# 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/
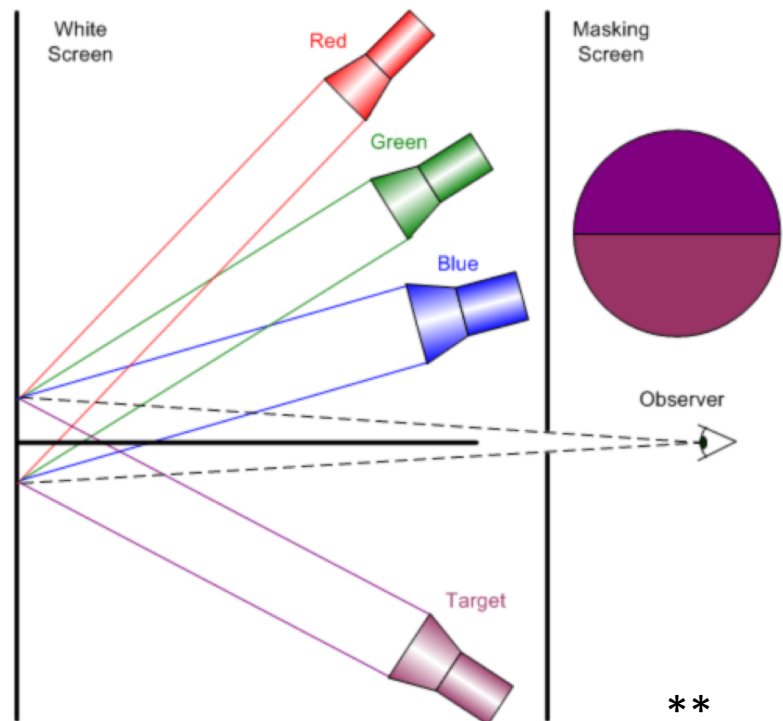
And Our Goal - Understand
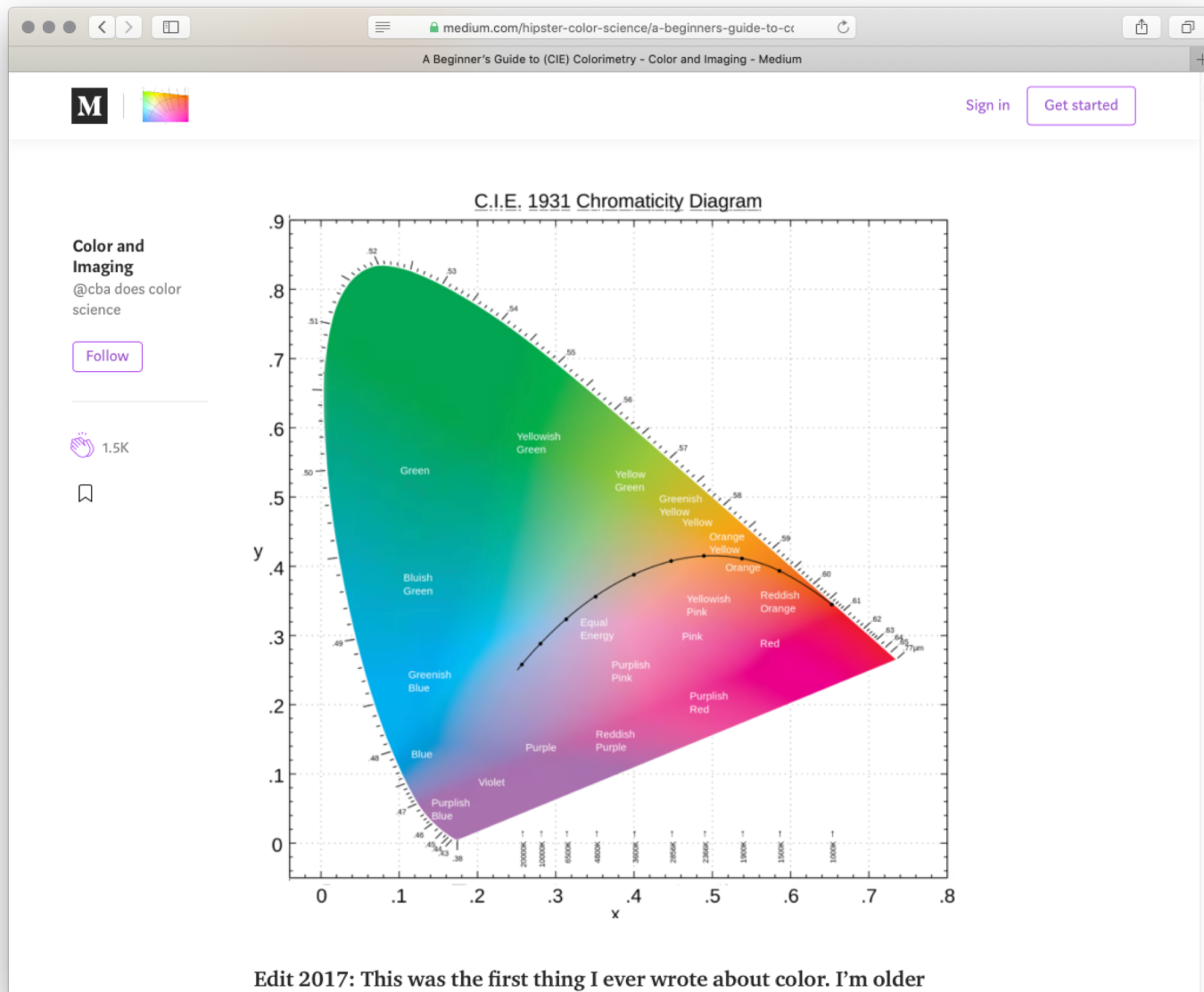
Credit Where Credit is Due

