

# Lecture 11: A Bit More Color

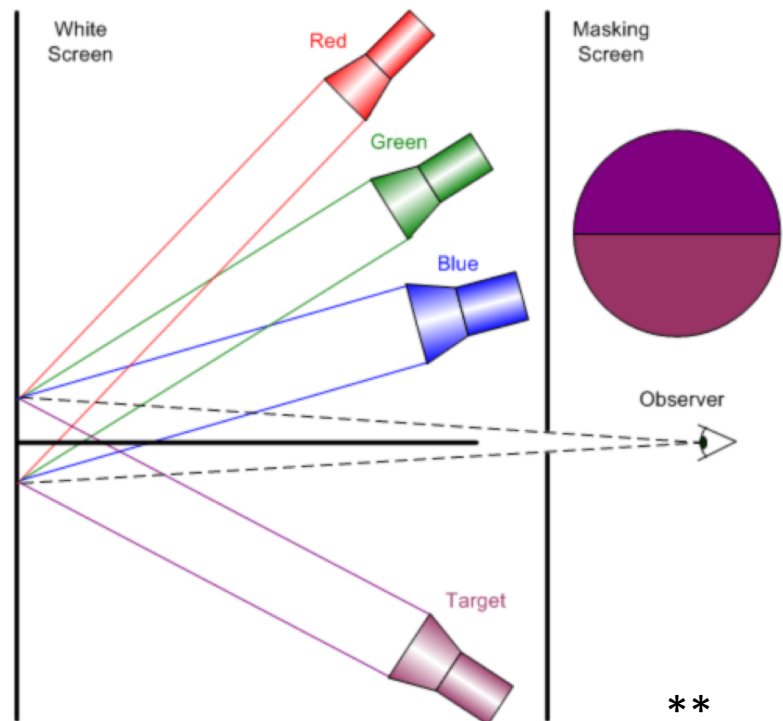
October 8, 2019

# Back to the 1930s

- When are 2 colors perceived the same?

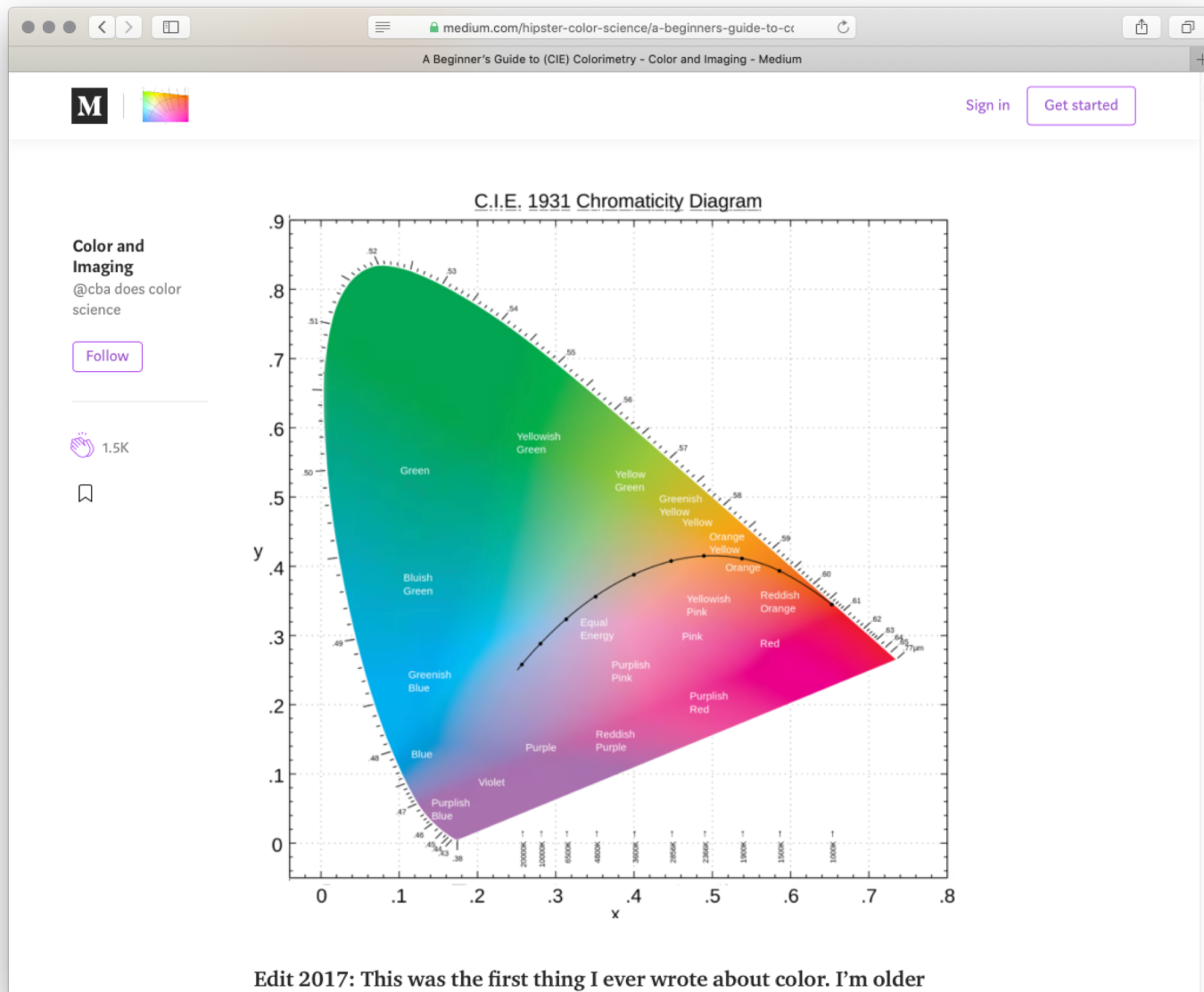
“In the 1920s two color scientists, W. D. Wright and J. Guild, each performed similar color vision experiments. Wright performed his experiment on 10 subjects, Guild used 7. Their results agreed with each other so well that they were combined by CIE to create the RGB color matching functions ...” \*

\* A Beginner’s Guide to (CIE) Colorimetry, Chandler Abraham, Sep 10, 2016



\*\* <http://betterphotographytutorials.com/2011/08/01/light-and-colors---part-3/>

# And Our Goal - Understand



# Credit Where Credit is Due

The next couple of slides are going to draw upon images and flow from ....

