Tim S. Kang

Husband, Dad, Cinematographer

Principal Engineer, Color & Imaging— QUASAR SCIENCE

Founder & Chair — Lighting Committee, ASC Motion Imaging Technology Council

Education

MFA – Cinematography, American Film Institute Conservatory

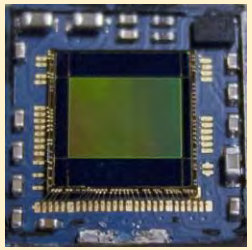
BS – Biomedical Engineering, Johns Hopkins University

Photographic Color Pathway

Light

Object

Sensor



Display

Observer

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Test the 4 F’s

How does ***colored*** light work with Familiar…

Faces

Fabrics & Paints

(Includes test charts)

Fruits & Vegetables

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What to Evaluate

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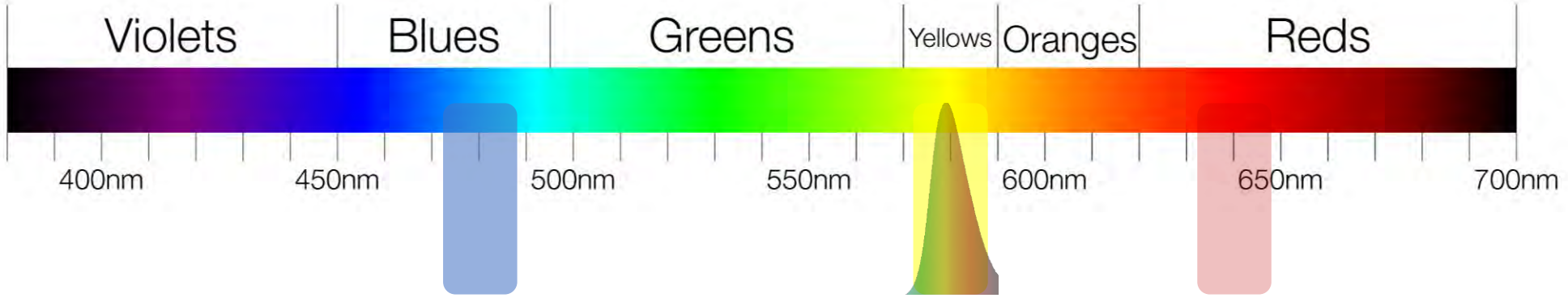
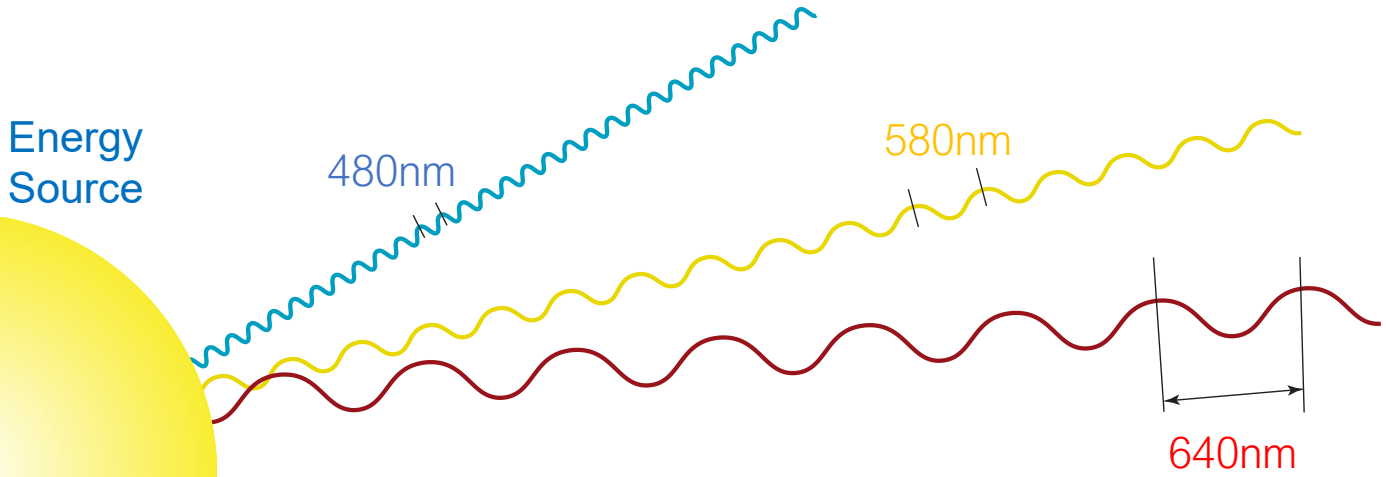
What is Light?

Physics: a collection of emitted energy (i.e., electromagnetic radiation)





Wavelength:

“nanometers” (nm)

distance that a single energy vibration travels in any medium

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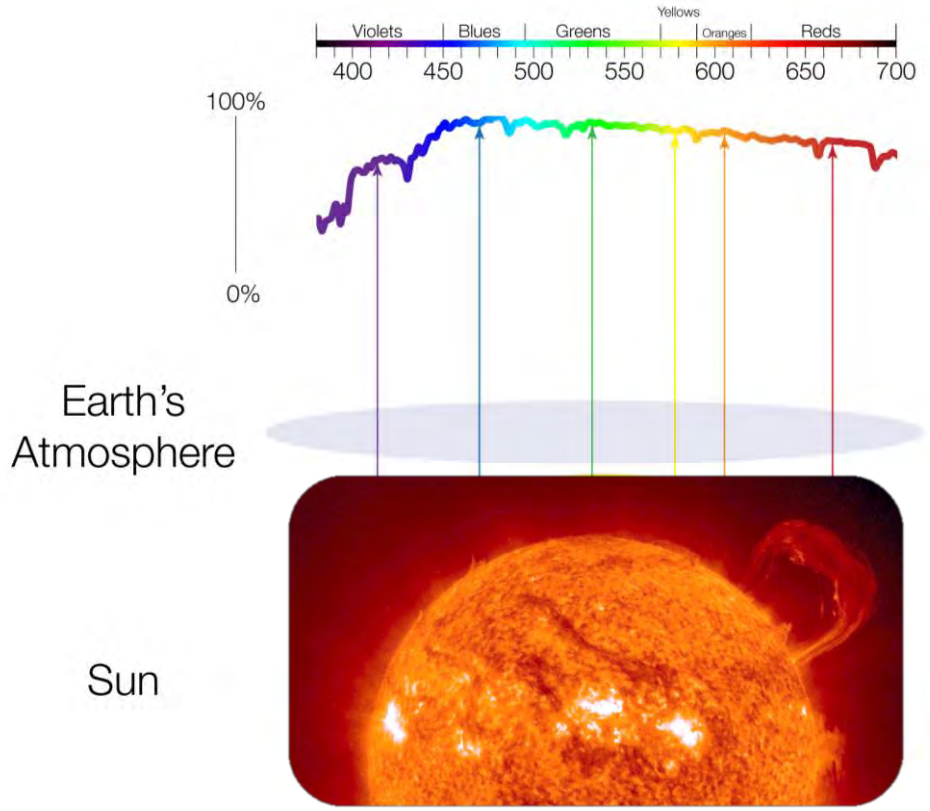
Spectral Fingerprints

Illuminants (Emitted colors)



Daylight:

Collection of energy emitted from a burning star and filtered through Earth's Atmosphere

HMI: 6000K, 0CC

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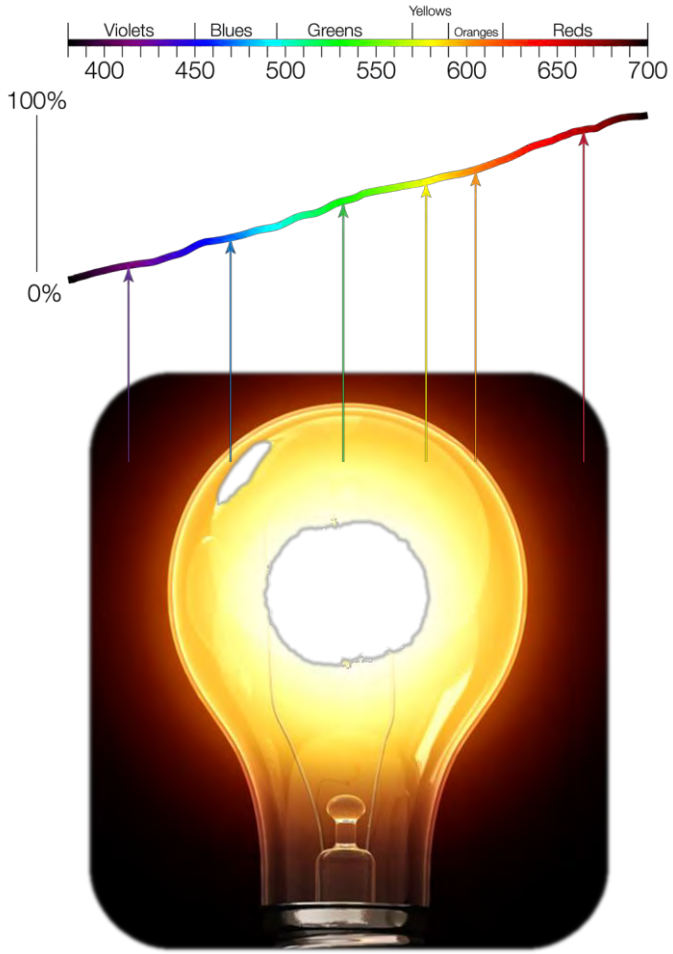
Spectral Fingerprints

Illuminants (Emitted colors)

Incandescent Light:

Collection of energy emitted from tungsten filament heated by electrical current



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Tungsten

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HMI

Tungsten

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HMI

Tungsten

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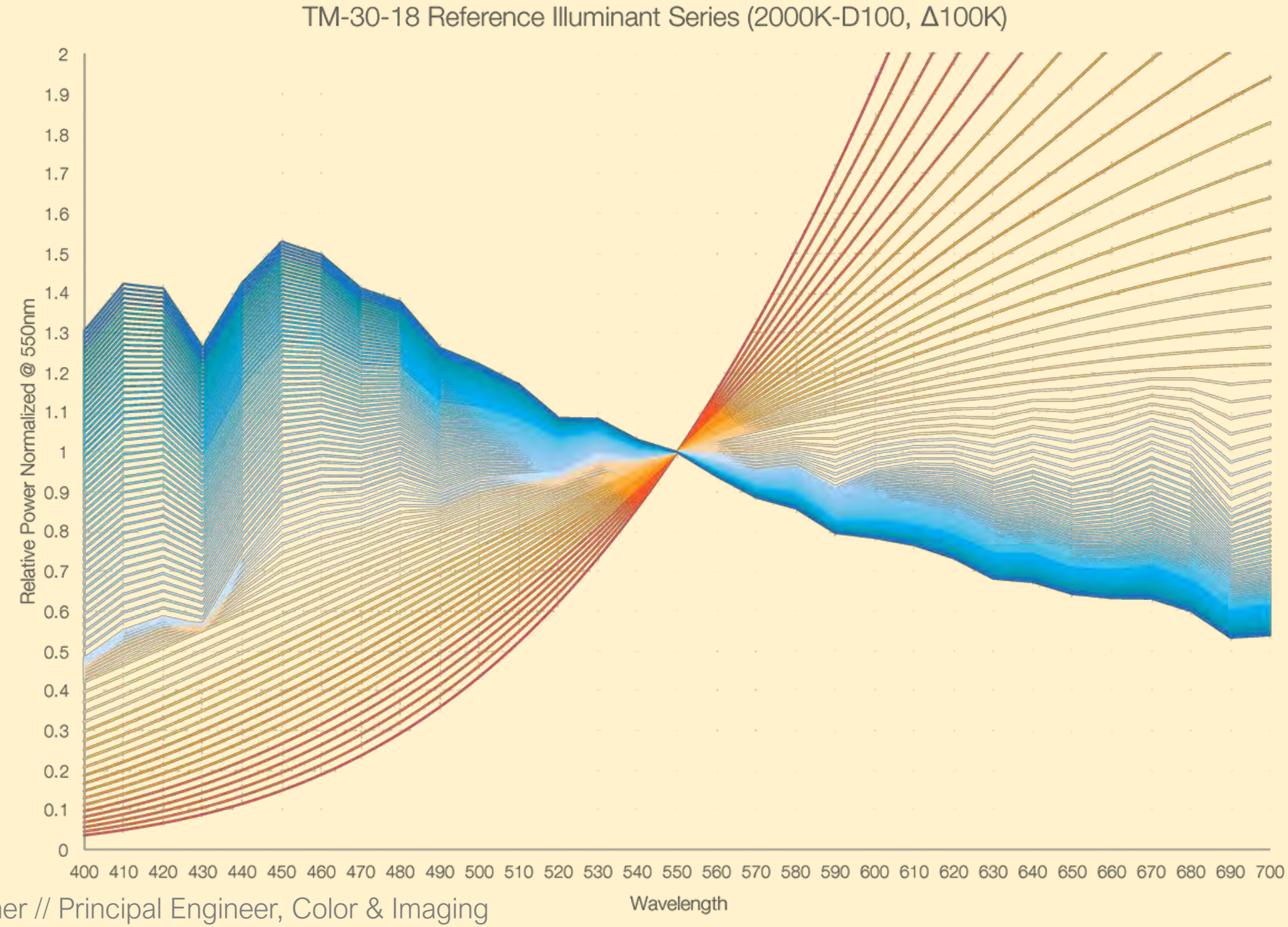
Accepted White Light Standard: TM-30 Reference Illuminants

CCT ≤ 4000K: Blackbody Spectrum

4000K < CCT < 5000K: Blackbody Spectrum proportionally blended with CIE Daylight Spectrum

