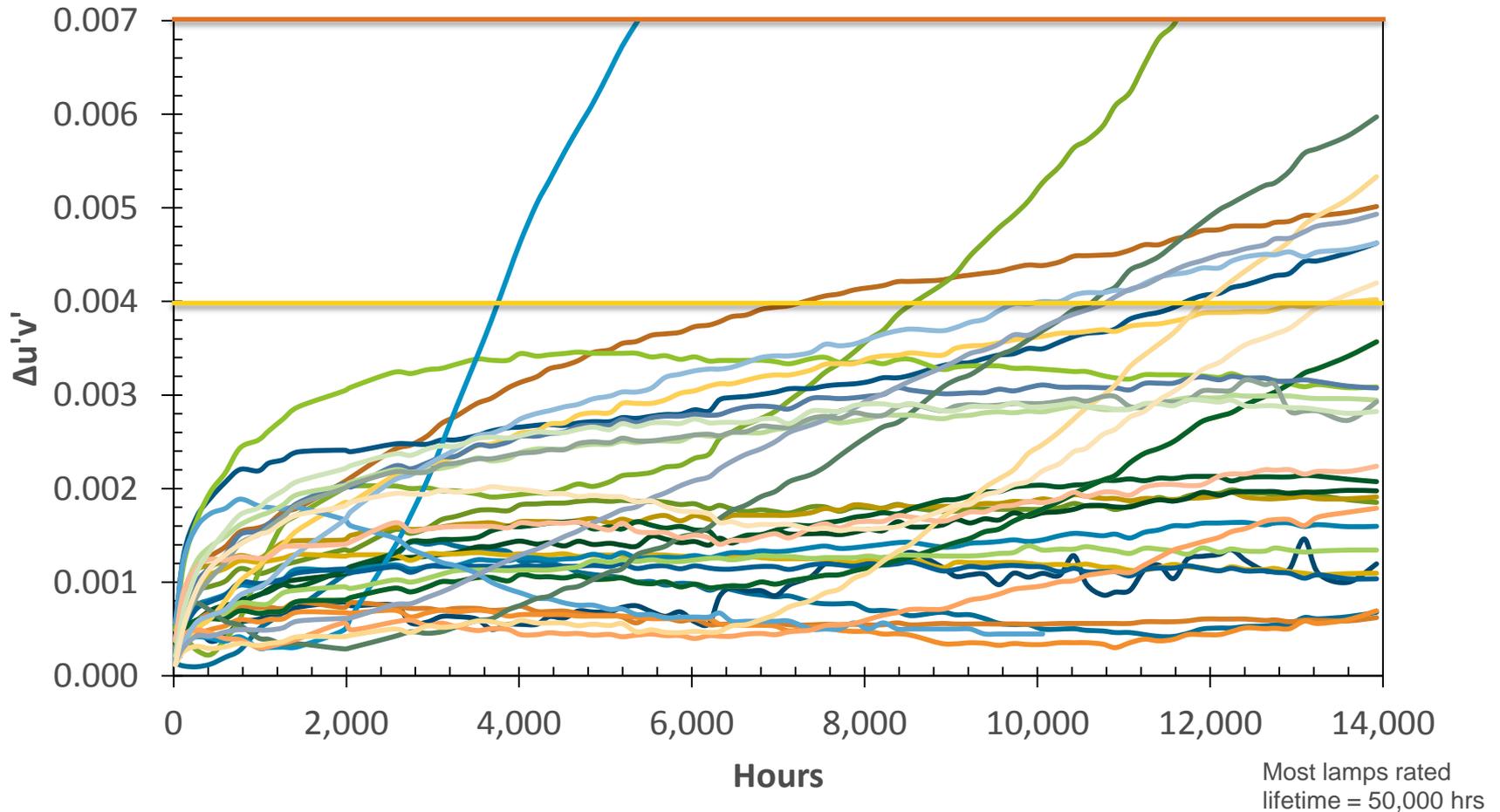
Is color shift a problem for LEDs?