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

Combine Three Light Sources
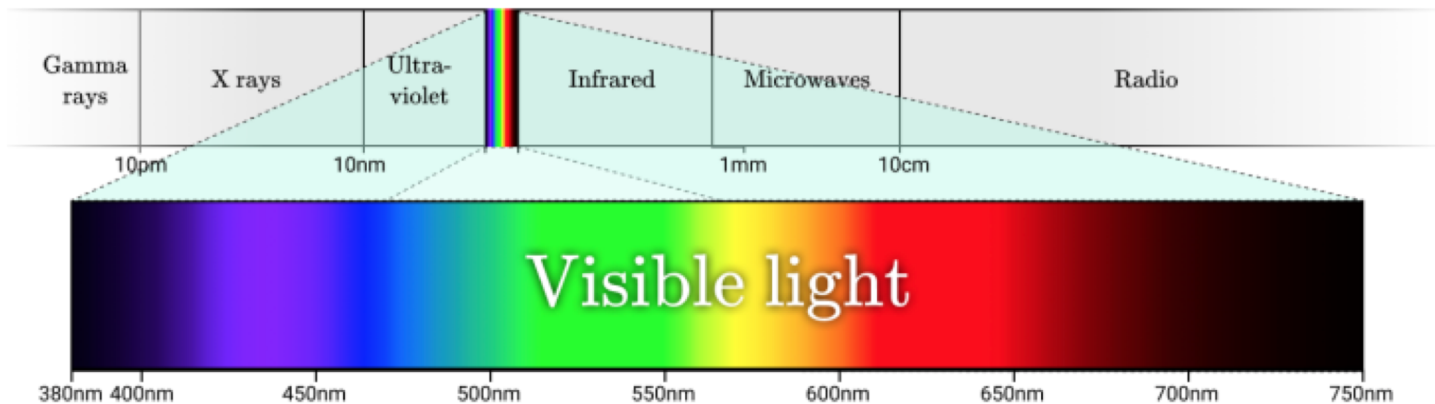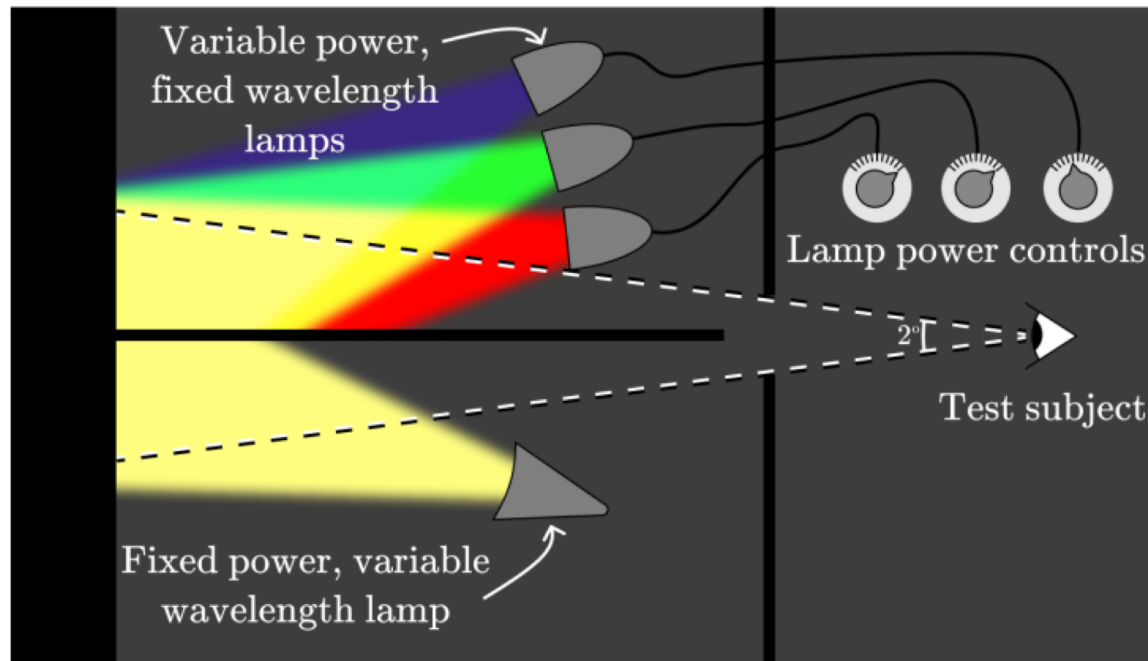
RGB Matching Spectrum Curves

