

**2018 U.S. DEPARTMENT OF ENERGY SOLID-STATE LIGHTING
R&D WORKSHOP AGENDA
January 29–31, 2018 • Nashville, TN**

PANEL | R&D DIRECTIONS OF COLOR-TUNABLE LIGHTING

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Agenda

- Introduction
- Tunable spectrum
- Reflected Spectrum of Objects
- Light Source Spectrum
- Summary
- Demo



The Recording and Playback of Light

- Founded 2007 – Silicon Valley, CA
- Purpose – Replicate any spectral power distribution
 - Products and services to create and playback light
- Privately owned
- Current products:
 - Light Replicator (16 color light player)
 - Octa (8 color light player)
 - LumenScripts (content)
 - Recordings, created, composed digital data

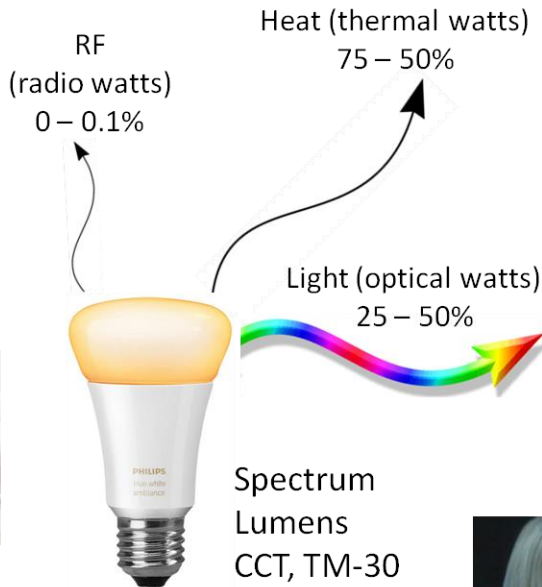
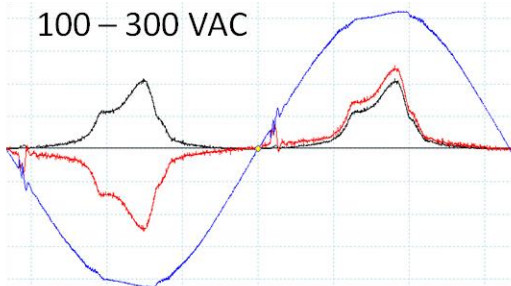
Target Applications

- Healthcare – faster healing, wake/sleep improvement
- Retail – make products more appealing
- Workplace – increase productivity, wellbeing
- Lighting company – designer spectrum, focus group evaluations
- Horticulture – plant growth
- Aquariums – fish, coral
- Sensors (cameras) – firmware development
- Color quality – consistency, metrics, studies
- Movie, TV – outdoor scene and filter replication

SSL Ecosystem

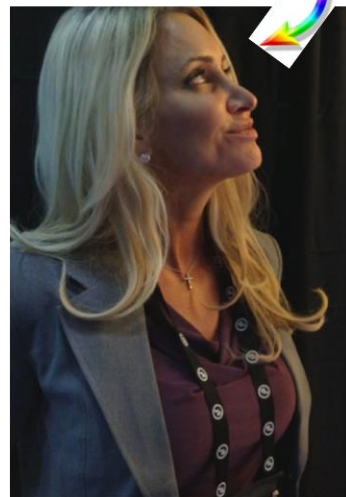


Electrical watts
Voltage
Current
Time
PF, THD



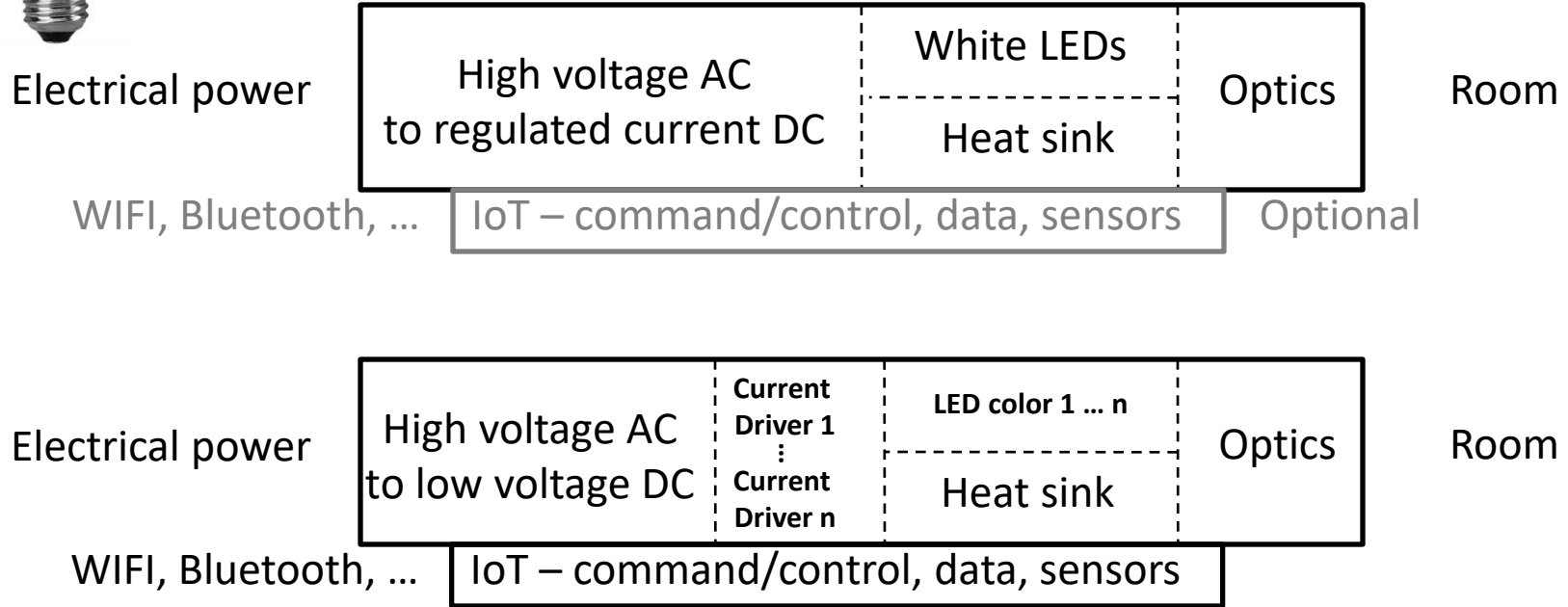
Spectrum
Lumens
CCT, TM-30
Time
Angle
Space
Flicker

Reflection





Fixed color and tunable lamp/luminaires



Terminology

- Dimmable – change illumination level
- Warm-dim – change level and CCT
- Tunable white – WW-CW, WW-NW-CW
- Tunable color – RGB
- Tunable spectrum – 4 or more colors
 - Many solutions for given chromaticity

SPD is the definitive description of color
and its properties,
CCT and chromaticity are not enough.

Tunable Spectrum Goals

- What are the target SPDs?
 - Blackbody and daylight locus.
 - Actual daylight and synthetic spectrum.
 - **Any spectrum.**
- What are the metrics for success?
 - CRI, TM-30, CIE51.
 - **Any reference spectrum and any reference palette.**
 - **Best fit SPD to target SPD.**

Tunable spectrum challenges

- Multi-channel current sources
 - Ideally both AM and PWM under digital control
- Multi channel color sensors
 - At least one sensor channel per color channel
 - Both product embedded and space deployed

Tunable spectrum challenges

- Color mixing
 - Less challenging for area sources
 - May not be desirable in all cases
 - More challenging for directed beam sources
 - No colored shadows

Tunable spectrum challenges

- Controls
 - Its not a color wheel or chromaticity diagram
 - “Create your own” is to complex and time consuming
- Simple, intuitive user interface
 - “Channel change” and “volume control”
- Back end facilitates time changing SPD
 - CCT tuning is not enough

Tunable spectrum challenges

- Missing, inefficient wavelengths
 - Green gap, amber
 - No gaps from UV through IR
 - Efficiency a better metric than efficacy

Efficacy vs. Efficiency

- Efficacy = lumens per electrical watt
- Efficiency = optical watts per electrical watt

- Lumens are a weighted measure of optical watts with a peak at 555nm (green) and falling off toward red and blue.