CALiPER Series 20
LED PAR38 c. 2012



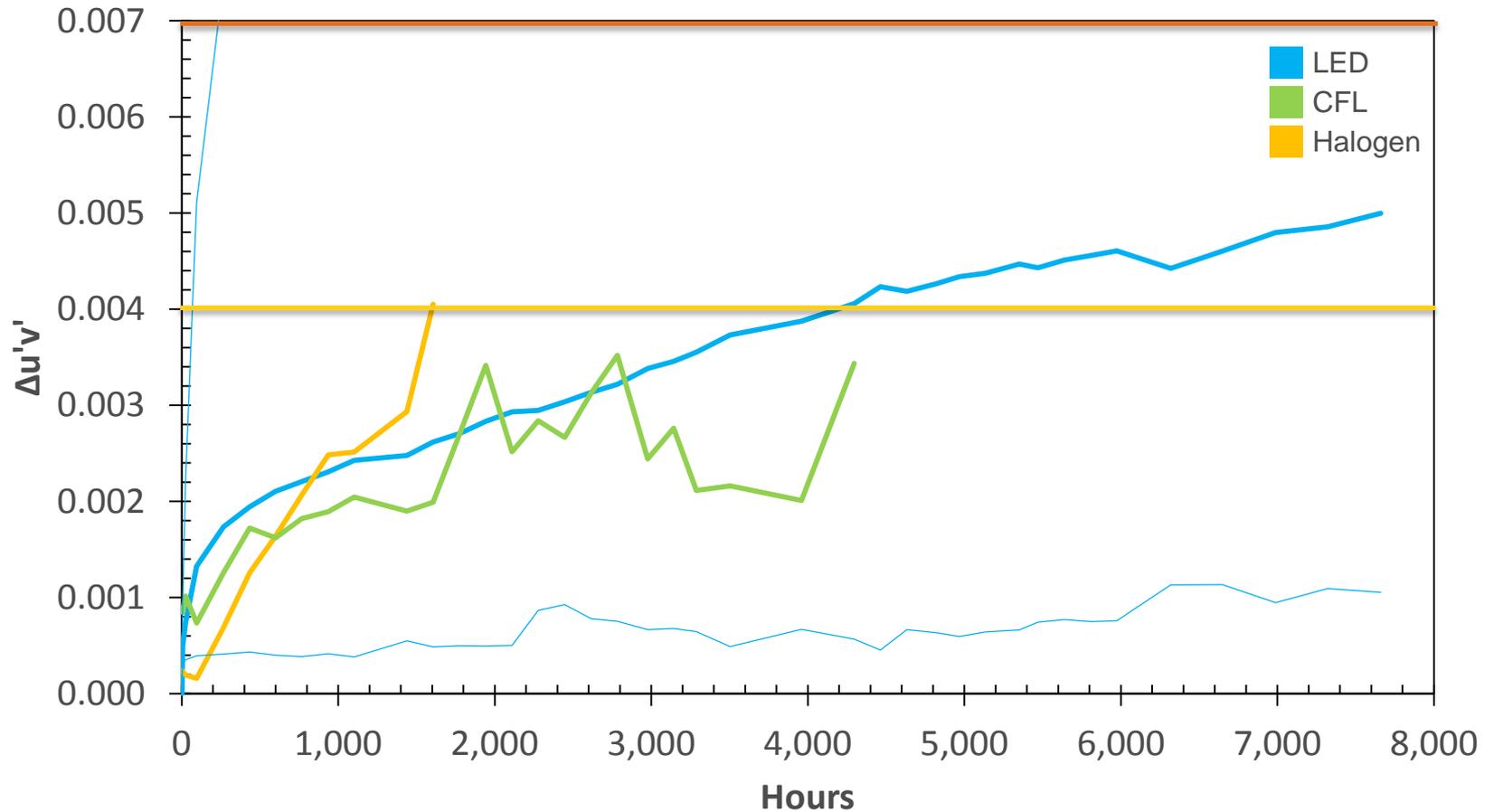
Is color shift a problem for LEDs?