CIE 1931 RGB color matching functions

$\bar{r}(\lambda)=0.34$

$\bar{g}(\lambda)=0.062$

$\bar{b}(\lambda)=0.00$

Negative Red ??
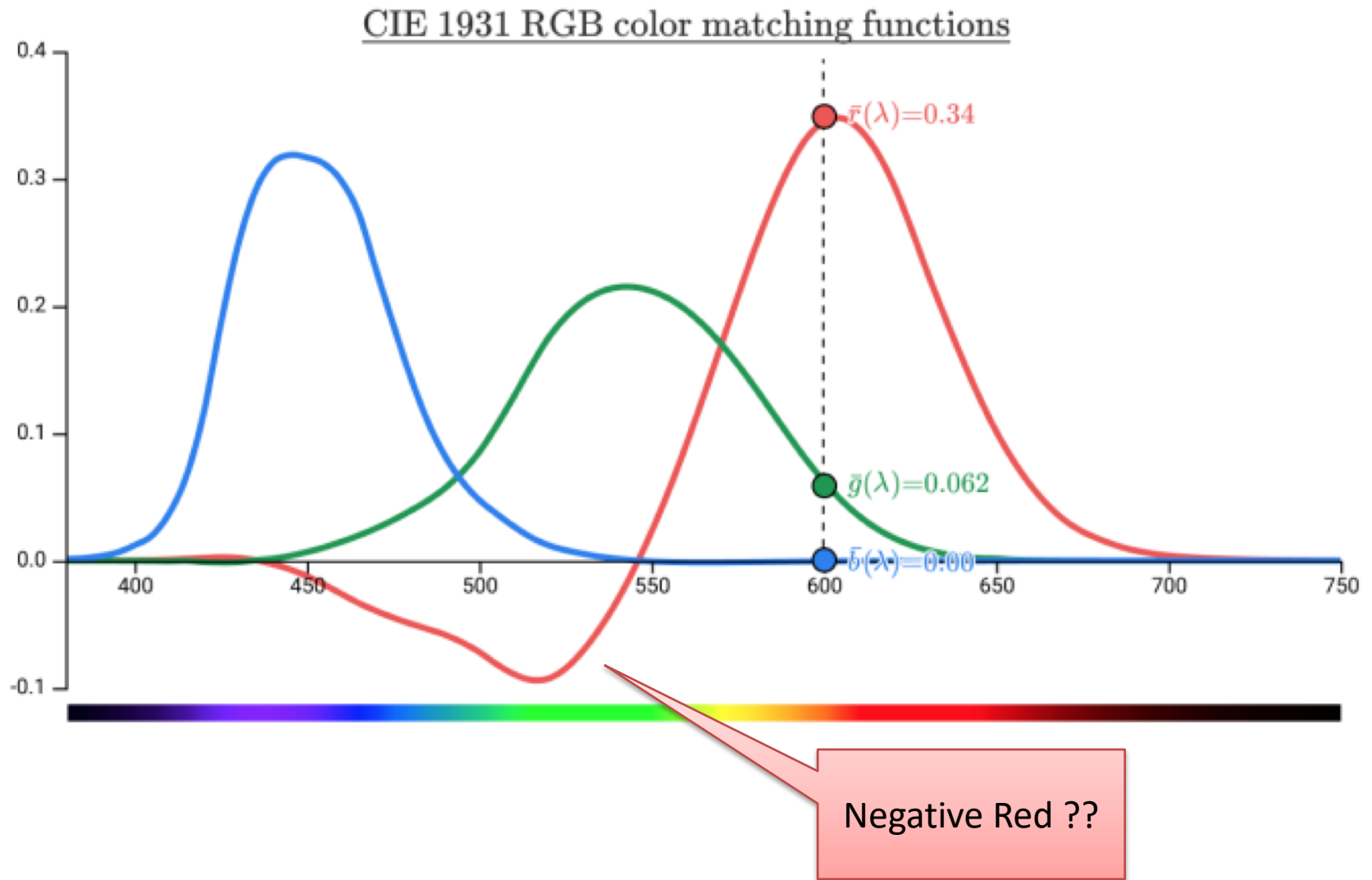
A Clever Idea – Add to Other Side
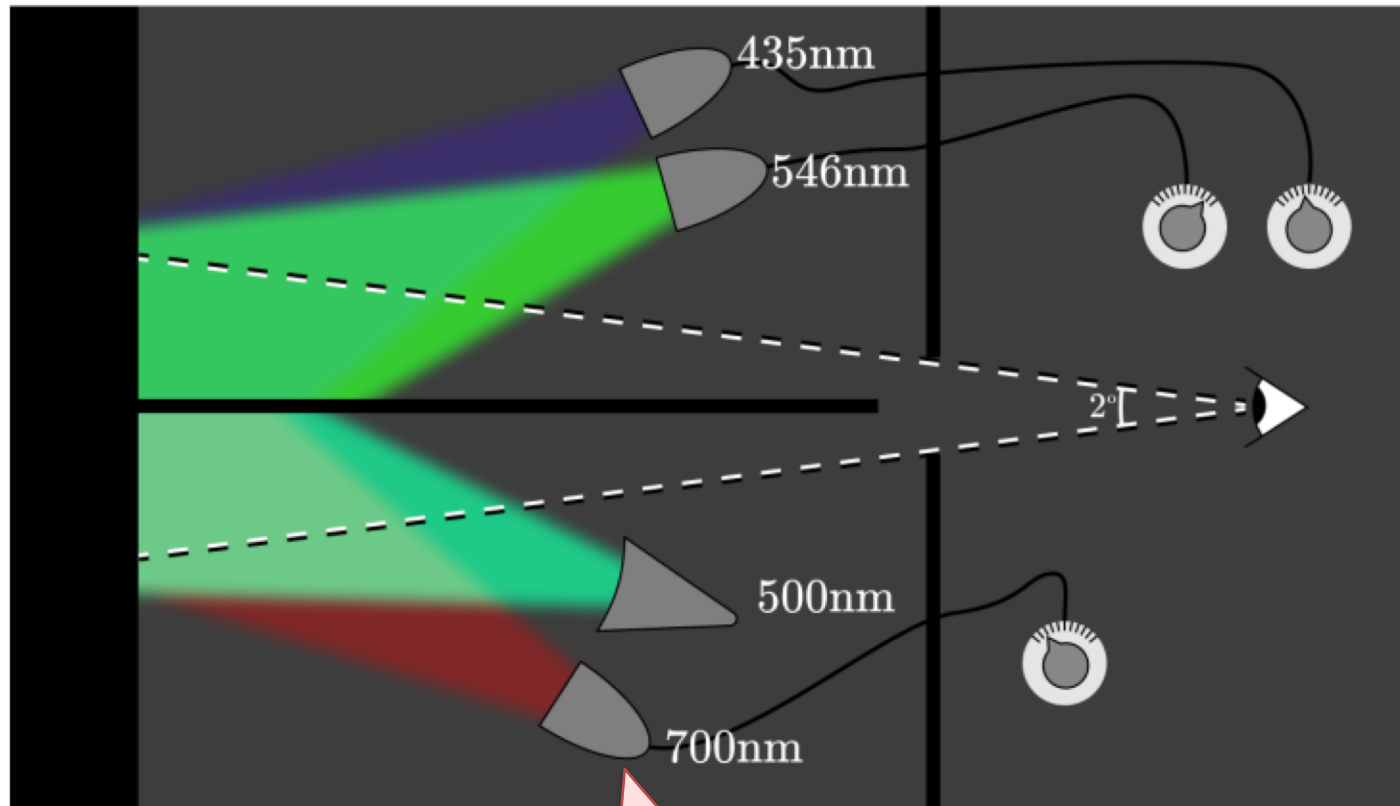

Adding on in this side is subtraction on the other.