Future work

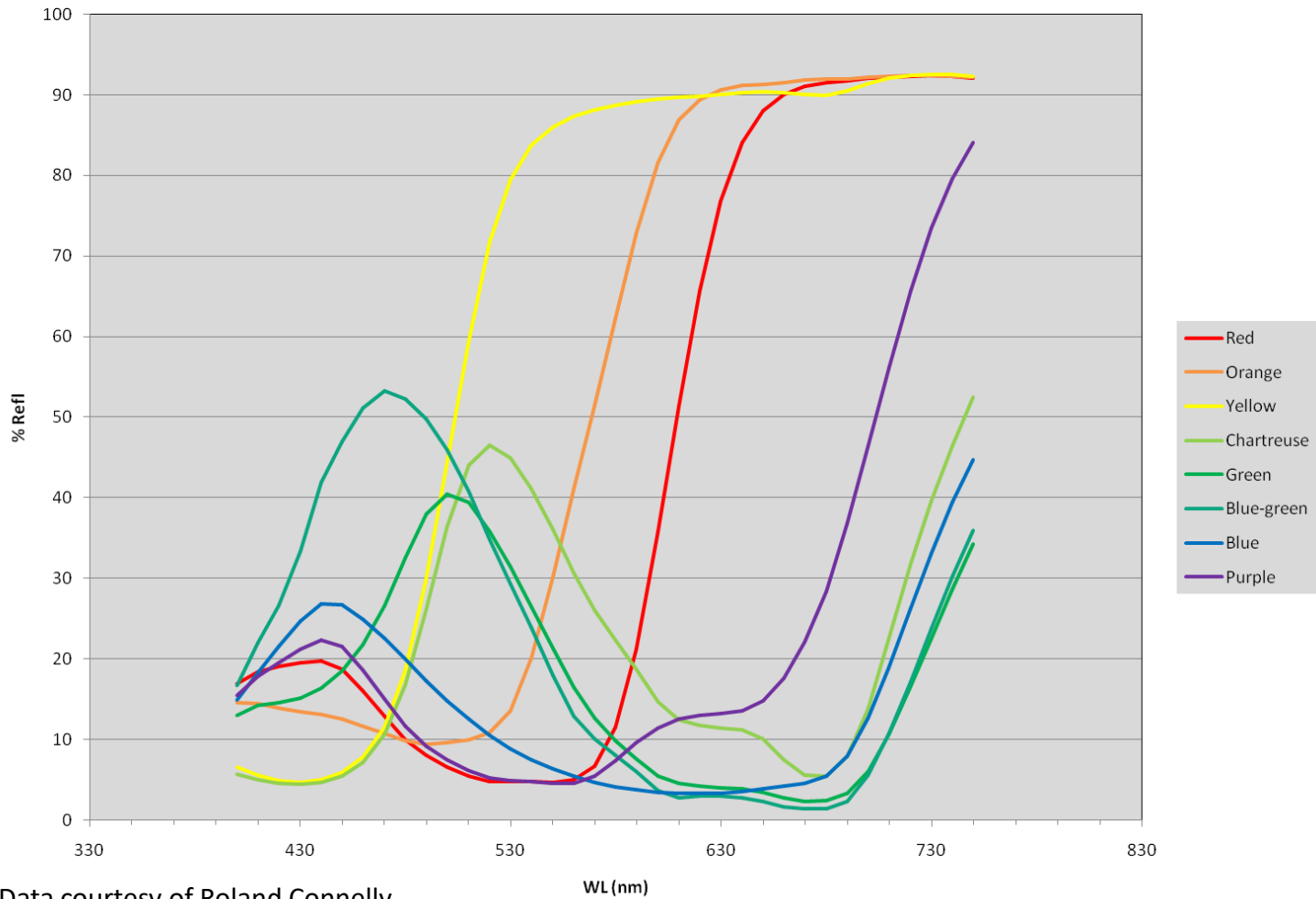
- The lumen should be revisited including how LED sources behave (both mono and poly-chromatic) across the spectrum and how we perceive light across our entire visual field.
- As we move to using more of the spectrum beyond optimizing the central cone response and for tunable spectrum systems, efficiency may be a more useful metric than efficacy.

Non-energy benefits

- Health and well being
 - Needs evidence based clinical studies
- Object appearance enhancement
 - Saturation, time changing, fluorescence
- Enjoyment, relaxing, energizing, ...
 - Does not need clinical studies

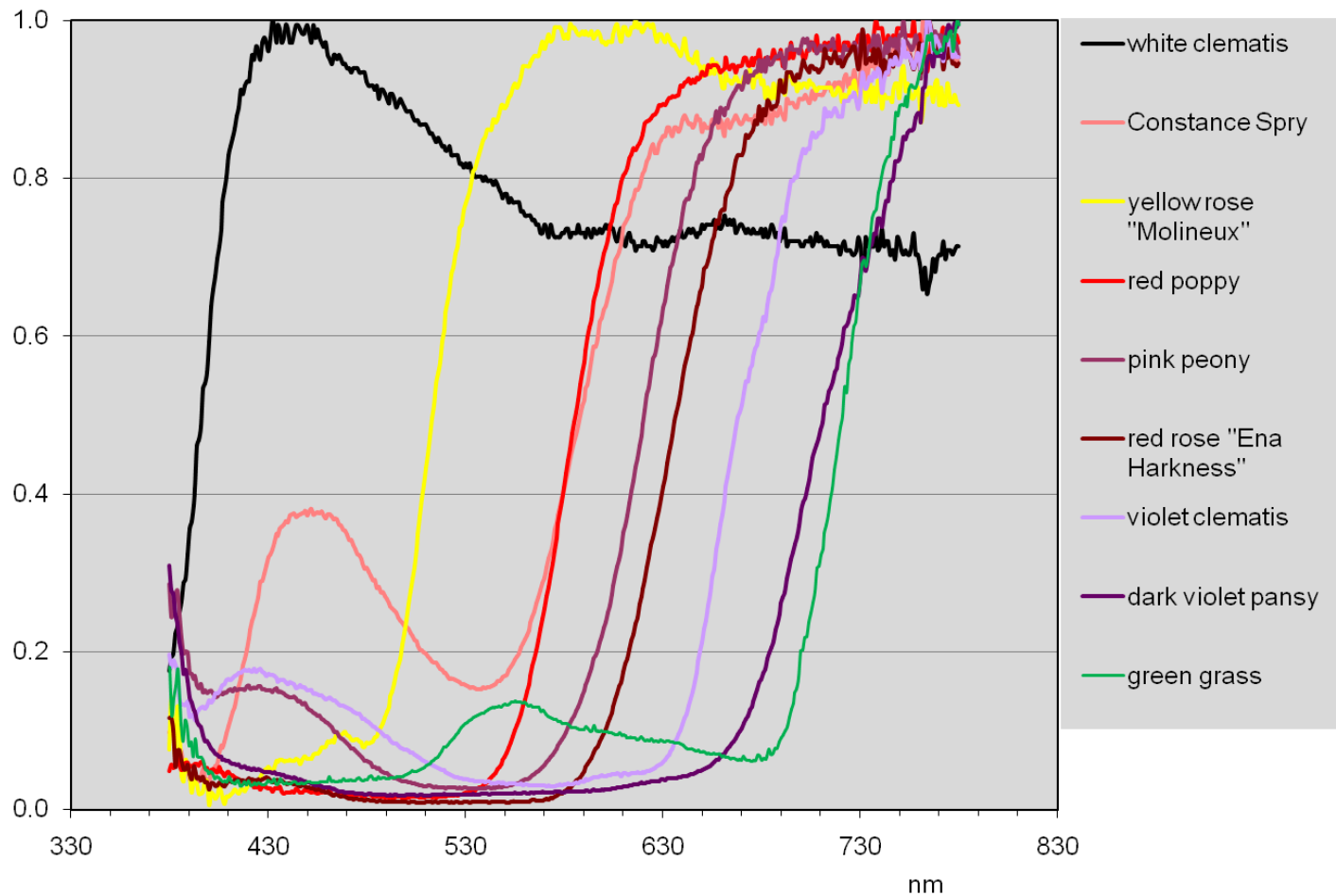
Spectral Characteristics of Illuminated Objects