CCT ≥ 5000K: CIE Daylight Spectrum



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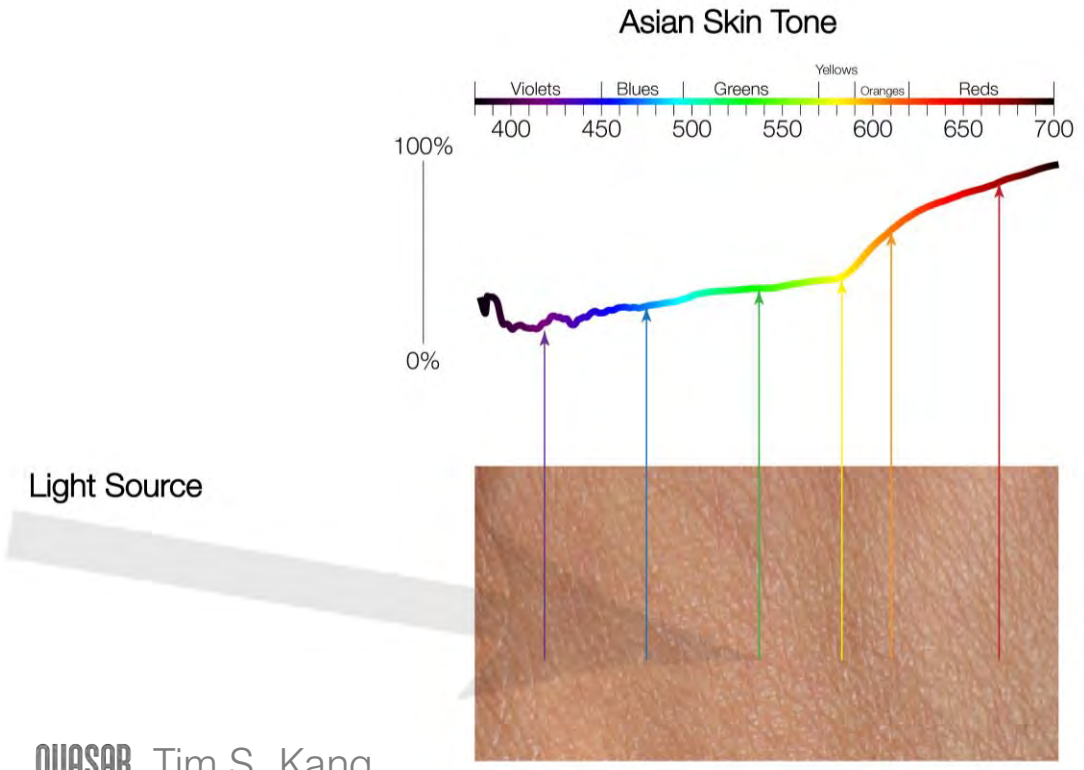
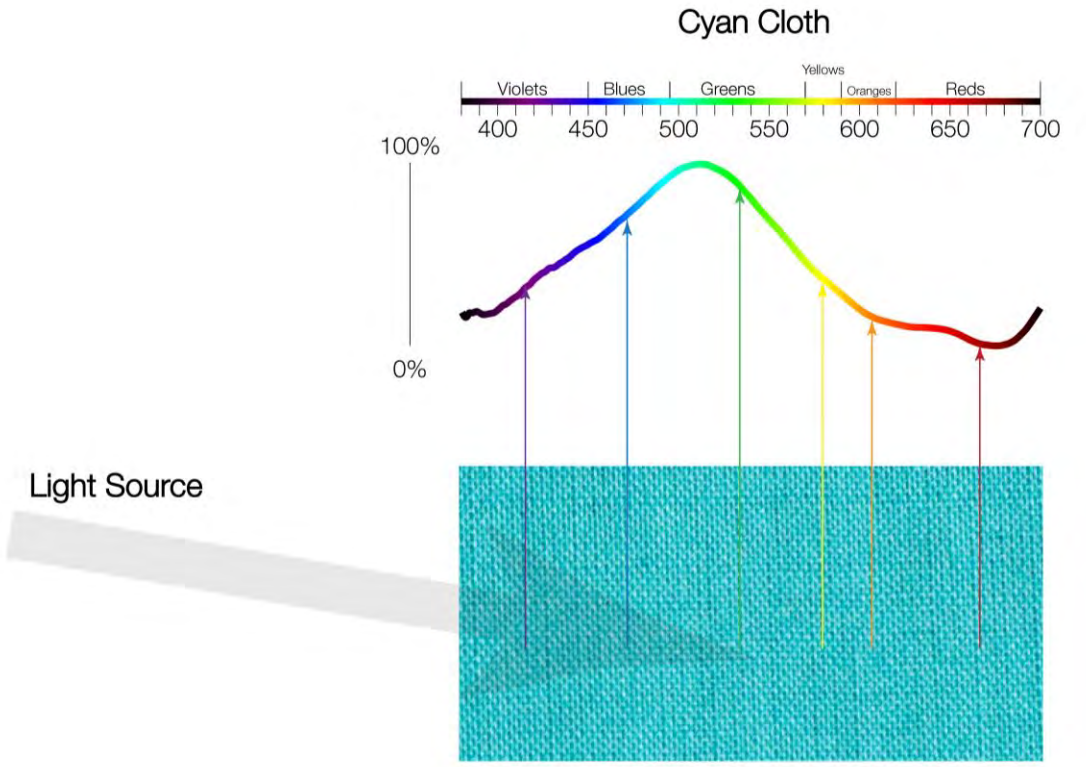
Spectral Fingerprints

Physical Objects uniquely modify light energy





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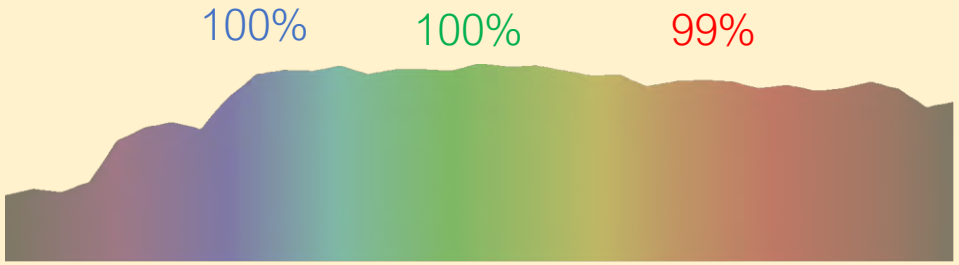
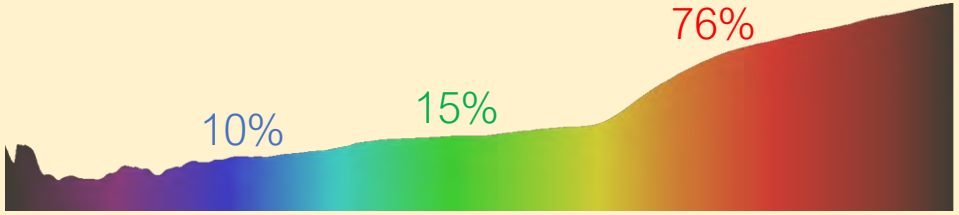
Light Carries Object Spectrum Information

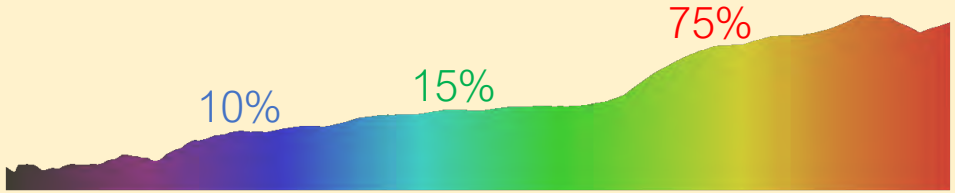
Illuminant: Daylight



Subject: Asian Skin



Color: Reflected Light



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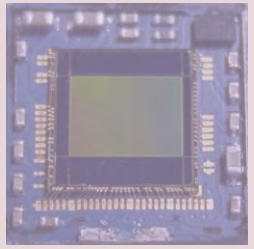
Color Science Pathway

Lighting Color Science

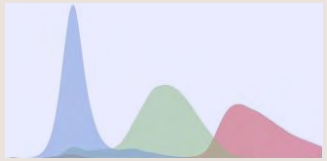
Light

Object

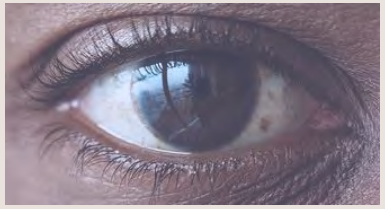
Sensor



Display



Observer



Camera & Post Color Science

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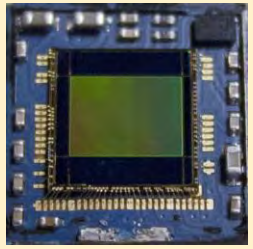
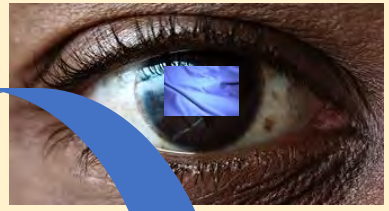
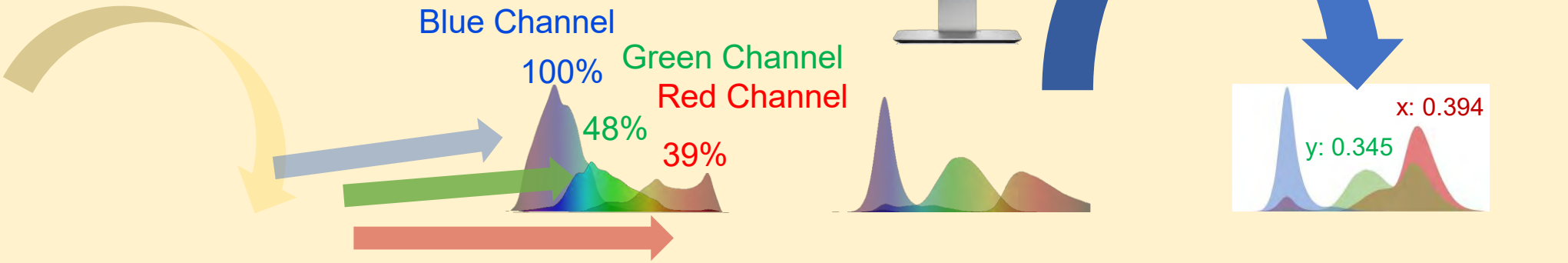
Color Pathway Summary

Lighting Color Science: Spectral Physics

Light Object Sensor Display Observer







Camera & Post Color Science: Colorimetery

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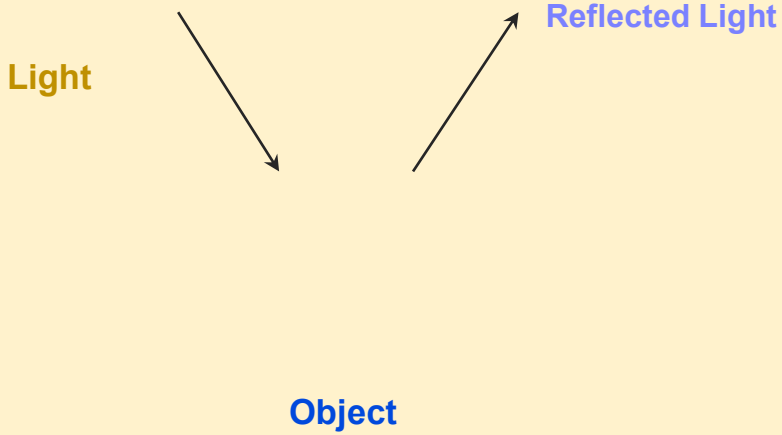
LIGHT COLOR SCIENCE:
Spectral Physics



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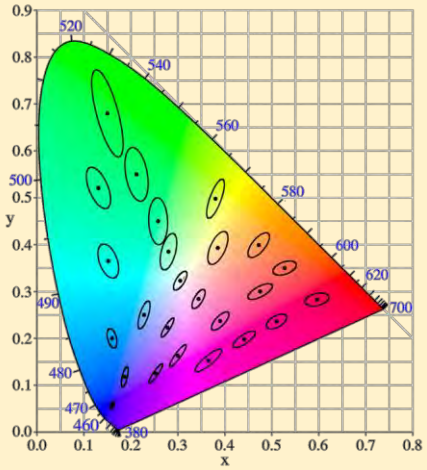
SENSOR, POST PROCESING, & DISPLAY COLOR SCIENCE:
Psychophysics & Colorimetry

R: 255
G: 200
B: 100



$$\begin{bmatrix} R_d \\ G_d \\ B_d \end{bmatrix} = \begin{bmatrix} m_{rr} & m_{rg} & m_{rb} \\ m_{gr} & m_{gg} & m_{gb} \\ m_{br} & m_{bg} & m_{bb} \end{bmatrix} \times \begin{bmatrix} R_s \\ G_s \\ B_s \end{bmatrix}$$

x = 0.1492
y = 0.1109

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Myth:

Lights that Appear Same Color Are the Same Color

?

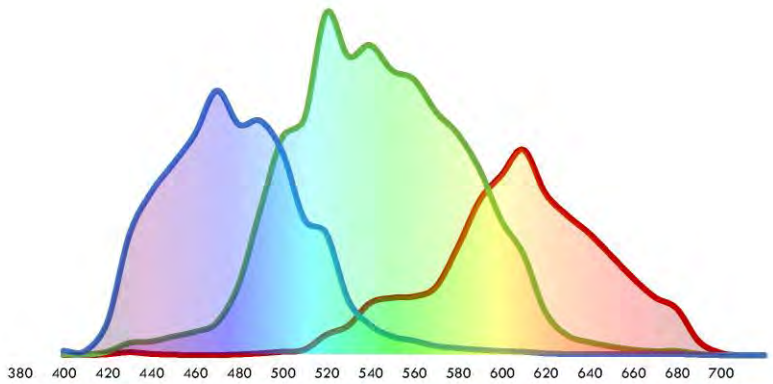

+


=

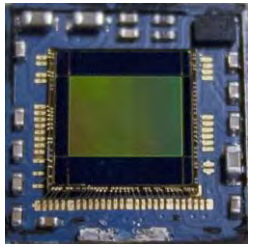
+


Spectral Fingerprints

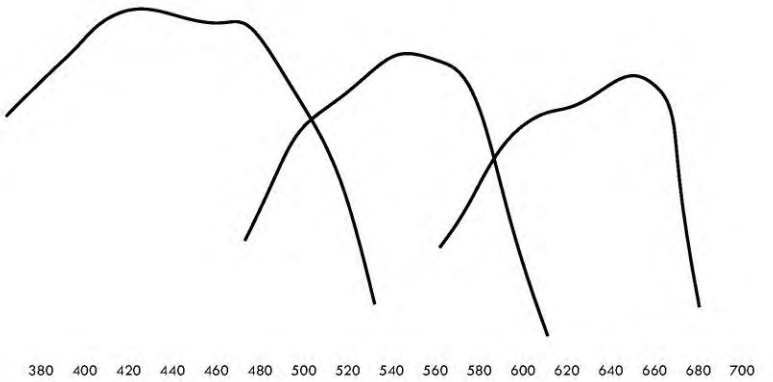
Different Sensors see spectrum differently