All Postive

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

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

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:

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 0.418\,47 & -0.158\,66 & -0.082\,835 \\ -0.091\,169 & 0.252\,43 & 0.015\,708 \\ 0.000\,920\,90 & -0.002\,549\,8 & 0.178\,60 \end{bmatrix} \cdot \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$
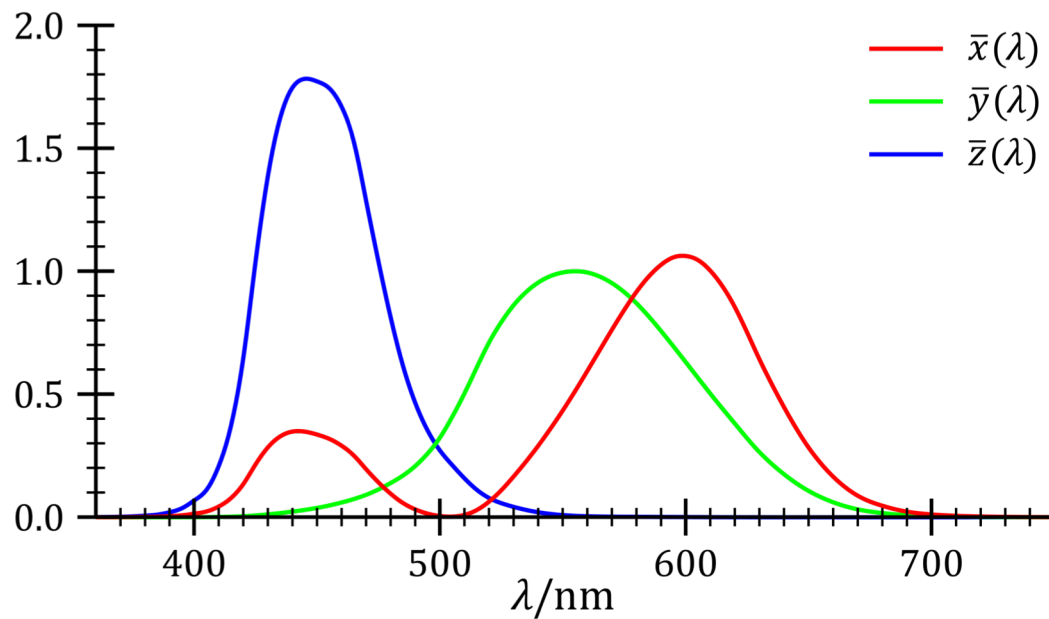
https://en.wikipedia.org/wiki/CIE_1931_color_space

Another Great Reference

Excerpted on the following two slides.

https://www.youtube.com/watch?v=82ItpxqPP4I

The XYZ Color Plane

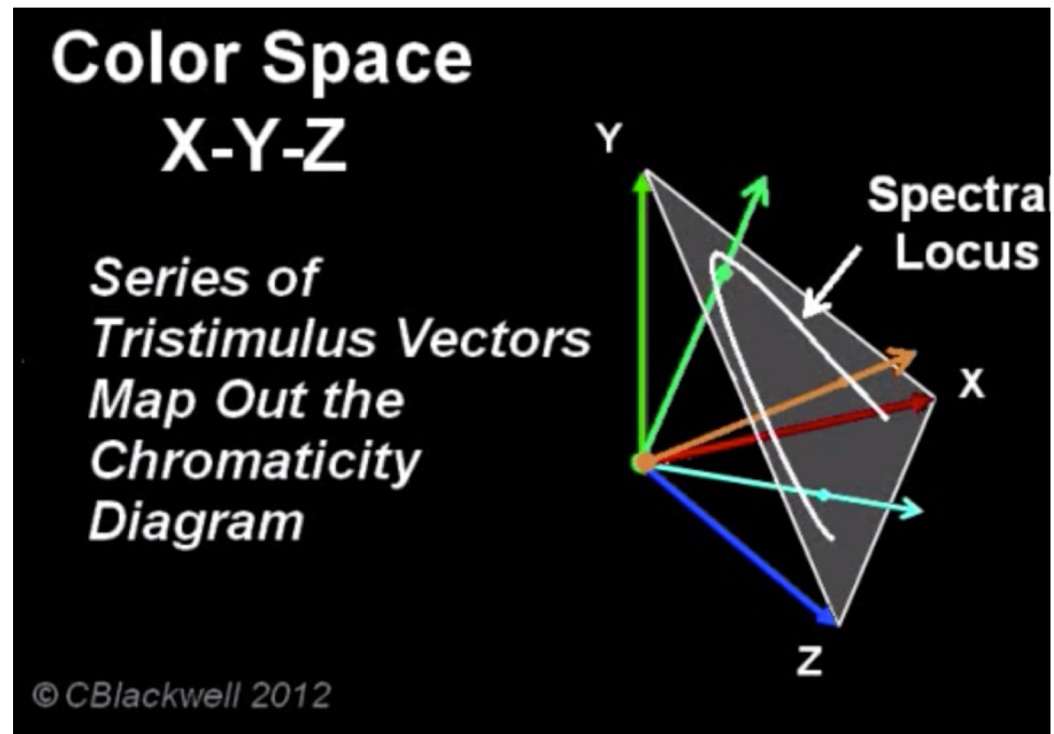Color Space
X-Y-Z

Unit Plane:
at 1 unit
on each
color axis
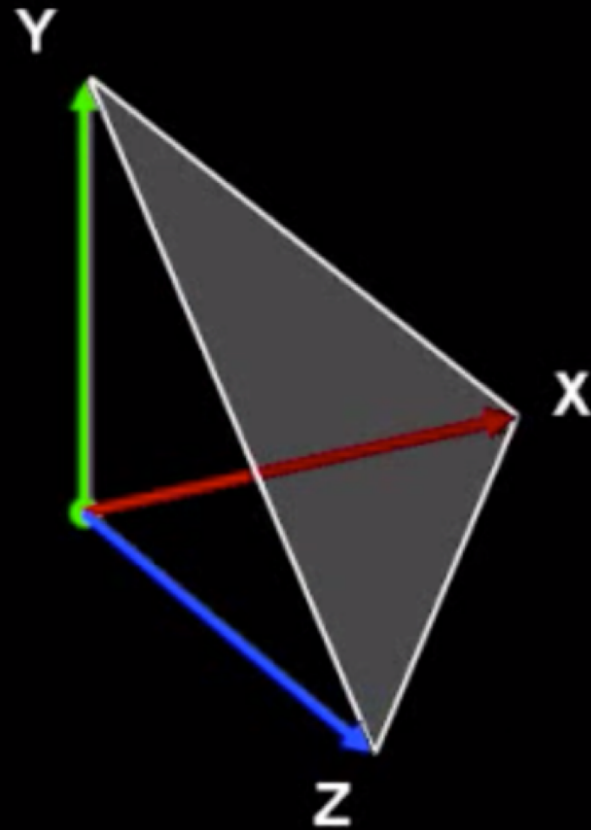
© CBlackwell 2012

