Color

Dr. Tushar Sandhan

Introduction

- Color of the Universe

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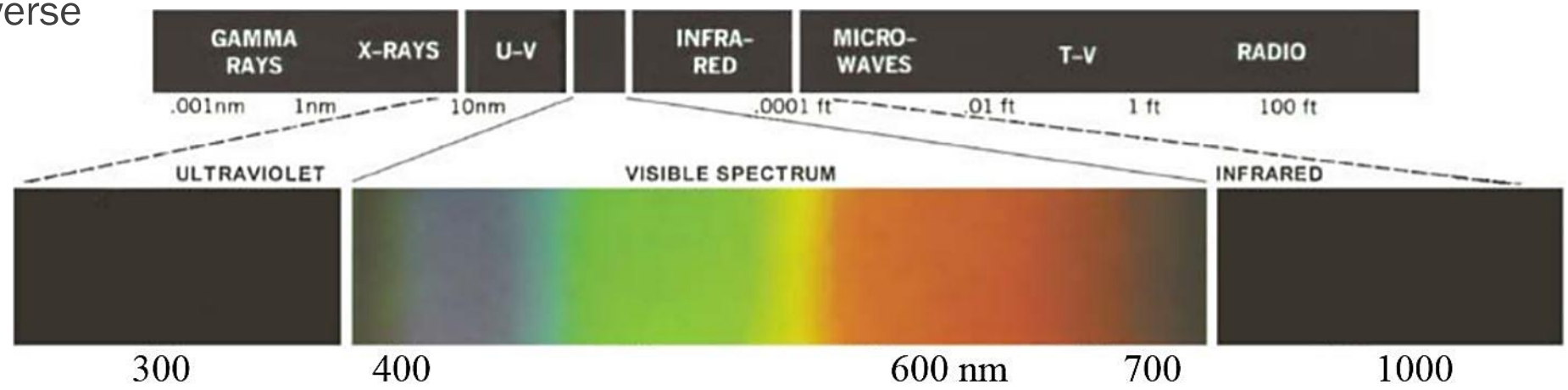