Textile Reflectance Data



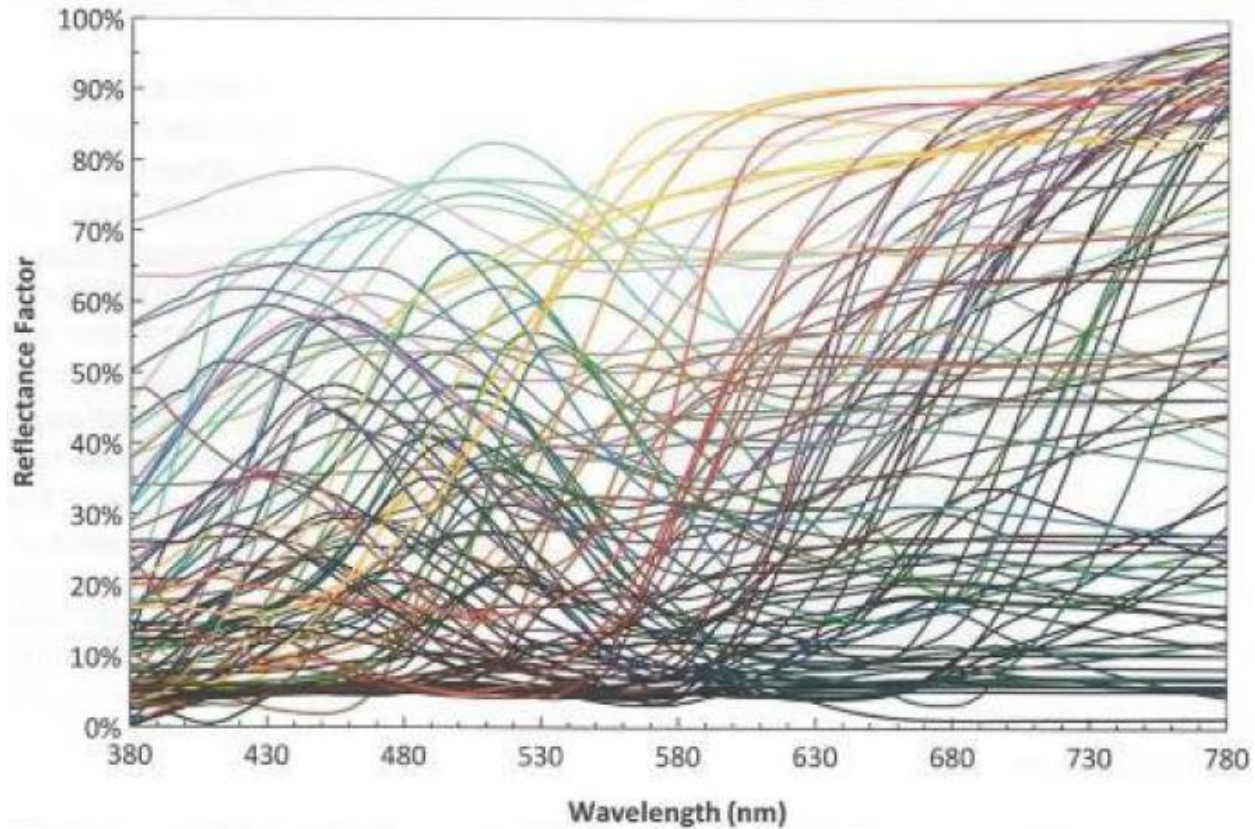
Data courtesy of Roland Connolly

Remission of flowers



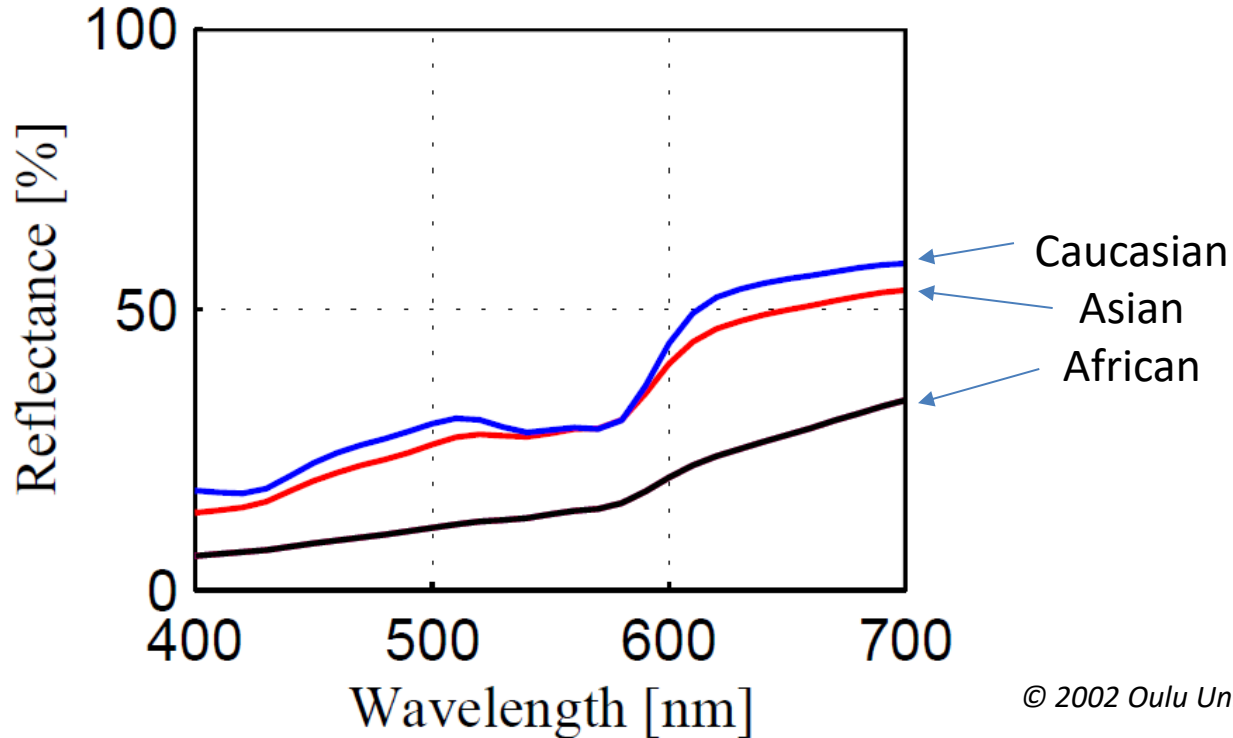
Data courtesy of Dieter Lang, LEDVANCE, Germany

TM-30 colors - 99



Reflectance Spectra of Skin

half is between 600nm – 700nm



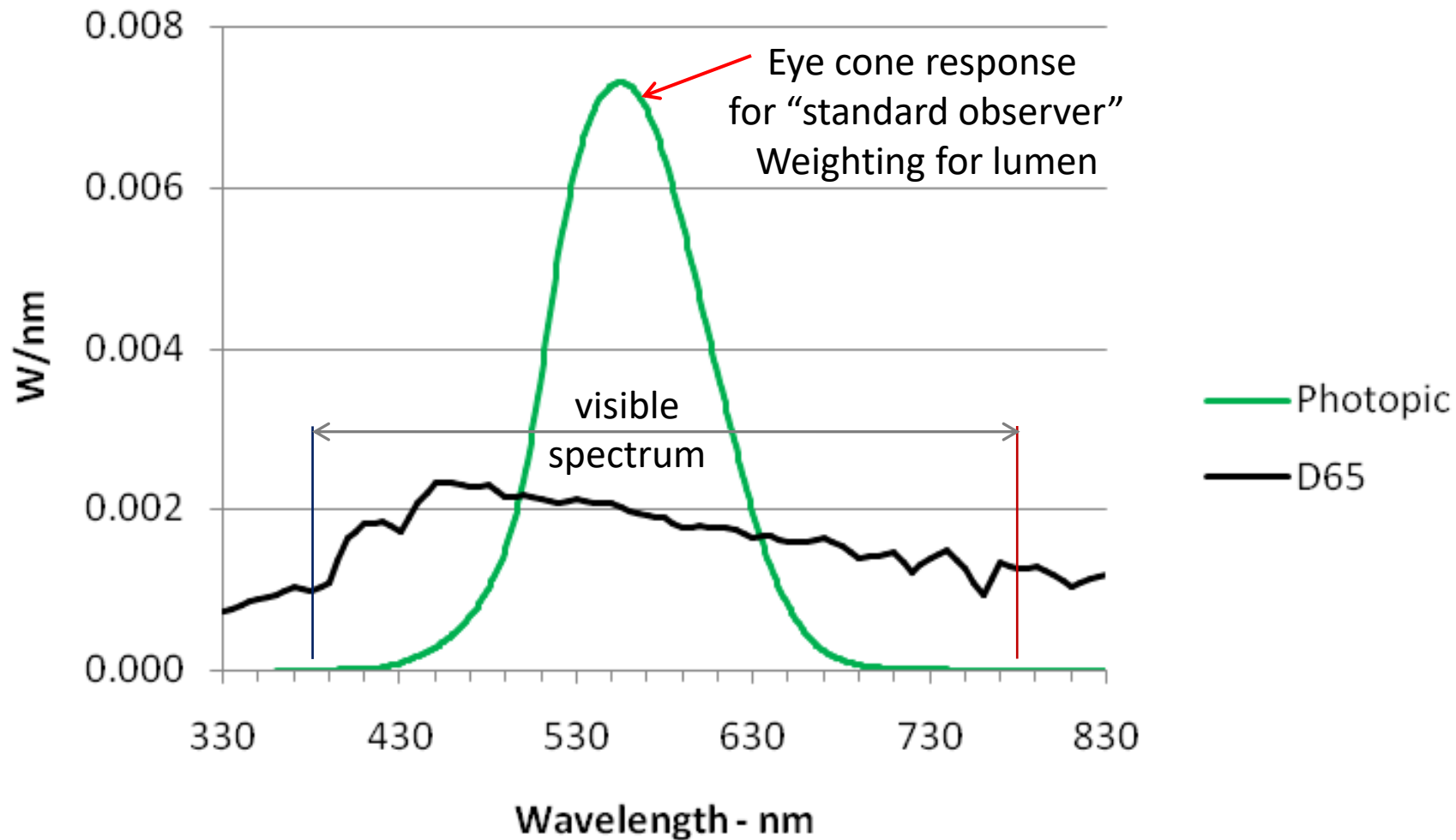
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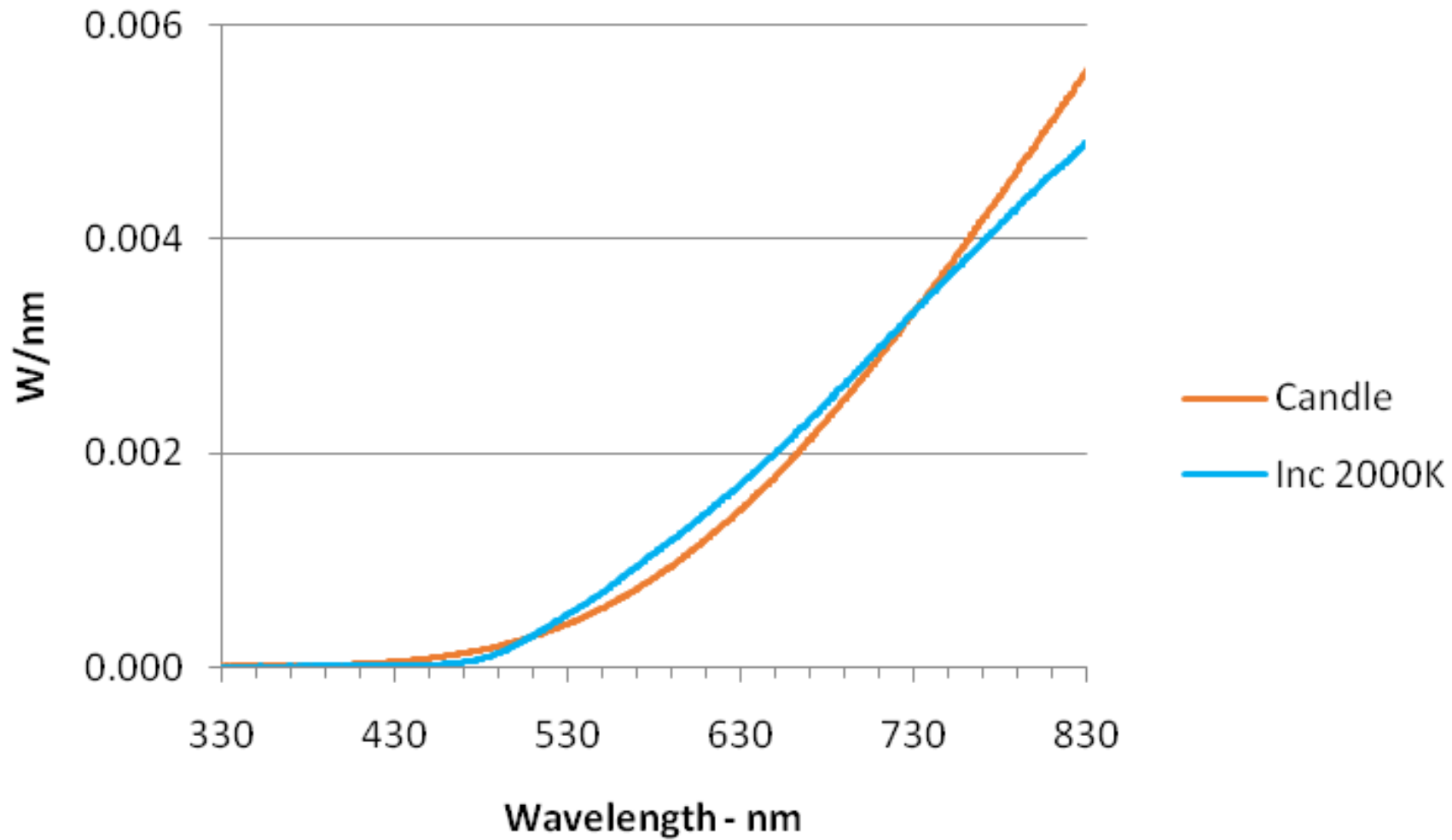
Light Source Spectrum