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: [11]

$$x = \frac{X}{X+Y+Z}$$
$$y = \frac{Y}{X+Y+Z}$$
$$z = \frac{Z}{X+Y+Z} = 1 - x - y$$

*

Color Space
X-Y-Z

Series of
Tristimulus Vectors
Map Out the
Chromaticity
Diagram

Y

Spectral
Locus

X

Z

© CBlackwell 2012

* https://en.wikipedia.org/wiki/CIE_1931_color_space
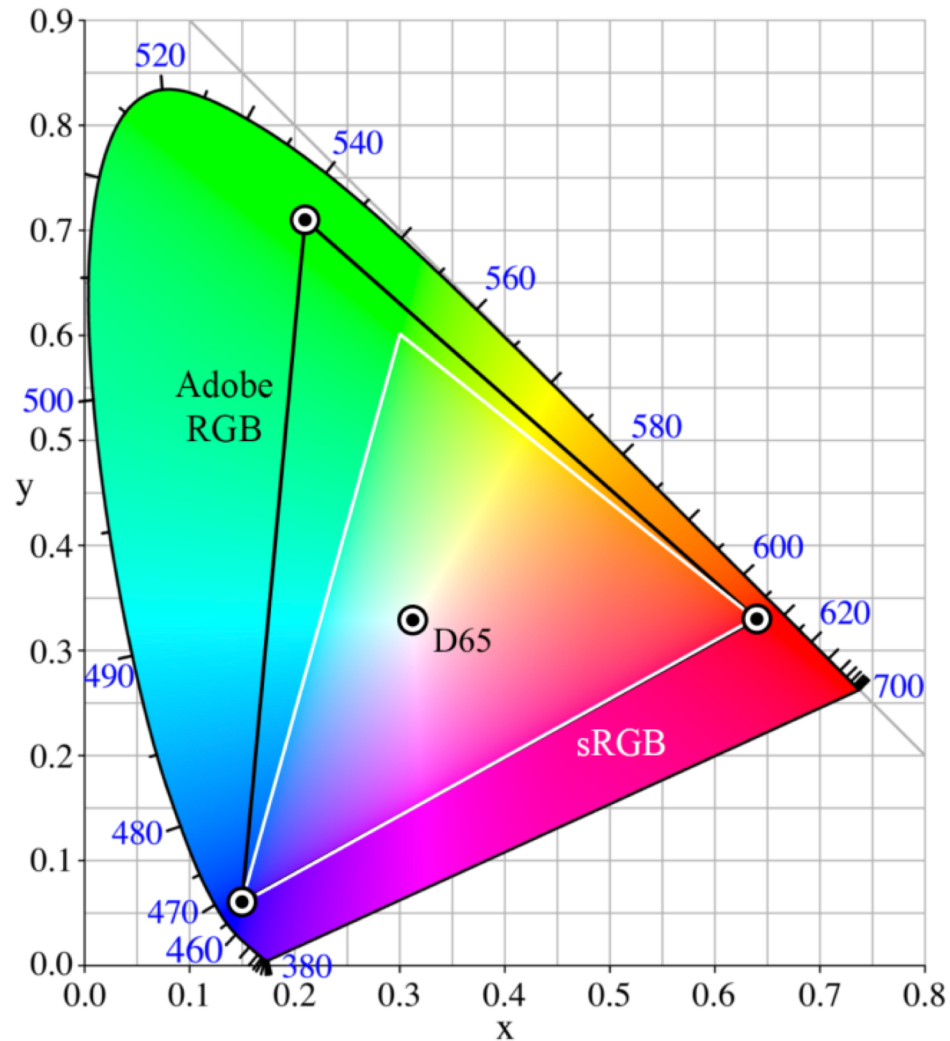
Now, Chromaticity Again
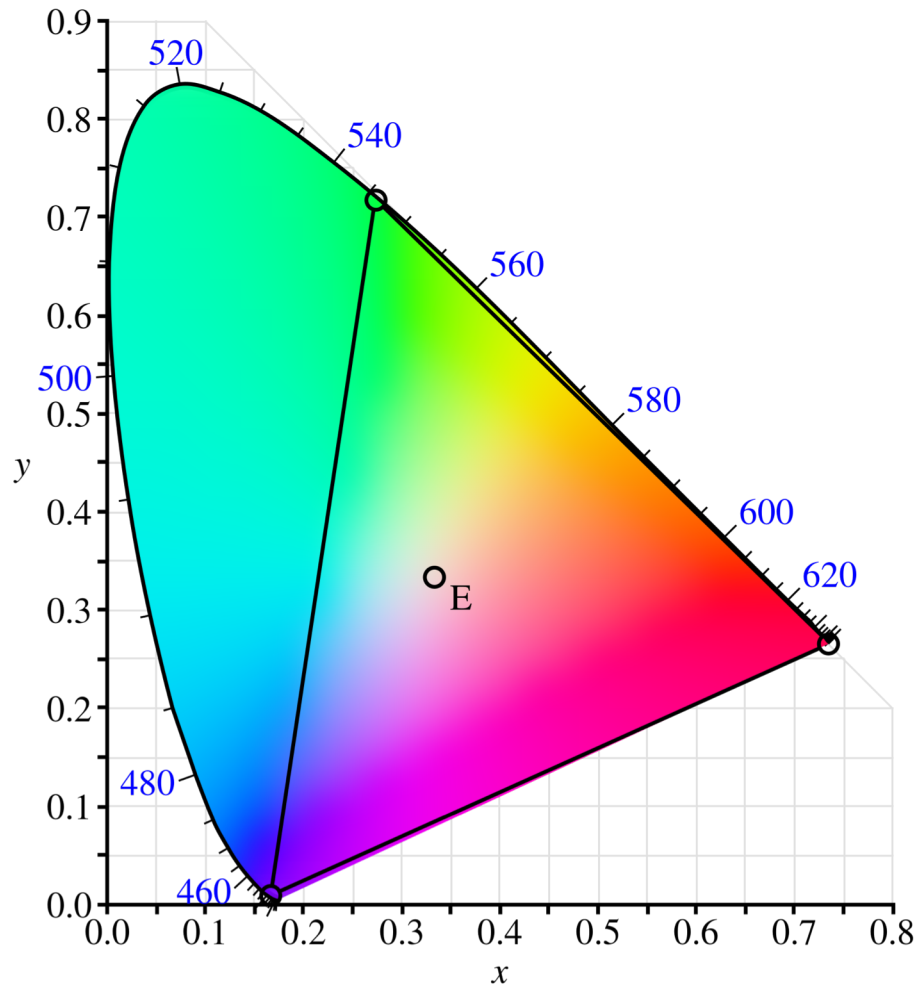
Around the outside, pure monochromatic light.

