



Electronic Illumination – much more than replacing light bulbs

Steve Paolini – President, Telelumen LLC
September 22, 2016

Outline

- Introduction
- Replacing light bulbs (Lamps)
- Experiencing light
- Why go beyond RGB?
- LEDs etc.
- Collecting daylight data
- Sky shots
- Summary



- Founded 2007 – Silicon Valley, CA
- Purpose – create any light for human consumption
 - Products/services to create/playback light
- Privately owned
- Current products:
 - Light Replicator (16 color light player)
 - Octa (8 color light player)
 - Light Recorder (spectrometer)
 - LumenScripts (content)
 - Recordings, created, composed digital data

Target Applications for Researchers

- Consumer/Home – daylight experience indoors, better circadian cycle
- Retail – make products more appealing
- Healthcare – faster healing, wake/sleep
- Workplace – increase productivity
- Sensors – time varying spectrum
- Movie, TV – outdoor scene or filter replication



Brooklyn, N. Y. Dec 1910
Mr. J. J. ...



The BROOKLYN CALCIUM LIGHT CO. Dr.
PURE OXYGEN GAS AND CALCIUM LIGHTS
FOR ALL OCCASIONS.
TELEPHONE, 3162 MAIN LABORATORY: 112 FRONT STREET.





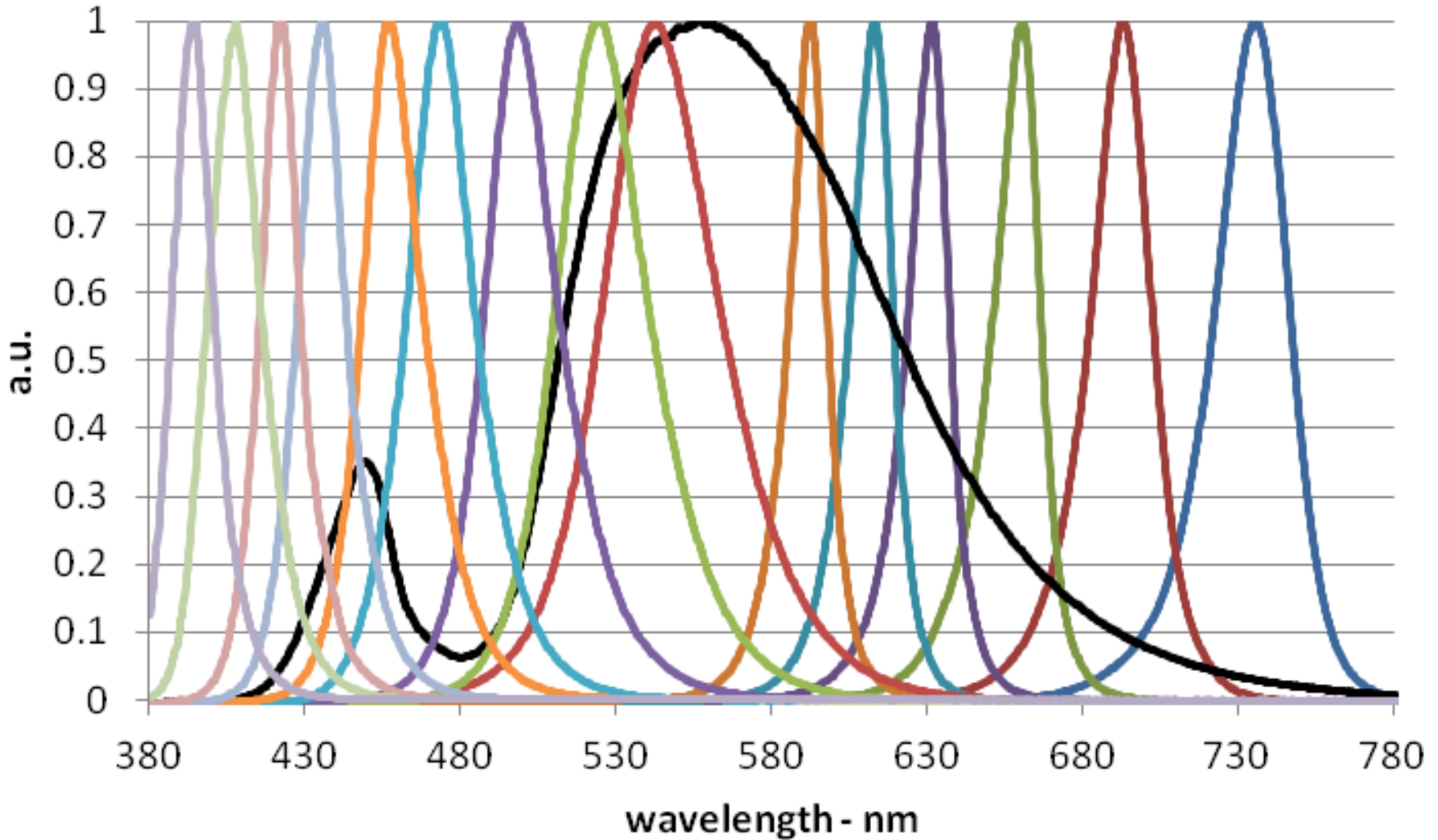


Electronic Illumination – economic value

- Energy savings is icing on the cake (value).
- The cake will be something more substantial.
- We will not save ourselves into prosperity.
- We will build something new and prosper.
- But what, how, when...

Some technical perspective...

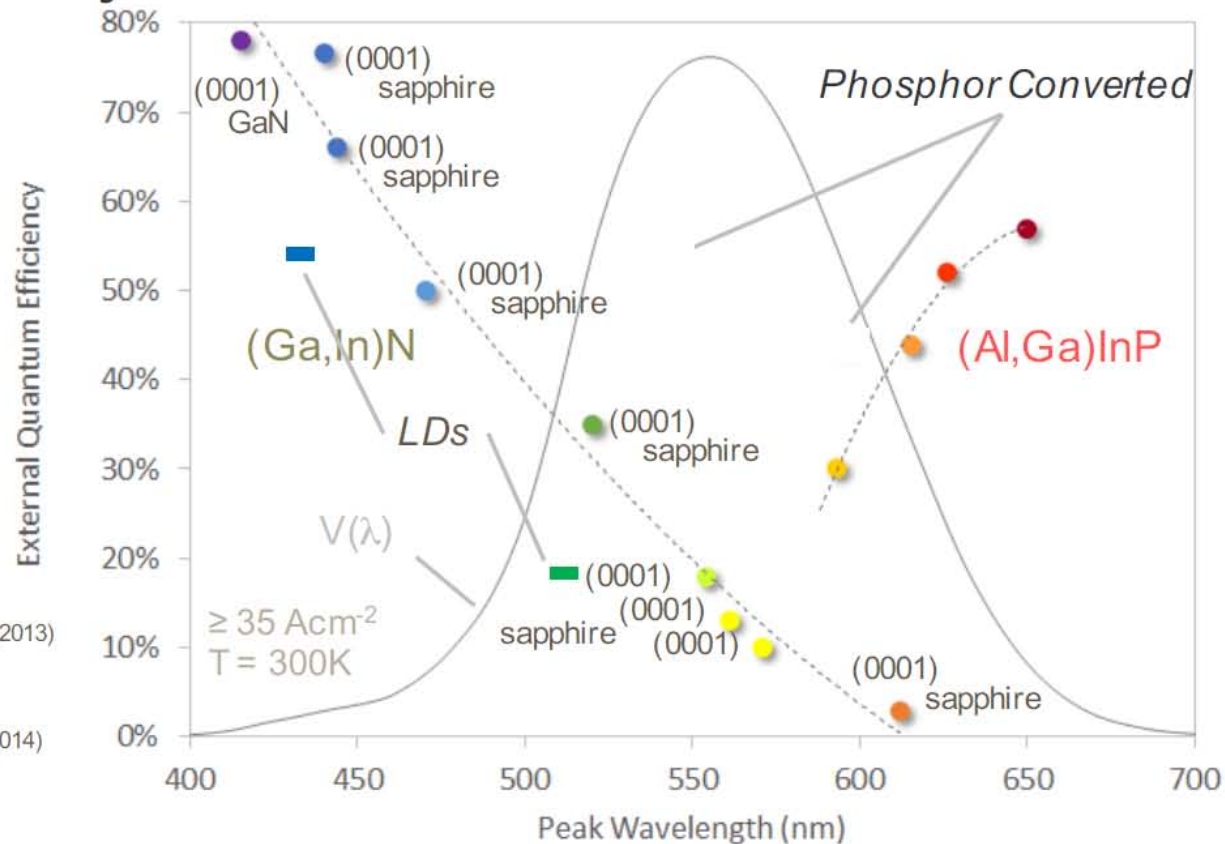
Telelumen Light Replicator



Best Reported Primary LED Efficiencies

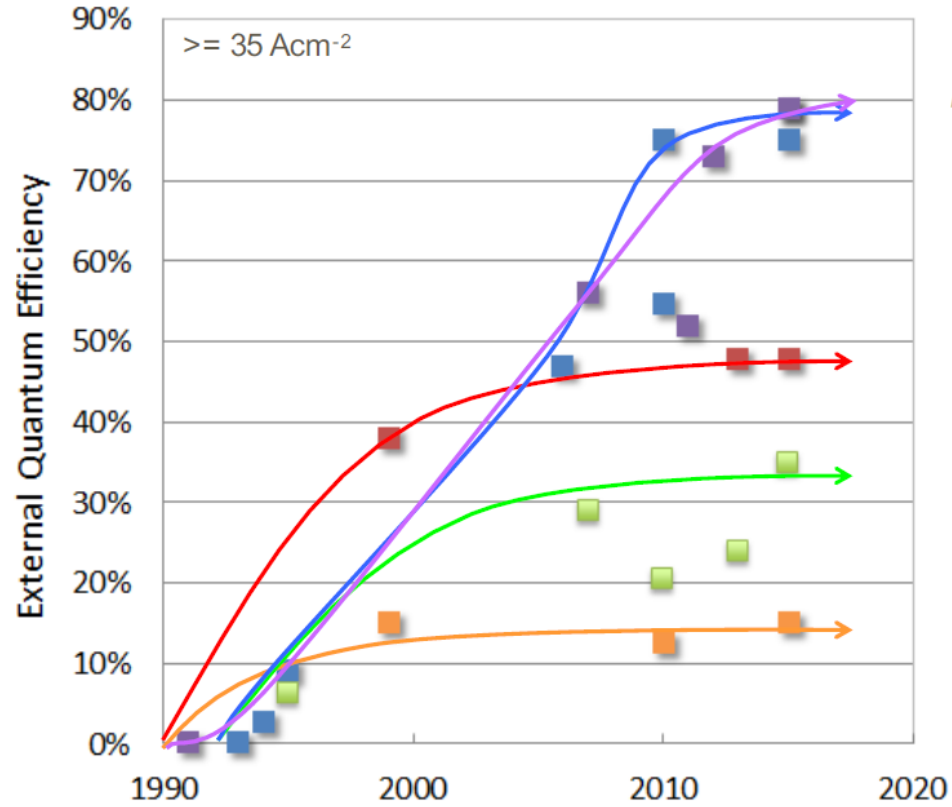
- “Green gap” is alive and well for primary LEDs
- Best (Ga,In)N performance *still* follows Nobel work from 1980s-90s
- Fully down-converted phosphor-based LEDs are best emitters for green and amber
- “Green gap” even more challenging for laser diodes