CALiPER Series 20
LED PAR38 c. 2012



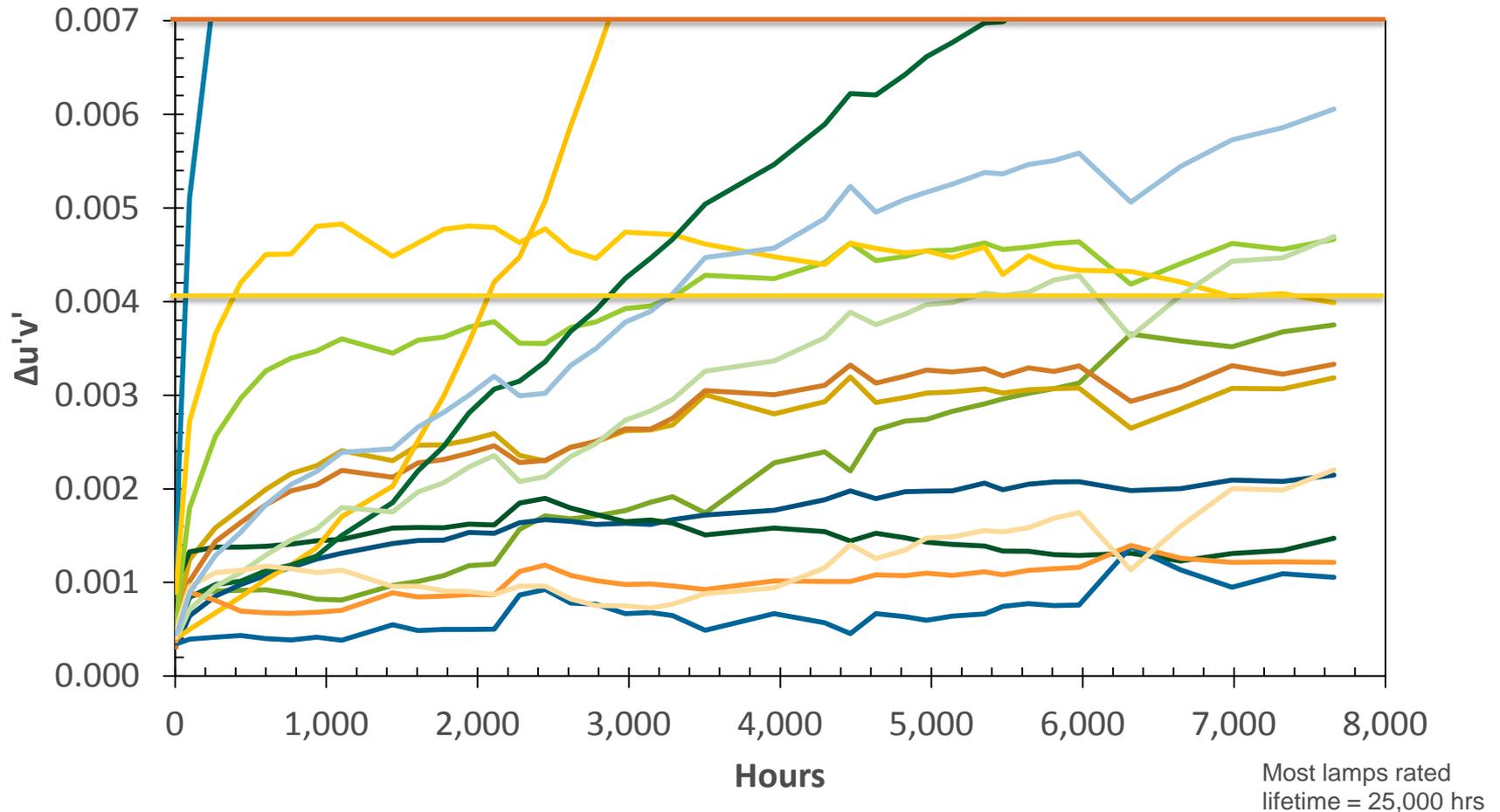
Is color shift a problem for LEDs?