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
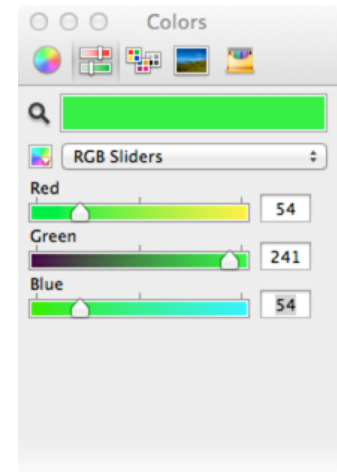
Back to Good Old RBG

- Recall basic RGB triple and Hex

Red   Green   Blue

| 0 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 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 | 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 …

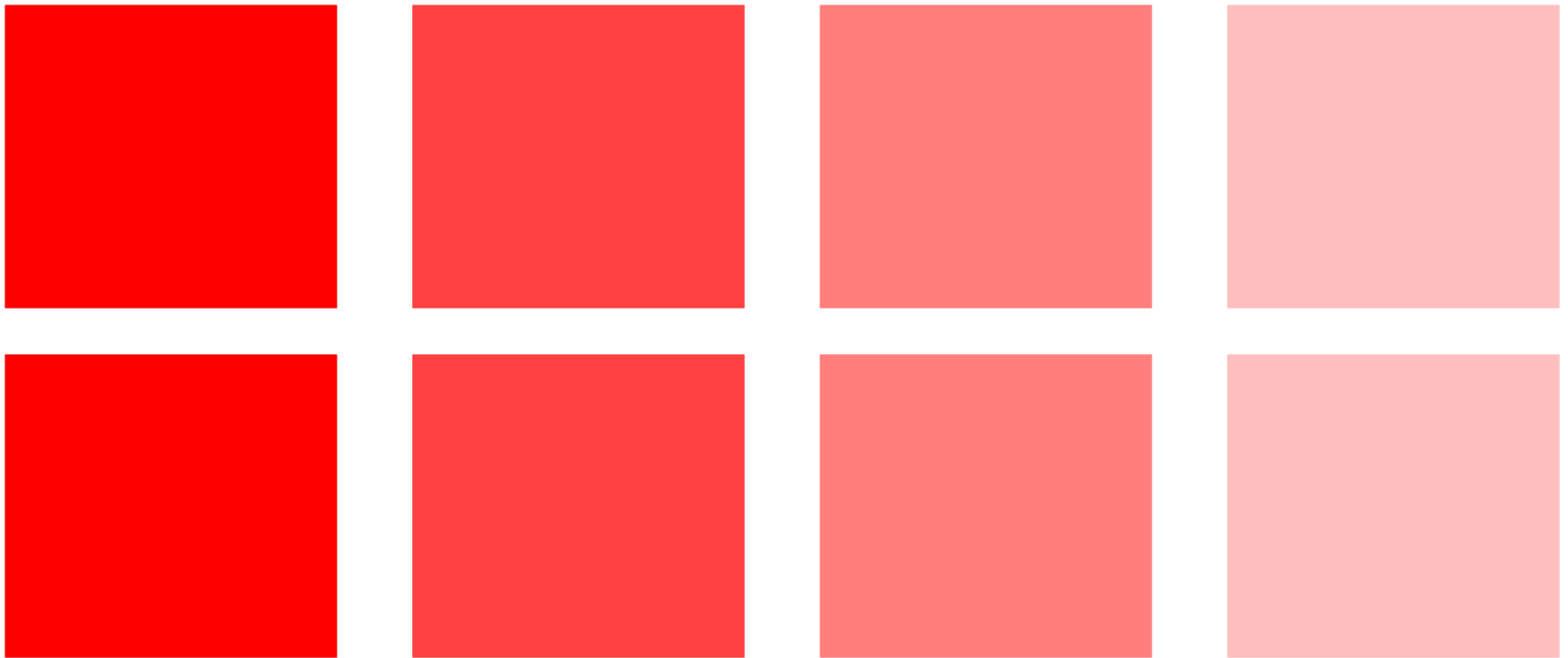| Alpha	Red	Green	Blue
1 0 0 0 0 0 0 0	0 0 1 1 0 1 1 0	1 1 1 1 0 0 0 1	0 0 1 1 0 1 1 0

80 36 F1 36

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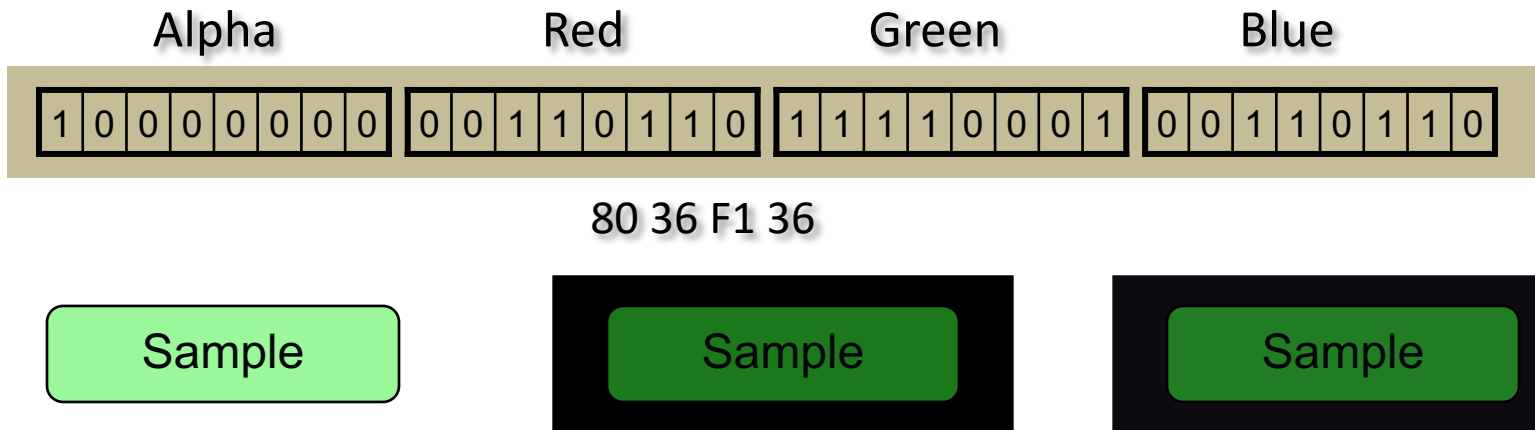
- Alpha controls blending
  - Alpha equals zero means transparent
  - Alpha equals one (255) completely covers
  - Alpha equal one half (127) is 50/50 mix

