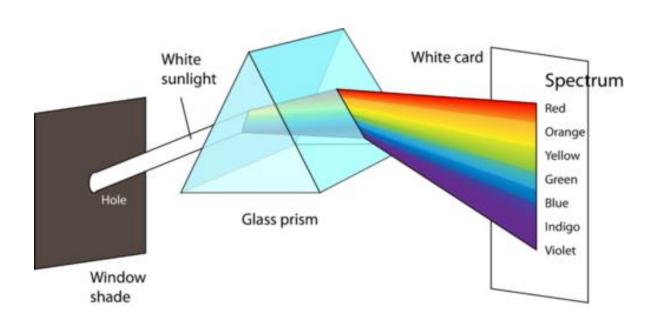


## What is Color?

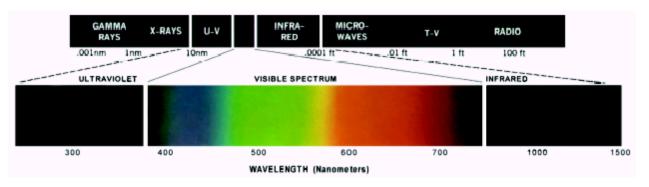
Physical Phenomenon

Physiopsychological Phenomenon

# Color as a Physical Phenomenon



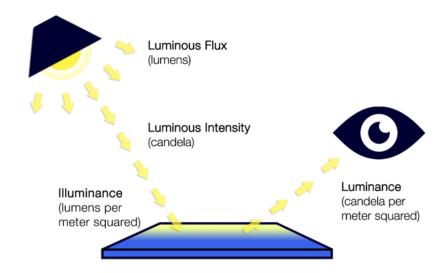
# Color as a Physical Phenomenon



**FIGURE 6.2** Wavelengths comprising the visible range of the electromagnetic spectrum. (Courtesy of the General Electric Co., Lamp Business Division.)

# Physical Quantities

- Radiance: Total amount of energy flow from the light source, measured in watts (W)
- Luminance: amount of energy an observer perceives from a light source, measured in candela/m<sup>2</sup>
  - Far infrared light: high radiance, but 0 luminance
- Brightness: <u>subjective</u> descriptor that is hard to measure, (similar to the achromatic notion of intensity)



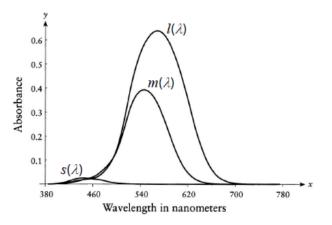
## What is Color?

Physical Phenomenon

Physiopsychological Phenomenon

# **Biology of Color Vision**

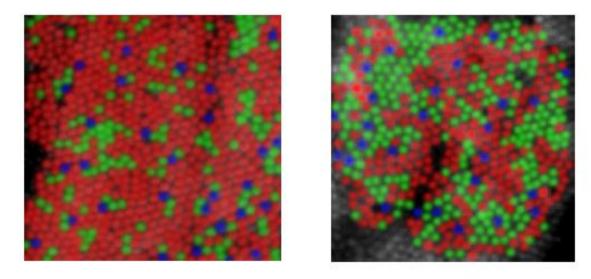
Cones come in three varieties: L, M, and S.



Cone photopigment absorption (Glassner, 1.1)

Cones are active under high light levels, i.e., they are responsible for **photopic** vision.