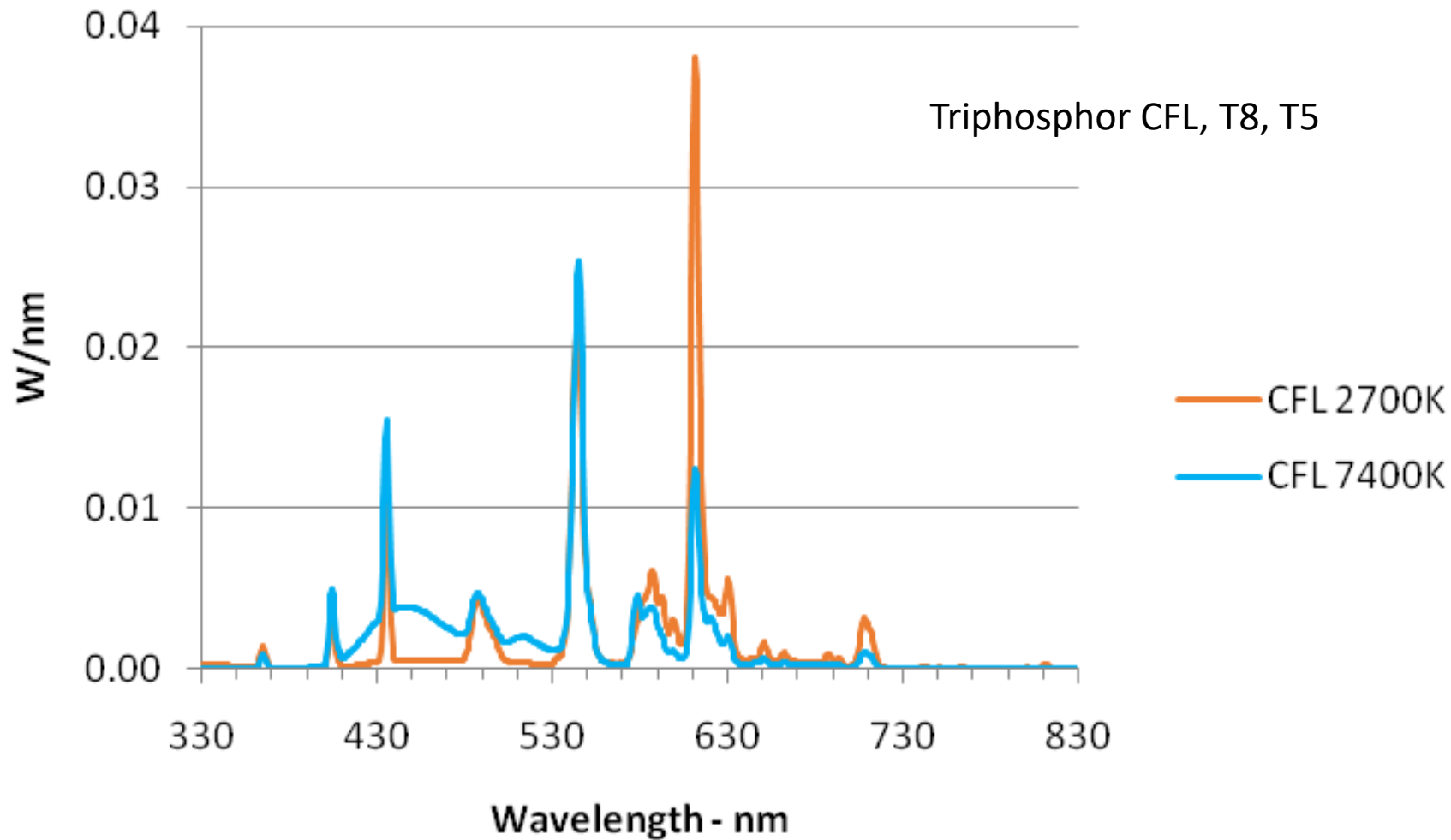
Light Source Spectrum (in the beginning)