B G R

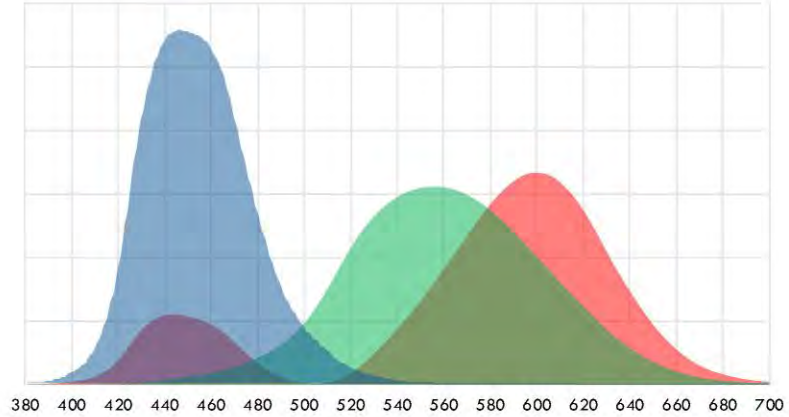


CMOS Sensor



B G R

Negative Film Stock



$\bar{z}$ $\bar{y}$ $\bar{x}$

Typical Human Eye

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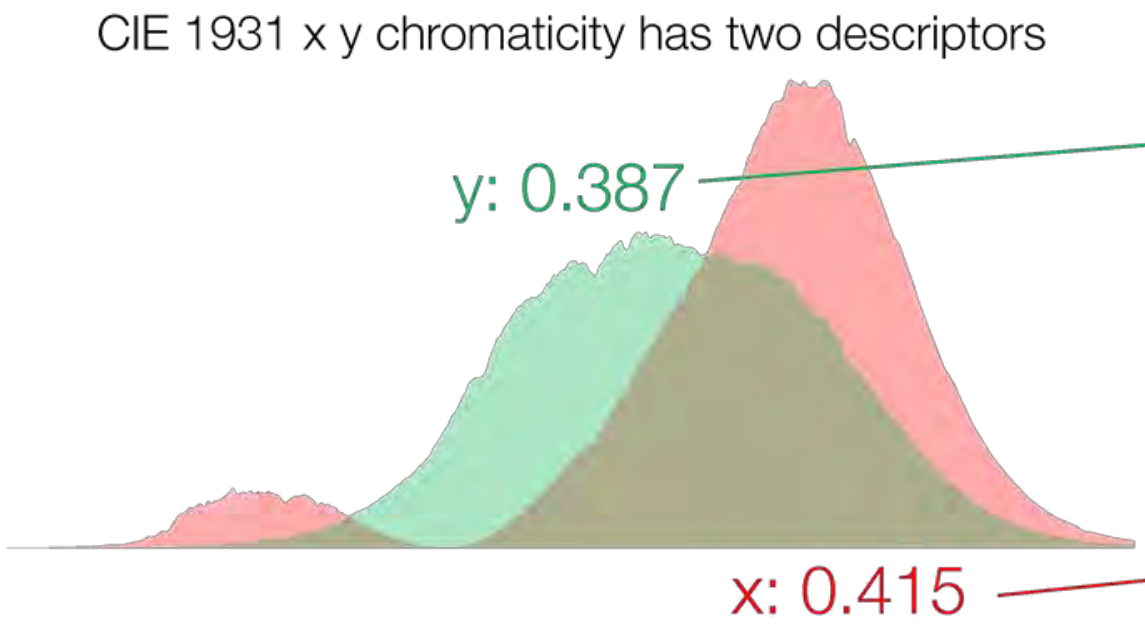
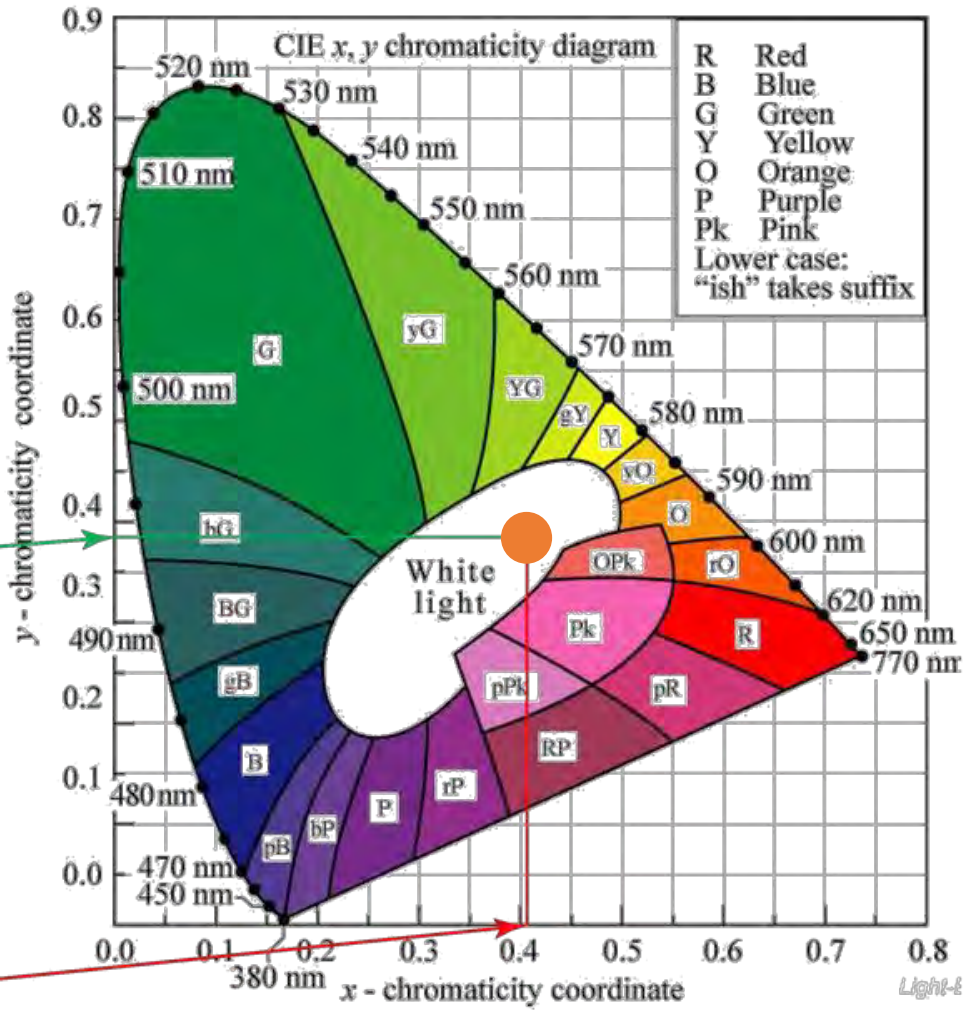
Foundation: “CIE 1931 x y Chromaticities”

A Hue and Saturation Color Map…

created from the human eye

(Commonly used for camera, post, display color calculations)





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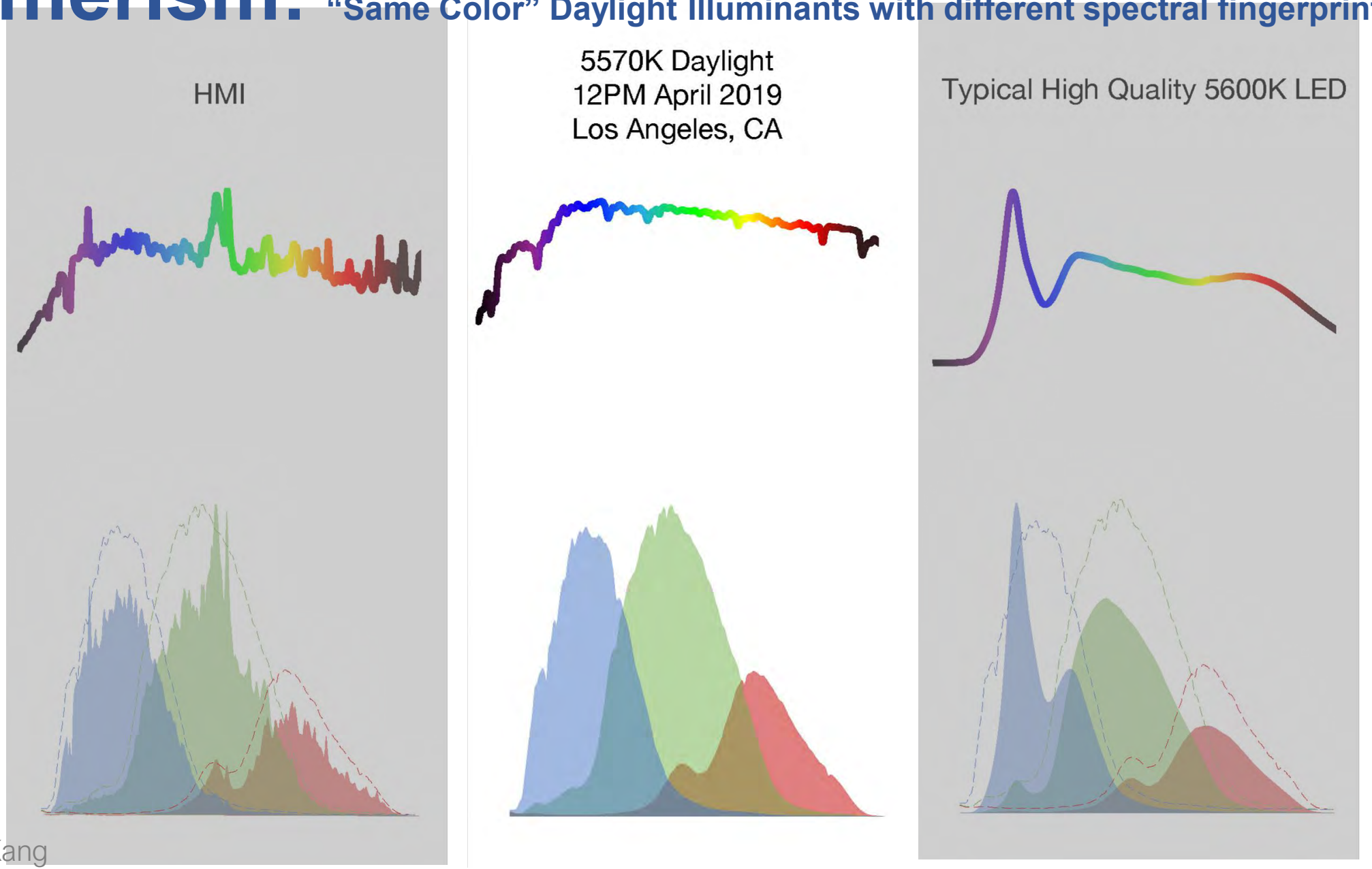
Metamerism: “Same Color” Daylight Illuminants with different spectral fingerprints

Illuminant Spectral Fingerprints

Camera RAW Spectral Fingerprints



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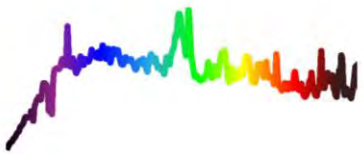
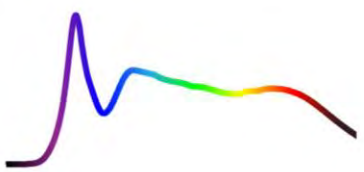
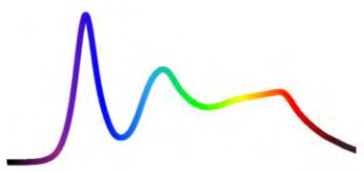
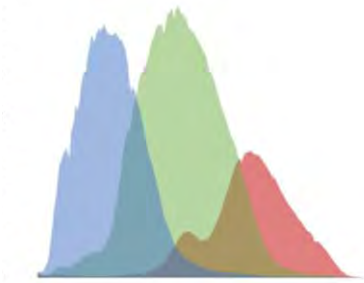
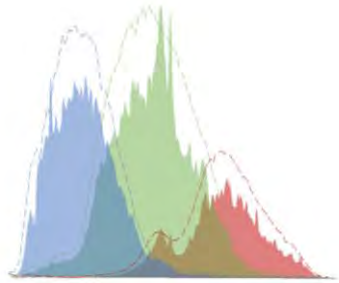
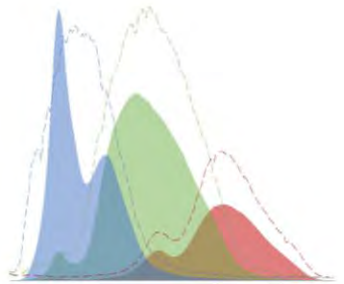
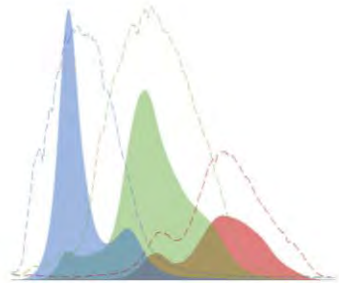
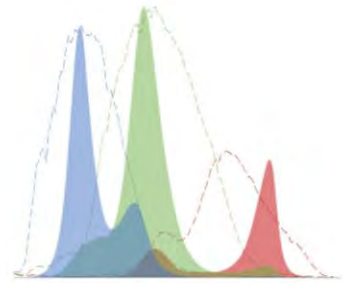
Daylight Illuminants & Captured Sensor Spectral Fingerprints

	x: 0.3302 y: 0.3391	x: 0.3302 y: 0.3391	x: 0.3302 y: 0.3391	x: 0.3302 y: 0.3391	x: 0.3302 y: 0.3391
	5570K Daylight 12PM April 2019 Los Angeles, CA	HMI	Typical High Quality 5600K LED	Typical RGBA LED @ 5600K	Typical RGB LED @ 5600K
Illuminant Spectral Fingerprints					
Camera RAW Spectral Fingerprints					

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HMI: 6000K, 0CC
PROD. HMI
ROLL
SCENE
TAKE
DIRECTOR
CAMERA T. KANG
DATE
NIGHT INT
FILTER
SYNC


Aputure 300D Mk II: 5500K
PROD. Aputure 300D
ROLL
SCENE
TAKE
DIRECTOR
CAMERA T. KANG
DATE
NIGHT INT
FILTER
SYNC


ARRI Skypanel: 5600K, 0CC
PROD. Skypanel 5600K
ROLL
SCENE
TAKE
DIRECTOR
CAMERA T. KANG
DATE
NIGHT INT
FILTER
SYNC
QUASAR
SCIENCE


Quasar Science Rainbow: 5600K 0CC
PROD. Quasar Science Rainbow
ROLL
SCENE
TAKE
DIRECTOR
CAMERA T. KANG
DATE
NIGHT INT
FILTER
SYNC