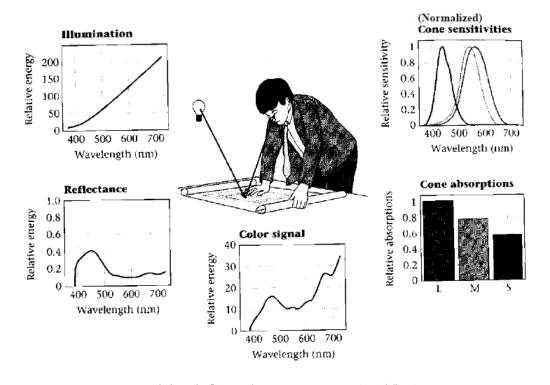
## Cone distribution



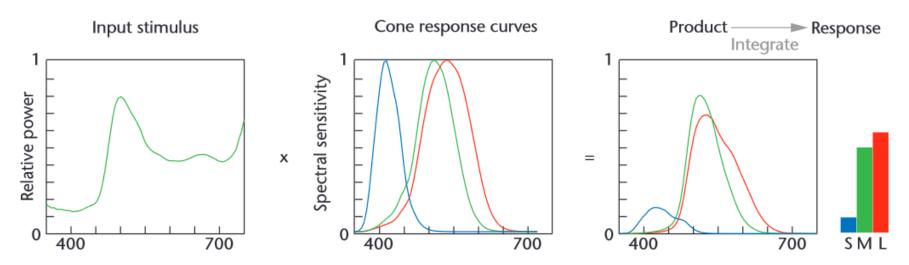
Here are images of near-fovea regions for two different human subjects, with colors to indicate the L (red), M (green) and S (blue) cones:

Remarkably, both subjects have normal color vision!

# Light source vs. reflected light



### Color signal to the brain

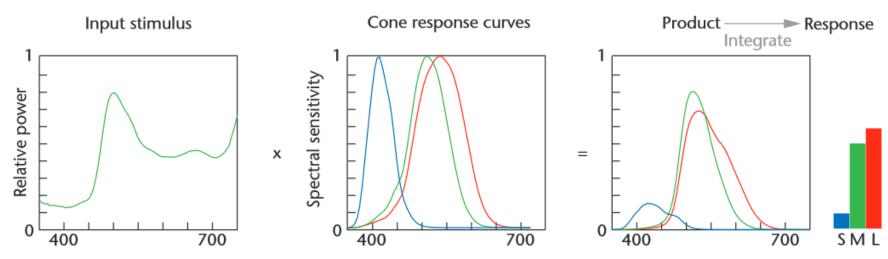


Note that intensity is a weighted function of the r, g, b values.

The human eye doesn't weight each component identically!

intensity = 0.299\*Red + 0.587\*Green + 0.144\*Blue

### Color signal to the brain



"... the Rays to speak properly are not coloured. In them there is nothing else than a certain Power and Disposition to stir up a Sensation of this or that Colour." - Isaac Newton, *Opticks*, 1704

- The perception of colour is an entirely arbitrary creation of our nervous system
- It is not contained in the wavelengths themselves



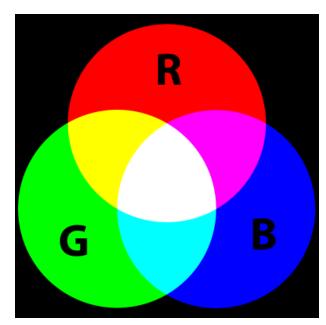
QuotesIdeas.com

The Matrix

### Primary Colors (color as three numbers)

- Additive (CRT displays, projectors etc.)
  - Combining red, green and blue light produces lighter colors, offering a good contrast to dark screens.
  - (Usually) Combined on a surface which reflects all light that falls on it

Magenta = Red + Blue Cyan = Blue + Green Yellow = Green + Red







Mrs M - an English social worker, and the first known human "tetrachromat", discovered at Cambridge in 1993.

# ORDINARY PEOPLE SEE 5 COLORS IN THE RAINBOW can differentiate one million colors



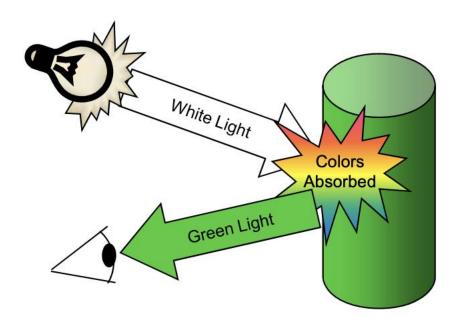


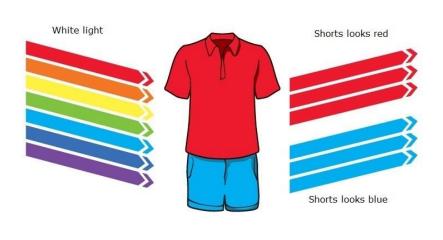
### Mantis shrimp 12 primary color receptors