Narukawa *et al.*, *J. Phys. D: Appl. Phys.* 43, 354002 (2010)
 Hashimoto *et al.*, *Phys. Status Solidi C* 10, No. 11, 1529– 1532 (2013)
 Saito *et al.*, *Applied Physics Express* 6, 111004 (2013)
 Broell *et al.*, *Proc. SPIE* 90030L, Feb 2014
 Hwang *et al.*, *Applied Physics Express* 7, 071003 (2014)
 Hashimoto *et al.*, *Phys. Status Solidi C* 11, No. 3–4, 628– 631 (2014)
 Deb, Lumileds, private discussion, Sept. 2015
 Hurri *et al.*, *Applied Physics Letters* 106, 031101 (2015)



Evolution of Primary LED Performance

- Blue & Violet exhibit classic “s-curve” behavior → nearing theoretical limits
- Green, Amber, & Red emitters do not → efficiencies have stalled
- Opportunities for new research & development



Best reported performance in the literature:

InGaN

- Violet 380-440 nm
- Blue 440-500 nm
- Green 500-560 nm

AlGaIn

- Amber 560-600 nm
- Red 600-630 nm

LED Down-Conversion Materials

Phosphors



- $(Y,Al)O:Ce$ – yellow; from scintillators
- $(Lu,Al)O:Ce$ – green; another “gamet”
- 2-5-8 Nitrides – red, amber; “new” last decade
- GE’s “PFS” – line-emitter for LEDs

Quantum Dots



- Semiconductor nanoparticles, aka “quantum dots”
- $Cd(S,Se)$
- $(In,Ga)P$
- Now deployed in flat-panel displays

Organization and Value

- There is a tendency for the value to increase as the organization of the waves or particles increases.
- Sand, glass, poly-silicon, single crystal silicon
- Coal, graphite, diamond abrasive, flawless diamond
- White light, LED, RC-LED, SLD, multimode LD, single mode LD

One dimensional improvement

- Most of the LED industry has been focused on improving the efficiency of a 450nm LED and lowering the cost.
 - Blue-pump for YAG phosphor gives white light
- Running out of headroom
 - The best material has 75% PCE
- One dimensional organization.
- There are other dimensions.

Other dimensions

- Other wavelengths – green, amber
- 3-terminal device (LET) – tuning
- Beam Angle – few devices between LED – LD
- Polarization – LCD
- Coherence (phase) – beam steering

From a marketing, product perspective...

- The customer doesn't know what they want
- Risk takers will need to lead the way

- Before smart phones, few realized they wanted to take and send pictures constantly
- In general neither the price nor the energy consumption of a phone is top priority
- Most of us replace our phone before it fails

Electric Lighting Ecosystem

Power Company



Electrical watts
Voltage
Current
Time
PF, THD

RF (watts)

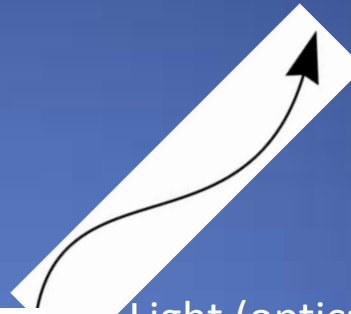


Light (optical watts)



Lumens
Spectrum
CCT, CRI
Time
Angle
Space

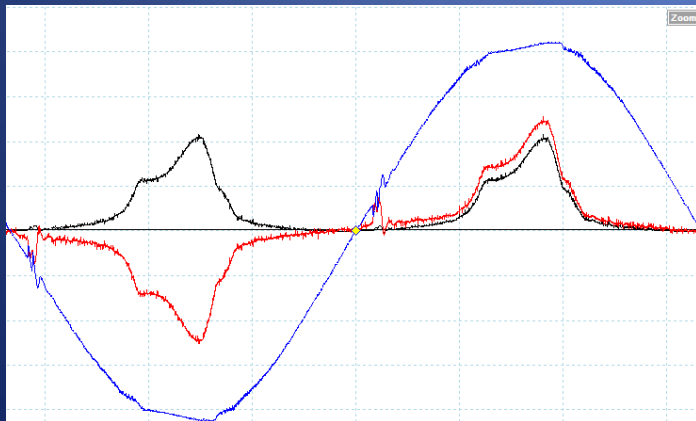
Heat (watts)



Reflection



Light Experience



Two ways of experiencing light

Illumination

- Look at people, objects
- Less saturated colors
- Changes slowly
- Low spatial density
- High spectral density
- CRI – important, RGBWA
- Collimated, Diffuse

- Electric lights, Daylight
 - RGB is NOT sufficient

Infotainment

- Look at the light
- Saturated colors
- Changes fast
- High spatial density
- Low spectral density
- CRI – don't care, RGB
- Collimated, Diffuse

- Computer Display, TV, Rock Concert
 - RGB is sufficient

The sky is a special case. It fits into both categories.

Underlying Philosophy

- Daylight is the gold standard for illumination.
- Firelight is the silver standard.
- Electronic illumination should over time do everything daylight and firelight can do.
- There is more to illumination but this is key.

Daylight and the sky

- Intense collimated light that moves across the space, sharp shadows (south, 80%*)
- Large, diffuse, low glare light (north, 20%*)
- Changing spectrum, changing time

* Depending on clouds and other atmospheric conditions



CoeLux



CoeLux



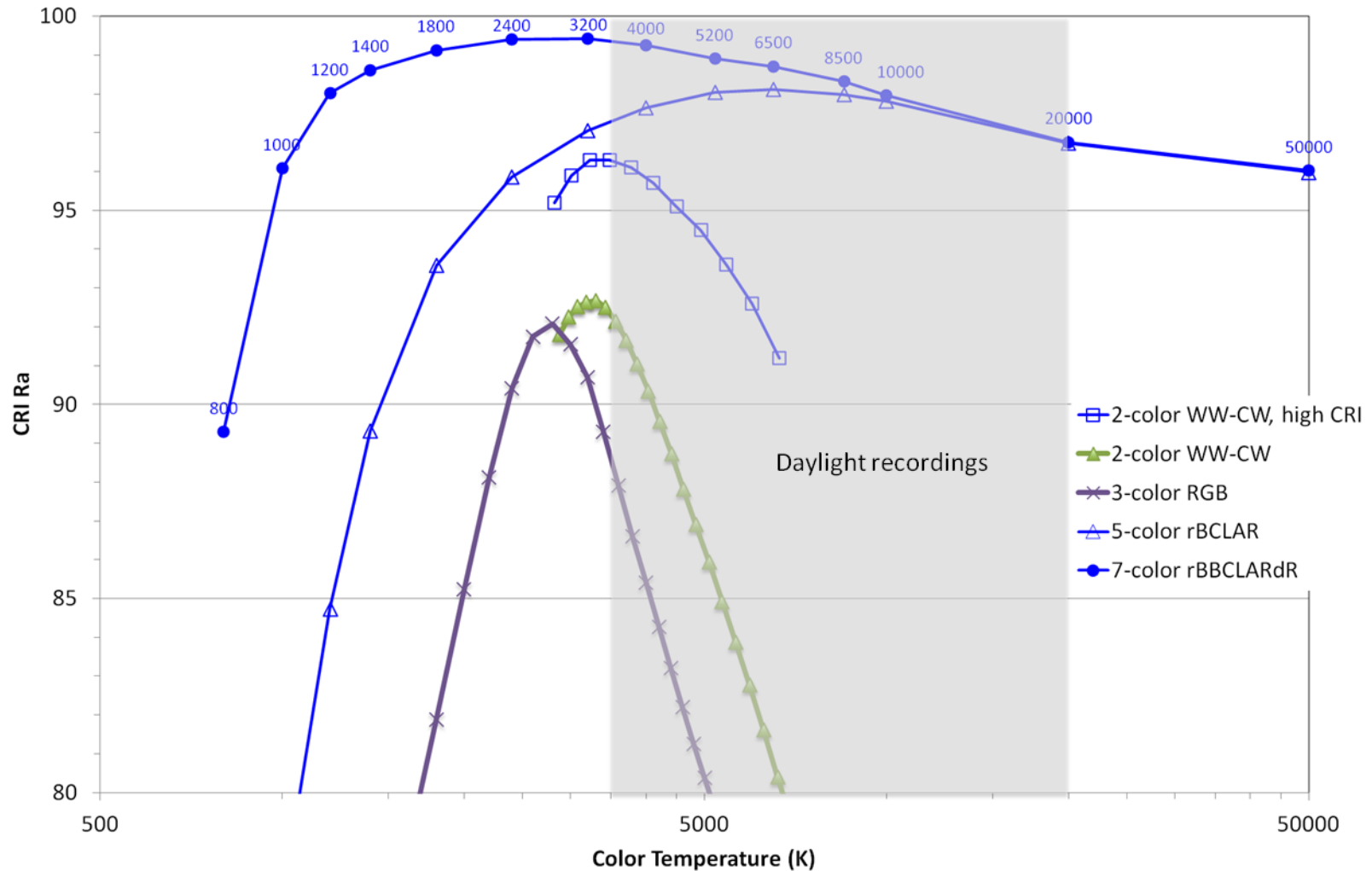
Fraunhofer



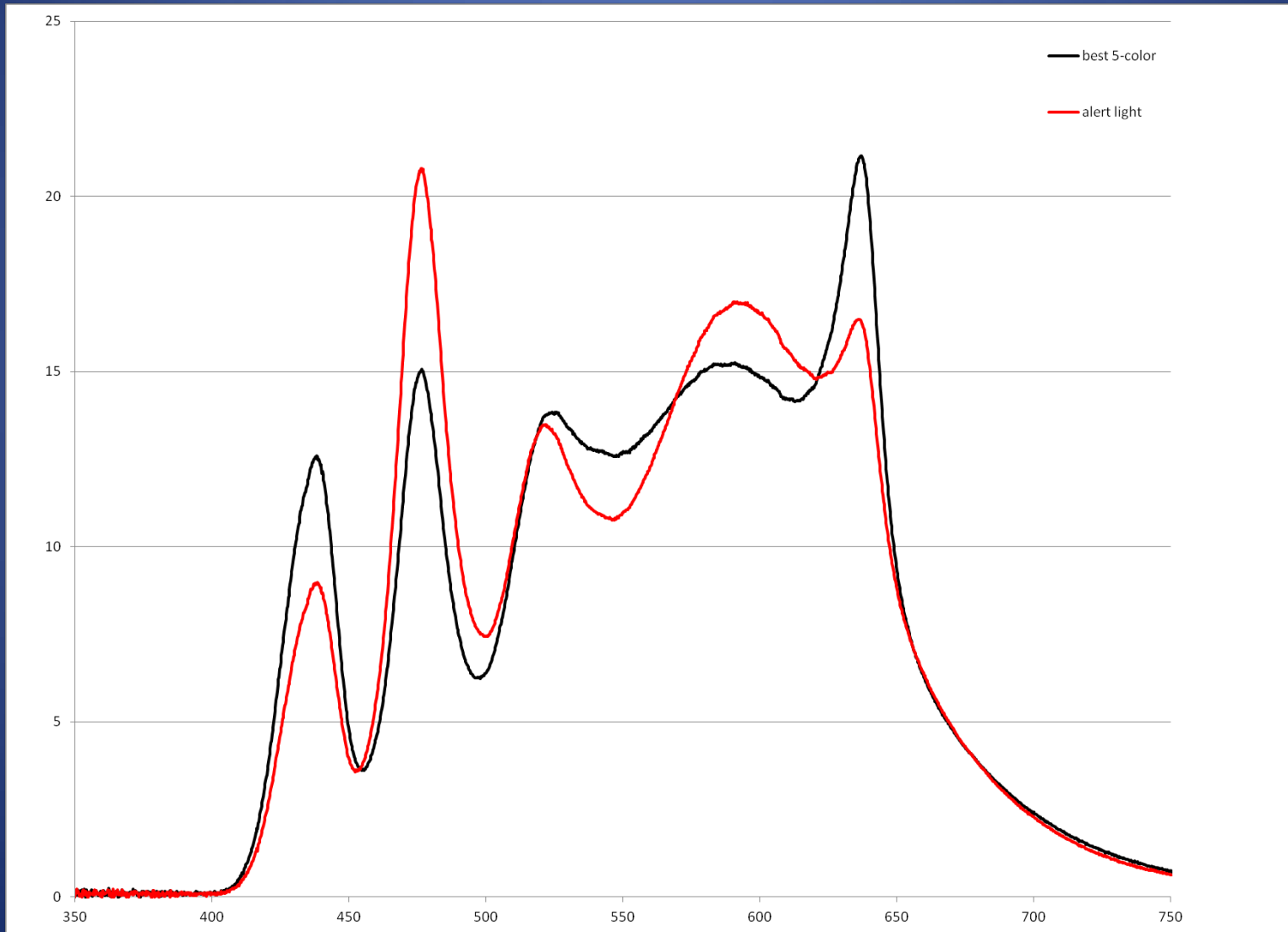
Why go beyond RGB

- Broader CCT range at higher color quality
- Multiple solutions for a given chromaticity
- Larger gamut area