HMI

Aputure 300D Mk II

Aputure Nova: 5600K 0CC

ARRI Skypanel: 5600K 0CC

Quasar Science Rainbow: 5600K 0CC

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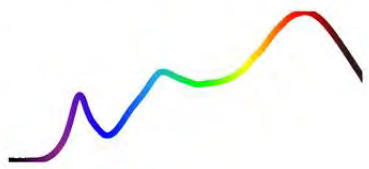
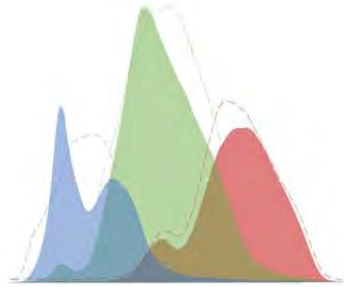
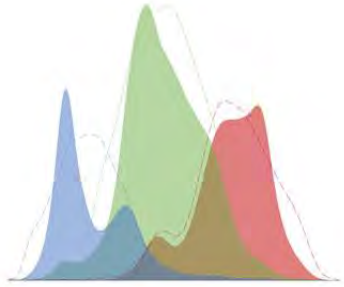
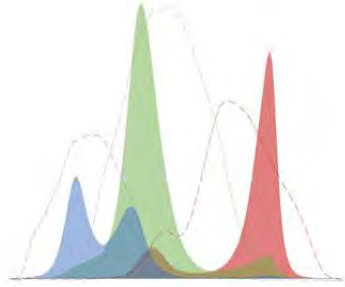
Tungsten Metamers & Captured Sensor Spectral Fingerprints

	x: 0.4234 y: 0.3990	x: 0.4234 y: 0.3990	x: 0.4234 y: 0.3990	x: 0.4234 y: 0.3990	x: 0.4234 y: 0.3990
	3000W Fresnel	Typical High Quality 3000K LED	Typical RGBWW LED @ 3000K	Typical RGBA LED @ 3000K	Typical RGBA LED @ 3000K
Illuminant Spectral Fingerprints					
Camera RAW Spectral Fingerprints					

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1K Fresnel
PROD. 1K
ROLL
SCENE
TAKE
DIRECTOR
CAMERA T. KANG
DATE
NIGHT INT
FILTER
SYNC


Aputure Nova: 3200K 0CC
PROD. Aputure Nova 3200K
ROLL
SCENE
TAKE
DIRECTOR
CAMERA T. KANG
DATE
NIGHT INT
FILTER
SYNC


ARRI Skypanel: 3200K 0CC
PROD. Skypanel 3200K
ROLL
SCENE
TAKE
DIRECTOR
CAMERA T. KANG
DATE
NIGHT INT
FILTER
SYNC
QUASAR SCIENCE


Quasar Science Rainbow: 3200K 0CC
PROD. Quasar Science 3200K
ROLL
SCENE
TAKE
DIRECTOR
CAMERA T. KANG
DATE
NIGHT INT
FILTER
SYNC

Tungsten

Aputure Nova: 3200K 0CC

ARRI Skypanel: 3200K 0CC

Quasar Science Rainbow: 3200K 0CC

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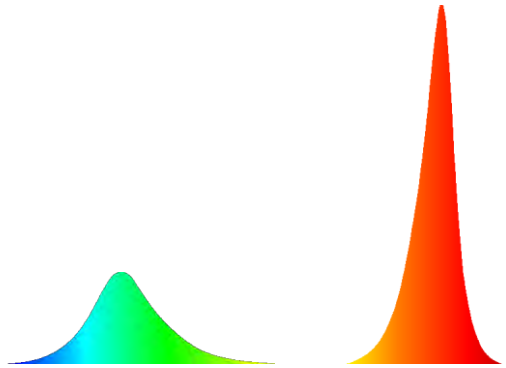
Tungsten + 101 Yellow Gel

RGBA LED @ 3200K + 101 Yellow Gel

RGB LED simulating “101 Yellow”



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HMI + 101 Yellow


Aputure 300D MK II + 101 Yellow


ARRI Skypanel: 5600K + 101 Yellow
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Quasar Science Rainbow: 5600K + 101 Yellow


Tungsten + 101 Yellow


Aputure Nova: 3200K + 101 Yellow


ARRI Skypanel: 3200K + 101 Yellow
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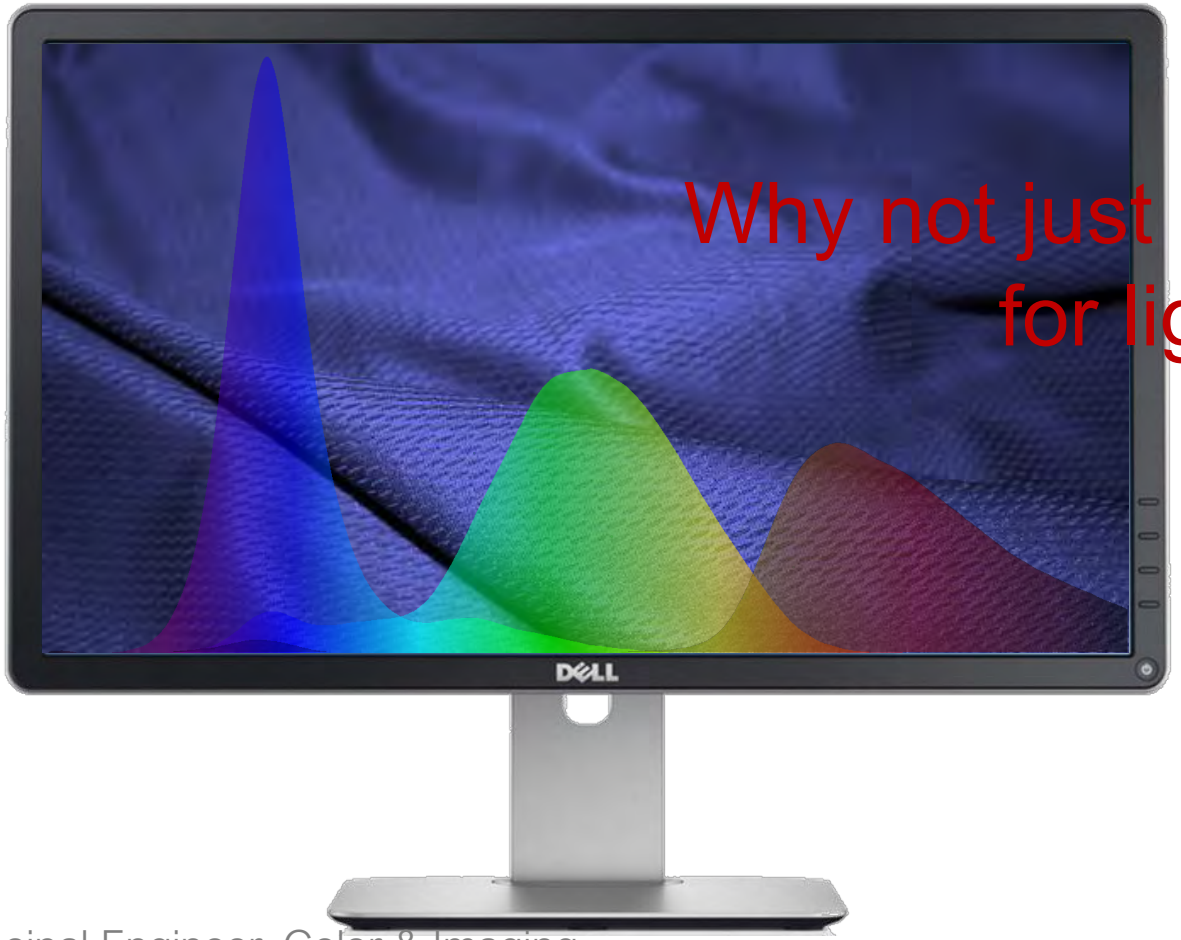
Quasar Science Rainbow: 3200K + 101 Yellow

Spectral Fingerprints

R, G, B Display Colors Generate a “full” palette of **Perceived** Color Light



Why not just use RGB alone for lighting?

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1kW Tungsten Fresnel: 3200K

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All RGB LED diodes only: 3200K

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Tungsten + 101 Yellow

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ARRI Skypanel: x, y color match Tungsten + 101 Yellow

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Tungsten + 101 Yellow

ARRI Skypanel: 3200K + 101 Yellow

ARRI Skypanel RGB x, y match: Tungsten + 101 Yellow

QUASAR SCIENCE


Tungsten + 101 Yellow
PROD. 1K + 101
ROLL
SCENE
TAKE
DIRECTOR
CAMERA T. KANG
DATE
NIGHT INT
FILTER
SYNC


Aputure Nova RGB x, y match: Tungsten + 101 Yellow
ROLL
SCENE
TAKE
DIRECTOR
CAMERA T. KANG
DATE
NIGHT INT
FILTER
SYNC


ARRI Skypanel RGB x, y match: Tungsten + 101 Yellow
ROLL
SCENE
TAKE
DIRECTOR
CAMERA T. KANG
DATE
NIGHT INT
FILTER
SYNC
QUASAR
SCIENCE


Quasar Science Rainbow RGB x, y match: Tungsten + 101 Yellow
ROLL
SCENE
TAKE
DIRECTOR
CAMERA T. KANG
DATE
NIGHT INT
FILTER
SYNC

Not only colored light may appear wrong on camera…

Object colors may appear wrong on camera

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Tungsten
QUASAR
SCIENCE


Typical RGB
“White”:
3200K 0CC
QUASAR
SCIENCE

Tungsten

Typical RGB “White”: 3200K 0CC

QUASAR SCIENCE

1kW Tungsten Fresnel

Typical RGB LED “White”: 3200K

QUASAR SCIENCE

Tungsten + 101 Yellow

Typical RGB color match Tungsten + 101 Yellow

QUASAR SCIENCE

Tungsten + 101 Yellow

Typical RGB color match: Tungsten + 101 Yellow

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What about “fixing it in post” with Color Grading?

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Tim S. Kang
Cinematographer // Principal Engineer, Color & Imaging

Tungsten + 101 Yellow

How would one fix mixed colored lighting?

Key Light: 1K Fresnel

Side Kicker: Typical RGB LED color match: Tungsten + 767 Oklahoma Yellow

Primary Color Grade

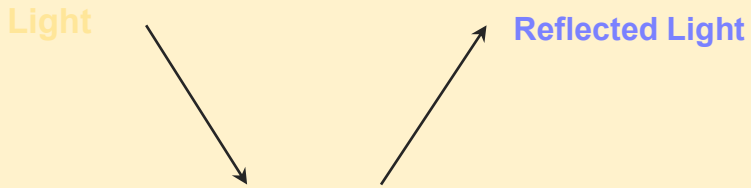
QUASAR SCIENCE

Conclusions

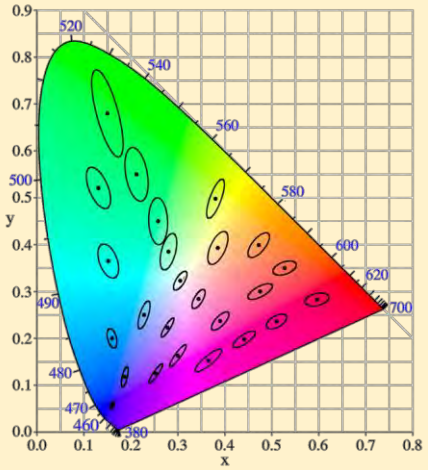
LIGHT COLOR SCIENCE: Spectral Physics

≠

SENSOR, POST PROCESING, & DISPLAY COLOR SCIENCE: Colorimetry



R: 255
G: 200
B: 100



$$\begin{bmatrix} R_d \\ G_d \\ B_d \end{bmatrix} = \begin{bmatrix} m_{rr} & m_{rg} & m_{rb} \\ m_{gr} & m_{gg} & m_{gb} \\ m_{br} & m_{bg} & m_{bb} \end{bmatrix} \times \begin{bmatrix} R_s \\ G_s \\ B_s \end{bmatrix}$$

x = 0.4234
y = 0.3990

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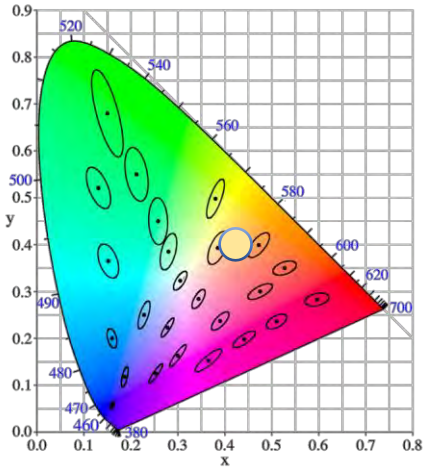
Cinematographer // Principal Engineer, Color & Imaging

Light Spectral Fingerprints
("RAW" light adjustable in post)

>

Light Chromaticity & "gamut"
(burnt into post)



x = 0.4234
y = 0.3990

3200K 0CC Light

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Cinematographer // Principal Engineer, Color & Imaging

Learn the **Strengths** & Limitations of Color Mixing Lights

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Cinematographer // Principal Engineer, Color & Imaging

Art, Hair, Makeup, & Wardrobe

Work and design decisions should be made in similar lights to set lights

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Cinematographer // Principal Engineer, Color & Imaging

Saturated Color Filters (gels)
&
“Full” Spectrum Light
(White LEDs, incandescent, daylight, HMI, plasma, etc)

still produce the best data for color rendition

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Cinematographer // Principal Engineer, Color & Imaging

Color Mixing Production Lights (RGB, etc) are still useful for the same obvious reasons