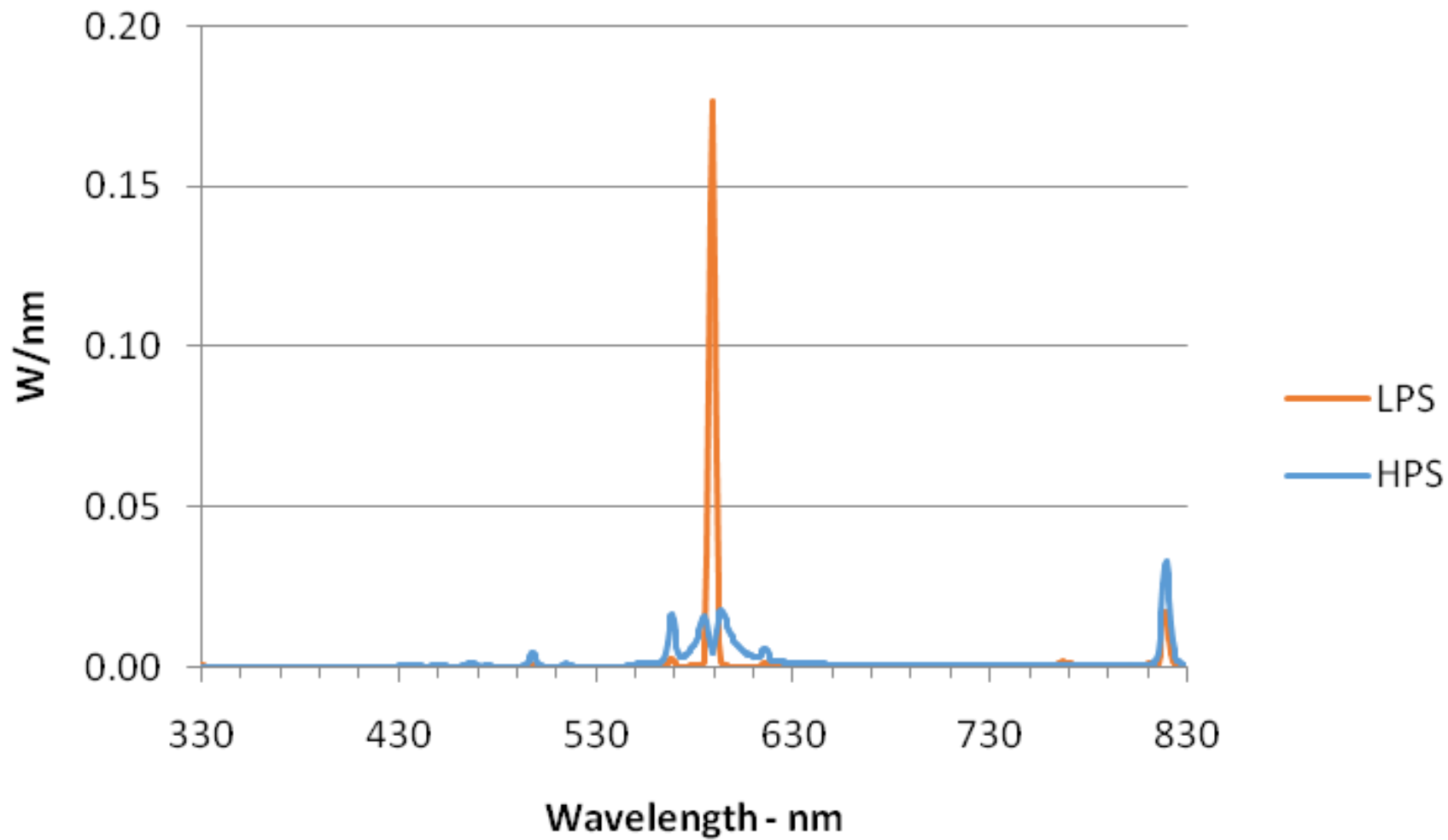
- Daylight
- Fire

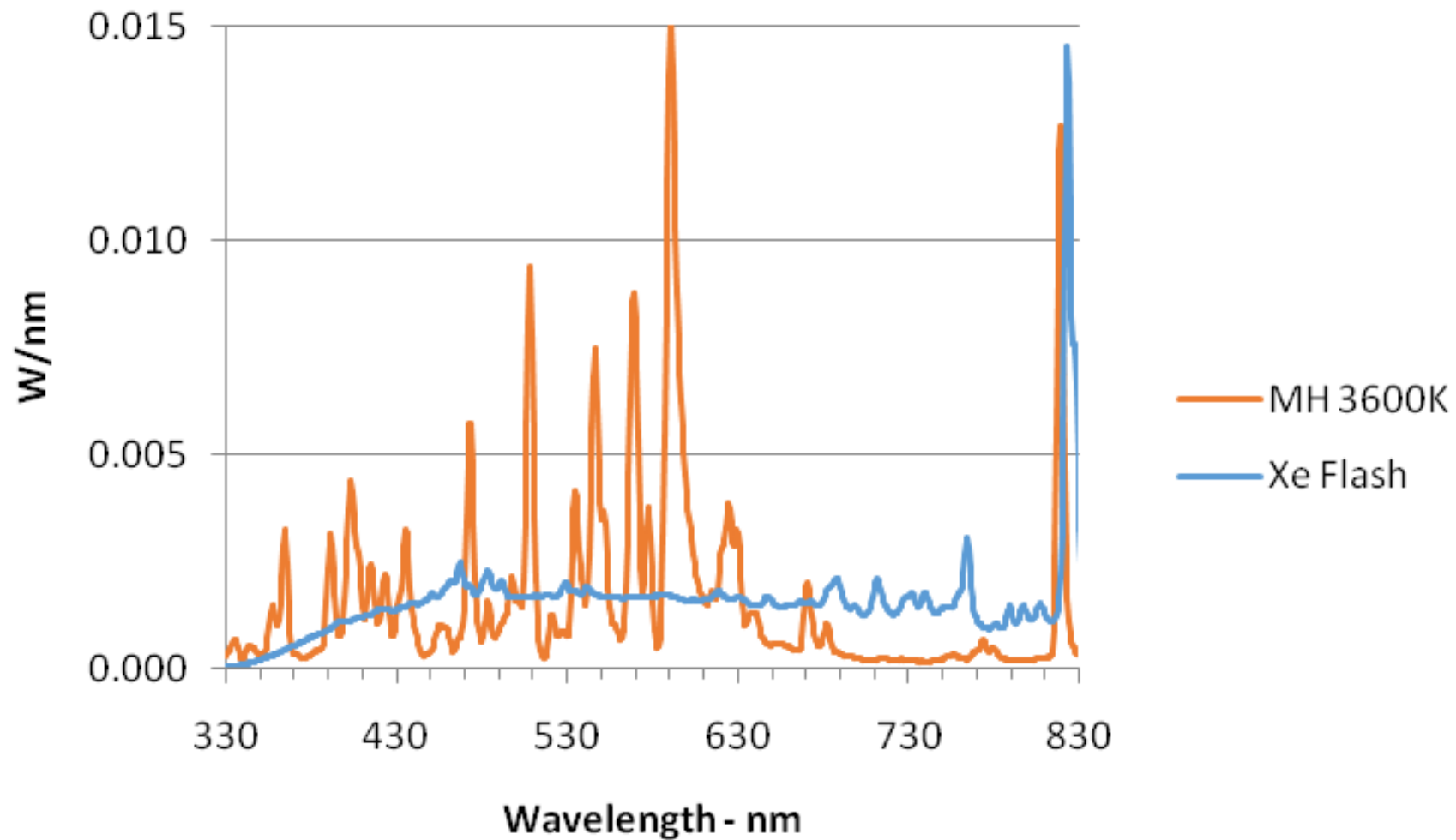
- **Continuous spectrum**
- Intensity and spectrum **change with time**