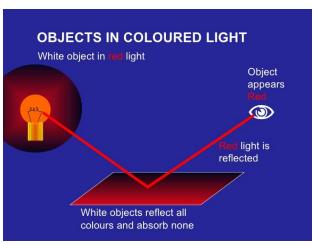
## 'Perceived' color

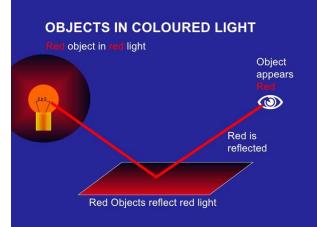
- Color is determined by nature of light reflected from an object
- E.g. green object reflects light from 500-570nm wavelength, absorbs other wavelengths

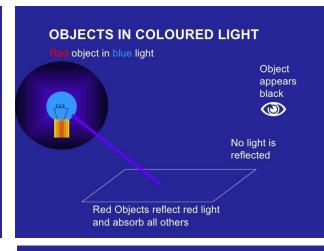


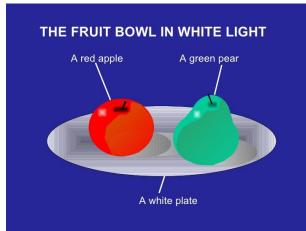


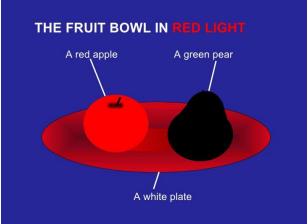
# Perceived Color = f(Light, Object)

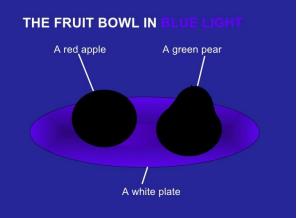














Full color







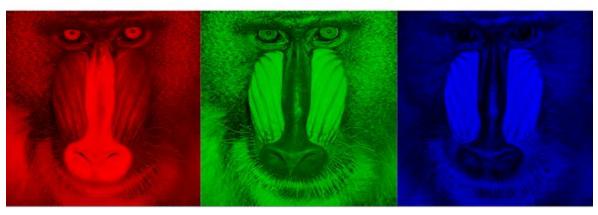
Red

Green

Blue

### **RGB** channels

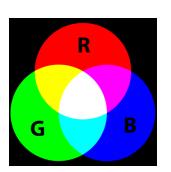


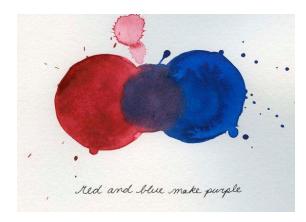


## **Primary Colors**

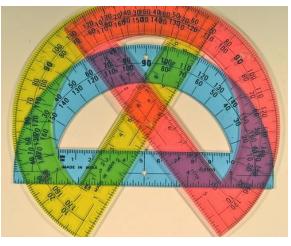
#### Subtractive

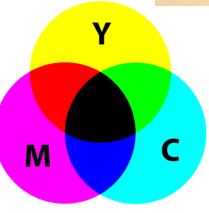
- Paints, Printing
- Starting with white paper, each addition of a colored ink "subtracts" available color from the starting medium.
- For pure white , leave the paper unprinted (nothing can be whiter than the paper it is printed upon).