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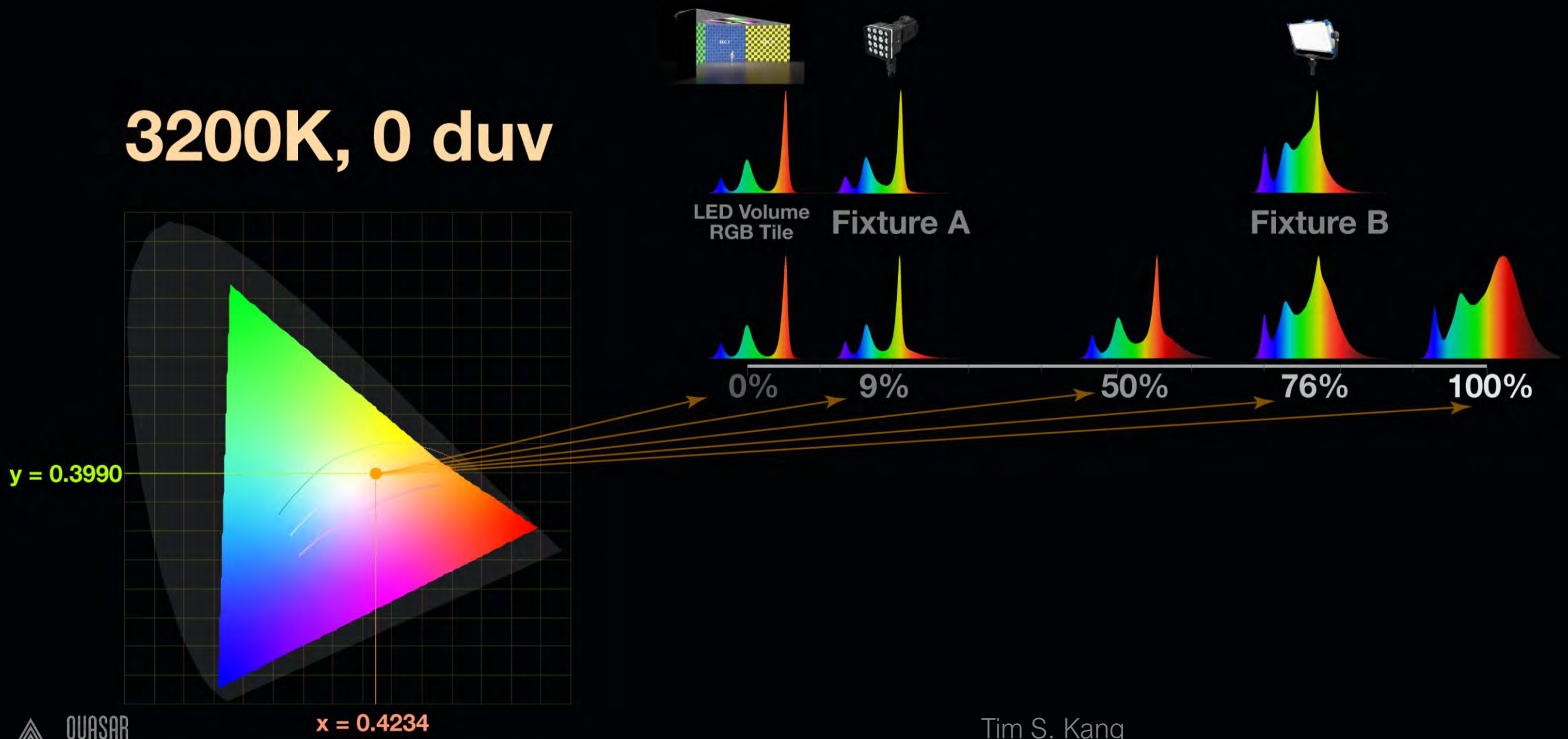
Cinematographer // Principal Engineer, Color & Imaging

Inevitable Reality: Spectrum blending & matching



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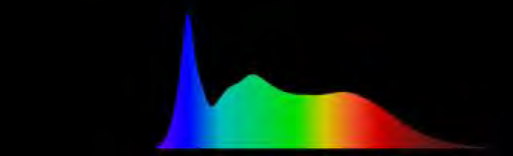
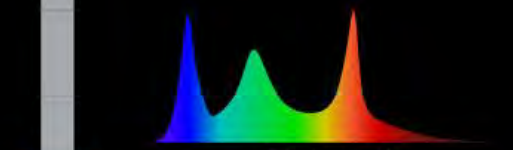
xy Spectrum Control



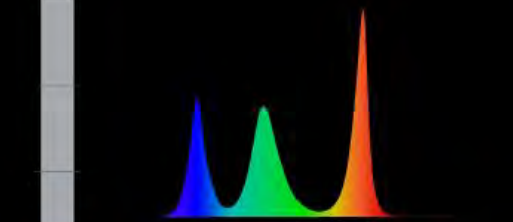
100%

SSI[CIE D5600] 74



50%

SSI[CIE D5600] 56



0%

SSI[CIE D5600] 20

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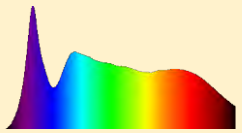
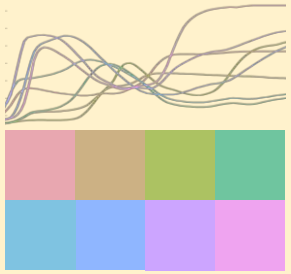
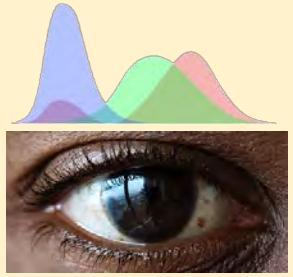
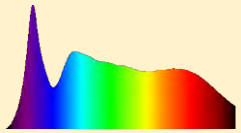
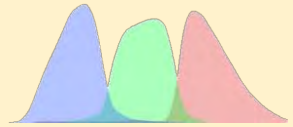
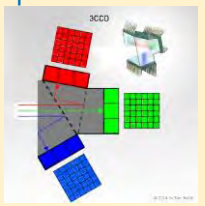
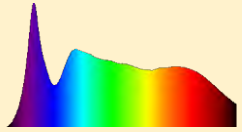
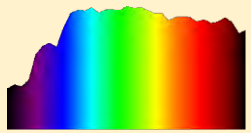
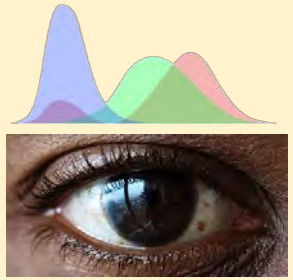
What about Color Metrics?

Tim S. Kang
Cinematographer // Principal Engineer, Color & Imaging

Tim Kang

Metric Methodologies

	Light	Standard	Objects	Sensor	"Post"	Score
CRI	LED CIE D 5600 5600K 	CIE D 5600 5600K Daylight Standard 			CIE 1964 	Ra 96
TLCI				 3 Chip Broadcast Sensor  Credit: tomkeller.ch	CIEΔE2000 	Qa 97
TM-30-18					CAM02-UCS 	Rf 96

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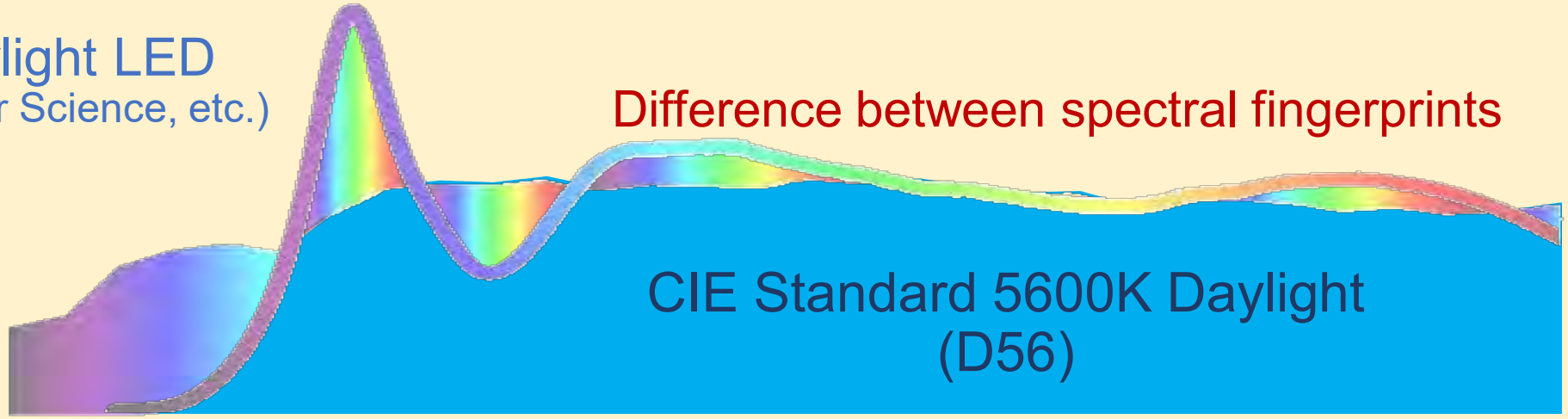
Cinematographer // Principal Engineer, Color & Imaging

Spectral Similarity Index (SSI)

High end daylight LED
(Aputure, Quasar Science, etc.)



Squared Sum

Reference within brackets

SSI[CIE D5600]: 78

Differences

Object spectral fingerprints reflecting near-UV, violet, & blue wavelengths will not match daylight

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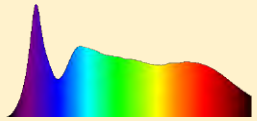
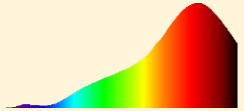
Cinematographer // Principal Engineer, Color & Imaging

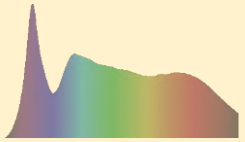
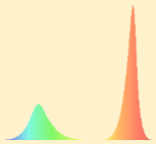
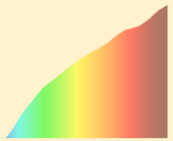
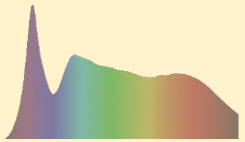
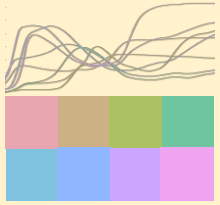
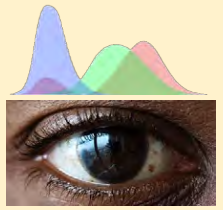
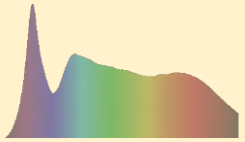
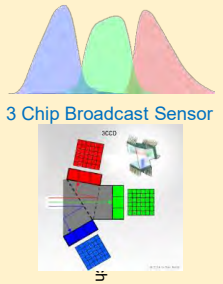
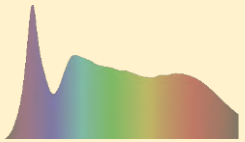
Qua
Scien
sar
Tim Kang

Spectral Similarity Index (SSI) Typical Results

	Light		Scores	Differences
	Daylight LED	SSI[CIE D5600]	71-78	
	2000K LED	SSI[P2000]	92	
	3200K LED	SSI[P2700] SSI[P3200]	83-86	
	RGBA LED	SSI[CIE D5600]	60-68	
		SSI[P2700] SSI[P3200]	73	

QUASAR SCIENCE

Metric Methodologies

	Light	Standard	Objects	Sensor	"Post"	Score
SSI[CIE D5600]					SSI Math 	74
SSI[3200K+101 Yellow] Can be used for colored light						40
CRI					CIE 1964 	Ra 96
TLCI					CIEDE2000 	Qa 97
White light only						
TM-30-18					CAM02-UCS 	Rf 96

LED Panel Image-Based Lighting in Visual Effects

"GRAVITY" LIGHT BOX
(2011)

ROGUE ONE: A STAR WARS STORY
(2016)

"USING THAT IMAGE-BASED LIGHTING TECHNIQUE TO LIGHT ACTORS AND SETS WAS REALLY SUCCESSFUL." - JOHN KNOLL, ILM

USC ETC LED Stage Lighting Reproduction Test

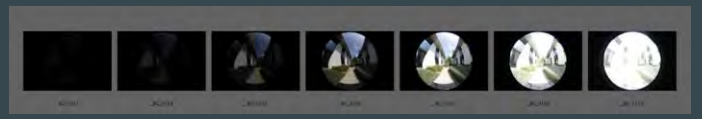
preliminary findings

Paul Debevec, Timothy Kang, Horst Sarubin, Erik Winquist, Erik Weaver, Greg Ciaccio, Eric Rigney, Michael Smith, Kathryn Brillhart, Thomas Mansencal, ErinRose Blair

May-June 2021

Lighting Reproduction Test Design

1) Photograph actors and lighting reference (mirror/diffuse spheres & chart) in a few real environments
2) Record the lighting with a high-res HDRI map
3) Display the HDRI Maps on a Virtual Production Stage
4) Compare how the actors look in the VP stage compared to how they looked in the real environments – hopefully the same!