Color: From Hexcodes to Eyeballs

**Zero Wind**  
Jamie Wong  
April 3, 2018

## Color: From Hexcodes to Eyeballs

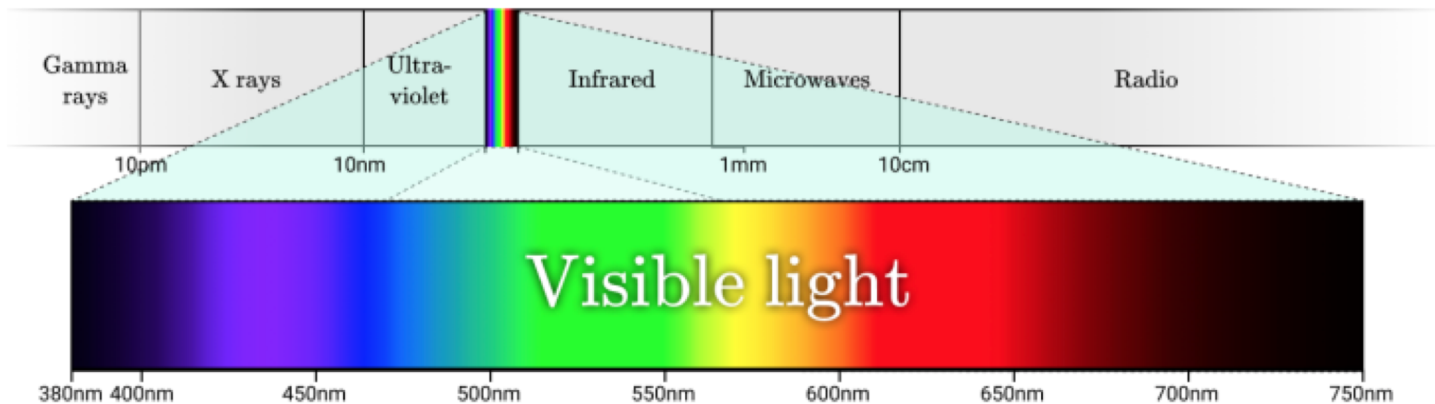
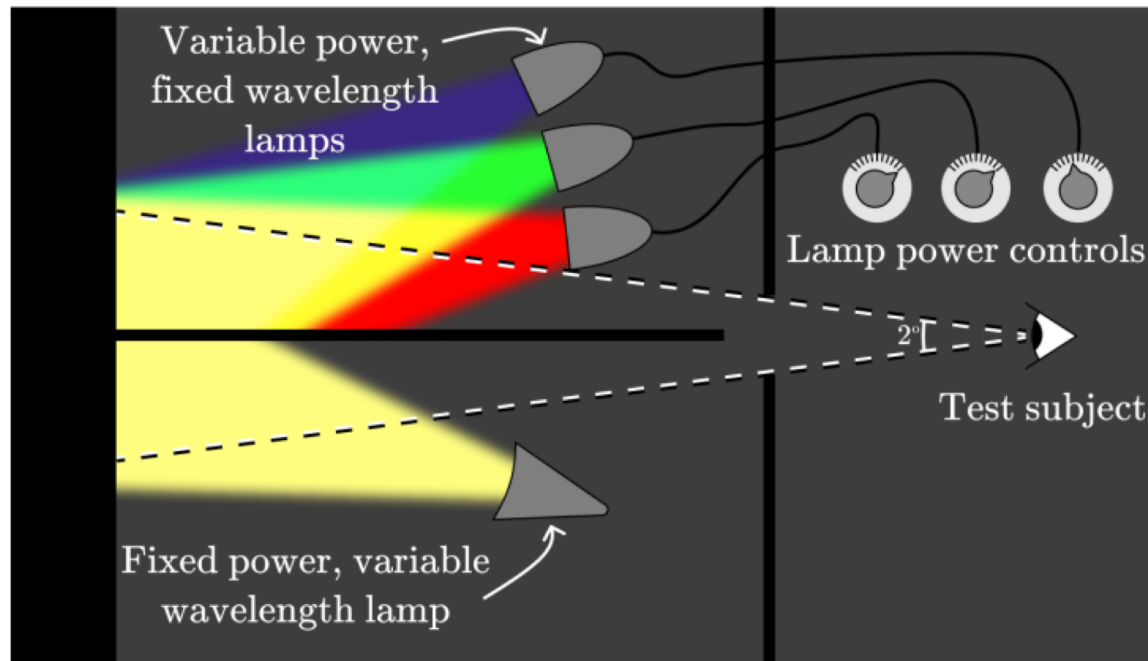
#**FF****E8****41**