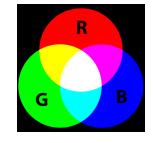


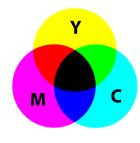


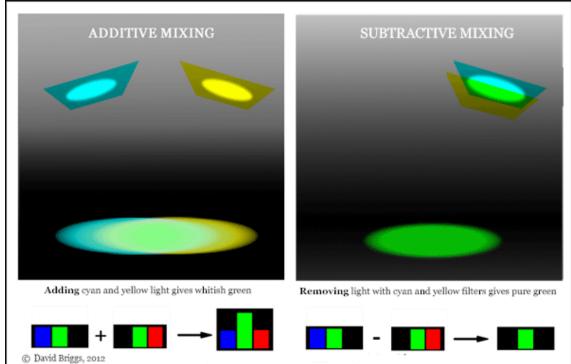
#### Viewed under white light

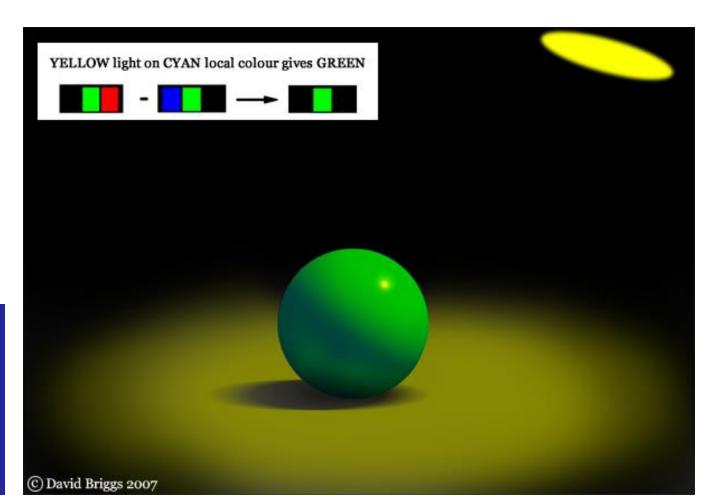


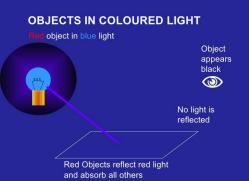






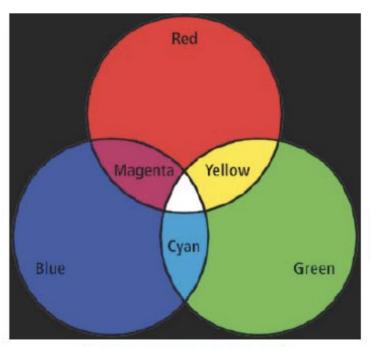




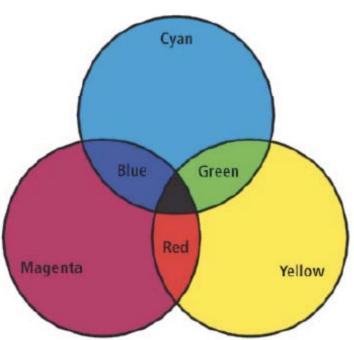


## Additive

## Subtractive



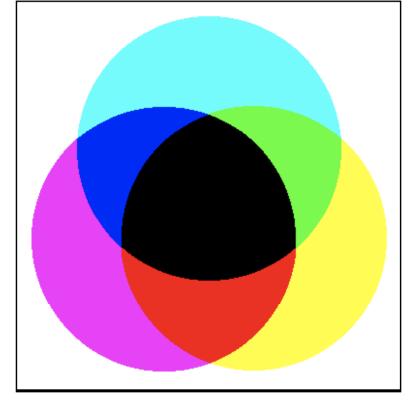
Magenta = Red + Blue Cyan = Blue + Green Yellow = Green + Red



Magenta = White - Green Cyan = White - Red Yellow = White - Blue







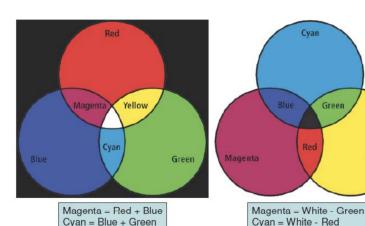
Passive displays, such as color inkjet printers, **absorb** light instead of emitting it. Combinations of **cyan**, **magenta** and **yellow** inks are used. This is a **subtractive** color model.