Value of more color channels



Multiple 4000K, high CRI solutions – 5-color



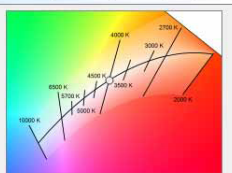
Beyond RGB



Palette Editor

10000 K 2000 K

Tint



Opacity: 255 100.0% Intensity: 255 100.0%

Default Swatches

- Red
- Orange
- Yellow
- Green
- Cyan
- Blue
- Violet
- Magenta
- White
- Silver
- Gray
- Black
- 2700 K / center of A...
- 3000 K / center of A...
- 3500 K / center of A...

Project Swatches

IntelliHue SkyRibbon

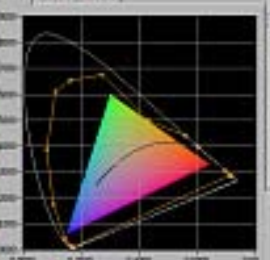
Red: 255 Green: 187 Blue: 184 Mint: 255 White: 255

Live Play

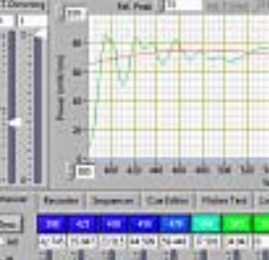
OK Cancel

Light Application Configuration

Spectrum Luminance About



CCT Converter

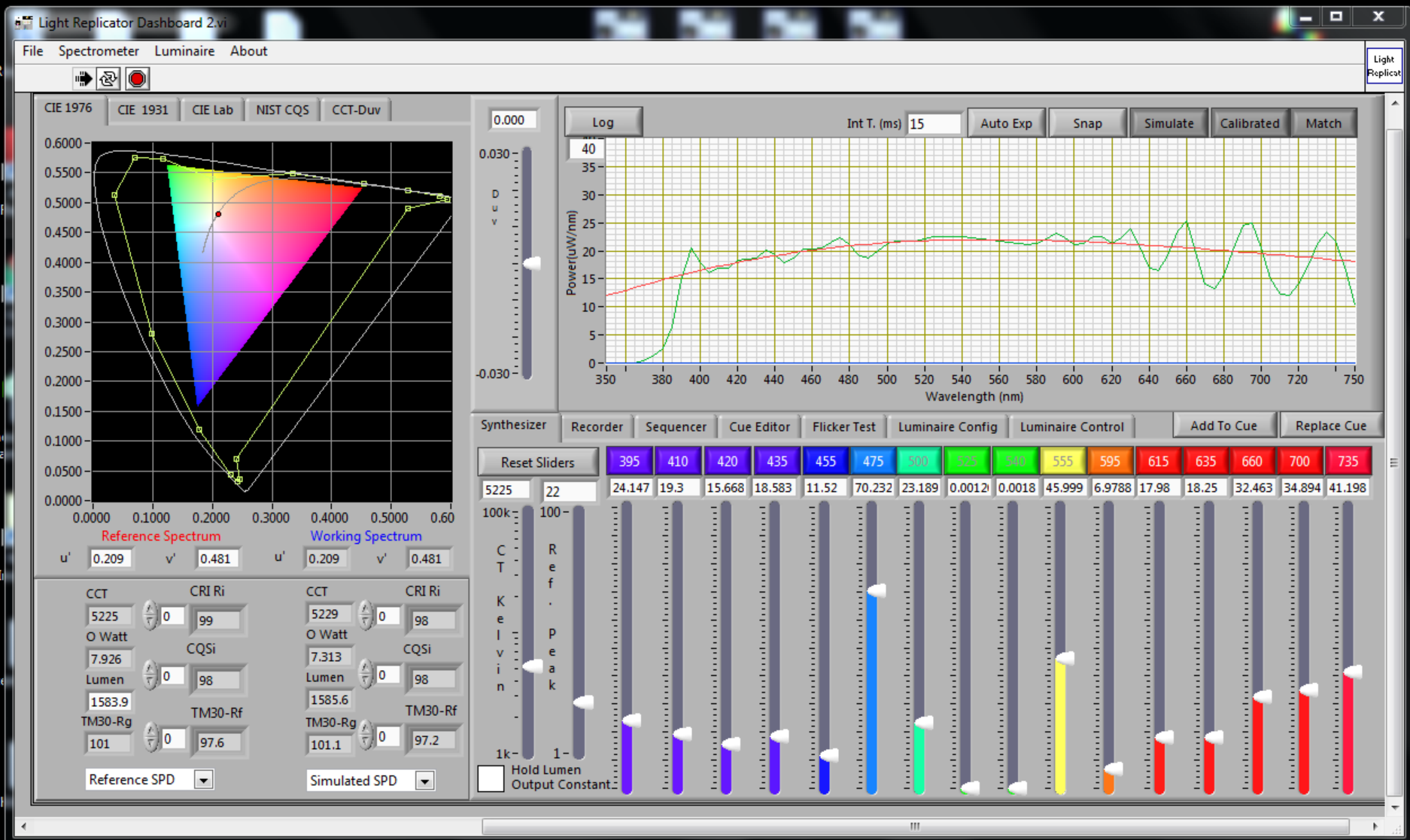


Reference Spectrum Working Spectrum

CCT: 2700 K CRI: 90 CCT: 2700 K CRI: 90

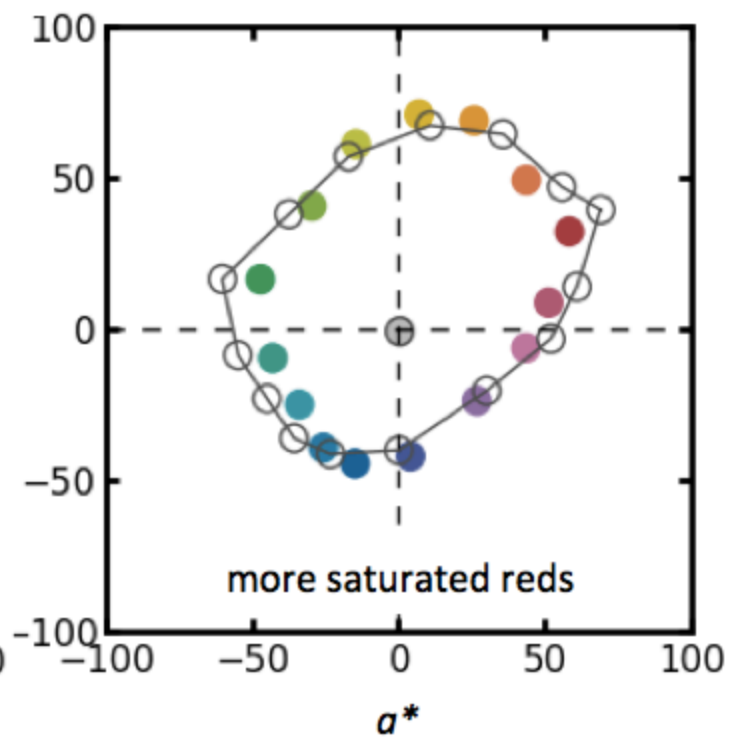
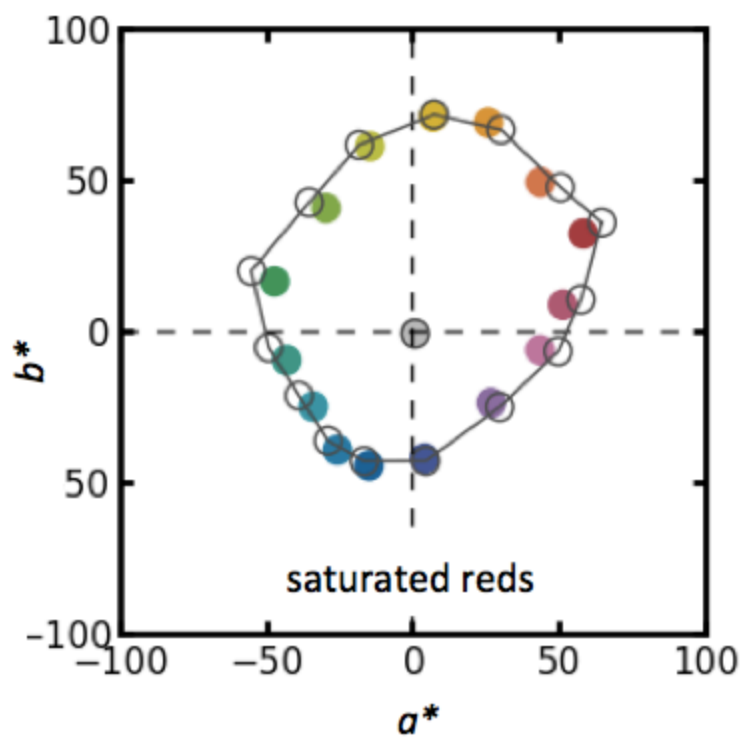
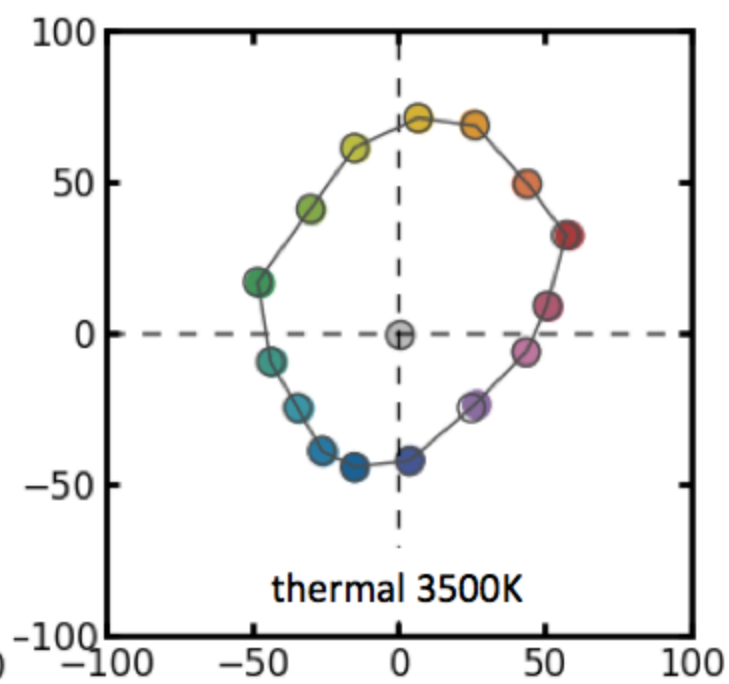
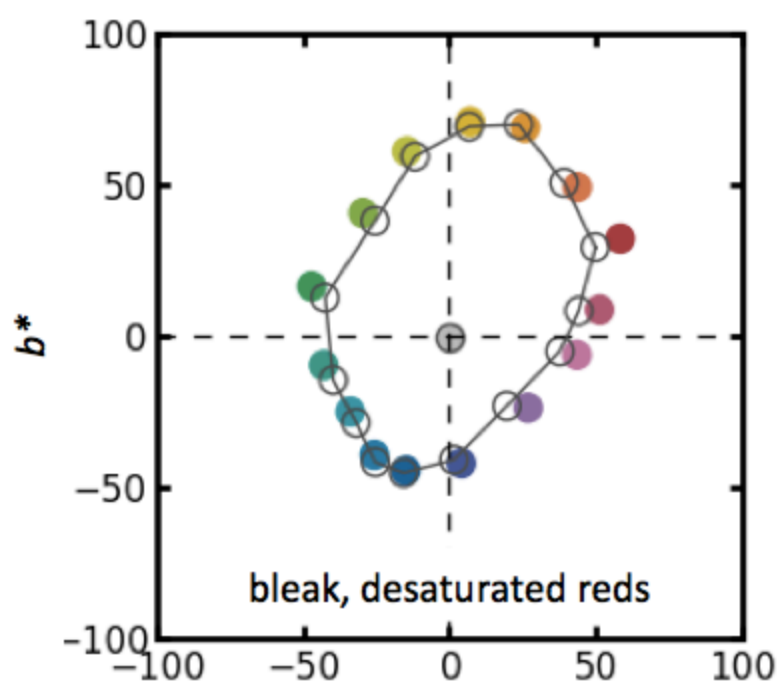
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Light Replicator – 5225K