$R_{sRGB} = \frac{0xFF}{0xFF} = 1.00$

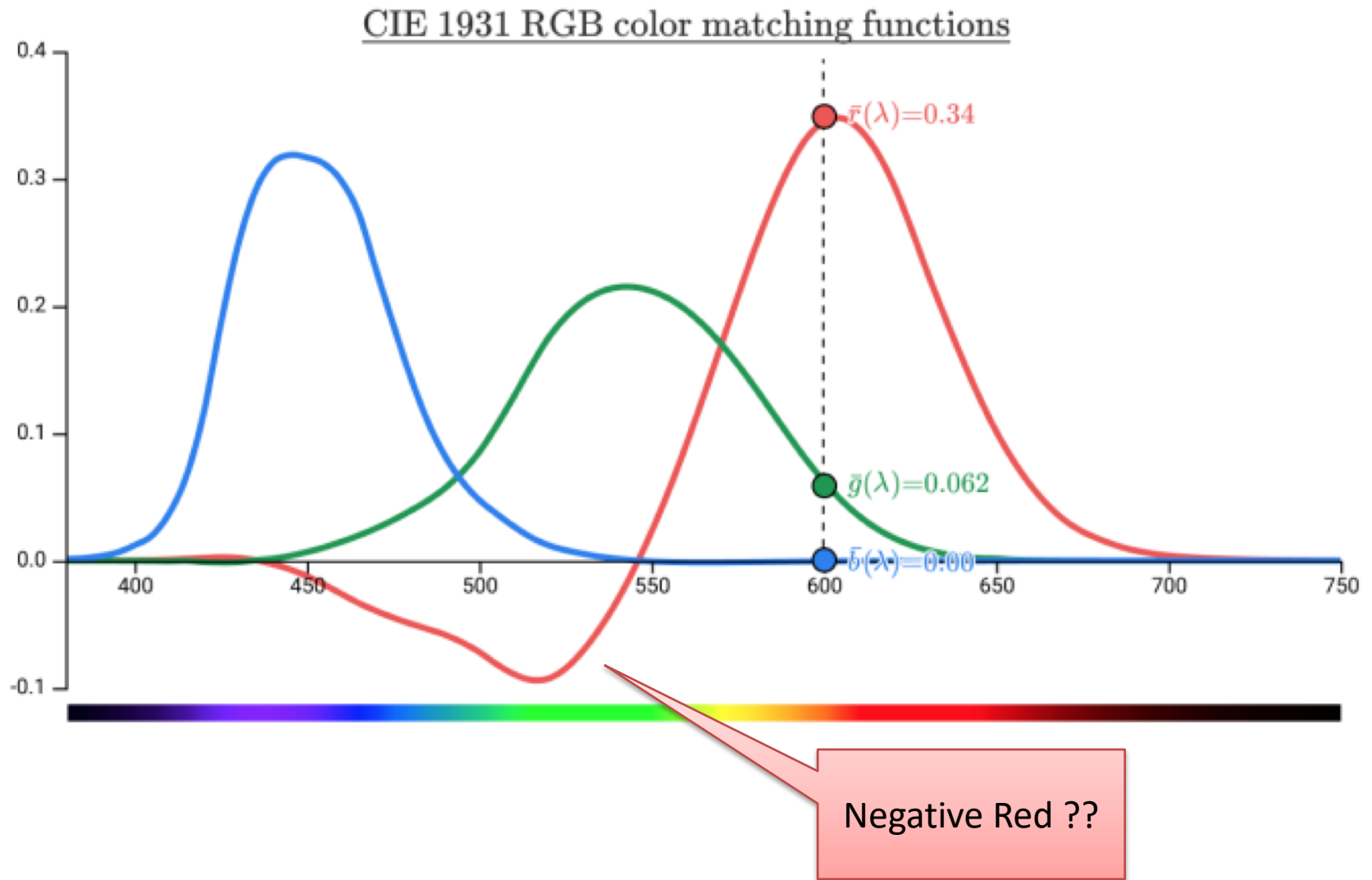
$G_{sRGB} = \frac{0xE8}{0xFF} = 0.91$

$B_{sRGB} = \frac{0x41}{0xFF} = 0.25$

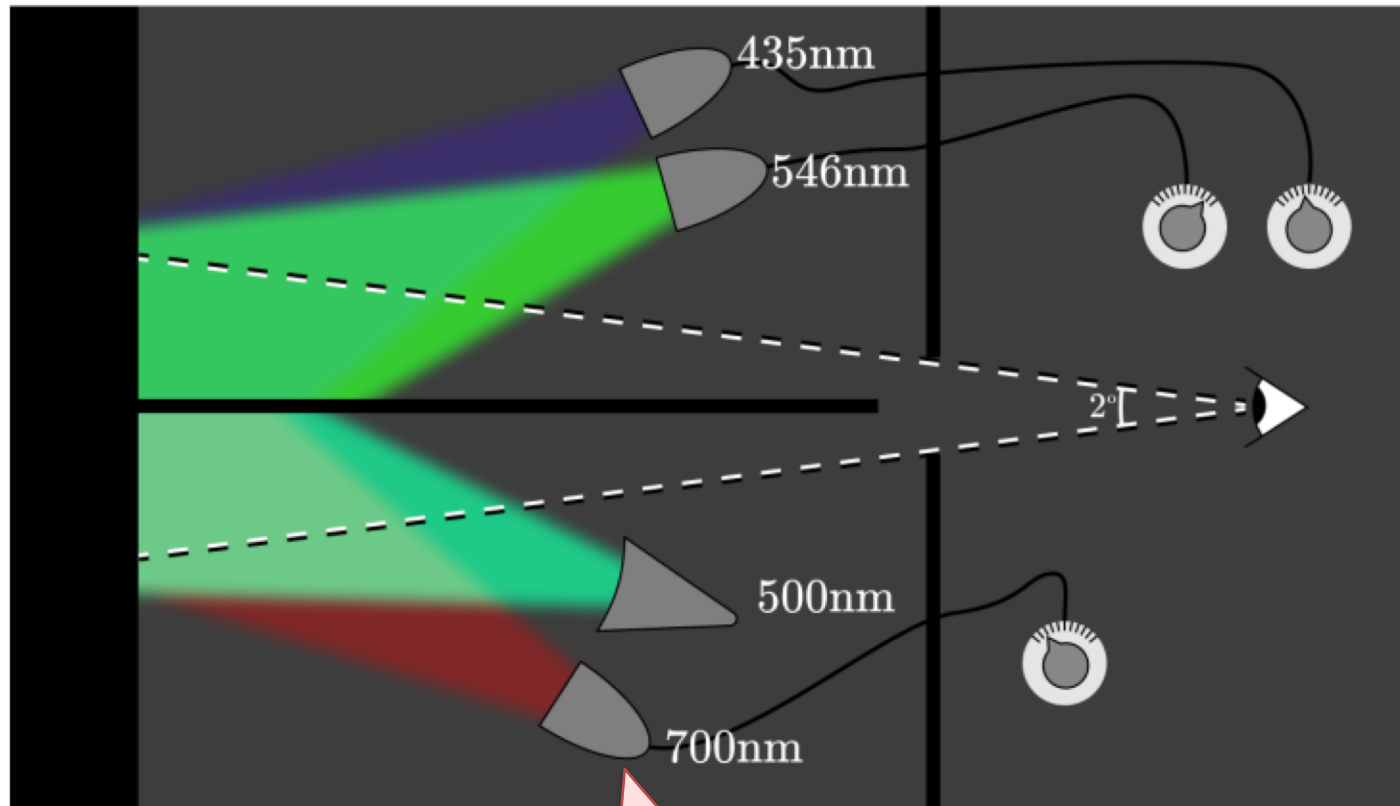
# Combine Three Light Sources



# RGB Matching Spectrum Curves



# A Clever Idea – Add to Other Side



Adding on in this side is subtraction on the other.

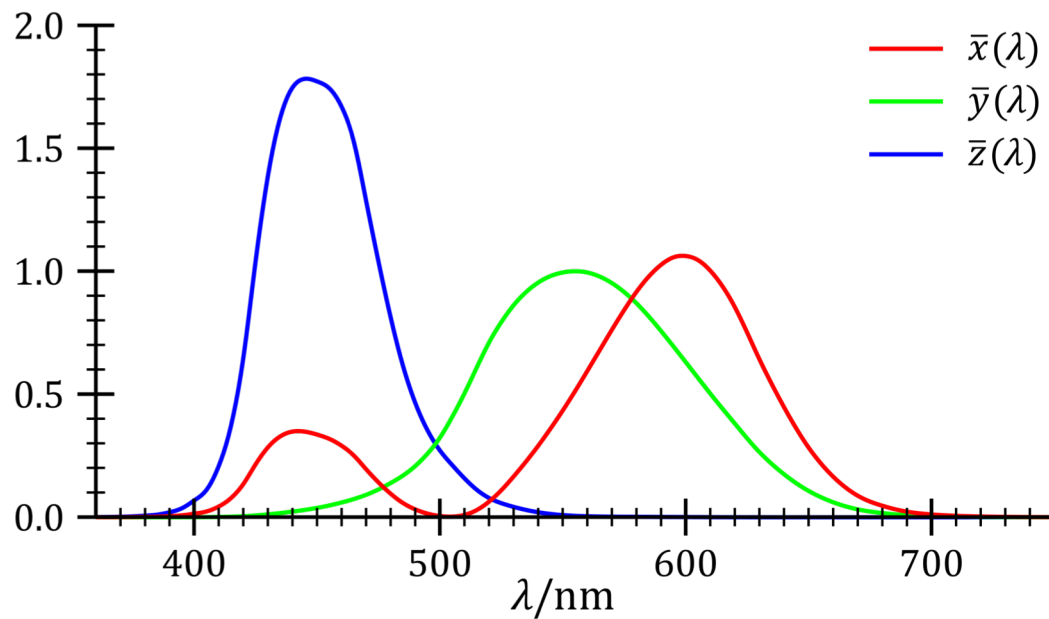
# All Positive

The numbers in the conversion matrix below are exact, with the number of digits specified in CIE standards.<sup>[14]</sup>

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \frac{1}{b_{21}} \begin{bmatrix} b_{11} & b_{12} & b_{13} \\ b_{21} & b_{22} & b_{23} \\ b_{31} & b_{32} & b_{33} \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} = \frac{1}{0.176\,97} \begin{bmatrix} 0.490\,00 & 0.310\,00 & 0.200\,00 \\ 0.176\,97 & 0.812\,40 & 0.010\,63 \\ 0.000\,00 & 0.010\,00 & 0.990\,00 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