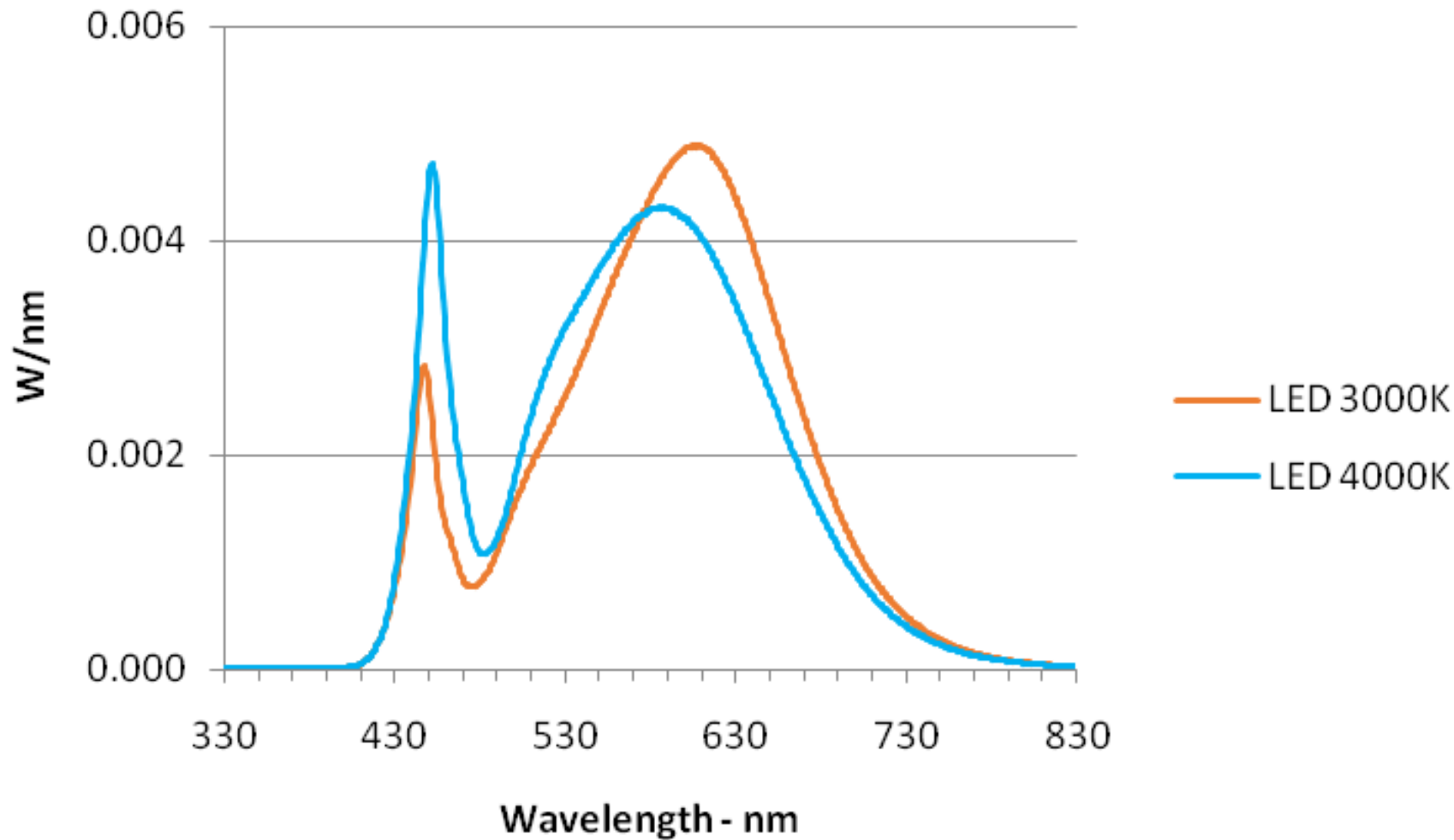


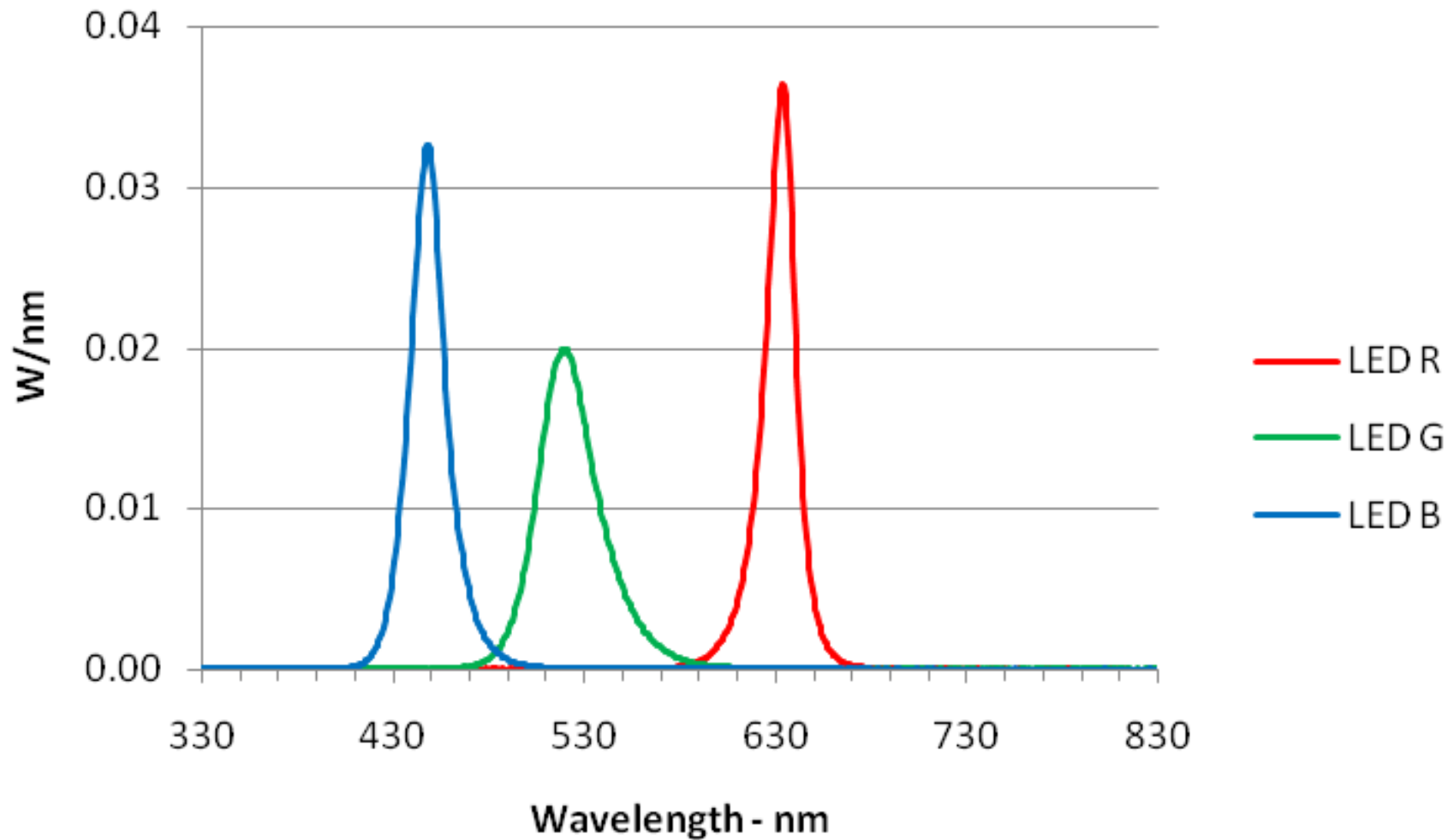


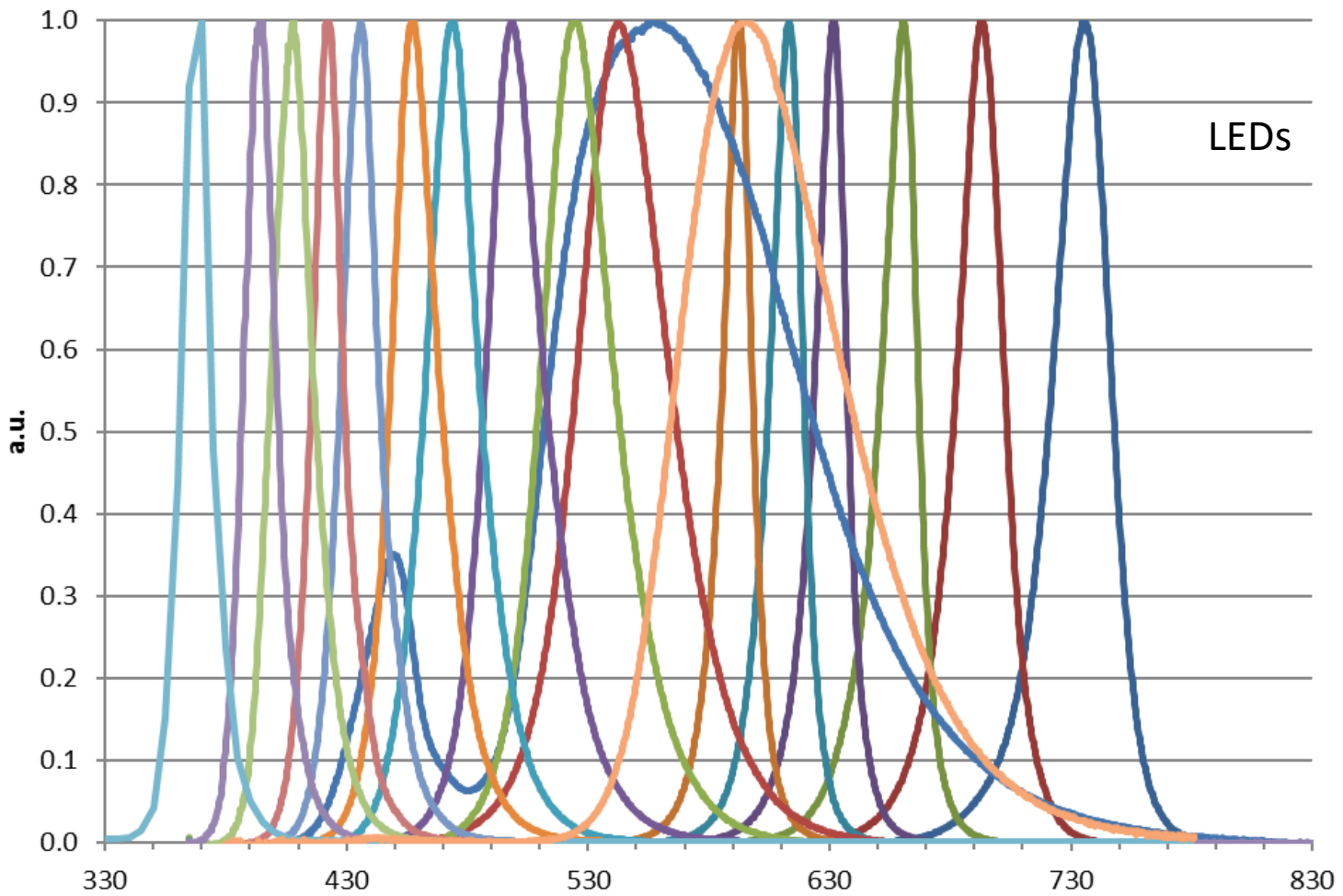


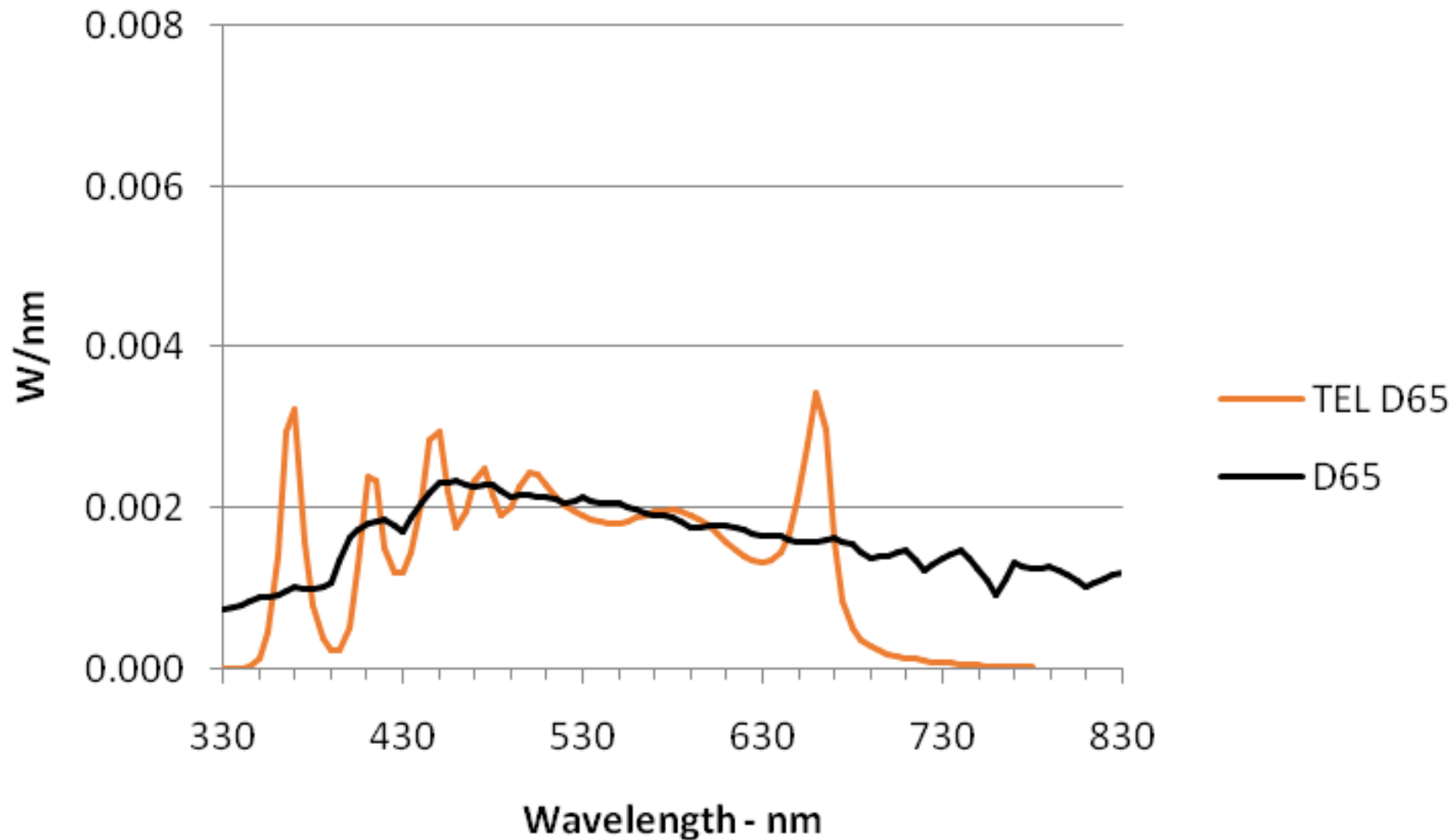


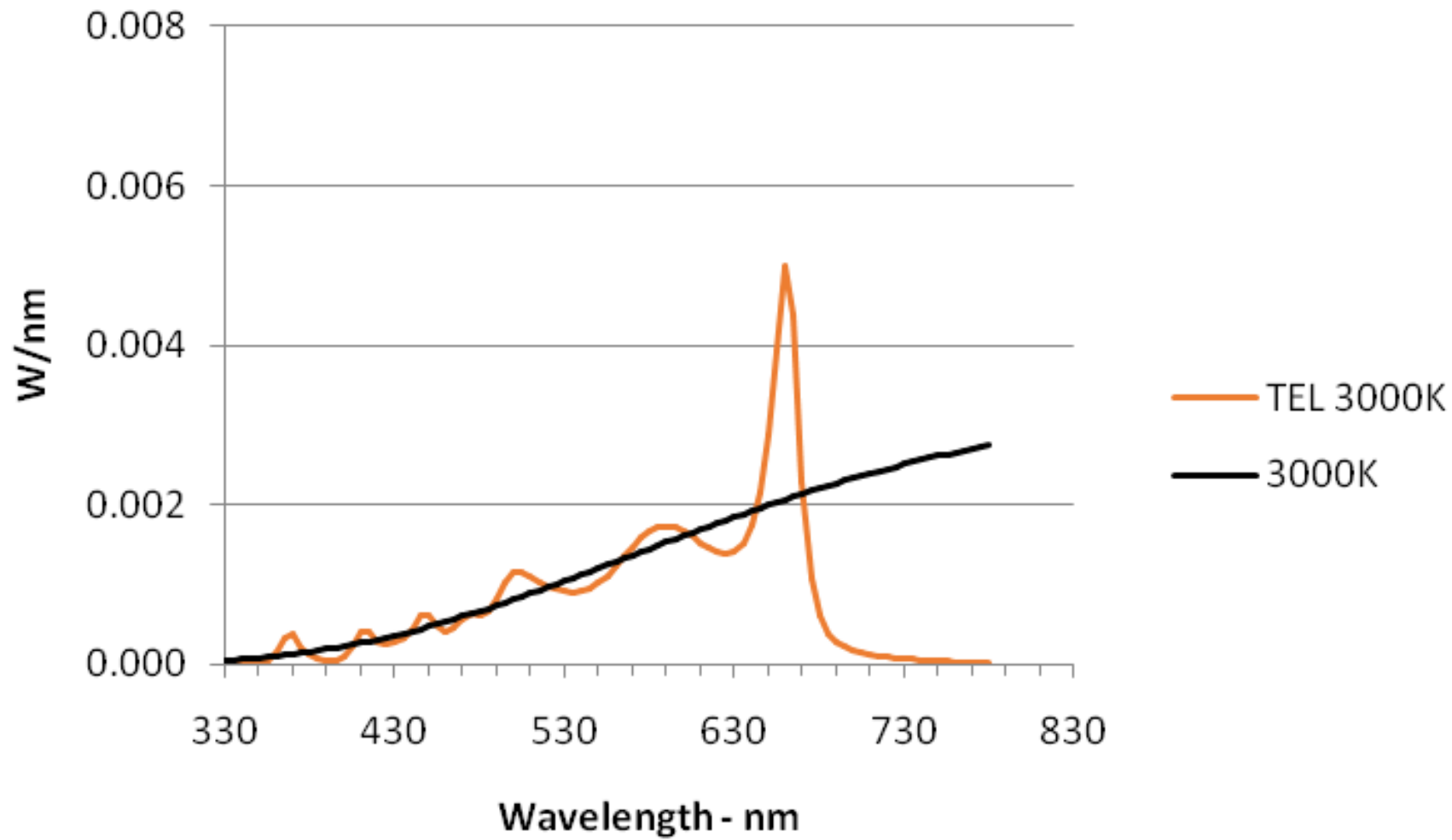