# Why CMYK in printers

- RGB colors already dark to begin with.
- Layering RGB inks produces even darker colors.
- Inks only <u>absorb, reflect colors in</u> <u>the light spectrum</u>, not emit them.
- This makes it difficult to produce lighter colors (yellow, lime green)



Yellow = White - Blue

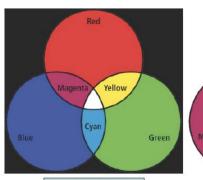


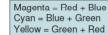
Yellow = Green + Red

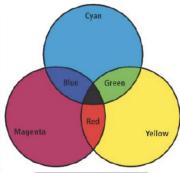
# Why CMYK in printers

- Cyan, Magenta, and Yellow are lighter than red, green, and blue.
- CMY cover most lighter color ranges quite easily compared to RGB.
- BUT CMY by itself will not be able to create very deep dark colors (e.g. "true black,")
- Black (designated "K" for "key color") is added to CMY to achieve a much wider range of colors.



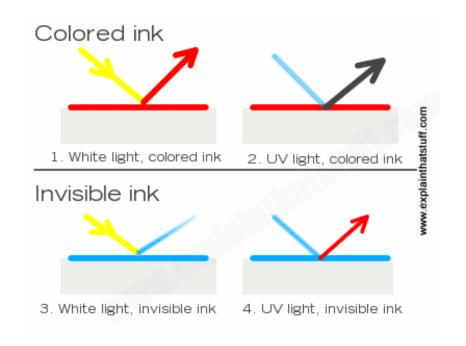






Magenta = White - Green Cyan = White - Red Yellow = White - Blue