Multiple Solutions Example

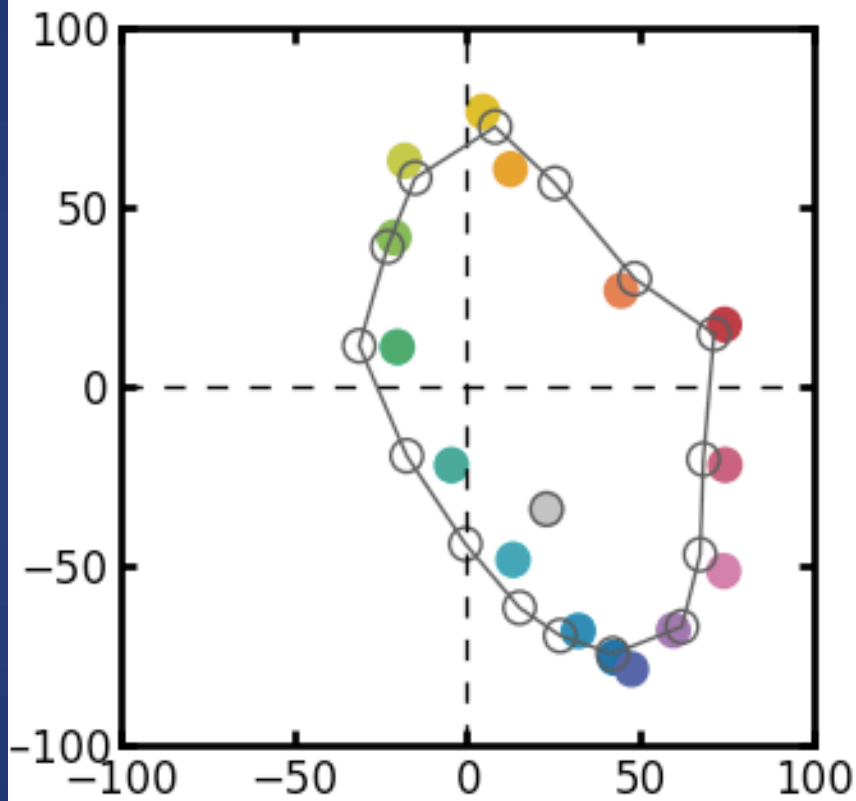
- 5-channel system producing 3500K with a progression from de-saturated reds to a thermal radiator to saturated reds
- In general more saturated reds and greens are more appealing.
- More saturated blues and yellows are less appealing.



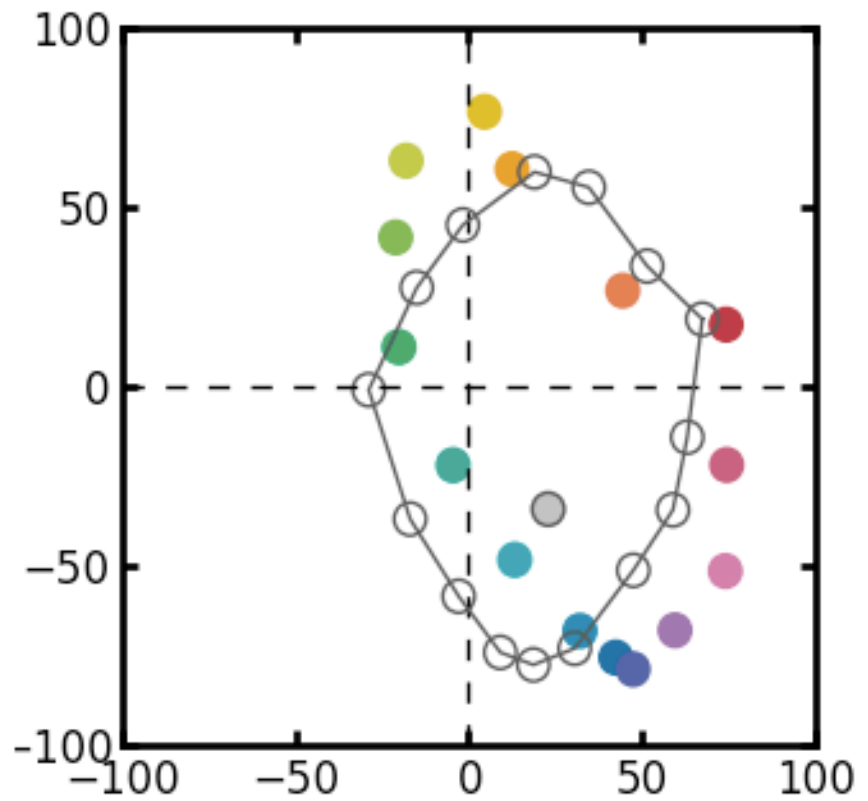
More Channels, More Fidelity

- Not all sources of interest are thermal radiators.
- The Aurora Borealis is an example of excitation and ionization of atmospheric gases.
- 12 and 7 channel systems are shown

Aurora Borealis



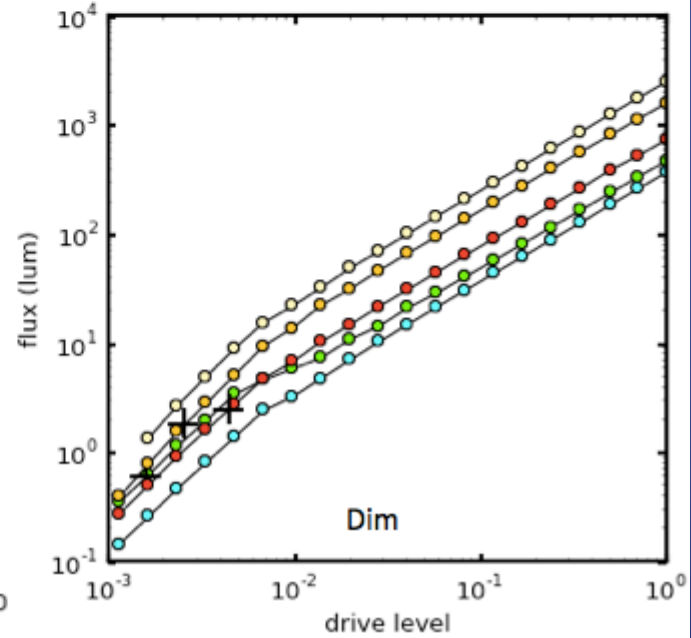
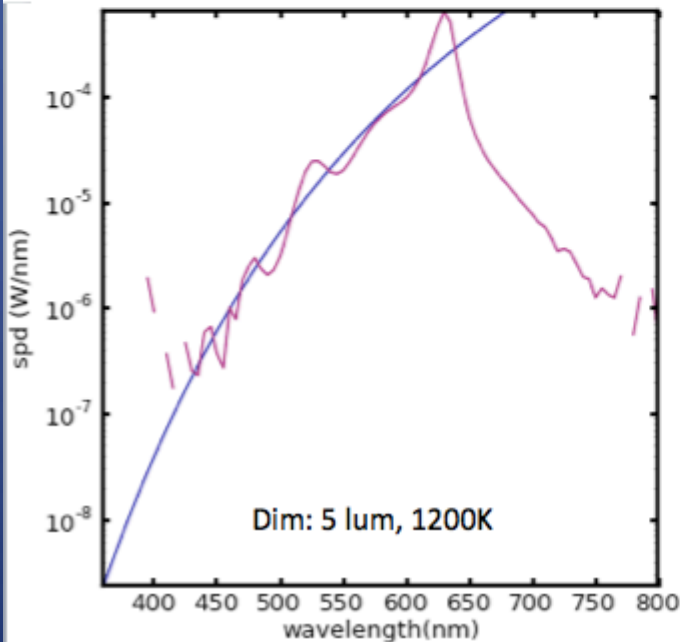
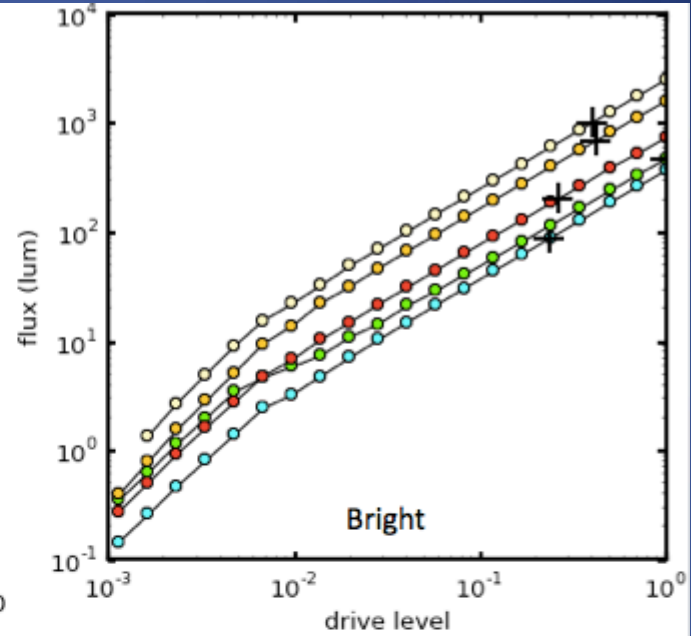
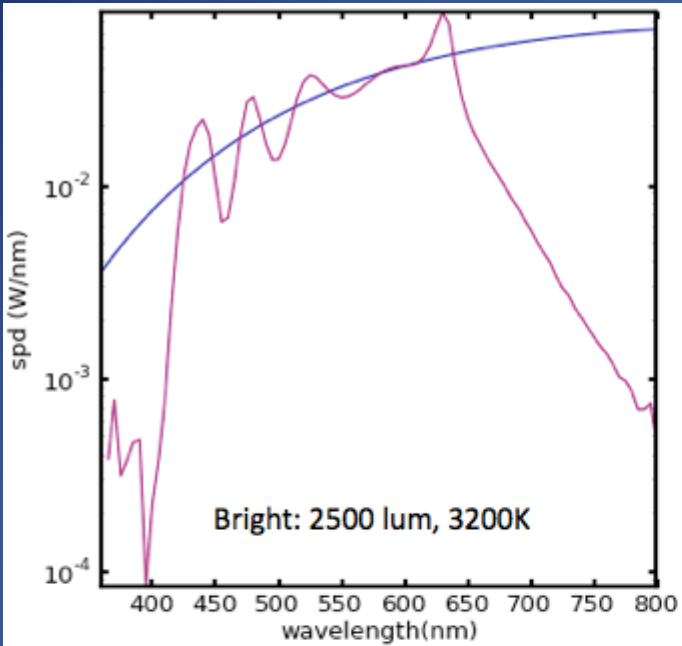
12-channel system