Color Temperature
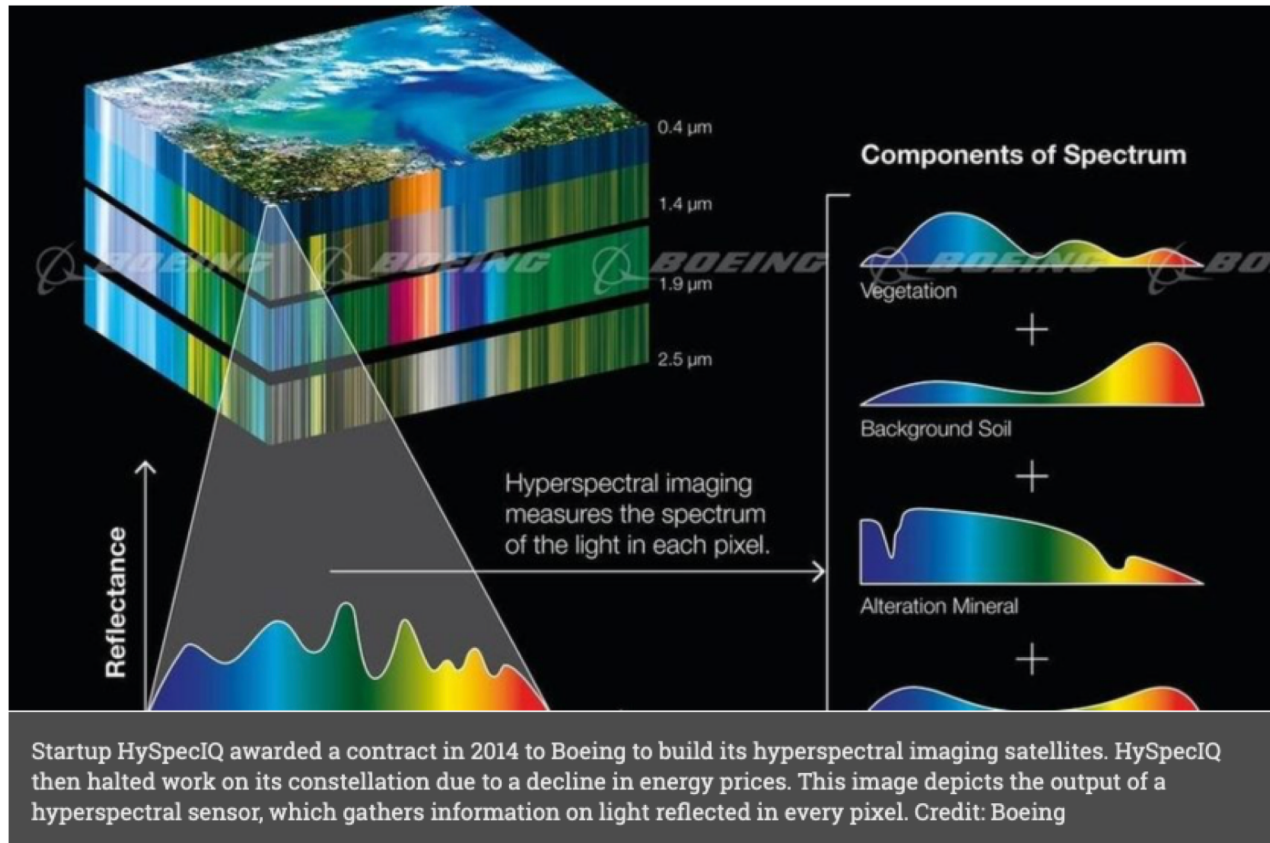
Examples of Blending

What About HDR

HDR … High Dymanic 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
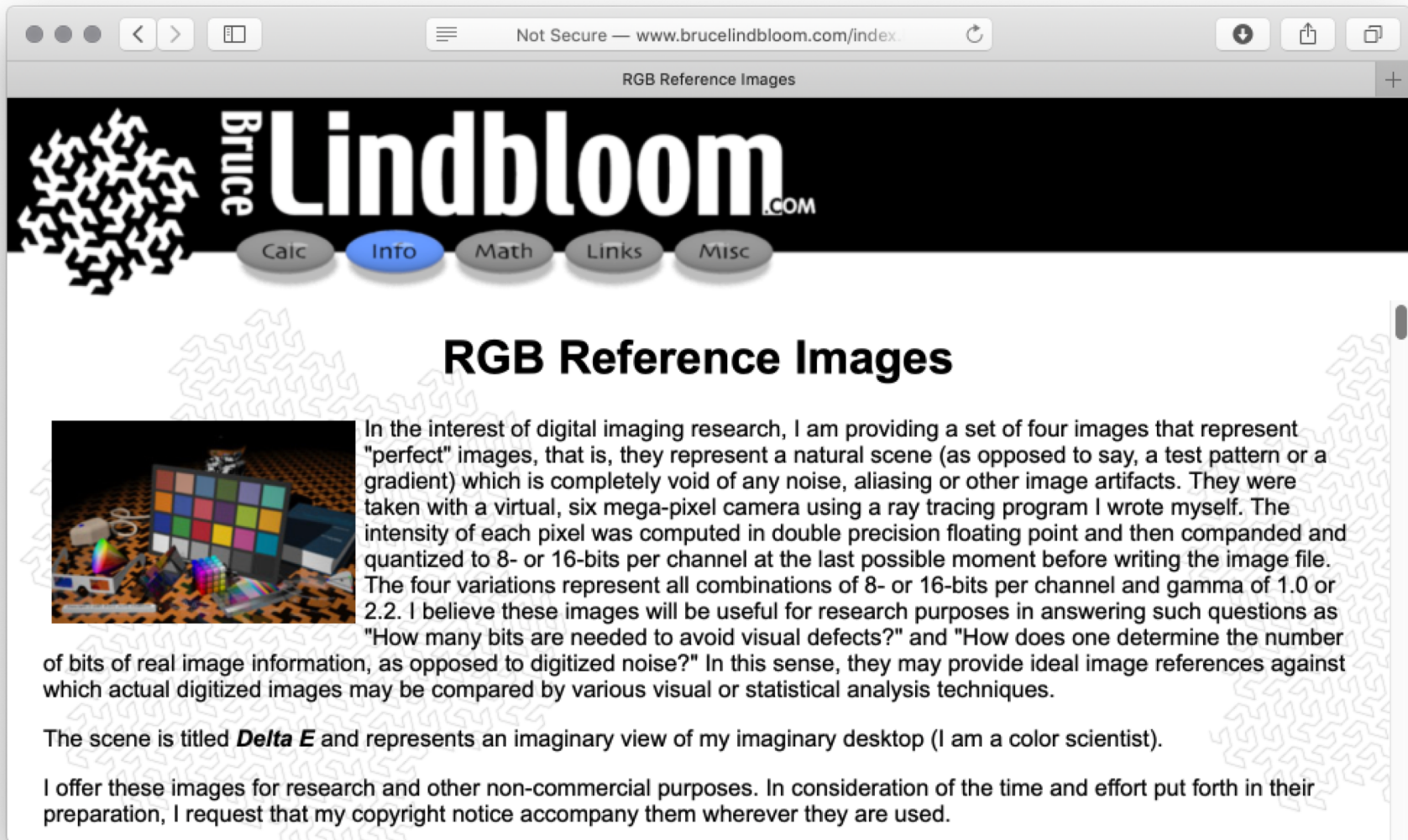 - 10 bits per channel?