#### White light shown as yellow for display

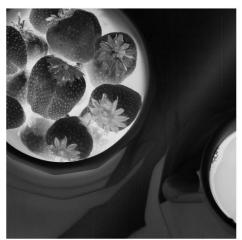




The Da Vinci Code

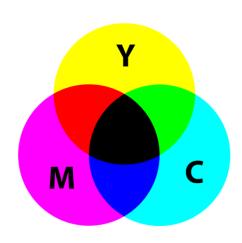


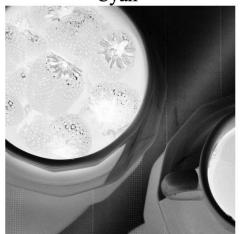
Full color



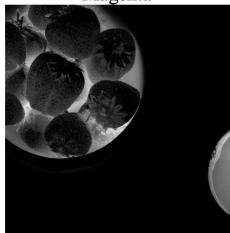
Cyan







Yellow



Black



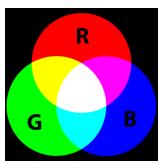
Full color

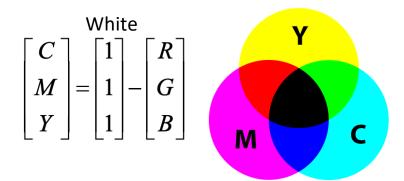


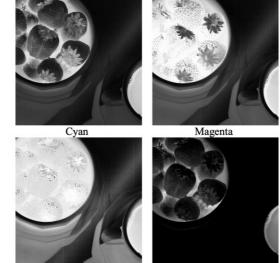




Red Green

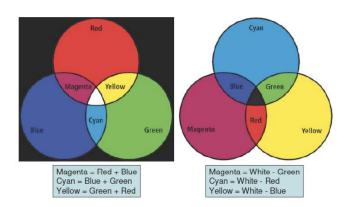


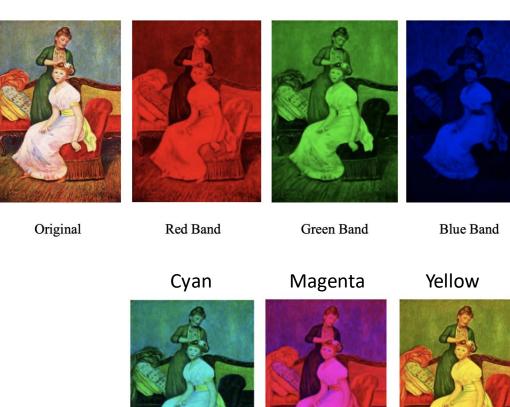




Yellow

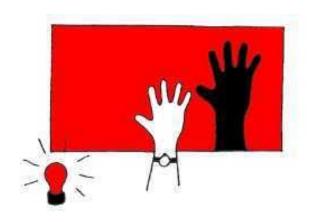
Black

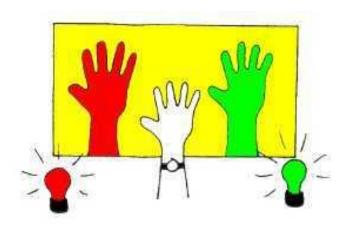






### **RGB** and **CMY**





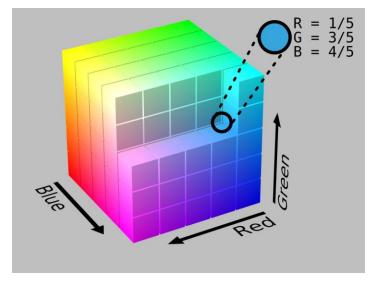


## **Color Models**

- RGB
- HSI / HSY
- CIE LAB

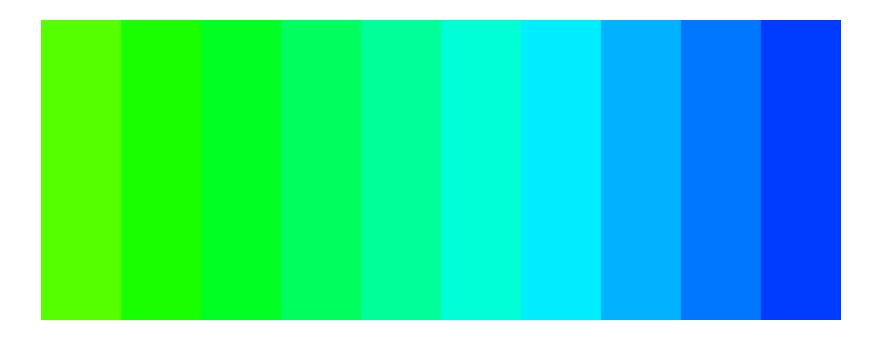
### RGB color space

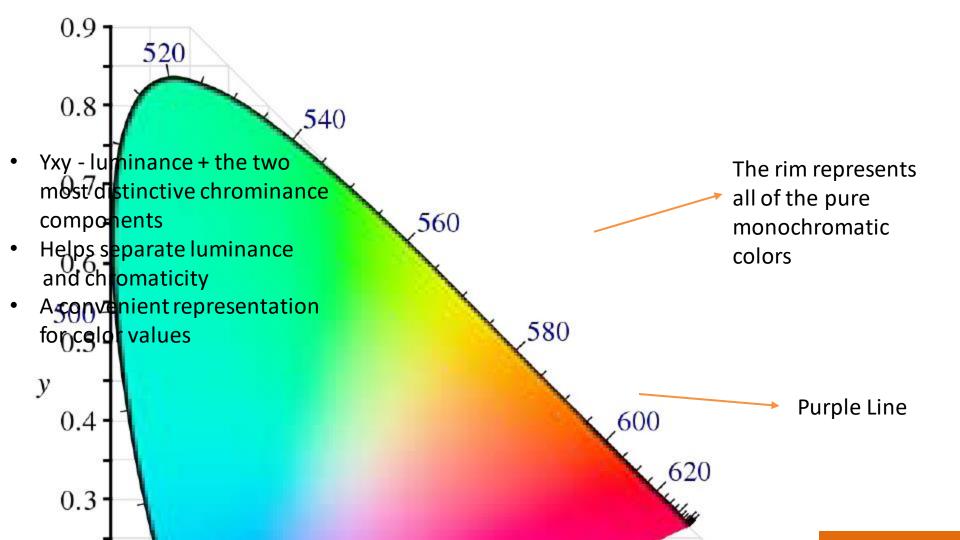
- Primary colors
- Additive color model  $f(x, y) = \alpha_1 R + \alpha_2 G + \alpha_3 B$
- Perceptually non uniform