7-channel system

Dynamic Range

- The dynamic range of the human visual system is at least a million to one (20-bits)
- This is about the range of bright daylight to moon light
- Intensity compression is useful to realize cost effective systems
- A 5-channel system emulating tungsten lamp dimming is shown



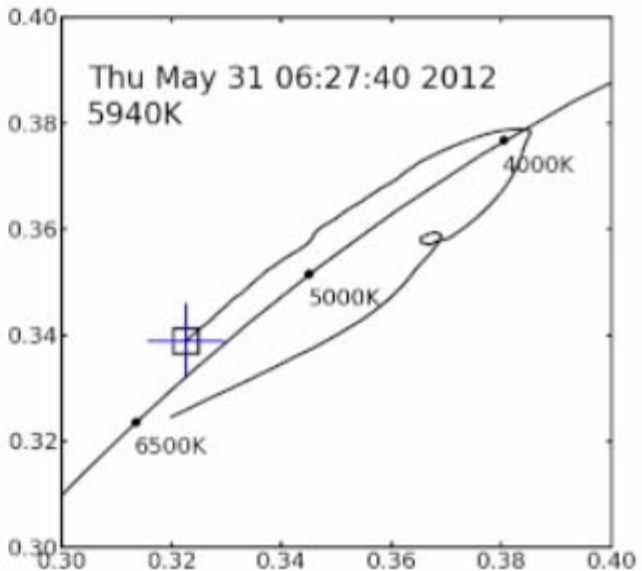
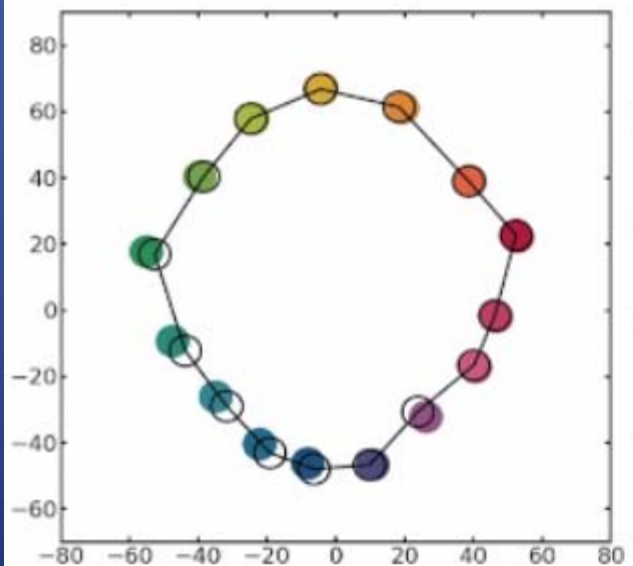
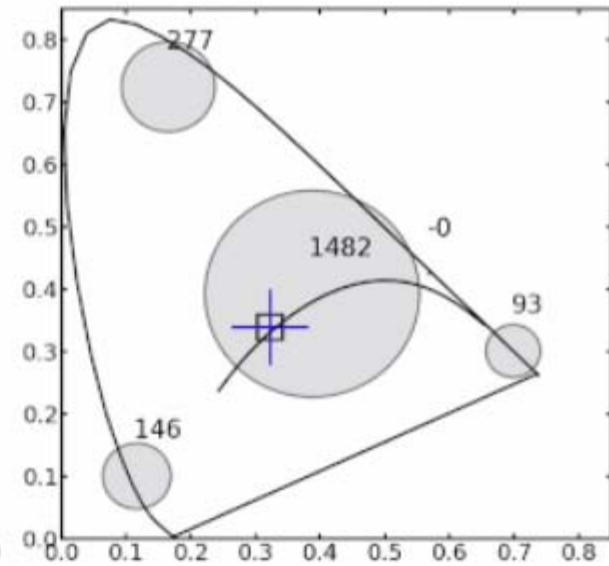
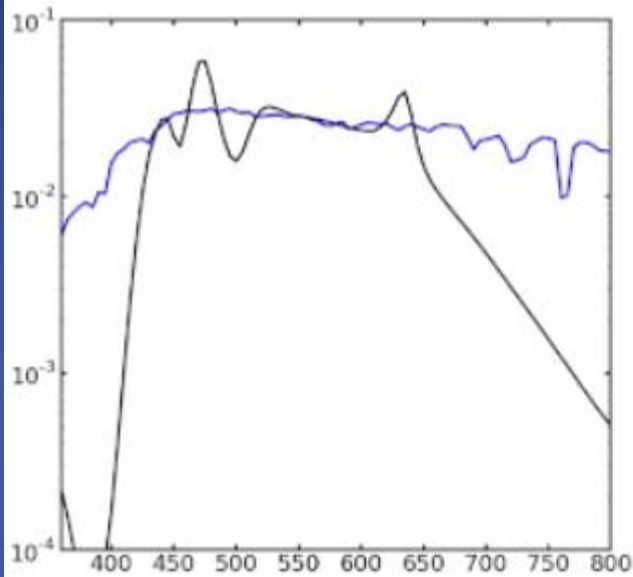
Accurate Replication Is a Good Thing

Historical Success Factor – Replication

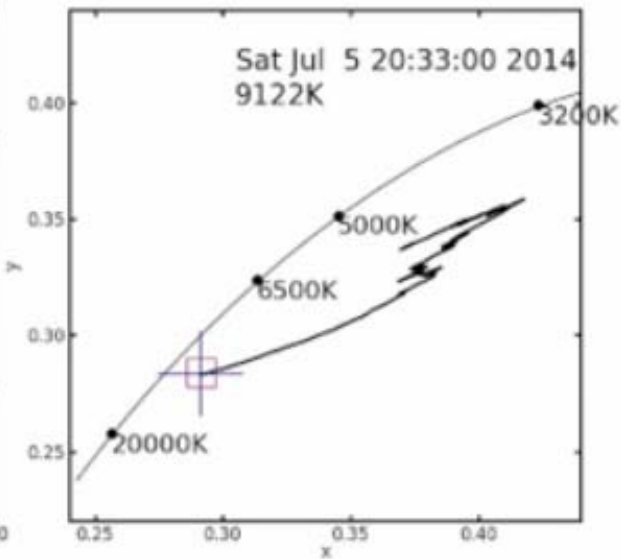
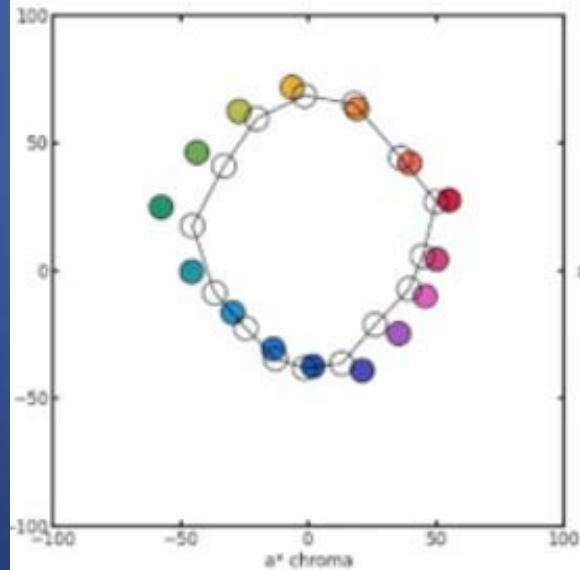
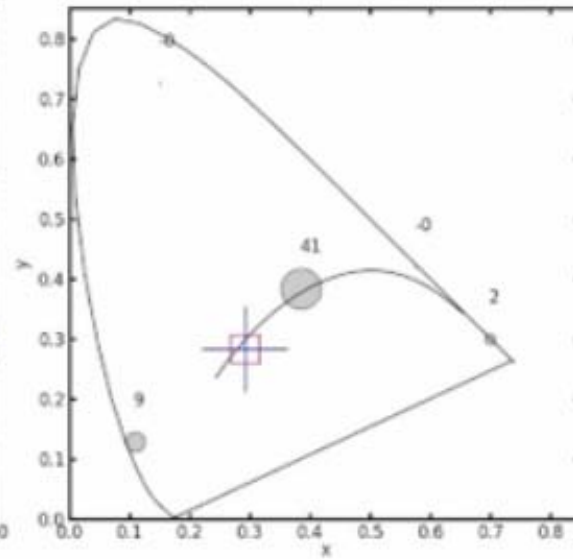
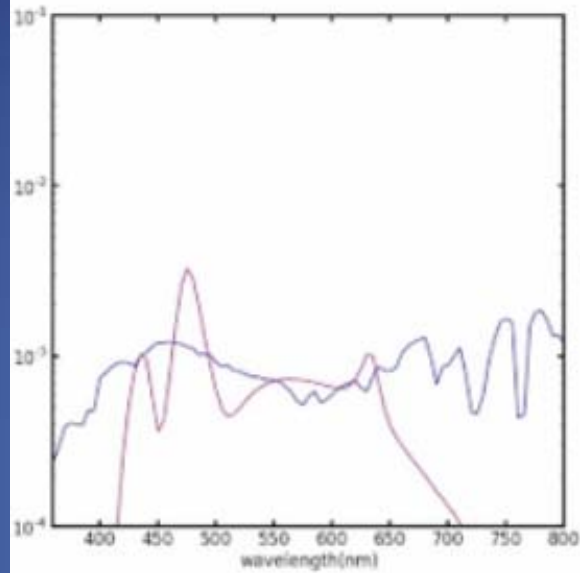
Replicator	Intention: 2x	Realization: 1,000x!
Printing Press	Sacred Book	Books and Newspapers
Camera	Formal Portraits	Casual Snapshots
Phonograph	Historic Oratory	Pop Music
Xerox copier	Replace carbon paper	Copy/print everywhere
Betamax	Studio Tape Deck	Personal TV/Movie library
MP3	Smaller, cheaper	Every song in your pocket
WWW	Office File sharing	Everyone, Everything
Light	Standard Illuminants	Skylight and beyond, at will