Hyperspectral Satellite

https://spacenews.com/hypersat-funds/
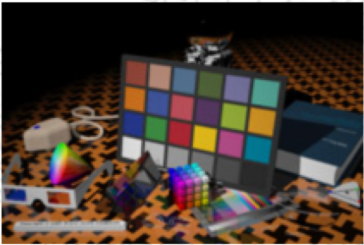
Sixteen Bits of Color

Not Secure — www.brucelindbloom.com/index.

RGB Reference Images

Bruce Lindbloom.com

Calc Info Math Links Misc
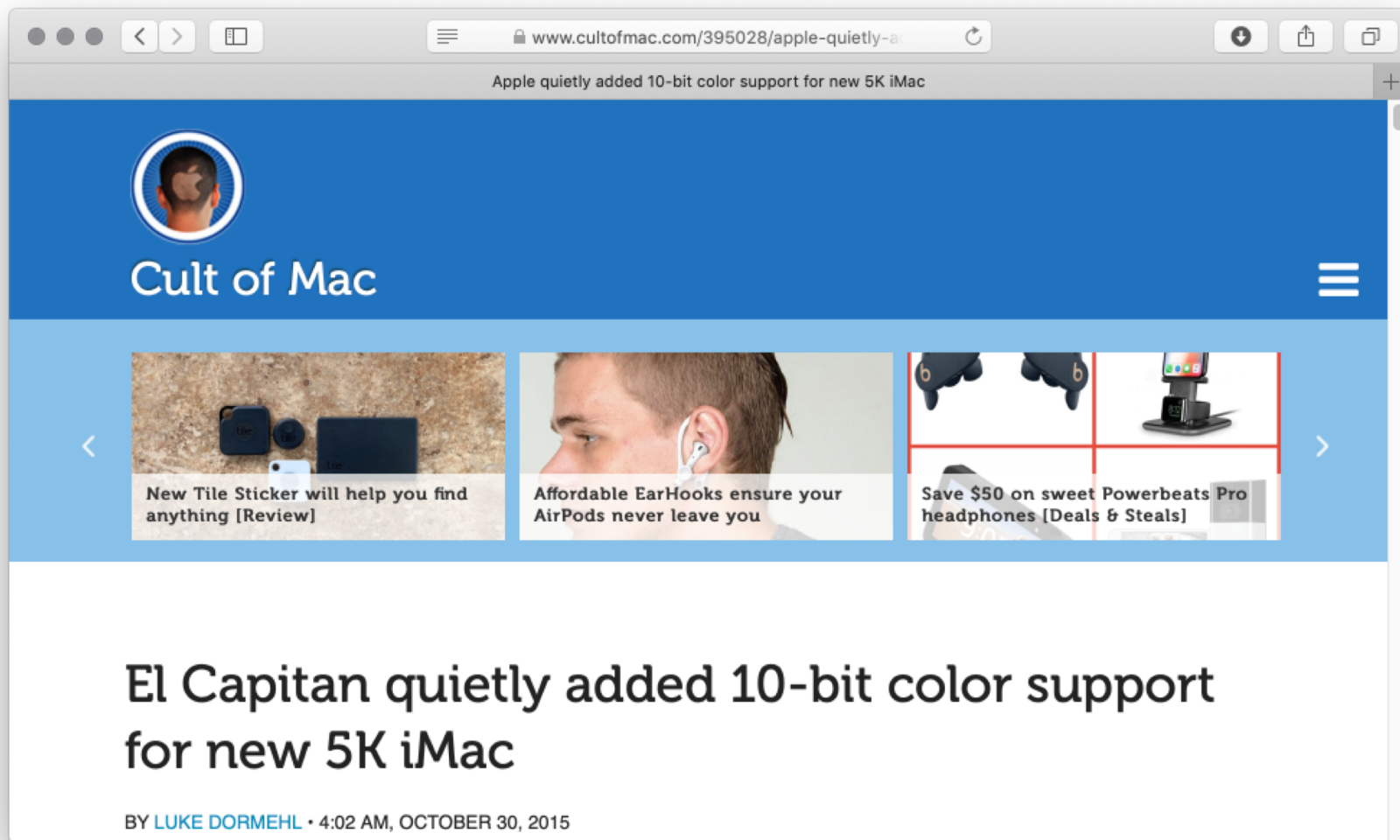
RGB Reference Images

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

CSU CS410 Fall 2019, © Ross Beveridge

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

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