While the above matrix is exactly specified in standards, going the other direction uses an inverse matrix that is not exactly specified, but is approximately:

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 0.418\,47 & -0.158\,66 & -0.082\,835 \\ -0.091\,169 & 0.252\,43 & 0.015\,708 \\ 0.000\,920\,90 & -0.002\,549\,8 & 0.178\,60 \end{bmatrix} \cdot \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$



[https://en.wikipedia.org/wiki/CIE\\_1931\\_color\\_space](https://en.wikipedia.org/wiki/CIE_1931_color_space)



# Another Great Reference



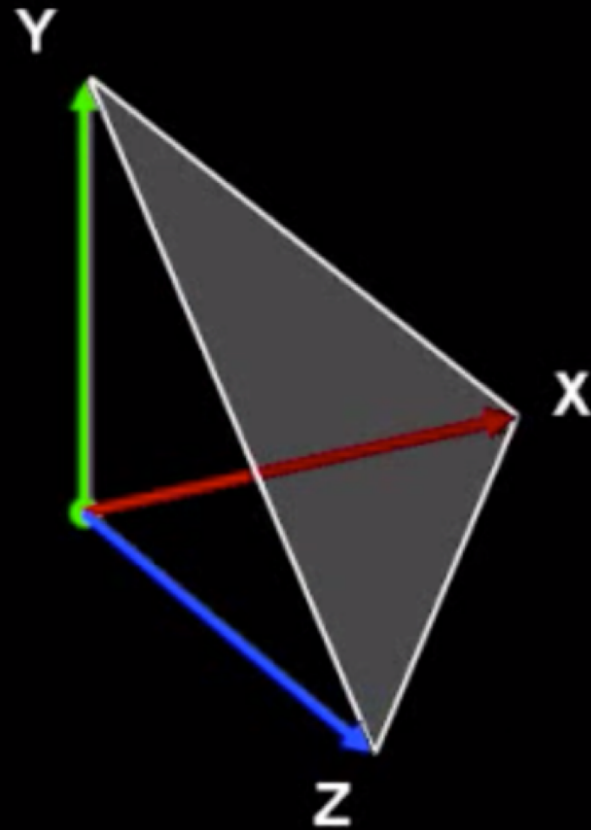
Excerpted on the following two slides.

<https://www.youtube.com/watch?v=82ltpxqPP4I>

# The XYZ Color Plane

## Color Space X-Y-Z

*Unit Plane:  
at 1 unit  
on each  
color axis*

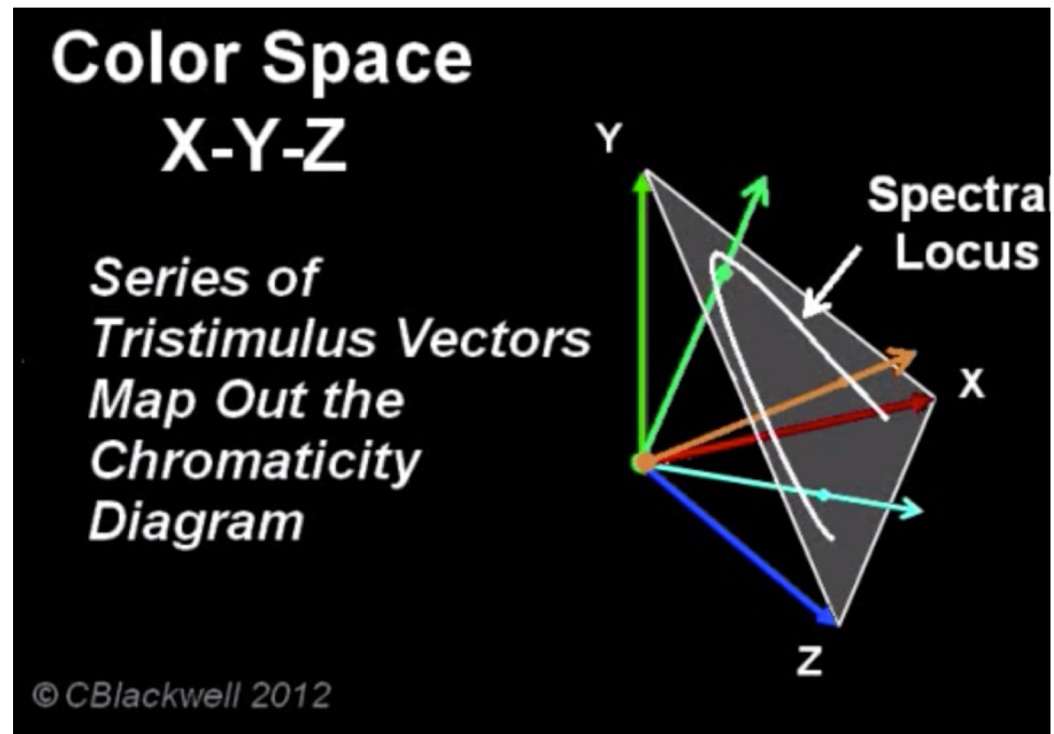


© CBlackwell 2012

# Spectrum Generates XYZ Curve

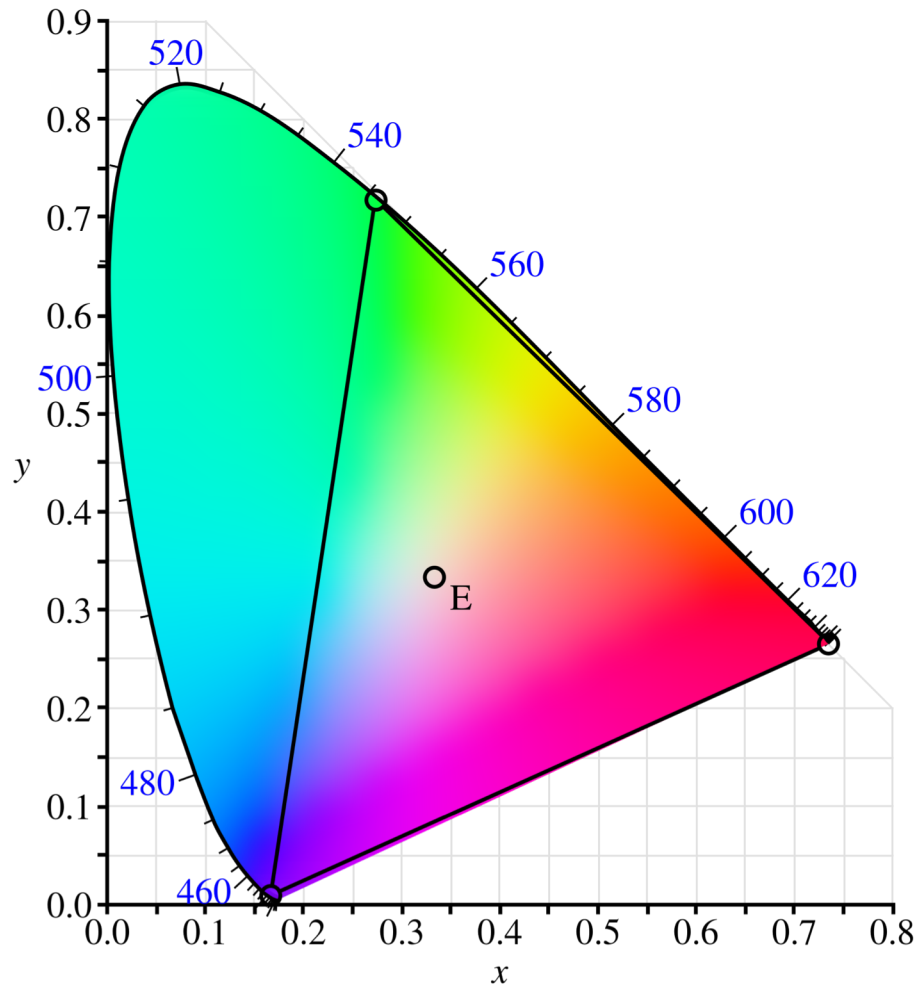
The CIE XYZ color space was deliberately designed so that the  $Y$  parameter is a measure of the **luminance** of a color. The chromaticity is then specified by the two derived parameters  $x$  and  $y$ , two of the three normalized values being functions of all three **tristimulus values**  $X$ ,  $Y$ , and  $Z$ .<sup>[11]</sup>