Shooting the Lighting Environments @ Ryot, Playa Vista, CA

May 17, 2021

Many thanks: James Kelly, Ryot


INT Front


INT Side


EXT Shade


EXT Sun

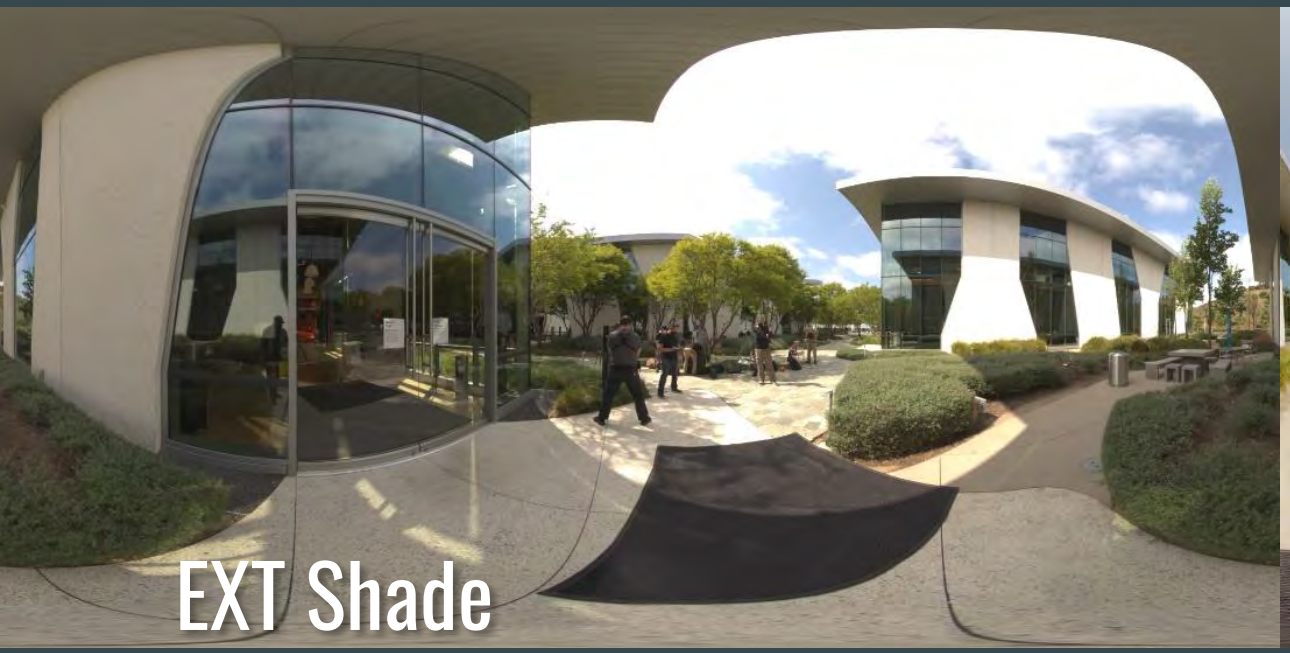
Capturing HDRI Maps at Each Location

Interior - Front Light - HDRI Series

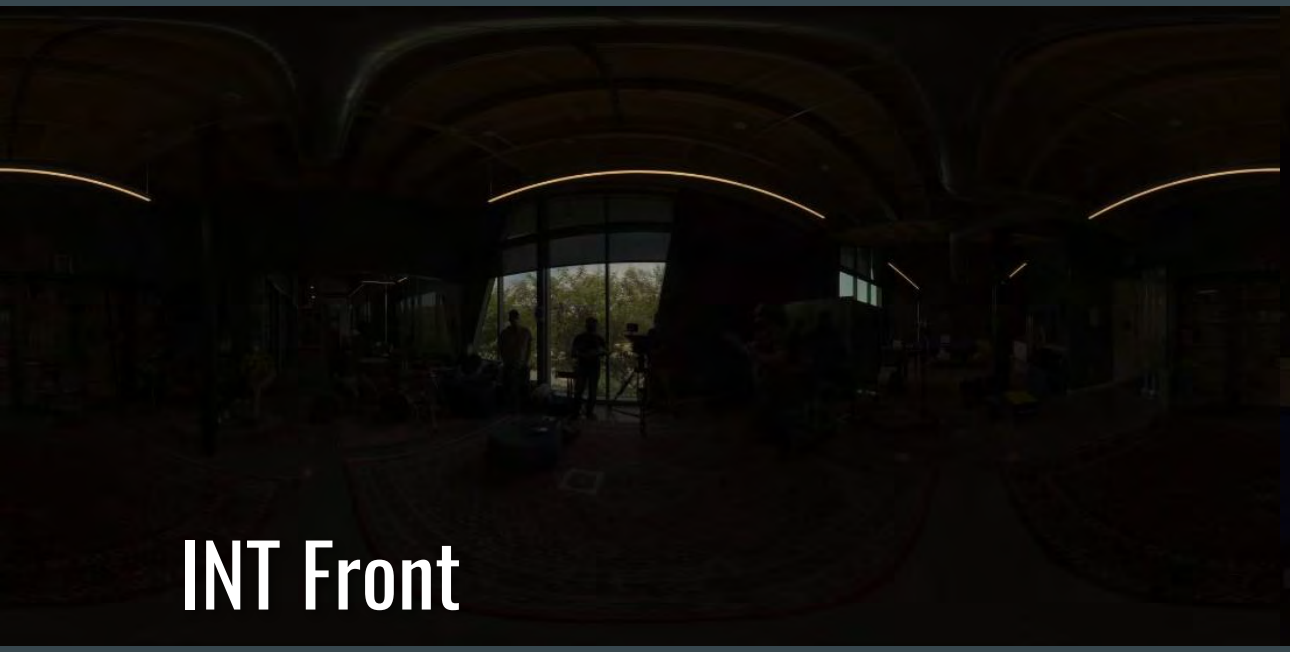
Canon 5D Mk IV, Canon 8mm-15mm fisheye @ 8mm
Exposures 1/8000, 1/2000, 1/500, 1/125, 1/30, 1/8, ½ sec
Interiors: ISO 400 f/11 Exteriors: ISO 100 f/16

See *The Definitive Weta Digital Guide to IBL* in fxguide

+0 stops

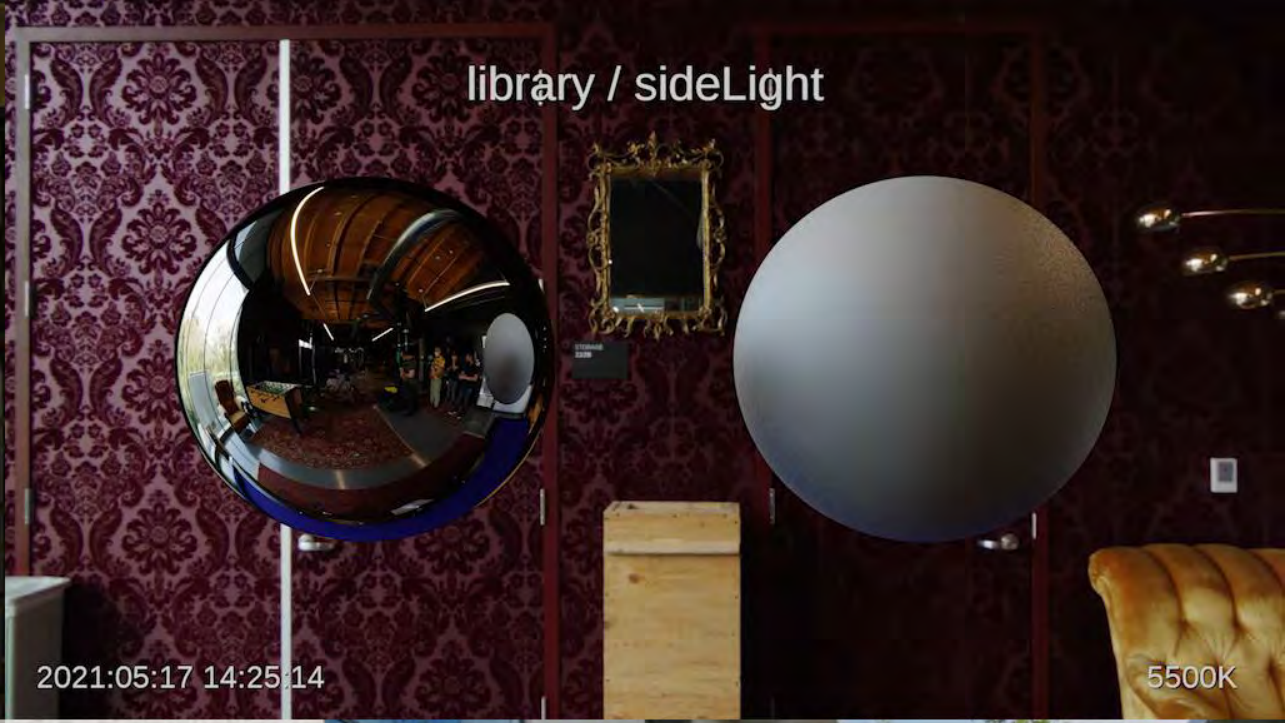


-5 stops



-9 stops


library / frontLight
2021:05:17 14:00:42
5500K


library / sideLight
2021:05:17 14:25:14
5500K

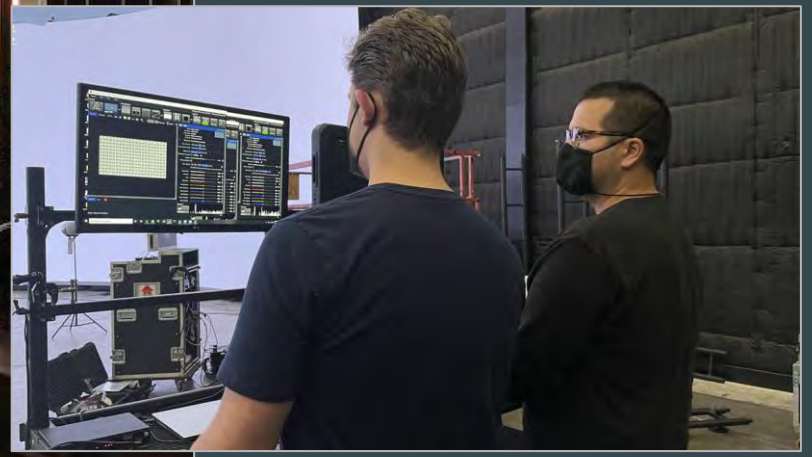

exterior / shade
2021:05:17 15:41:49
5500K


exterior / fullSun
2021:05:17 15:04:36
5500K

Line 204 XR Smart Stage, Pacoima, CA

Wall panels:
ROE Black Pearl 2
2.84mm pixel pitch
~1350 nits

Ceiling panels:
Planar
5mm pixel pitch
~5000 nits



Many thanks to **Isaac Campos** (owner), **Jay Spriggs** (VP tech), and **Chris Swiatek** (Playback)

Tricky Thing 1: Get the panels to display LINEAR values

- The HDRI Maps are carefully assembled so that the pixel values in the OpenEXR images are proportional to the number of photons striking the sensor
- We need the LED panels to emit photons in a way that's proportional to the pixel value numbers in the EXR files
- This isn't the default behavior - there are lots of places in the processing pipeline which may add contrast and color saturation to make the image more exciting to look at

Tricky Thing 2: Projection Geometry

Set dressing now requires understanding Windows 10 display drivers

Let's Shoot!

INT Front

Real

INT Front

Real

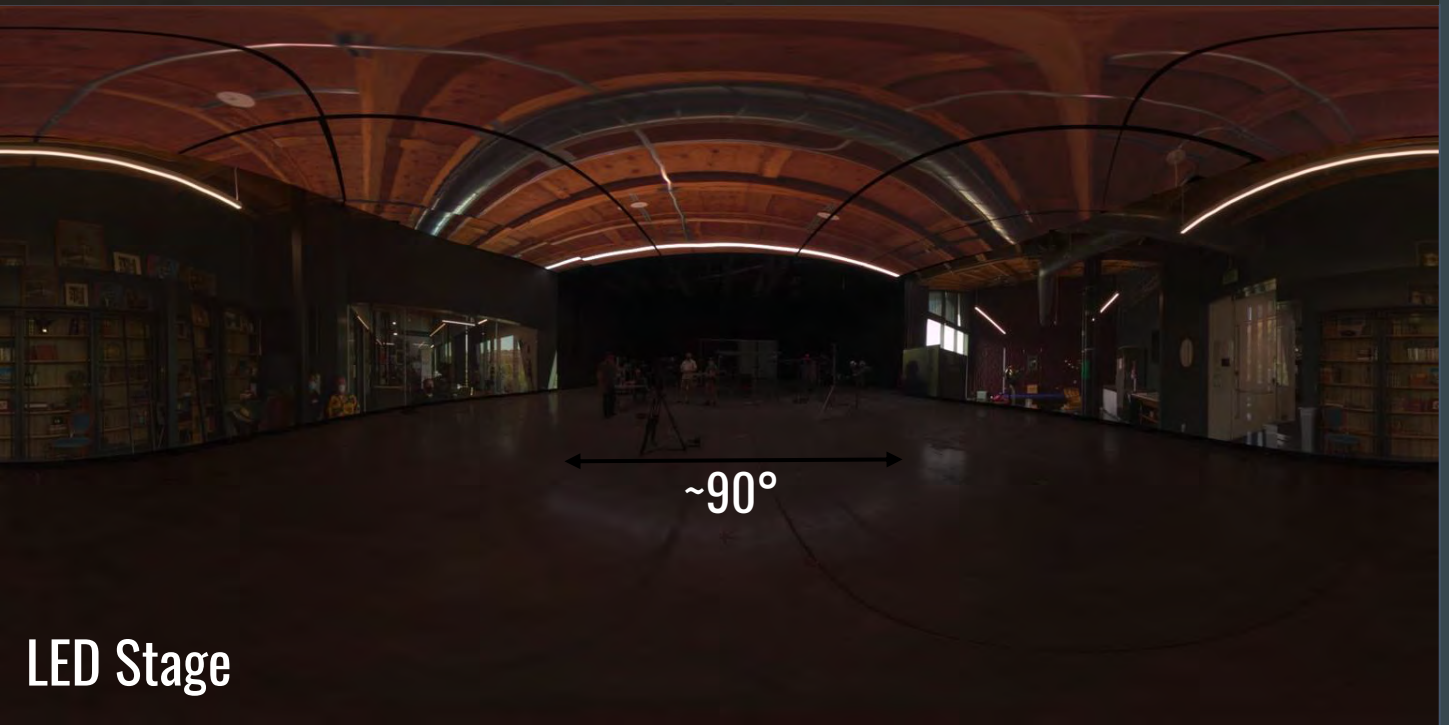
LED Stage

Subjects appear too dark relative to the background (Both white squares of the ColorCheckers are scaled to white)

INT Front HDRI Maps

(from the actor's perspective)

Real



LED Stage

But missing the light from the front window!

Open area of the stage is about a 90° section

Let’s Turn Things Around

- Faced actors *into* the stage to receive LED panel lighting from the front
- Actors see the environment better
- Added greenscreen so backgrounds could be composited later

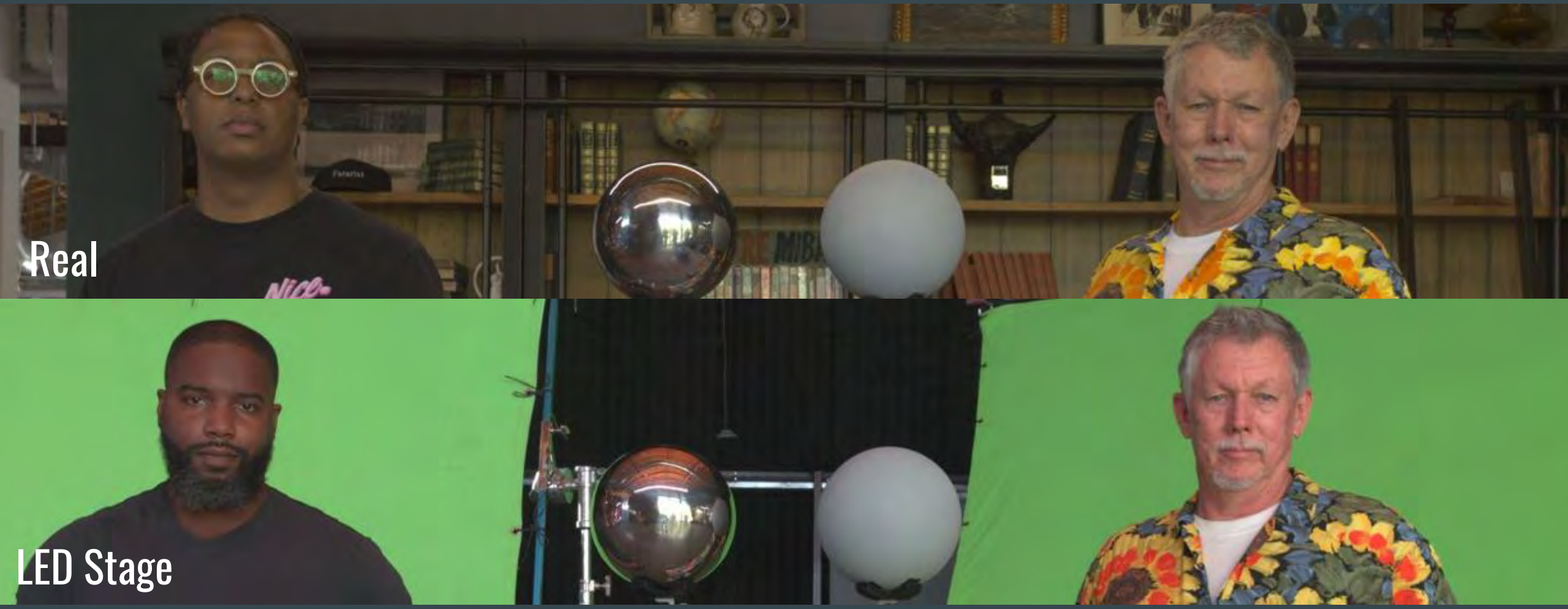
INT Front, Reversed

Real

LED Stage

Much better!