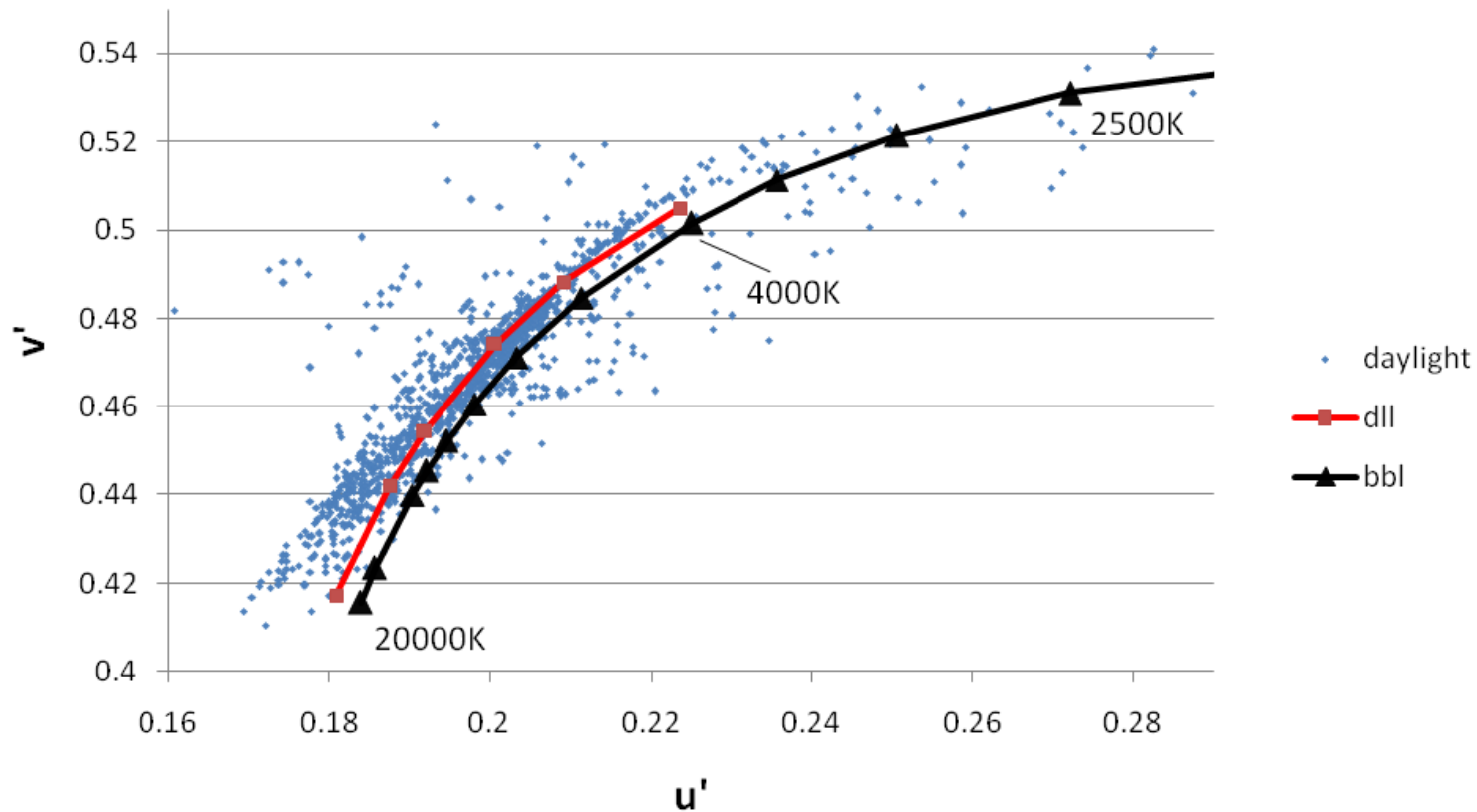
In general - SPD

- A more continuous spectrum and wider range of wavelengths produce higher color quality light sources.
- A less continuous spectrum and truncated range of wavelengths are often more efficacious.