$$\begin{aligned}x &= \frac{X}{X+Y+Z} \\y &= \frac{Y}{X+Y+Z} \\z &= \frac{Z}{X+Y+Z} = 1 - x - y\end{aligned} *$$



\* [https://en.wikipedia.org/wiki/CIE\\_1931\\_color\\_space](https://en.wikipedia.org/wiki/CIE_1931_color_space)

# Now, Chromaticity Again



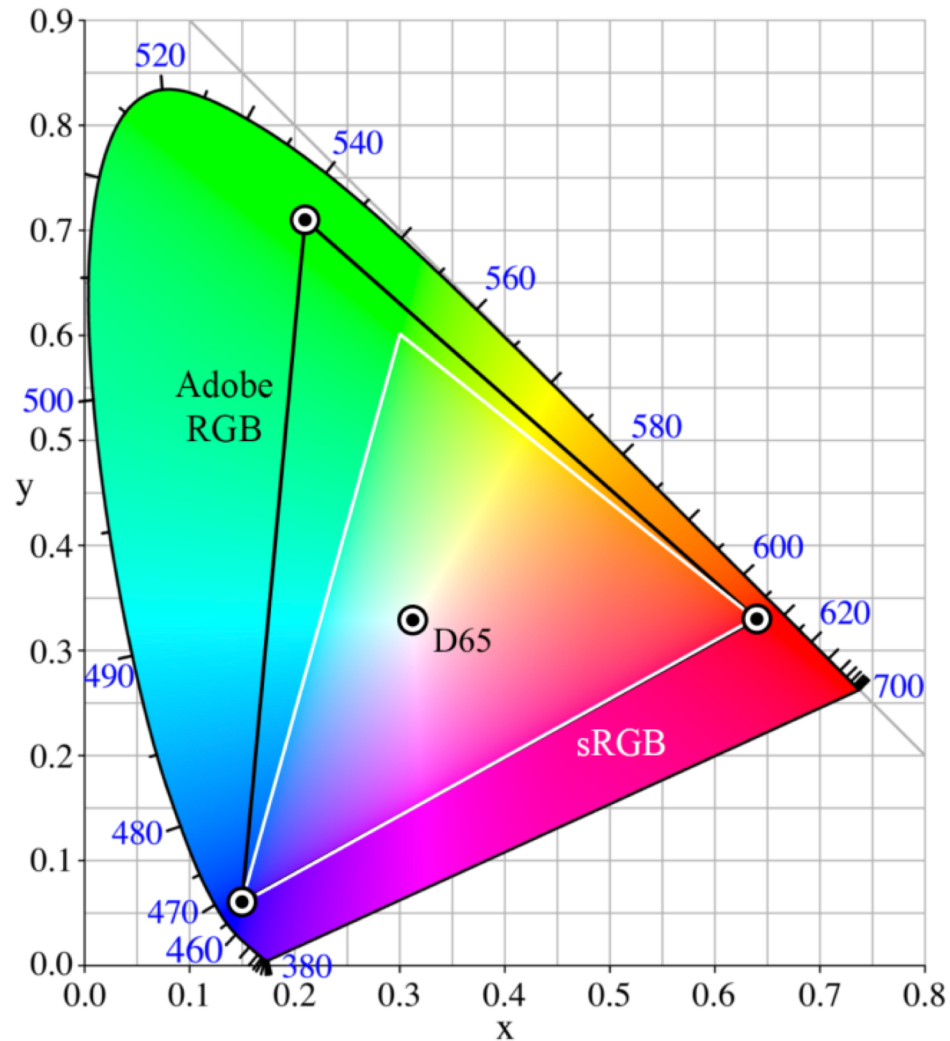
Around the outside,  
pure monochromatic  
light.

Inside blended XYZ  
colors.

Center is 'white'

Triangle is expressible  
with standard red, green  
blue emitters.

# Expanded Gamut



<https://medium.com/hipster-color-science/a-beginners-guide-to-colorimetry-401f1830b65a>

# Back to Good Old RGB

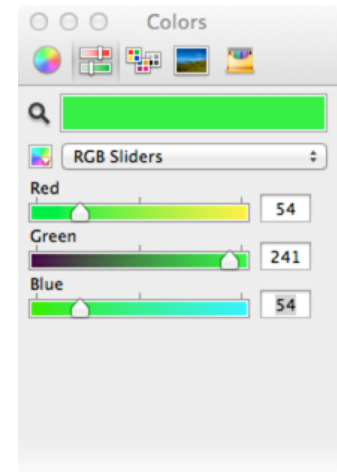
- Recall basic RGB triple and Hex

Red                      Green                      Blue

0	0	1	1	0	1	1	0	1	1	1	0	0	0	1	0	0	1	1	0	1	1	0
---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---