INT Front, Reversed



Looking good! Though there's a bit too much key/fill ratio, and shirt and skin colors are off
The mirror ball shows the ceiling wood looking too bright

INT Side, Reverse

Real

LED Stage

Pretty good! Key to fill ratio seems a little weak. Skin tones and colorful shirt colors seem off though.

INT Side, Reverse

Pretty good, key to fill ratio seems a little weak. Skin tones and colorful shirt colors seem off though.

INT Side HDRI Maps

Missing the floor

Directions match

Colors aren’t way off

Windows seem to match?

INT Side HDRI Maps -3 stops

The window is way too dark

And it’s neutral, instead of sky blue

The track lighting was clipped a lot, too!

INT Side HDRI Maps -4 stops

So let's put an underexposed version of, with almost no clipping

This actually required -4 stops to include the track lighting

Thing seem to match better!

INT Side, Reverse, -4 stops

Real

LED Stage

Key to fill ratio is closer, but missing some light from the right, and the colors are still off.

INT Side, Reverse, -4 stops

Key to fill ratio seems close, but skin tones and colorful clothing are still off.

EXT Shade

Real

EXT Shade

Real

LED Stage

A pretty close match! The lighting was diffuse enough that Exp 1 didn't have much clipping. But colors are still noticeably off. (Orange in the shirt, and skin.)

EXT Shade

A pretty close match! The lighting was diffuse enough that Exp 1 didn't have much clipping. But colors are still noticeably off. (Orange in the shirt, and skin.)

EXT Sun

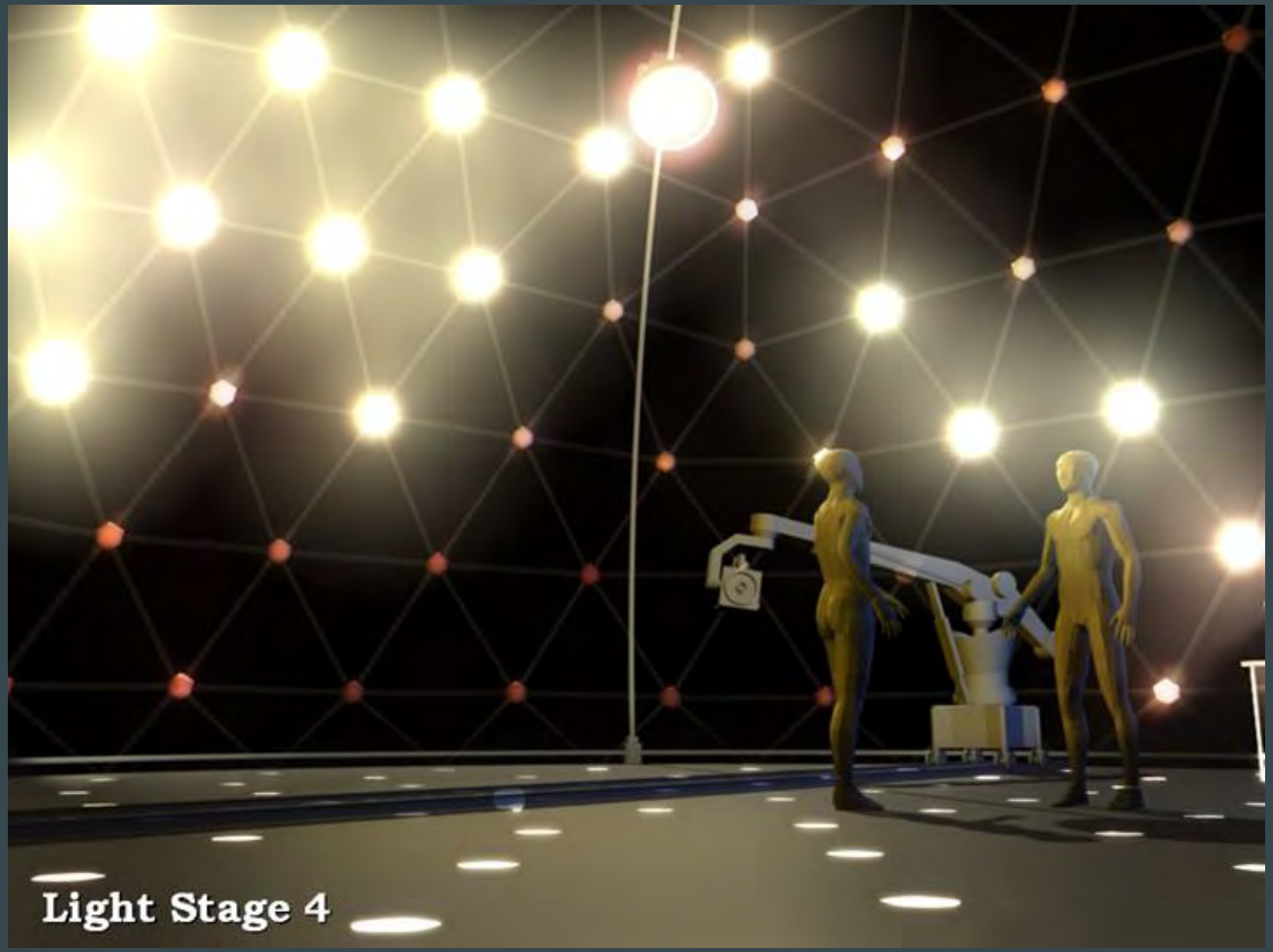
Real

LED Stage

Our sunny condition looks shady: no shadows, muted highlights, low key/fill ratio

SIGGRAPH 2002

Special-case “sun” light source on a moving gantry



Let’s bring in a special light for the sun!

Tim Kang brought in a high-quality, broad-spectrum light source to play the role of the sun, and set a measured key/fill ratio to match the original lighting condition

EXT Sun, LED Panels + Key Light

Real

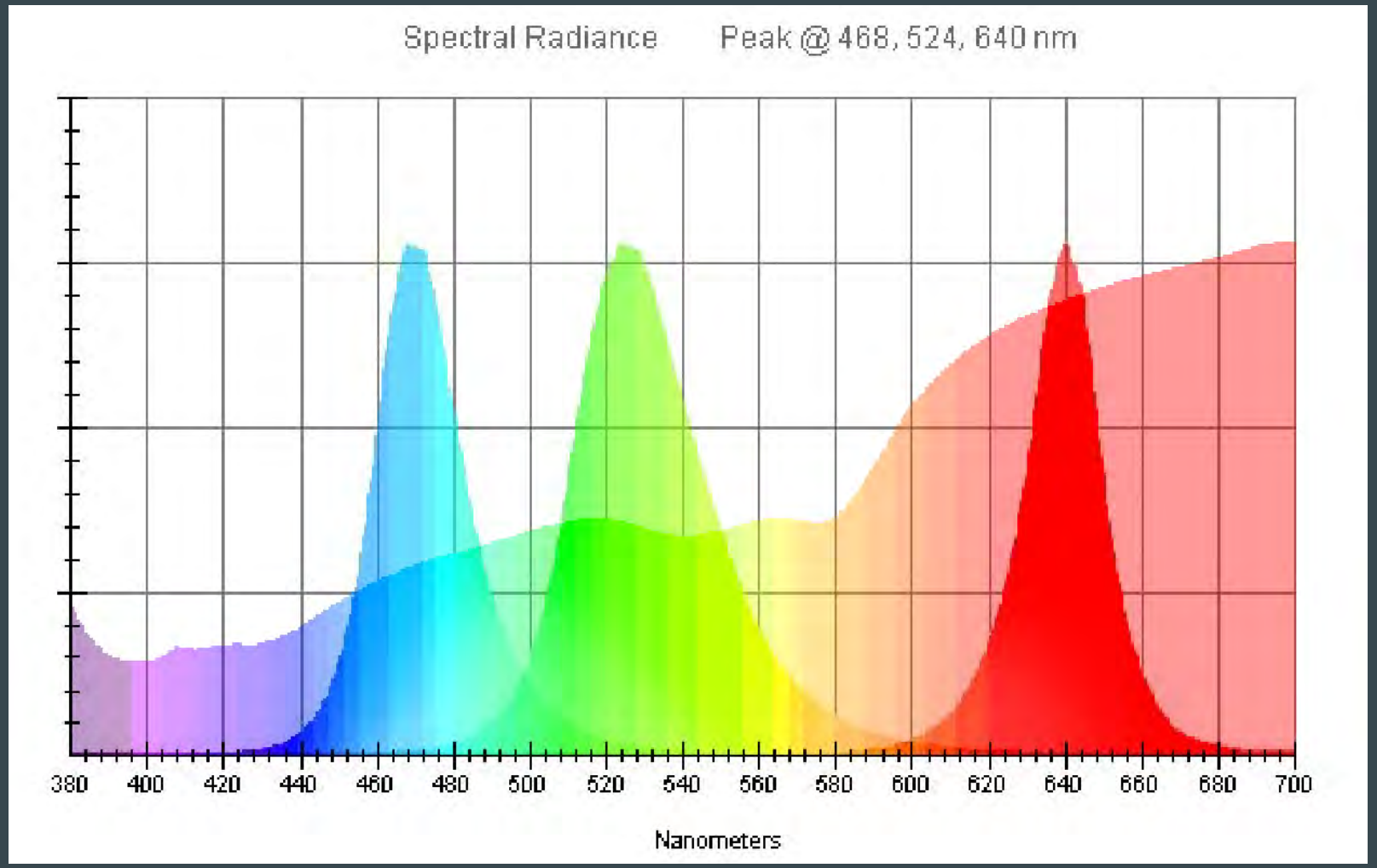
LED Stage

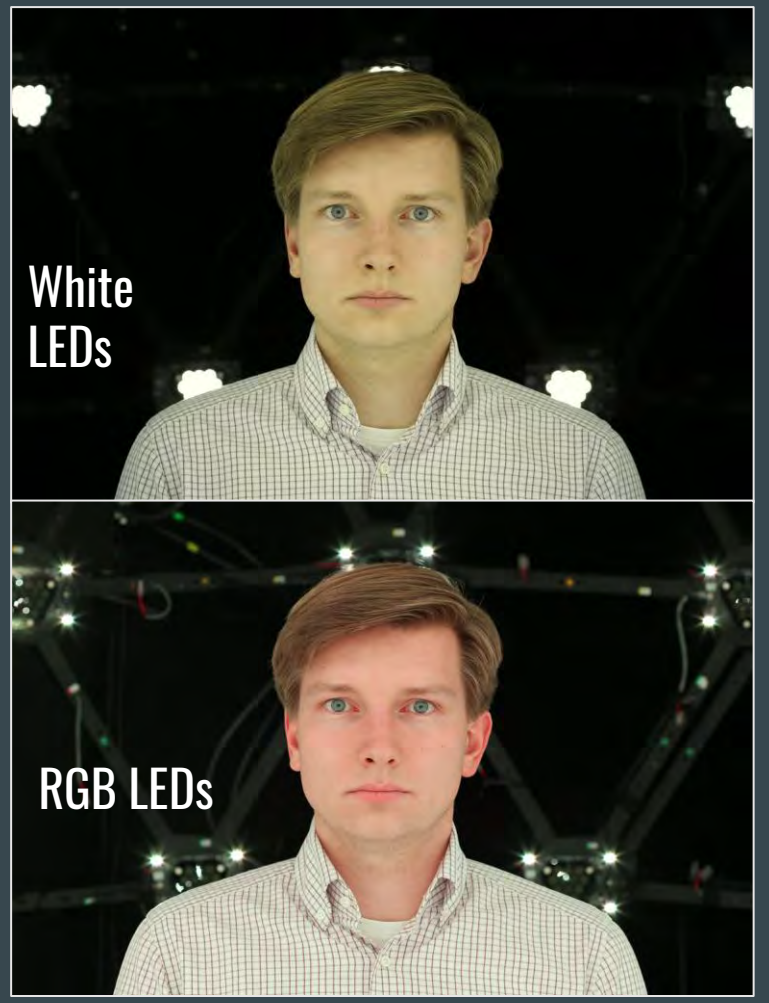
A satisfying match!