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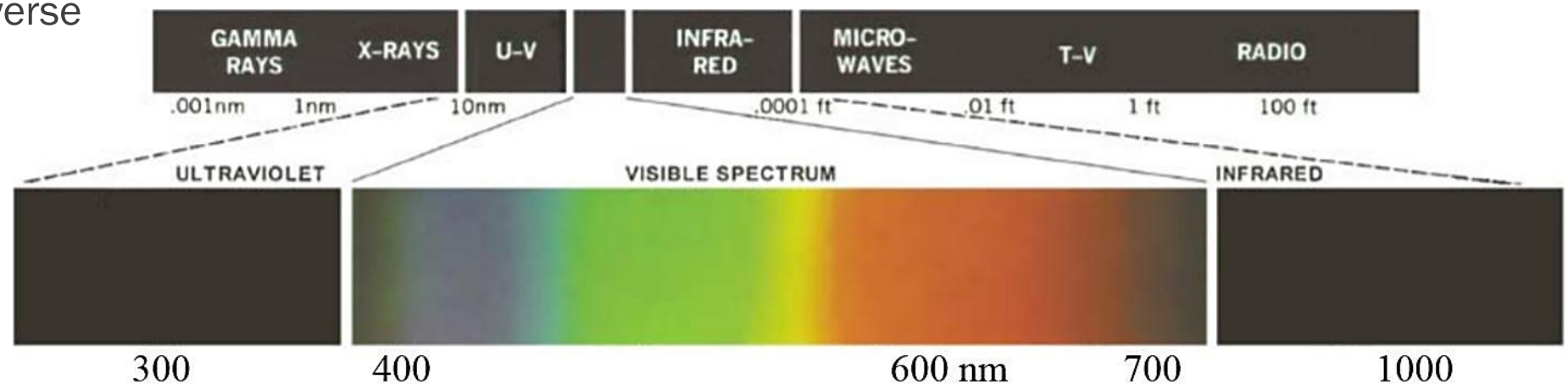
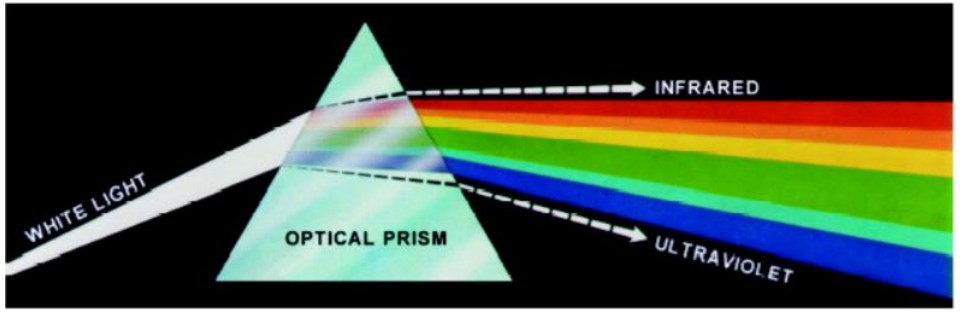
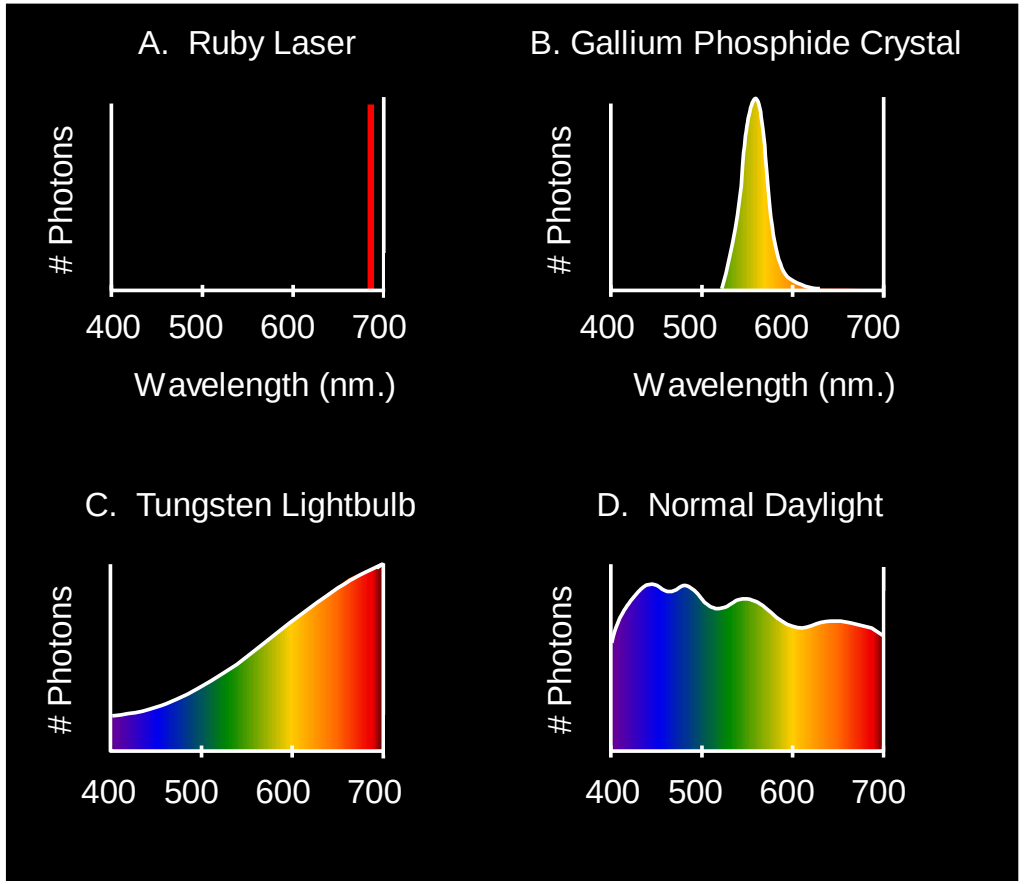


- Visible light (dispersion)