54 241 54

Sample



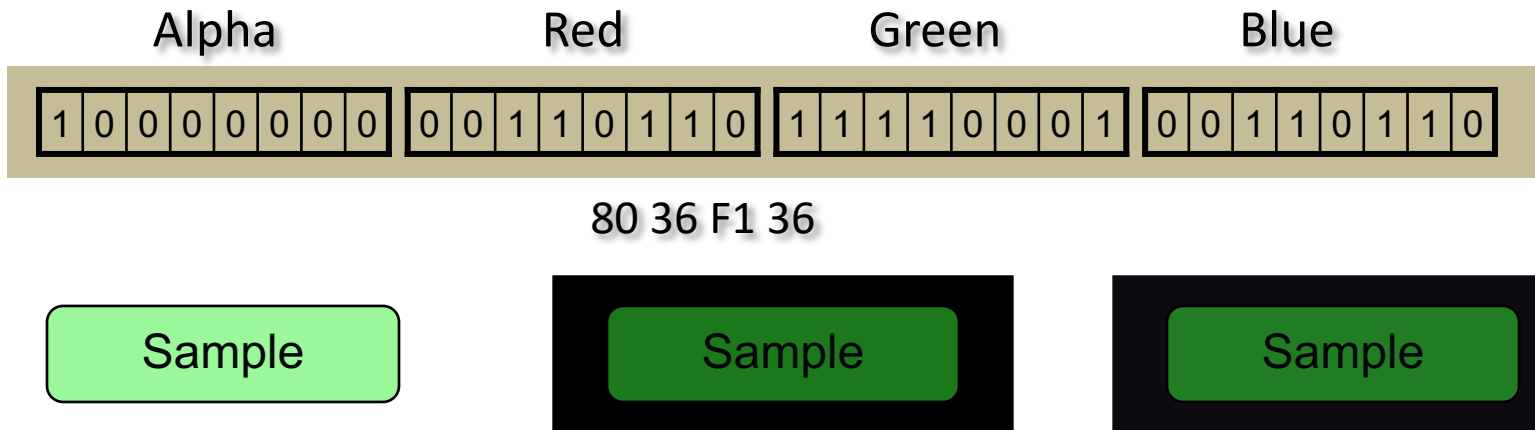
Red                      Green                      Blue

0	0	1	1	0	1	1	0	1	1	1	0	0	0	1	0	0	1	1	0	1	1	0
---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---

36 F1 36

# Something to See Through

- A good way to use the last byte :-)
- Consider a 32 bit word ...



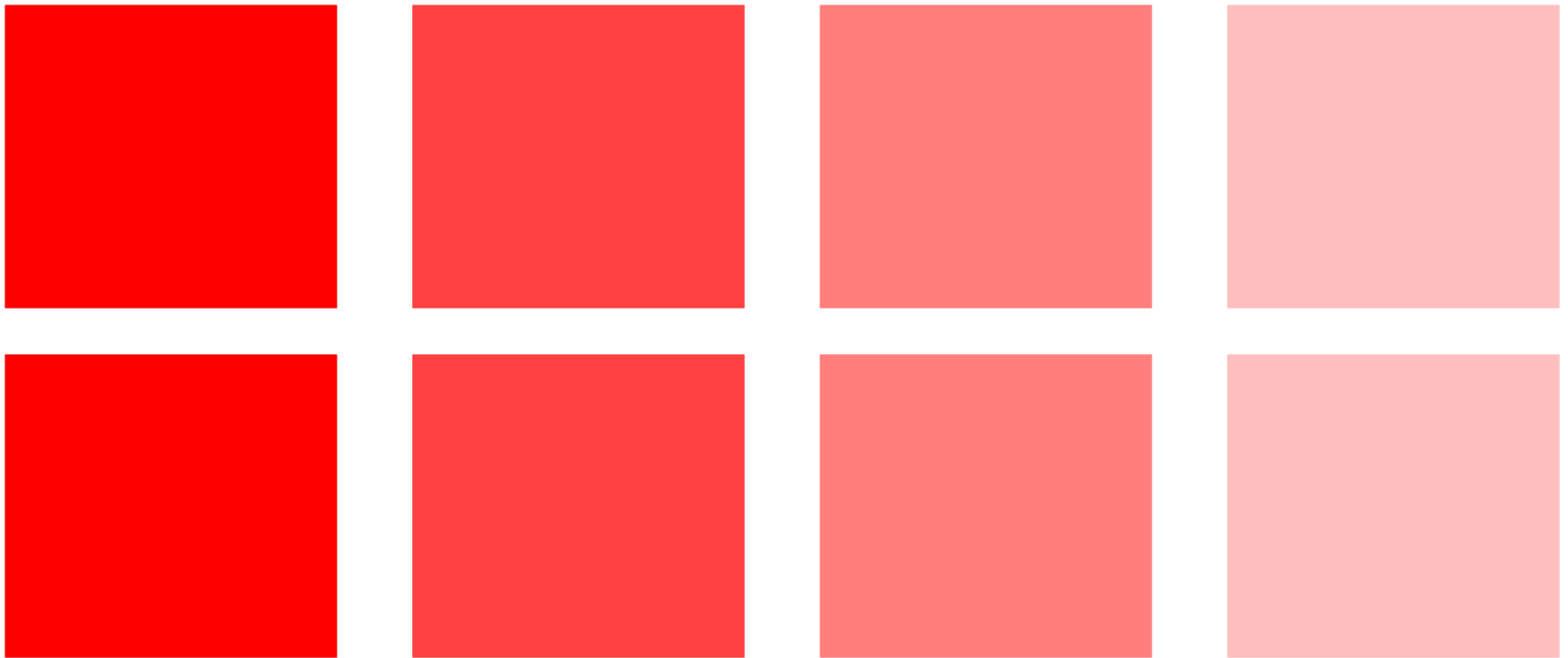
- Alpha controls blending
  - Alpha equals zero means transparent
  - Alpha equals one (255) completely covers
  - Alpha equal one half (127) is 50/50 mix

# Color Temperature

The screenshot shows the Wikipedia article for "Color temperature". The browser address bar is "en.wikipedia.org/wiki/Color\_temperature". The page title is "Color temperature - Wikipedia". The article content includes a navigation bar with "Article" and "Talk" tabs, and a search box. The main heading is "Color temperature". Below it, a note says "From Wikipedia, the free encyclopedia". A warning box states: "This article needs additional citations for verification. Please help improve this article by adding citations to reliable sources. Unsourced material may be challenged and removed. Find sources: 'Color temperature' - news · newspapers · books · scholar · JSTOR (June 2012) (Learn how and when to remove this template message)". The main text defines color temperature as the temperature of an ideal black-body radiator that radiates light of a color comparable to that of the light source. It mentions applications in lighting, photography, videography, publishing, manufacturing, astrophysics, horticulture, and other fields. A graph on the right shows the color spectrum with temperature labels (K) ranging from 1800 to 10000. The graph is a triangular shape with a color gradient from red at the bottom right to blue at the top left. The x-axis is labeled 'x' and the y-axis is labeled 'y'. The temperature labels are: 1800, 2000, 2500, 3000, 4000, 6000, 10000. The color labels are: 460, 470, 480, 490, 520, 540, 560, 580, 600, 620, 700.