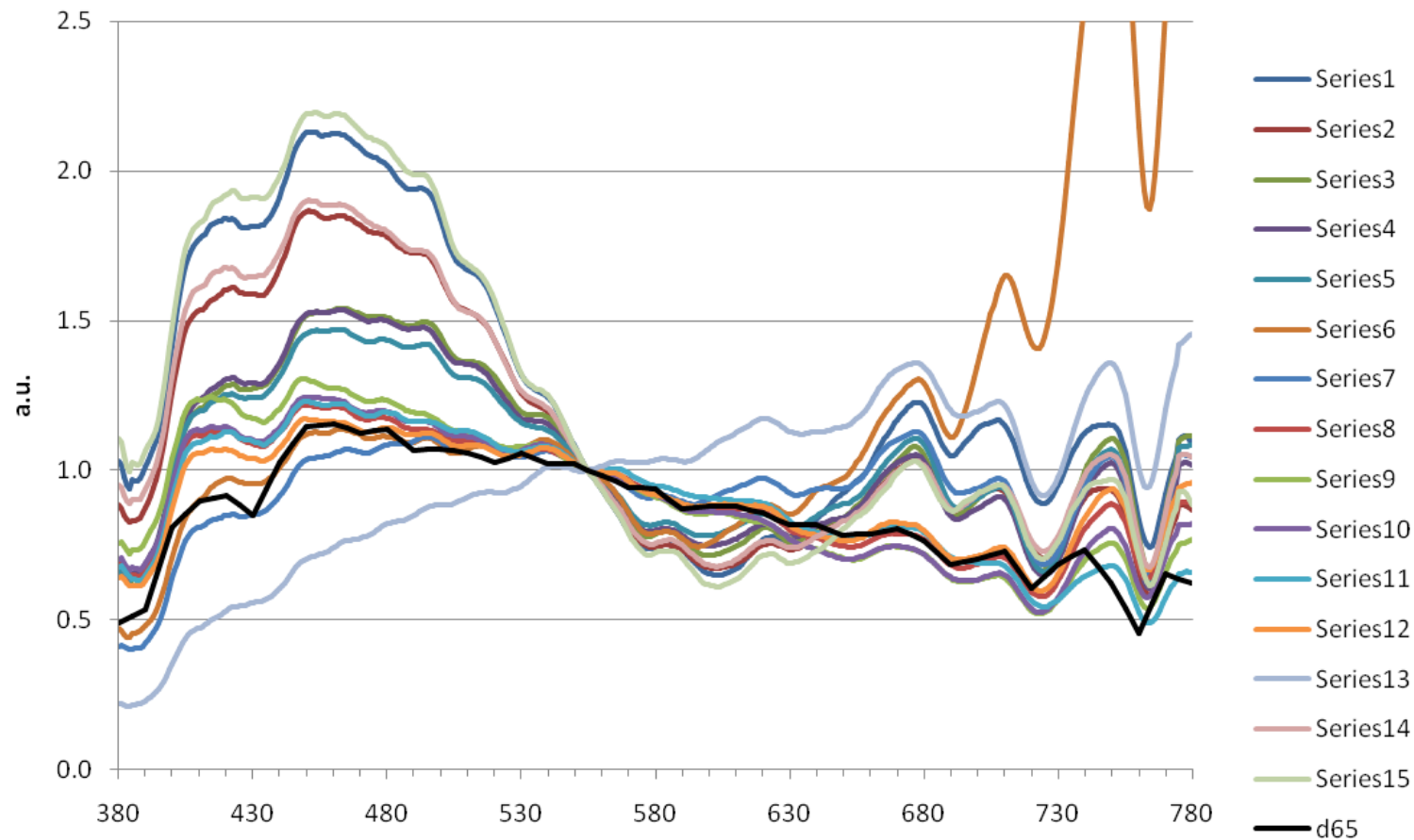
Daylight Data

Daylight Data

Aug15 to Jul17 (1400 recordings)

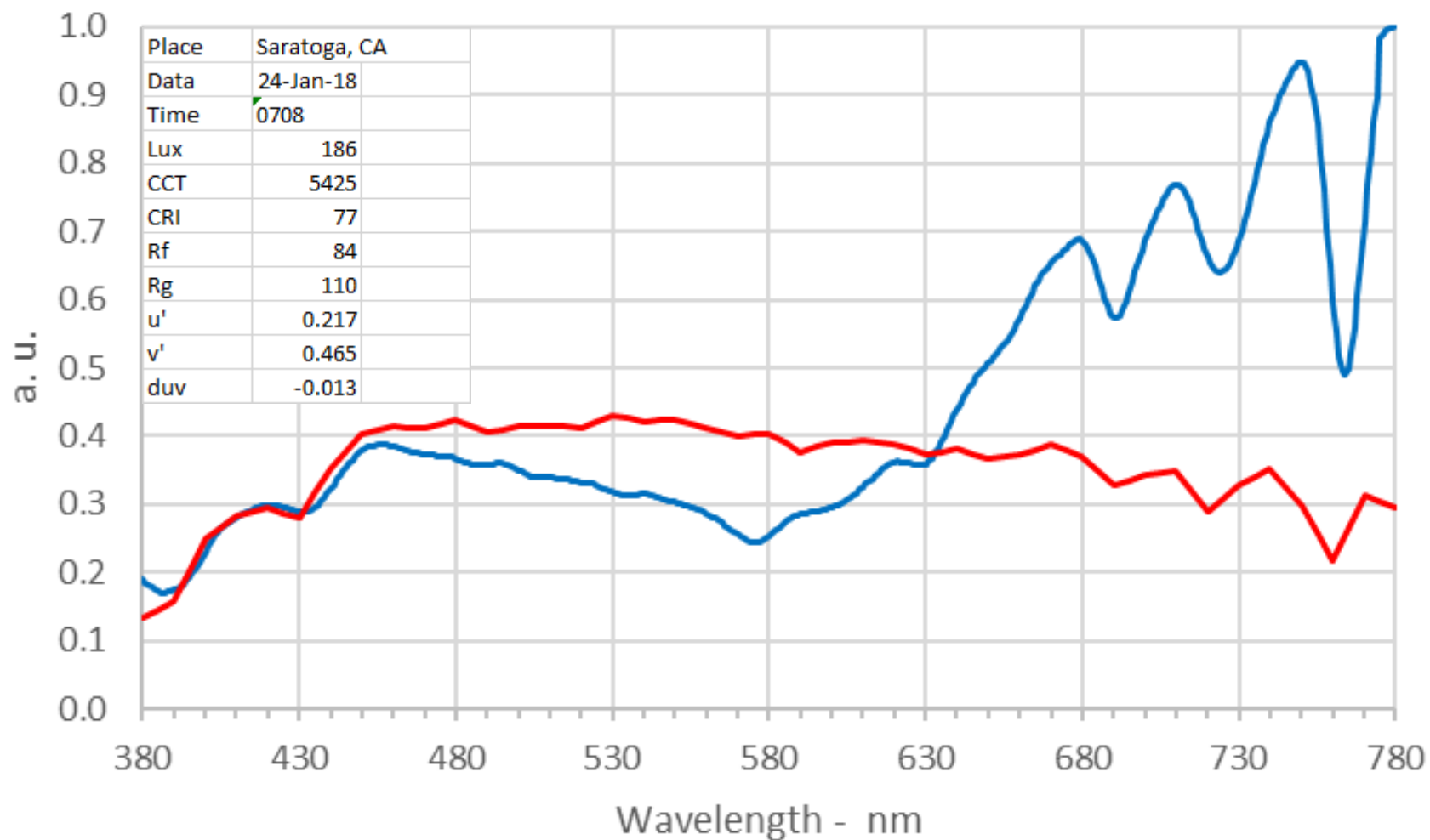


Como, Italy - 28may16



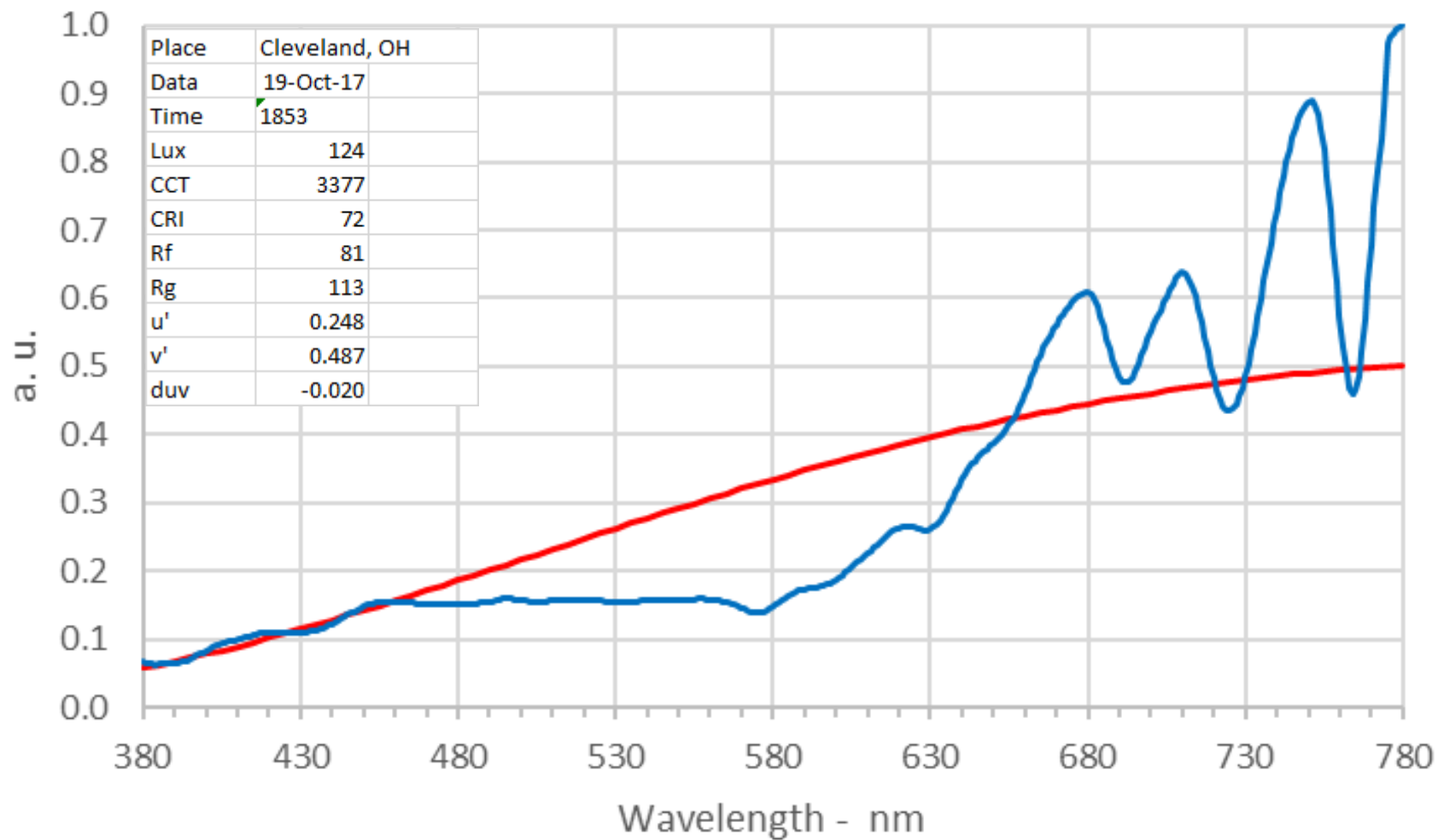
Saratoga morning sky
7:11AM, 24jan18





Cleveland evening sky
18:53PM, 19oct17





Summary and Demo Introduction

- Spectrum is important for fidelity and preference.
- Natural light sources have broad variable spectrum.
- Daylight is a good model for tunable systems.
- Broader wavelength range and less dropout in the SPD increases color quality and impact.
- Ask for a copy of the SPD.









Thank You

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