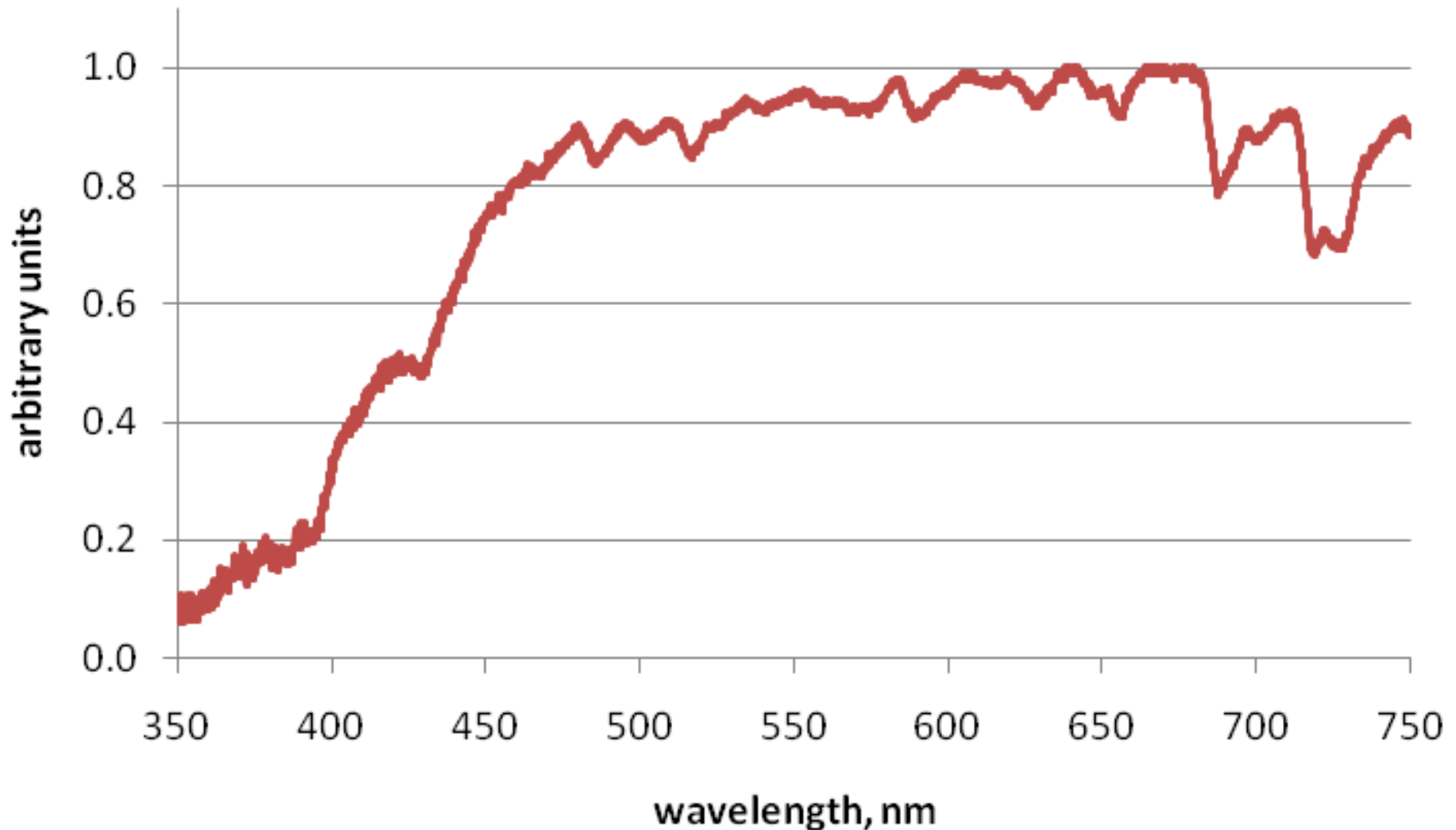
Valley of Fire sunrise, USA



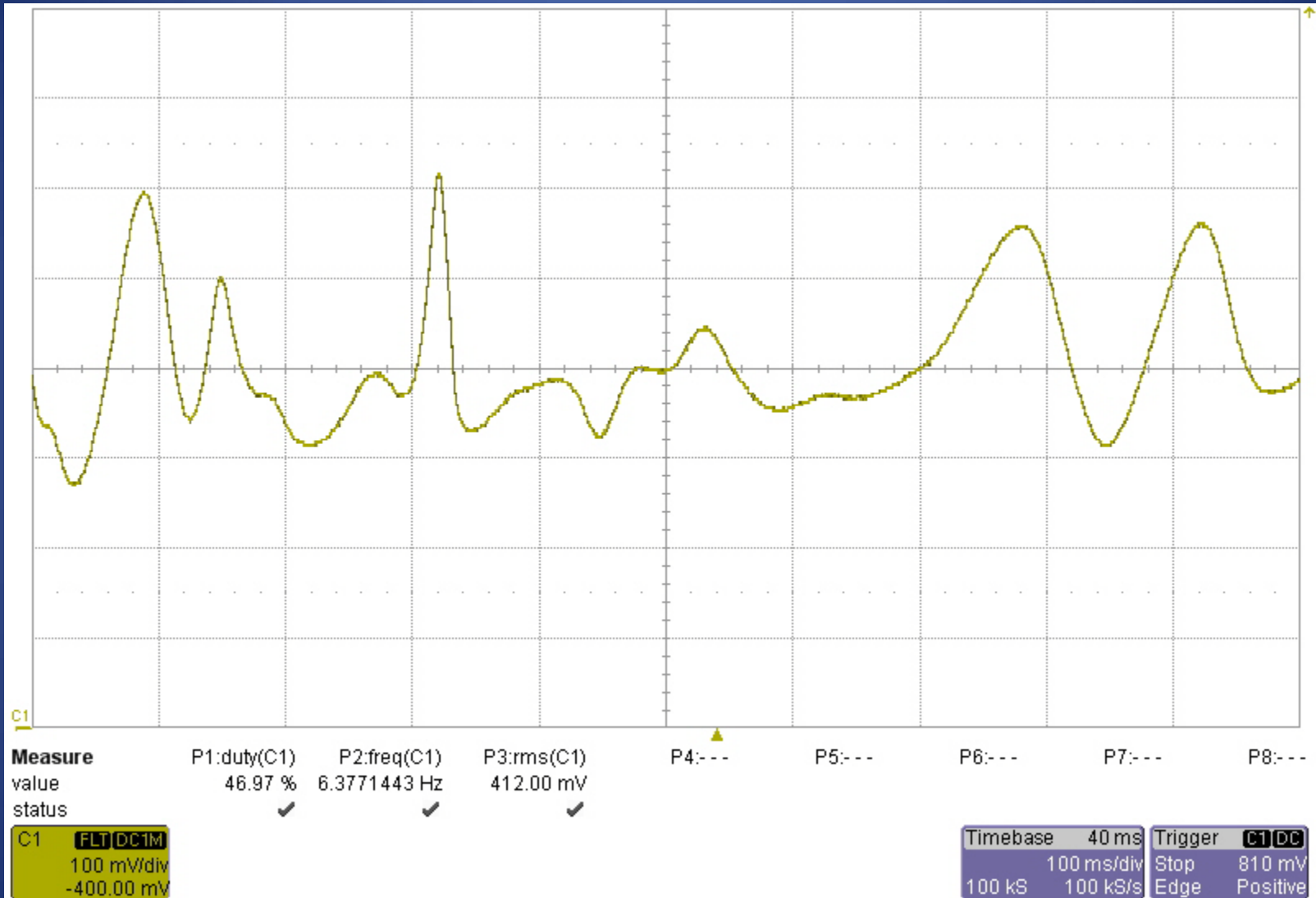
Santa Cruz sunset, USA

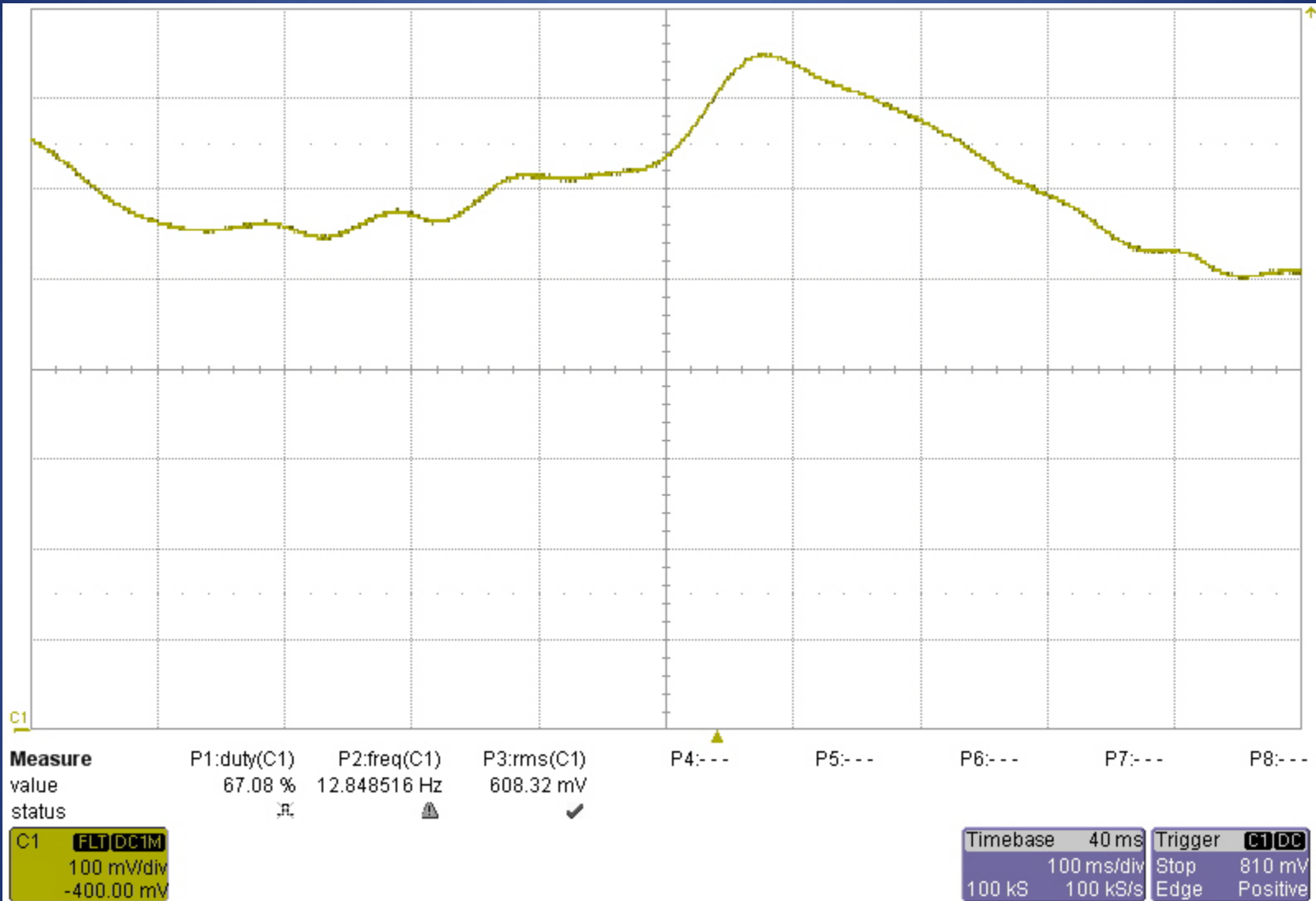


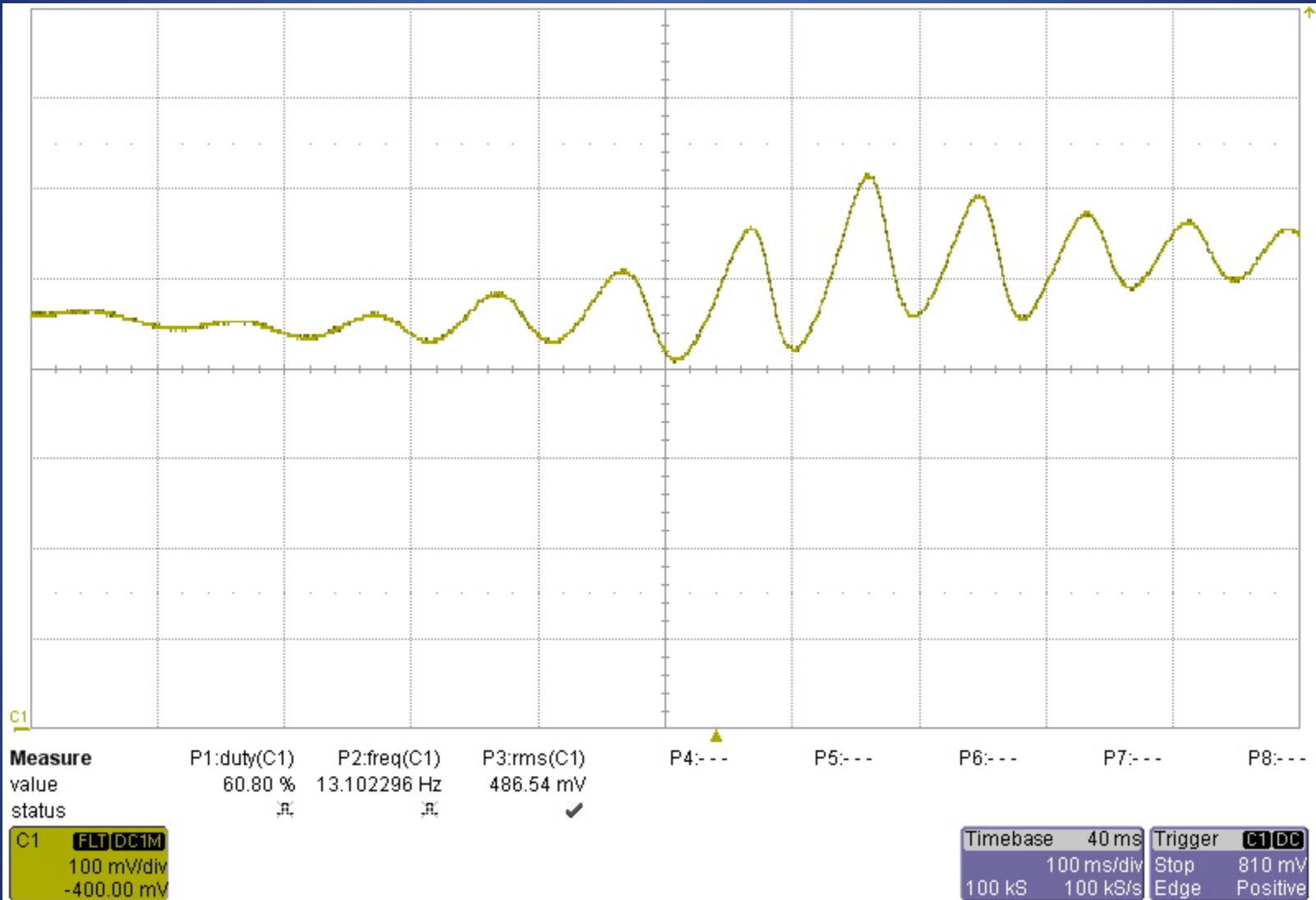
Moonlight at 3:20am, clear sky.
Recorded 22feb14 in Sunnyvale, CA USA
Approximately 0.7 lux, 4,700K, 98 CRI



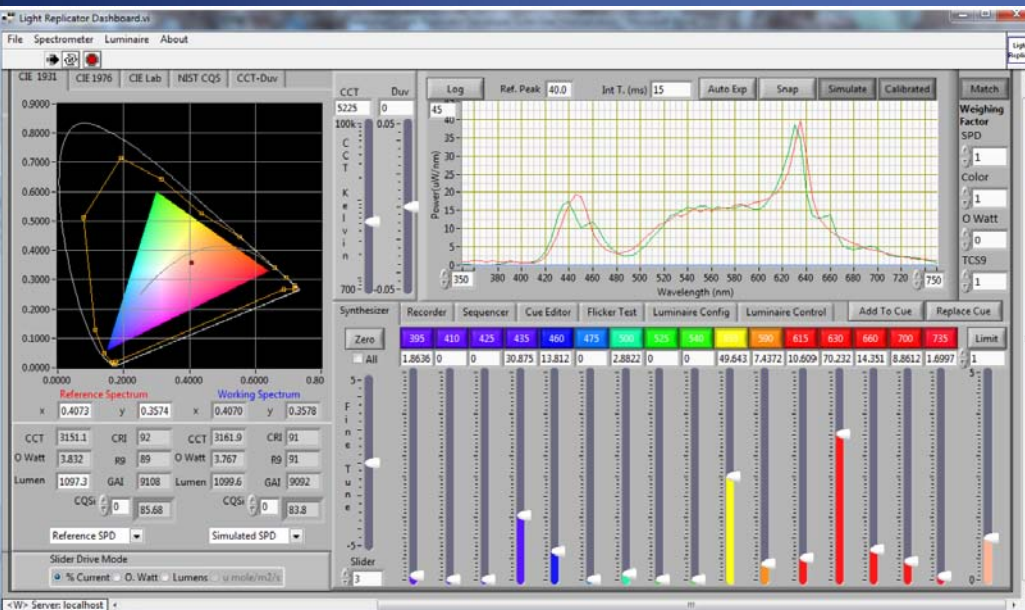
Candle Flame from Photometer – 1 sec







Create/Record, Edit, Playback GUI Example



This screenshot shows the 'Recorder' and 'Sequencer' sections of the software. The 'Recorder' section includes controls for 'Spectrometer' (On Line), 'Monitor', and 'Replicate'. It features input fields for 'No of Frames', 'Scan Interval', 'Start Time', 'Frame No.', 'Save Interval', and 'Current Time'. The 'Sequencer' section has a 'Frames to Add' field and playback controls (Load, Record, Play, Stop). The 'Active Spectrometer' section shows a list of serial numbers with 'Simulation' selected. Other options include 'Image File Type' (PNG, JPG) and 'Every Nth Frame'.

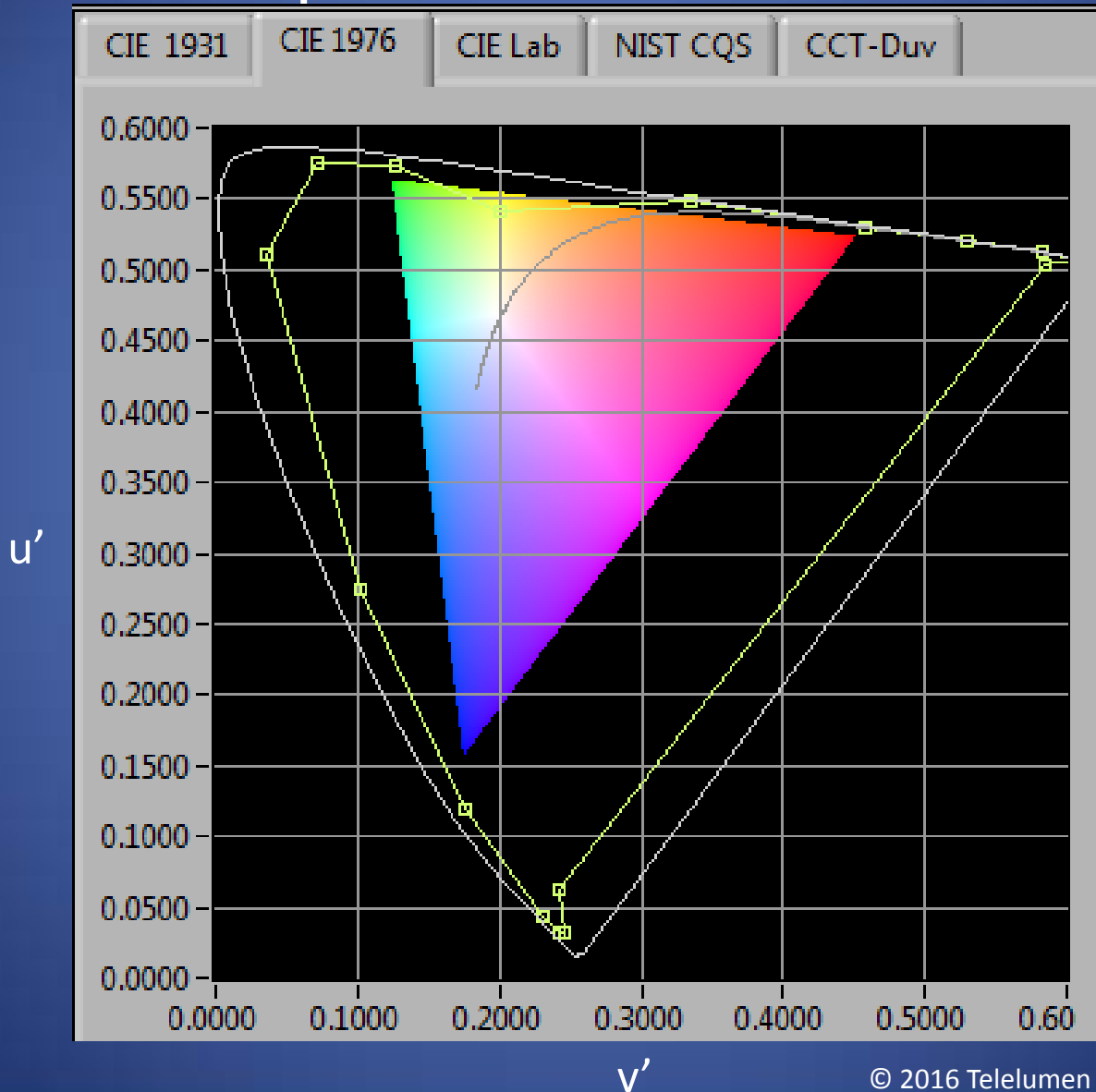
The screenshot displays the 'Cue Editor' section. It contains a table of cues with the following columns: Color, Name, Watt, Fade Up, Hold, and Fade Dn. The cues listed include 2000K, 3000K, 