CALiPER Retail 3
LED A19 c. 2013



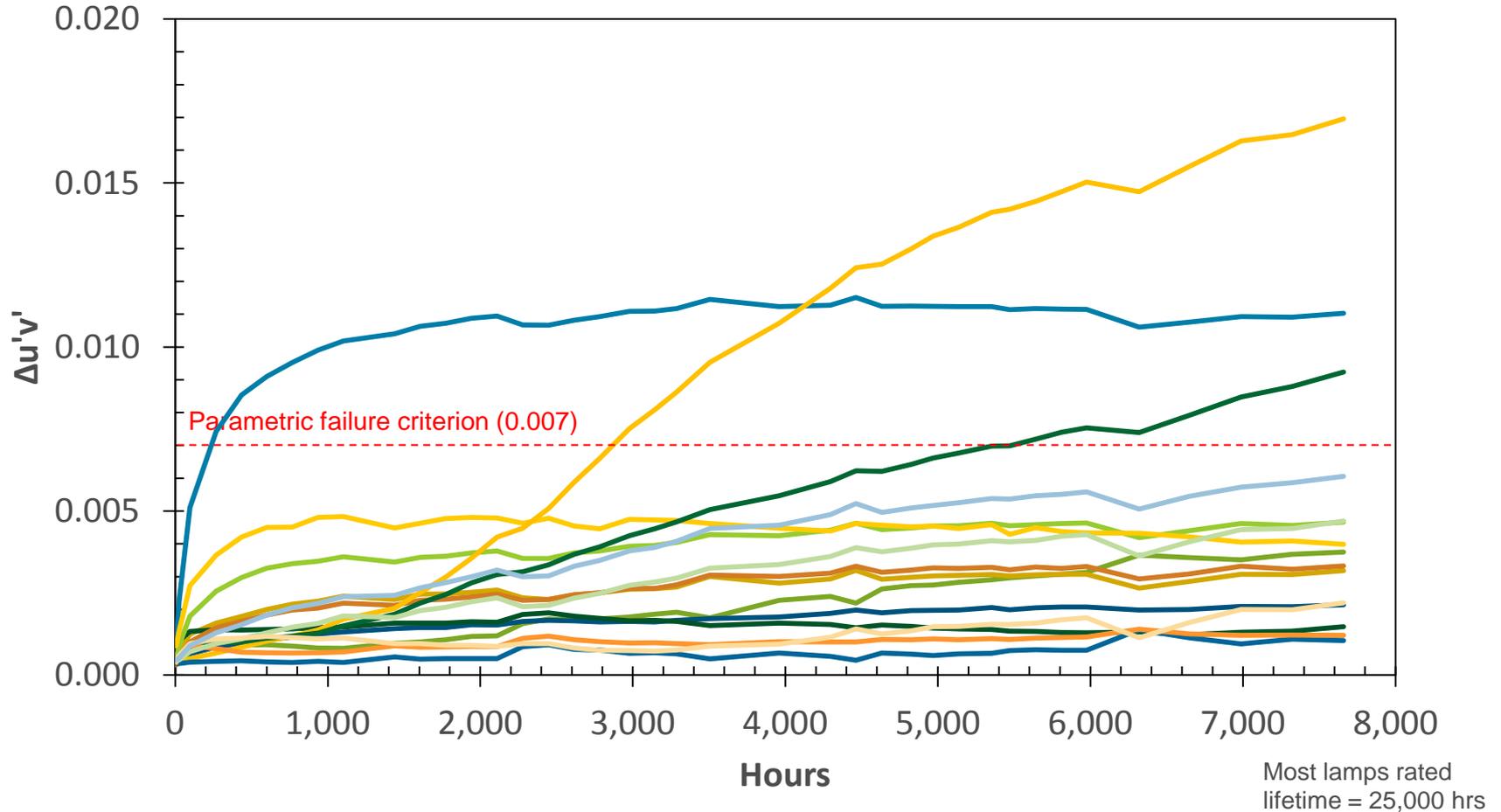
Is color shift a problem for LEDs?

CALiPER Retail 3
LED A19 c. 2013



Is color shift a problem for LEDs?