Spectra of objects

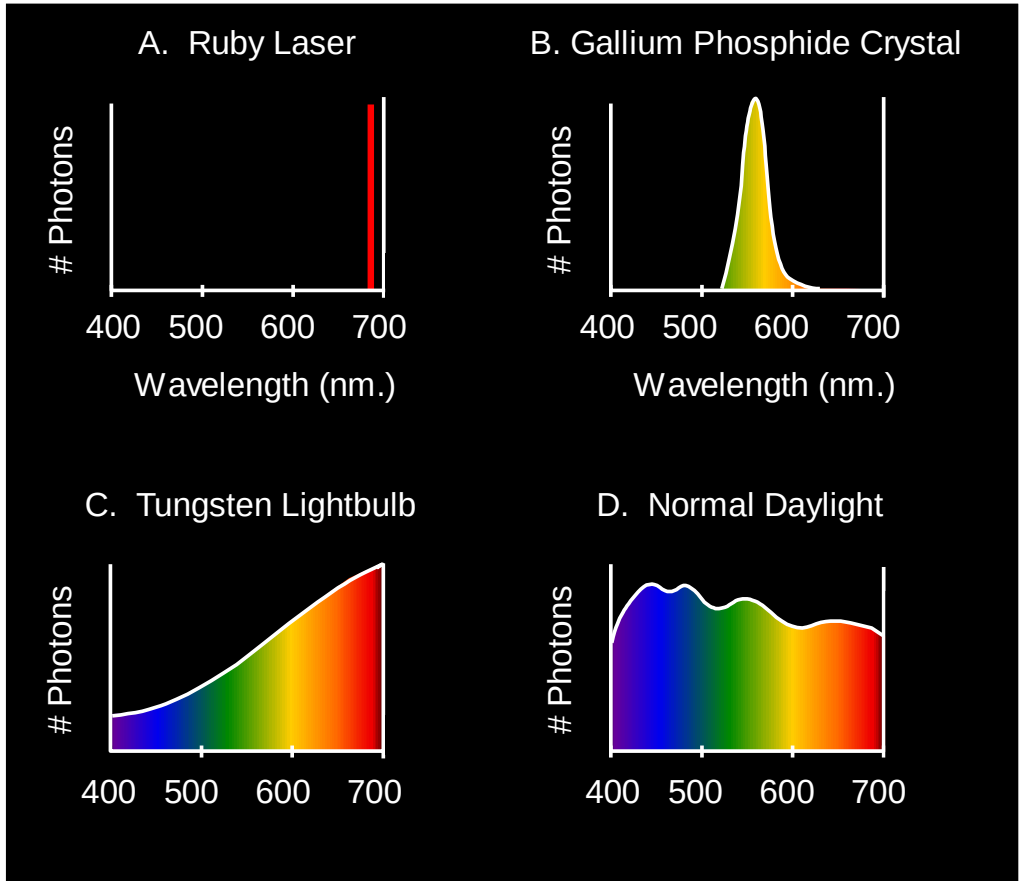
Light source spectra



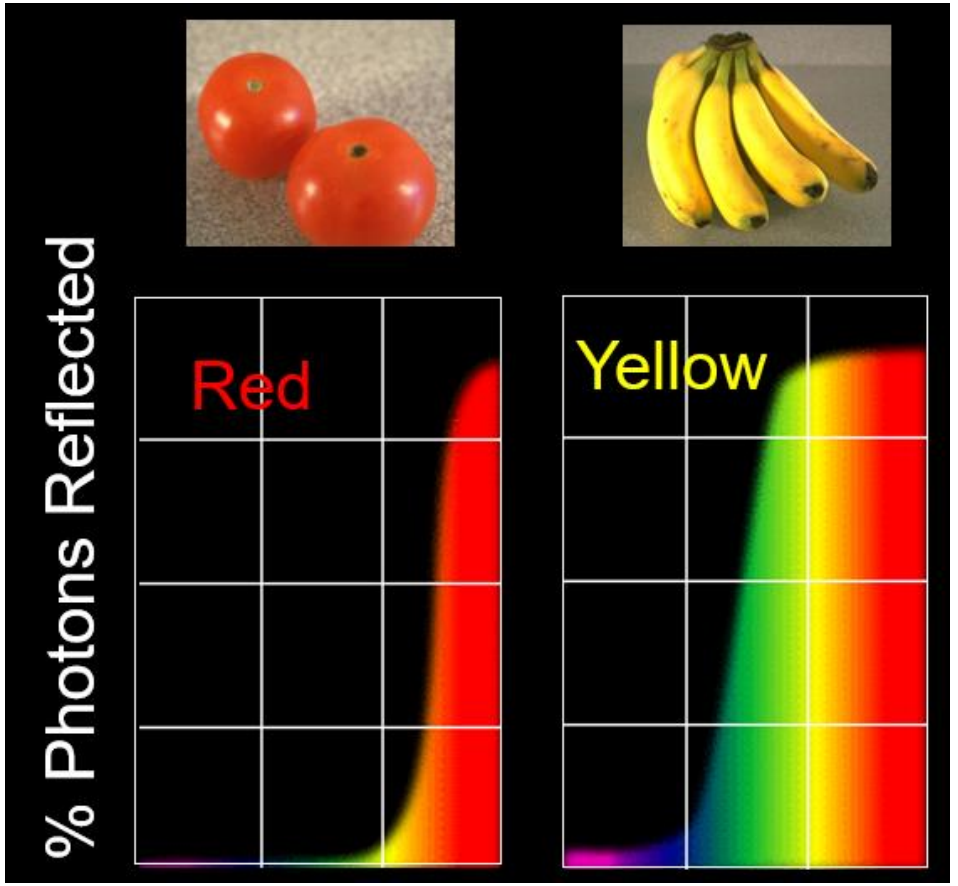
credit: E. Palmer

Spectra of objects

Light source spectra



Reflectance spectra of surfaces