20000, Blue Strobe, Pink, 5225K 35 Peak, and Precandle. To the right of the table is a 'GoTo Cue' field with a value of 13 and a 'Cue Pair' field with values 11, 12, 13, 14. Below these is a graph showing 'Amplitude (%)' versus 'Time (second)' from 0 to 23. The graph shows a dashed line that ramps up and then down. At the bottom, there are 'Clear Cue', 'Load Cue', and 'Save Cue Iso' buttons, along with radio buttons for 'Load Native Data (slider)' and 'Load Generic Data (SPD)'.

This screenshot shows the 'Sequencer' section. It includes 'Record time' (00:00:00) and 'Current time' (12:25:05) fields. Below these is a 'File Name to Receive/Delete' field. The main area contains a grid of playback controls for 12 tracks, each with a play button and a progress indicator. The tracks are numbered 1 through 12. To the right of the grid is a list of tracks with columns for 'Track' and 'Serial Number/File Name'. The list includes files like 'Black.Iso', 'Channel Scan Equal Optical Watt 2s.Iso', and '1000K.Iso'. On the far right, there are several control buttons: 'List Directory', 'Send File to Luminaire', 'Receive File to Disk', 'Receive File', 'Delete File', 'Get Luminaire Info', 'All Dark', 'Clear Screen', 'Reset Luminaire', 'Update Firmware', and 'Format SD Card'.