CALiPER Retail 3
LED A19 c. 2013

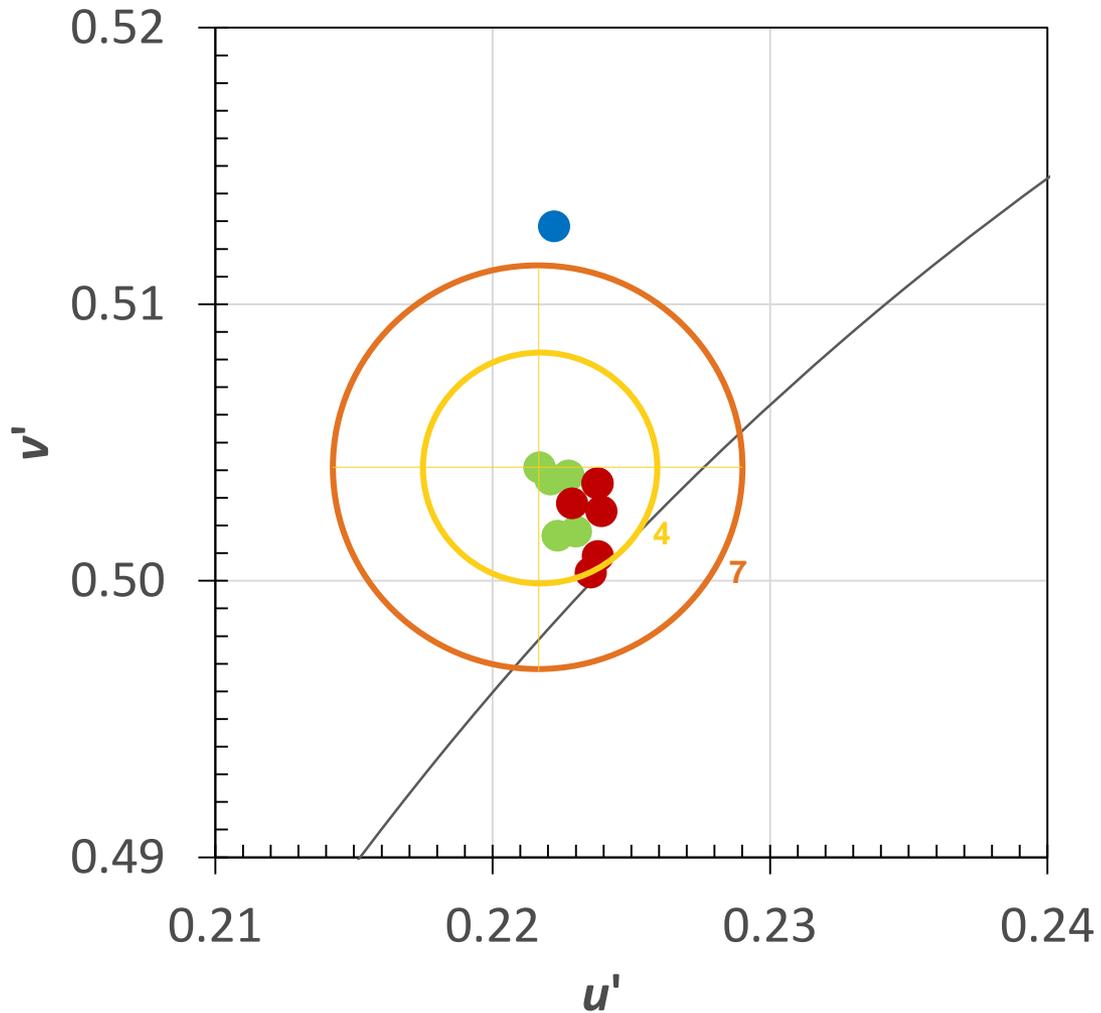


Is color shift a problem for LEDs?

U.S. Border
LED Area Lighting c. 2014



Is color shift a problem for LEDs?



U.S. Border
LED Area Lighting c. 2014

- LM-79 Test Data (Spec)
- 2,500 Hour In-Situ (Field)
- 5,000 Hour In-Situ (Field)

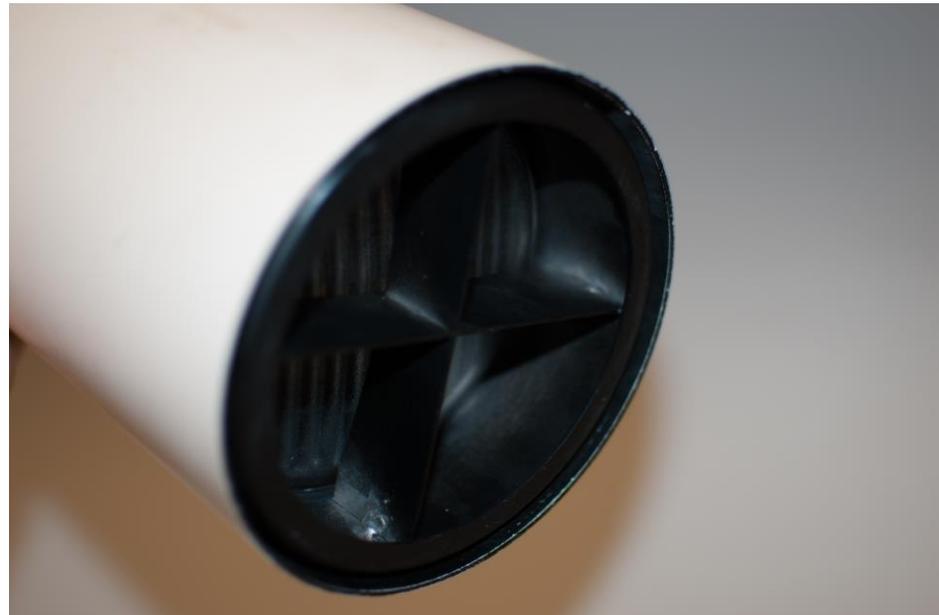
$$\Delta u'v' = 0.006$$

Smithsonian (Again)



What to do?

- LED Packages
- Lamp and Luminaire Materials (Optics)
- Driver
- Application considerations
- **HEAT!**



What to do?

- Determine if color shift is a concern, and to what degree.
 - Will early failures be a financial concern?
 - Is mitigation possible?
- Seek data (LM-80, LM-84 are only current relevant standards)
- Look for products with a warranty (there are few)
 - Understand what monitoring/measurement is necessary