# Examples of Blending



# What About HDR

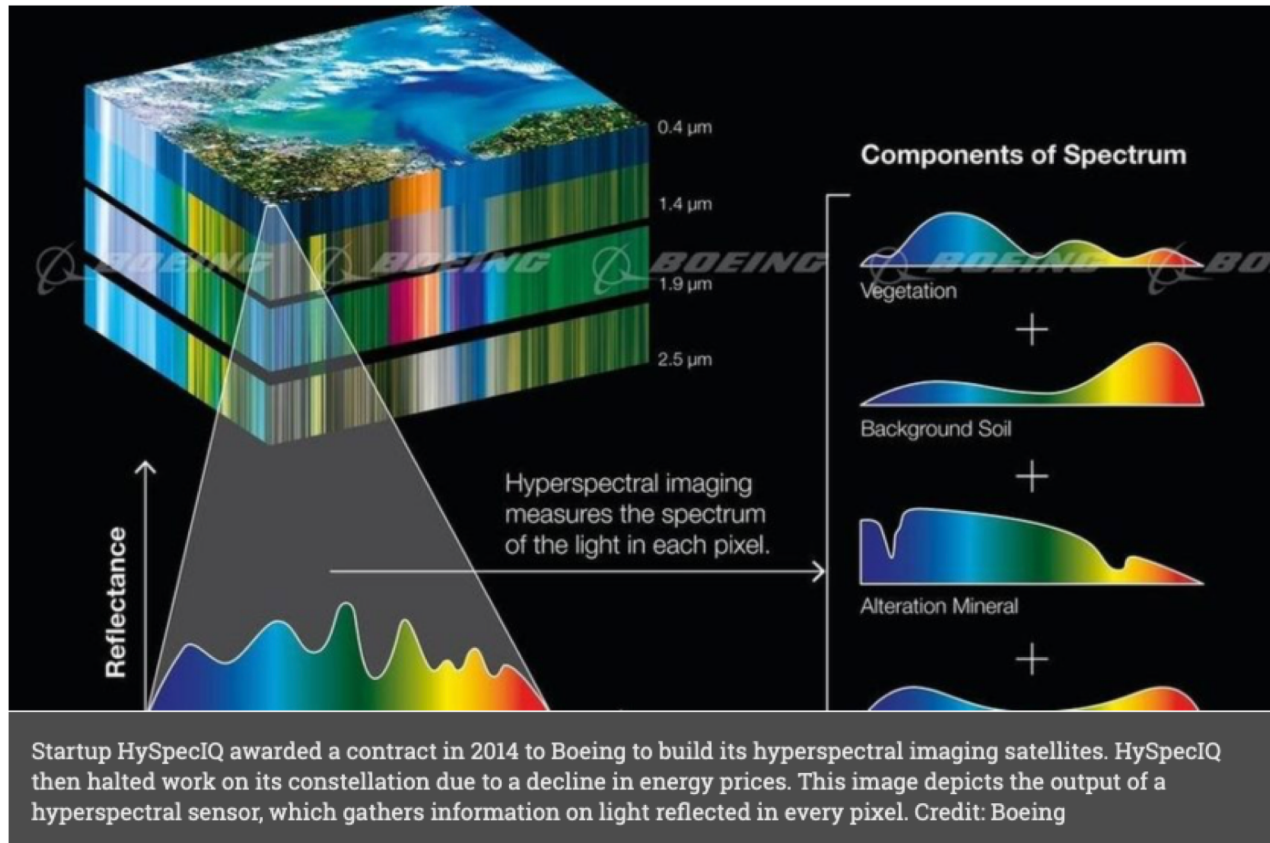
HDR ... High Dynamic Range (when applied to color)

- Think first about the sensor
  - Limiting case - Hyperspectral
- Next about the image representation
  - 16 bits per pixel per channel?
- Finally about the display
  - 10 bits per channel?

# Hyperspectral Satellite

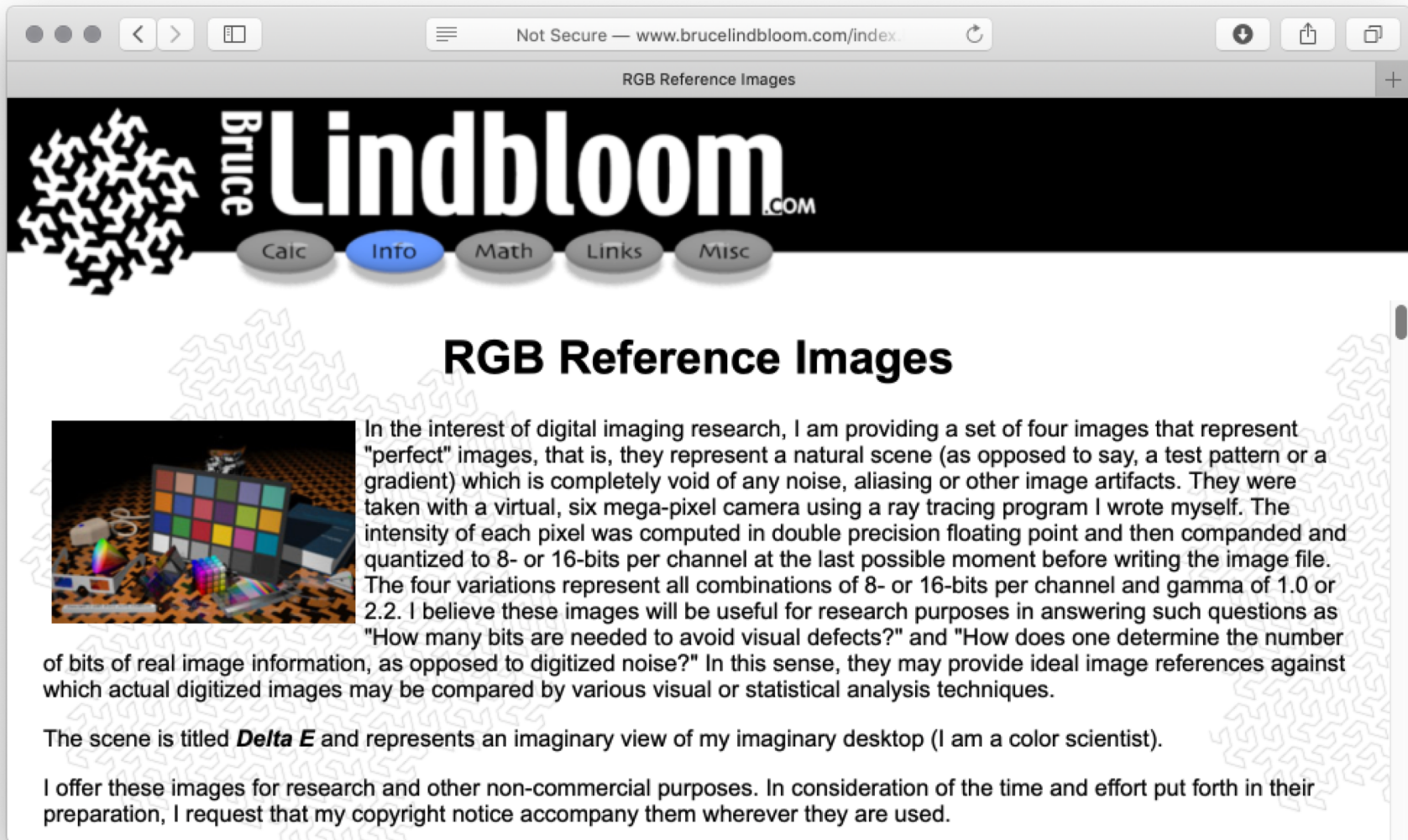
## HyperSat reveals hyperspectral plans

by Debra Werner — October 5, 2018



<https://spacenews.com/hypersat-funds/>

# Sixteen Bits of Color



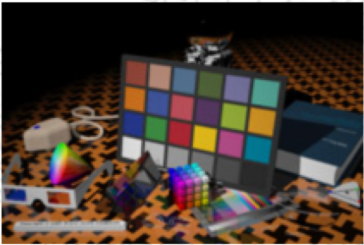
Not Secure — www.brucelindbloom.com/index