Courtesy: wikipedia

# RGB: Non-Uniform Perceptual Space

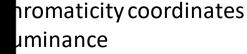




- Chromaticity coordinates:

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





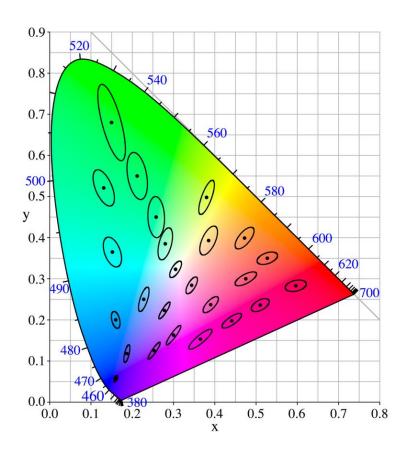
t its colour matching function exactly matches the eiency function for the human eye

Sum of these curves

610

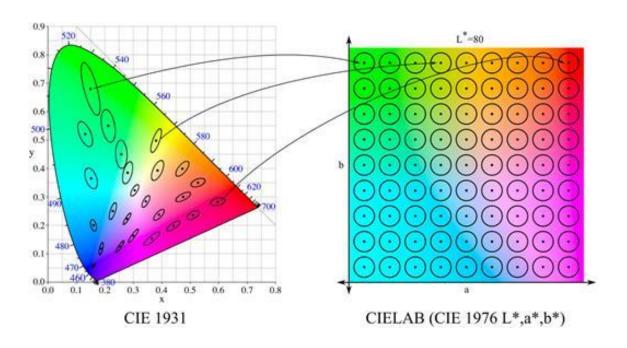
1931 2-degree Observer

### McAdam Ellipses



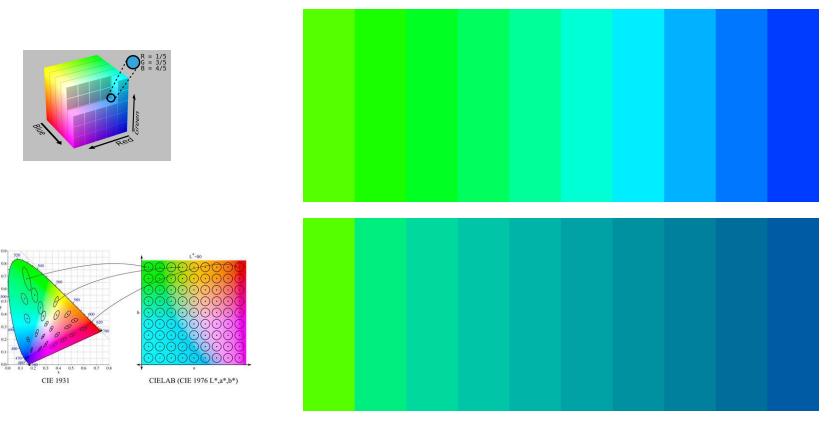
- McAdam ellipses refer to the region on a chromaticity diagram which contains all colors which are indistinguishable, to the average human eye, from the color at the center of the ellipse
- The contour of the ellipse represents the just noticeable differences of chromaticity

## CIE Lab color space



Ideal scenario

## Perceptually Uniform Color Spaces



https://matplotlib.org/3.1.1/tutorials/colors/colormaps.html