EXT Sun, LED Panels + Key Light

A pretty good match, and the skin tone and color balance is much better too!
Likely the result of the broad-spectrum light for the sun

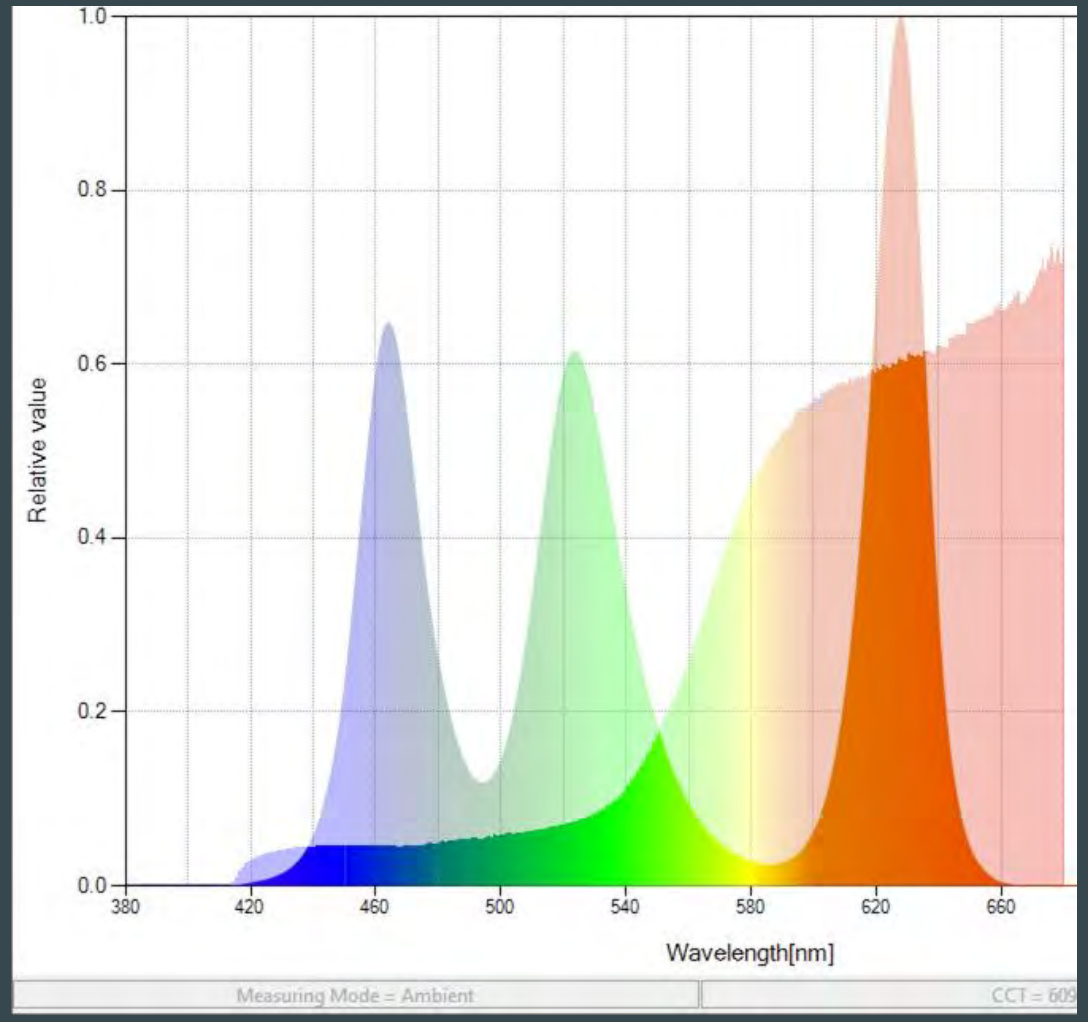
RGB LIGHTING AND SKIN SPECTRA

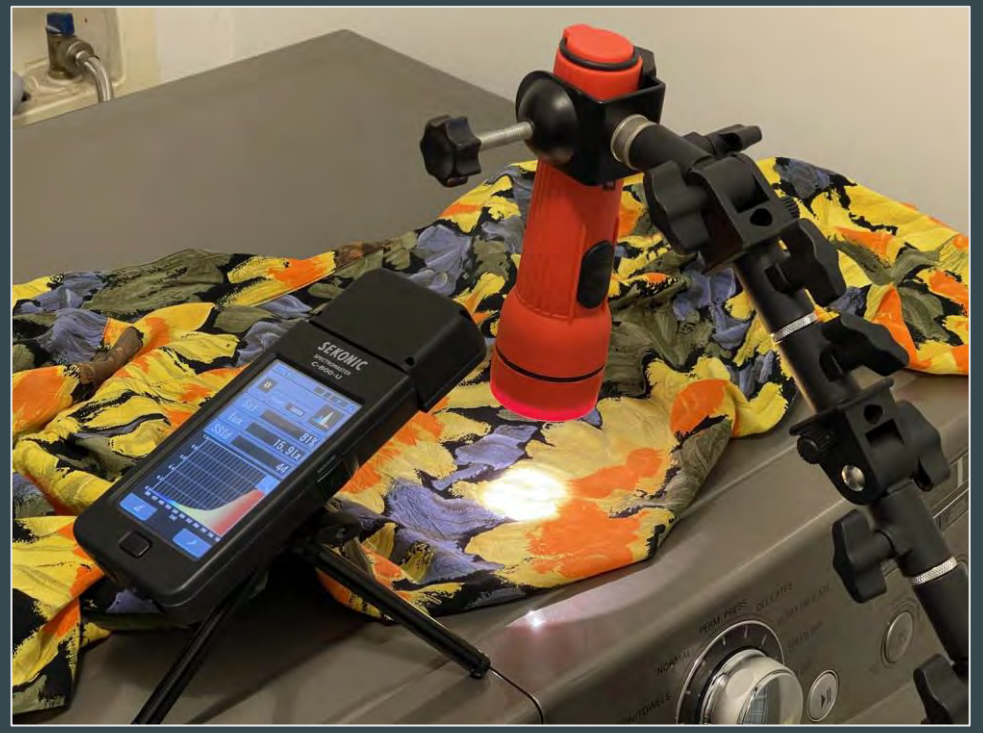




RGB LED Panels with a wider color gamut produce worse color rendition!

THE ORANGE SHIRT PATCH



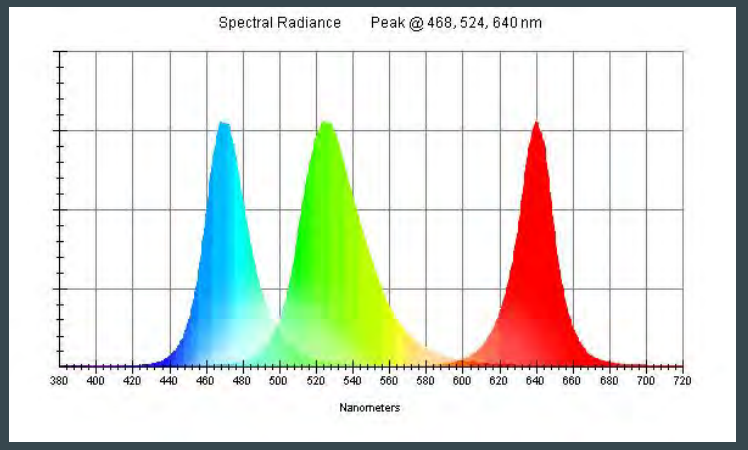


Laundry room reflectometry with a Sekonic C-800 Spectral Light Meter

SIGGRAPH 2002 SUGGESTION

COLOR KINETICS iColor MR
DMX LIGHT

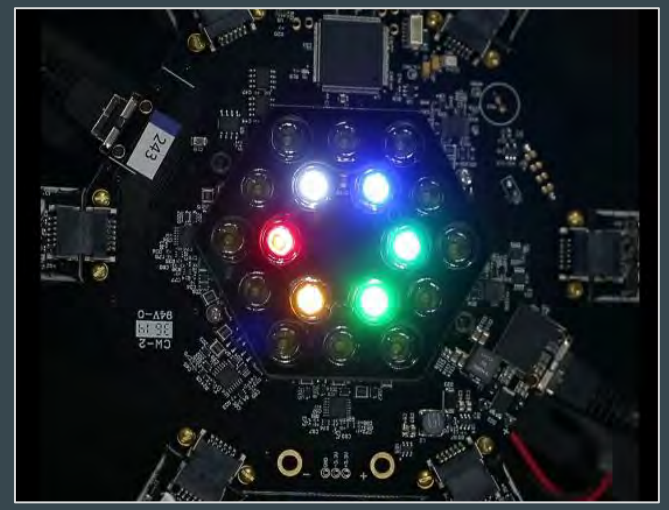
LIGHT STAGE 3
SIGGRAPH 2002

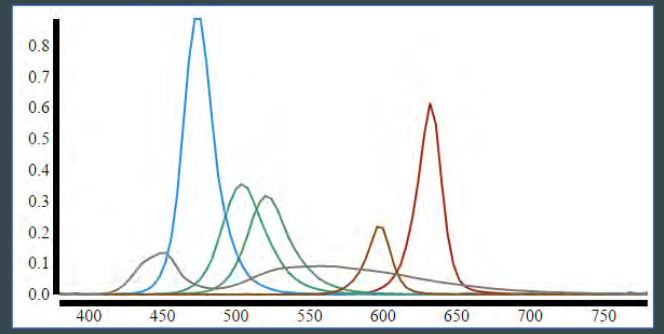


EMISSION SPECTRUM OF
RGB LED LIGHTING

"For illumination and surfaces with complex spectra ... the material's reflection of reproduced illumination in the light stage could be noticeably different that its actual appearance under the original lighting. This problem could be addressed through multispectral imaging of the incident illumination, and by illuminating the actor with additional colors of LEDs. **Adding yellow and turquoise LEDs** as a beginning would serve to round out our illumination's color gamut."

Multispectral Lighting Reproduction

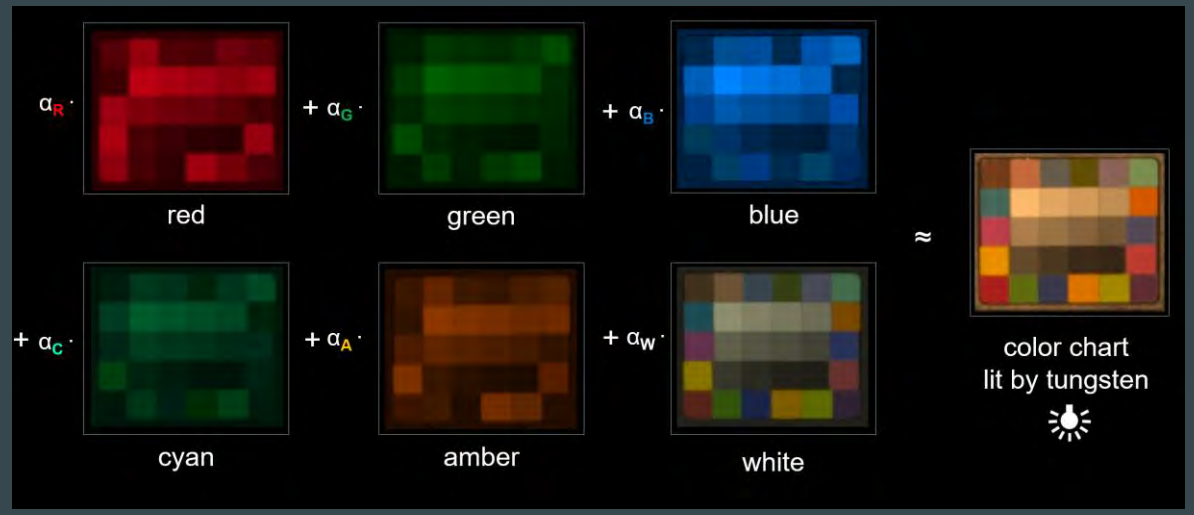




6 LED spectra

Practical Multispectral Lighting Reproduction
Chloe LeGendre, Xueming Yu, Dai Liu, Jay Busch, Andrew Jones, Sumanta Pattanaik, and Paul Debevec. **SIGGRAPH 2016**

Multispectral Light Probe
(Just add a Color Chart!)



Multispectral Lighting Calibration
(Just photograph the chart under each LED!)

Practical Multispectral Lighting Reproduction

Chloe LeGendre, Xueming Yu, Dai Liu, Jay Busch, Andrew Jones, Sumanta Pattanaik, and Paul Debevec.

SIGGRAPH 2016

subjects lit by real environment

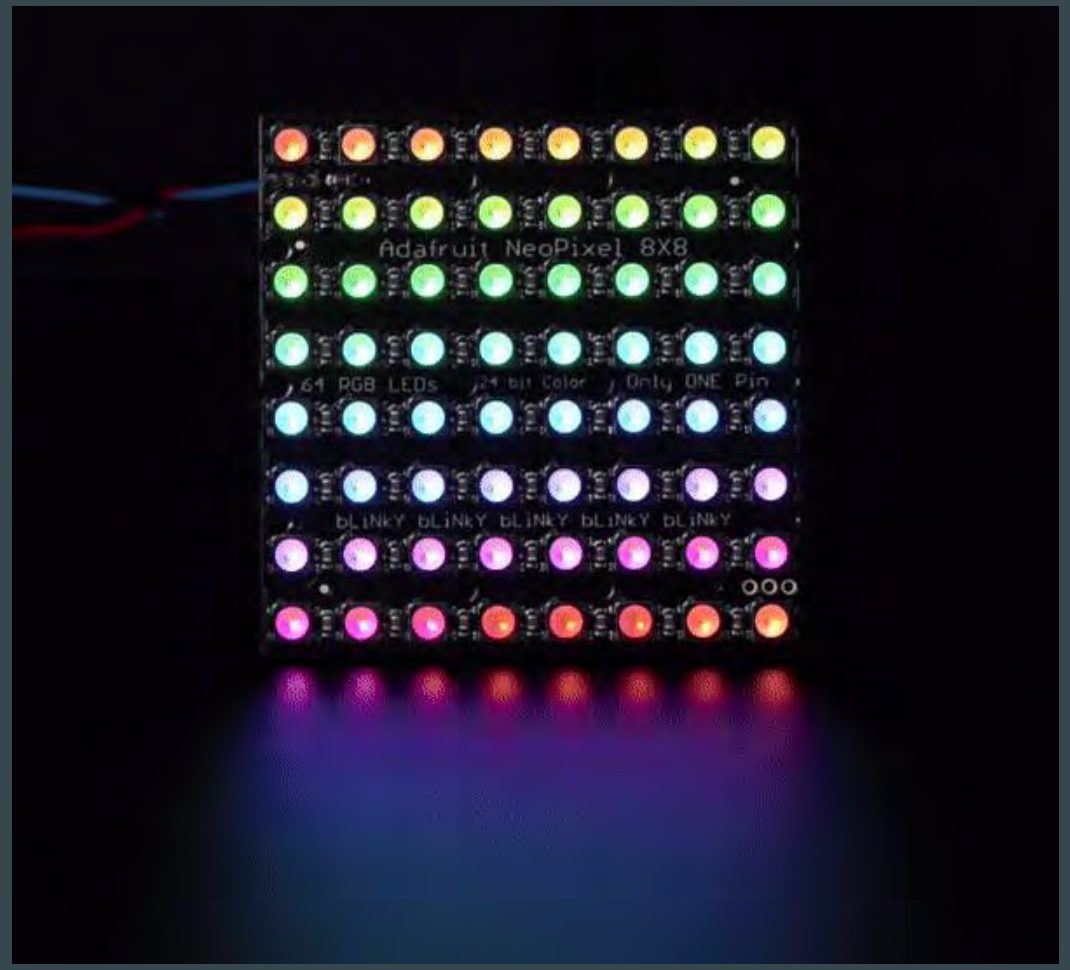
lighting capture

subjects lit by multispectral LED sphere

SOOVII 8m Light Stage by USC ICT (2017)

Used in a variety of feature films and TV series

Multispectral LED Panels: Existence Proof



Adafruit NeoPixel NeoMatrix - 8x8 RGBW LED Packages

In Conclusion

- Today's virtual production LED stages *don't* get the lighting right
  - Not enough angular coverage
  - Not enough dynamic range
  - Poor color rendition
- LED Panels were designed to be great displays, not light sources
- There's a lot of research to draw upon to achieve accurate lighting
- We have the opportunity to have actors be lit appropriately for the environments they are being composited into

Collaborators: Timothy Kang, Horst Sarubin, Erik Winquist, Erik Weaver, Greg Ciaccio, Eric Rigney, Michael Smith, Thomas Mansencal, ErinRose Blair, Kathryn Brillhart
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Paper and Data to appear at: www.etcenter.org

We're Hiring! debevec@netflix.com