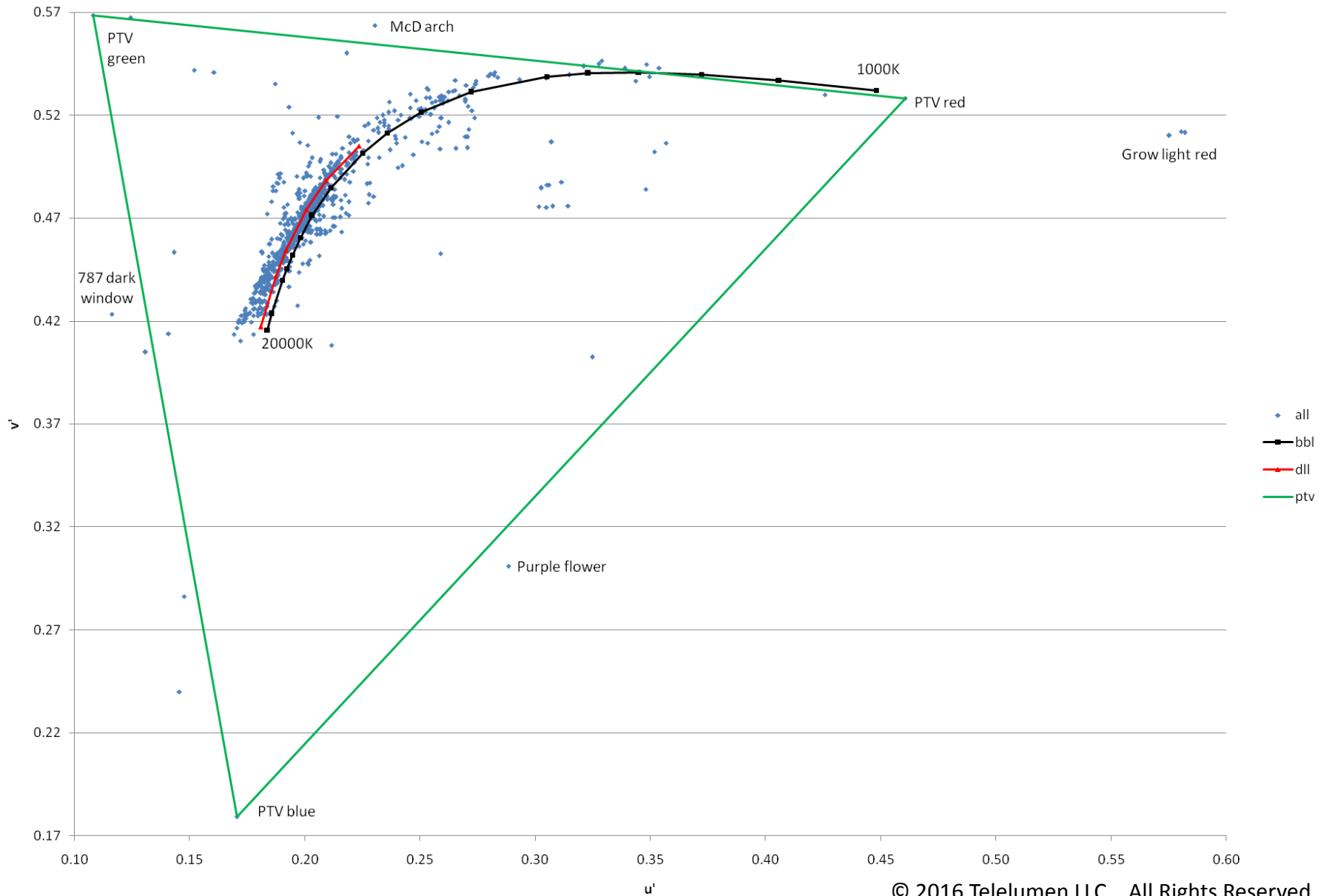
Collecting Daylight Data

- Spectrometer
- Camera with fish-eye lens

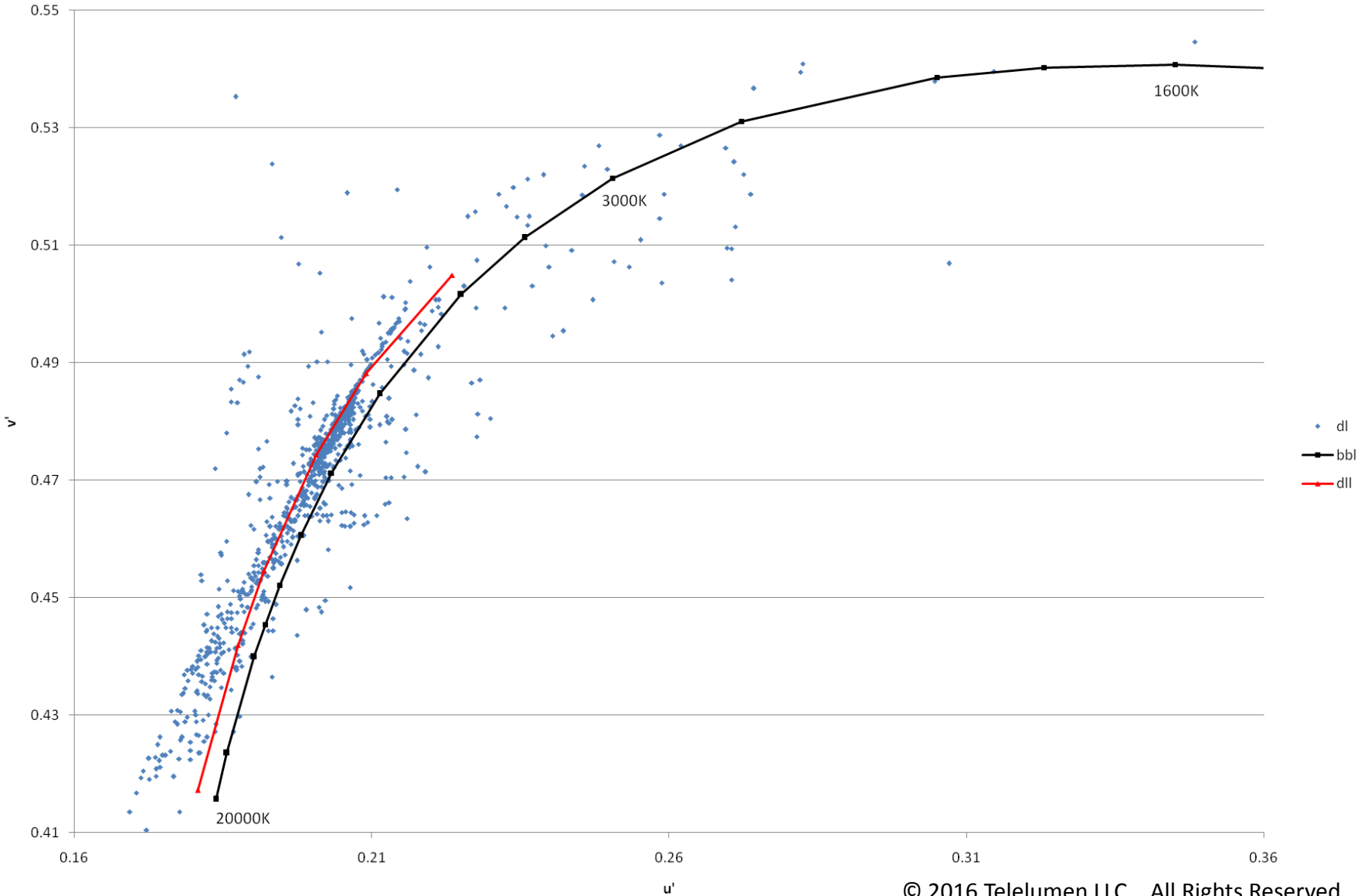
Chromaticity – objective specification of color independent of luminance



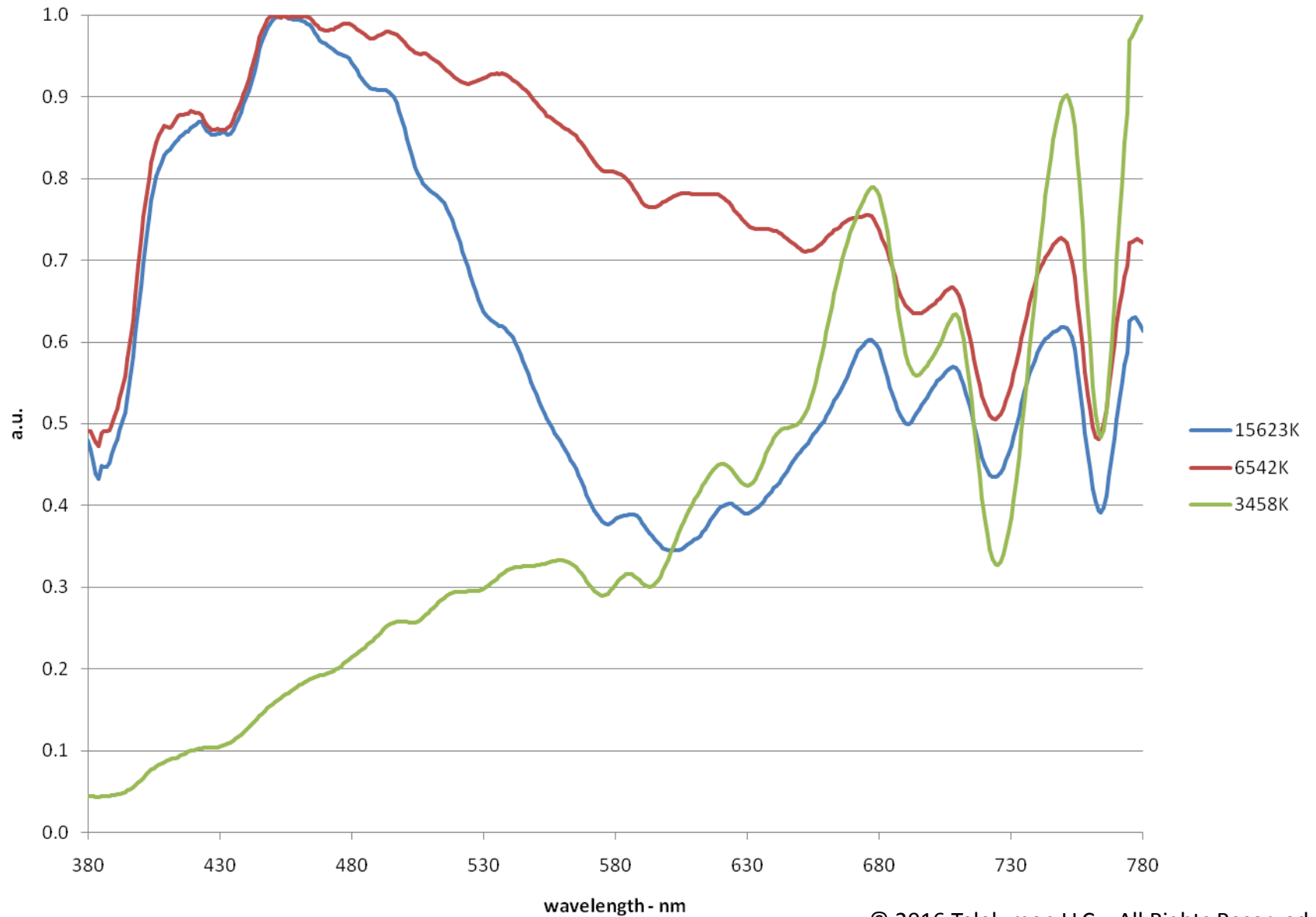
Spectrometer recordings



Daylight recordings



Daylight recordings



Sky Shots



































W
KUALA LUMPUR

















Beyond Replication

- “Fix” a cloudy day – fill in filtered daylight
- Augment real time
 - Stretch, compress, shift
- Designer spectrum – purposeful distortion
- Design from scratch
 - Health (studies needed)
 - Productivity (studies needed)
 - Enjoyment (art, fun, no study required)

Summary

- The blackbody locus is only a convenience
- Daylight is the model for electronic illumination
- Clock, calendar, location, many colors are key
- Solid state emitters are more than 450nm LEDs
- Its up to us to invent the future



Thank You

Steve Paolini
steve@teledumen.com