RGB Reference Images

**Bruce Lindbloom .COM**

Calc Info Math Links Misc

## RGB Reference Images

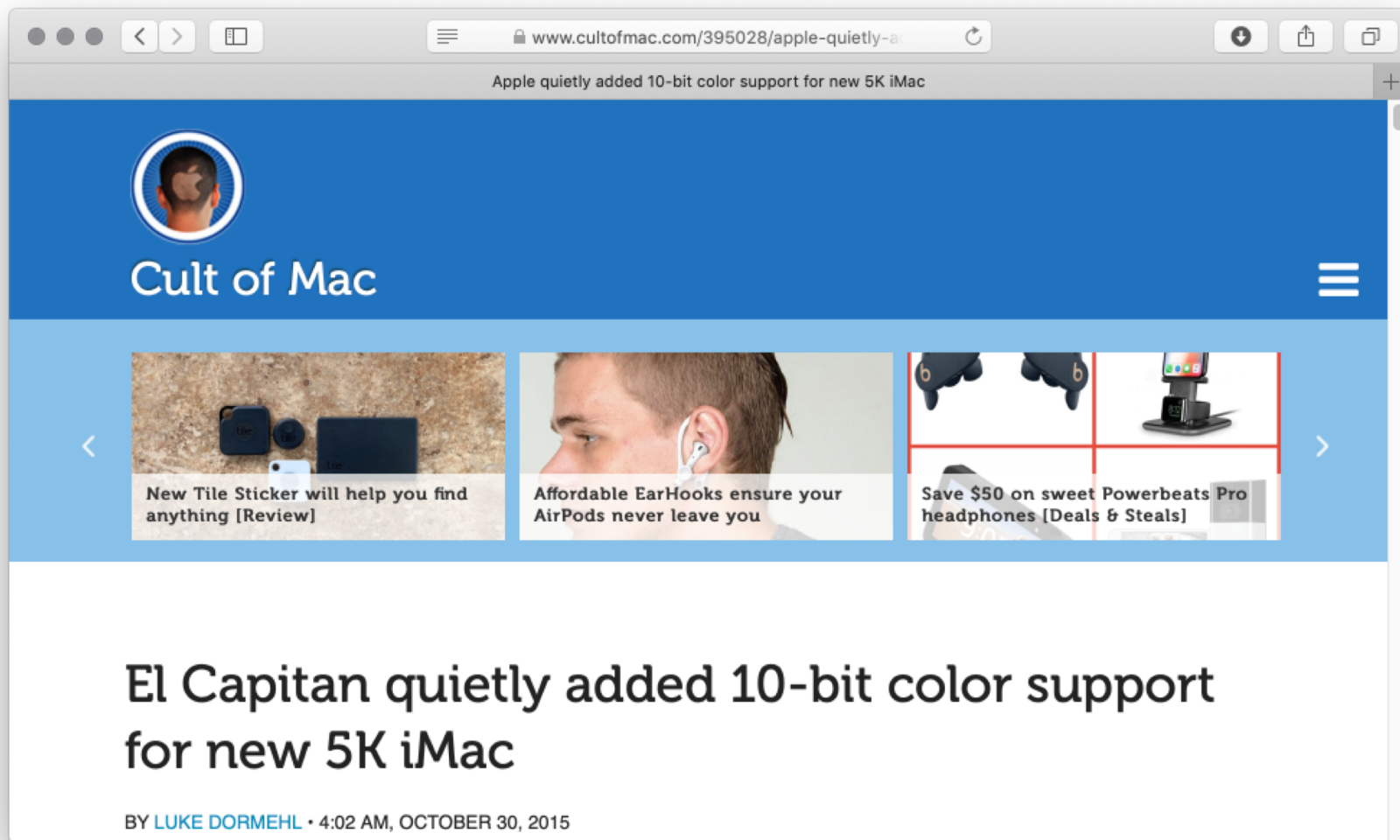


In the interest of digital imaging research, I am providing a set of four images that represent "perfect" images, that is, they represent a natural scene (as opposed to say, a test pattern or a gradient) which is completely void of any noise, aliasing or other image artifacts. They were taken with a virtual, six mega-pixel camera using a ray tracing program I wrote myself. The intensity of each pixel was computed in double precision floating point and then companded and quantized to 8- or 16-bits per channel at the last possible moment before writing the image file. The four variations represent all combinations of 8- or 16-bits per channel and gamma of 1.0 or 2.2. I believe these images will be useful for research purposes in answering such questions as "How many bits are needed to avoid visual defects?" and "How does one determine the number of bits of real image information, as opposed to digitized noise?" In this sense, they may provide ideal image references against which actual digitized images may be compared by various visual or statistical analysis techniques.

The scene is titled **Delta E** and represents an imaginary view of my imaginary desktop (I am a color scientist).

I offer these images for research and other non-commercial purposes. In consideration of the time and effort put forth in their preparation, I request that my copyright notice accompany them wherever they are used.

# Display Color HDR



The image is a screenshot of a web browser window. The address bar shows the URL [www.cultofmac.com/395028/apple-quietly-added-10-bit-color-support-for-new-5k-imac](http://www.cultofmac.com/395028/apple-quietly-added-10-bit-color-support-for-new-5k-imac). The page title is "Apple quietly added 10-bit color support for new 5K iMac". The website header is blue with the "Cult of Mac" logo and a hamburger menu icon. Below the header is a carousel of three featured articles: "New Tile Sticker will help you find anything [Review]", "Affordable EarHooks ensure your AirPods never leave you", and "Save \$50 on sweet Powerbeats Pro headphones [Deals & Steals]". The main content area features a large article title: "El Capitan quietly added 10-bit color support for new 5K iMac". Below the title, it says "BY LUKE DORMEHL · 4:02 AM, OCTOBER 30, 2015".

Apple quietly added 10-bit color support for new 5K iMac

Cult of Mac

New Tile Sticker will help you find anything [Review]

Affordable EarHooks ensure your AirPods never leave you

Save \$50 on sweet Powerbeats Pro headphones [Deals & Steals]

## El Capitan quietly added 10-bit color support for new 5K iMac

BY [LUKE DORMEHL](#) · 4:02 AM, OCTOBER 30, 2015

# Closing Thought: About Sound, Sight, Perception and Being Picky

- Are there 'audiofiles' of color?
- I grew up steeped in 'golden ears'
- What is a 'golden eye'?

## Beveridge 2SW loudspeaker system

By J. Gordon Holt • Posted: Dec 8, 2015 • Published: May 1, 1978

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This is an electrostatic column speaker, 6' tall and costing \$6000/pair. An integral, fan-cooled amplifier is located in the base (footnote 1). The 2SW is said to cover almost the entire frequency range and is based on a patent, number 3,668,335, issued to manufacturer/designer Harold Beveridge on June 6, 1972. Internal acoustic lenses in front of the electrostatic panels widen the speaker's dispersion: In

<http://www.stereophile.com/content/beveridge-2sw-loudspeaker-system#kVx50V6YADZ6ve7x.97>