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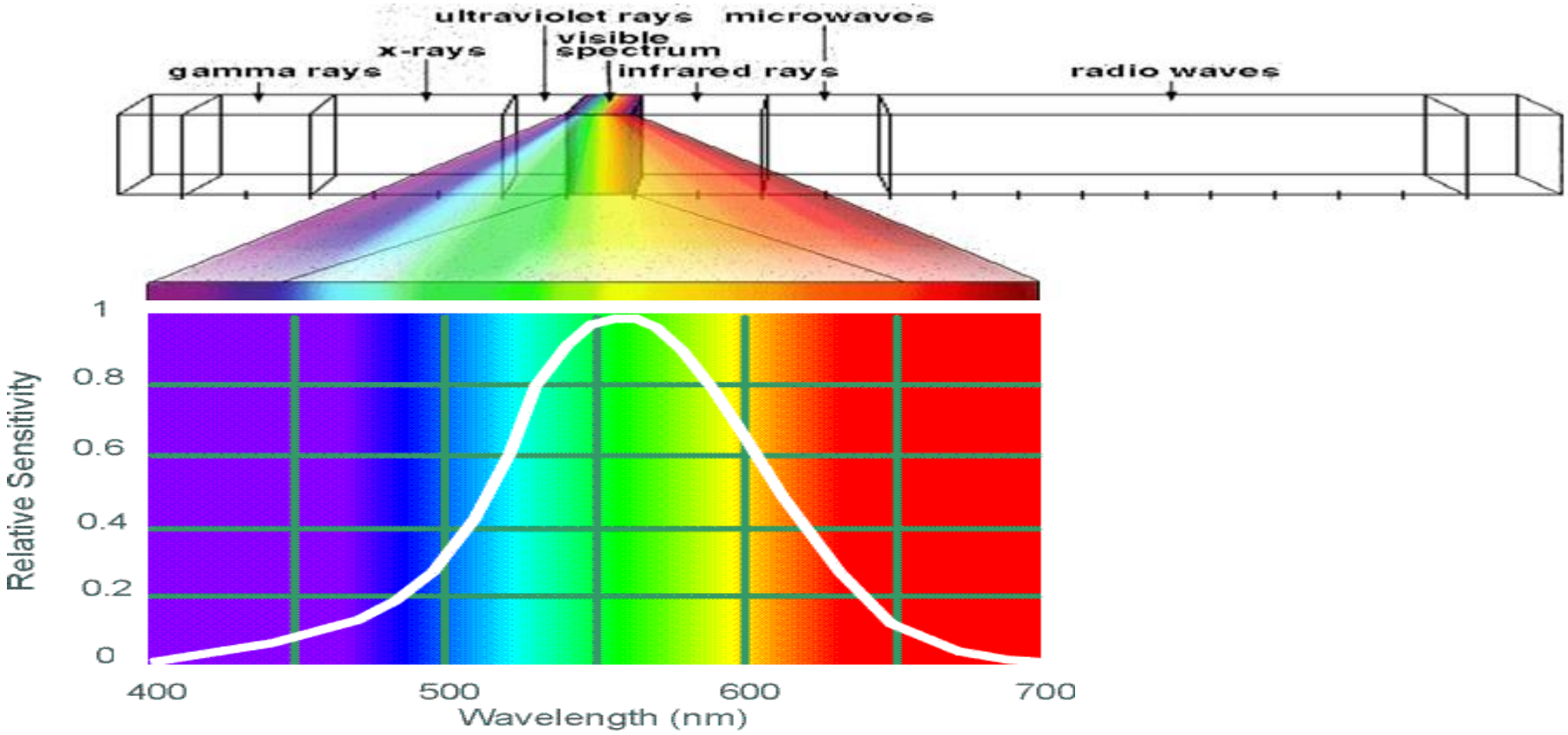
Color

- Human Luminance sensitivity



credit: Efros

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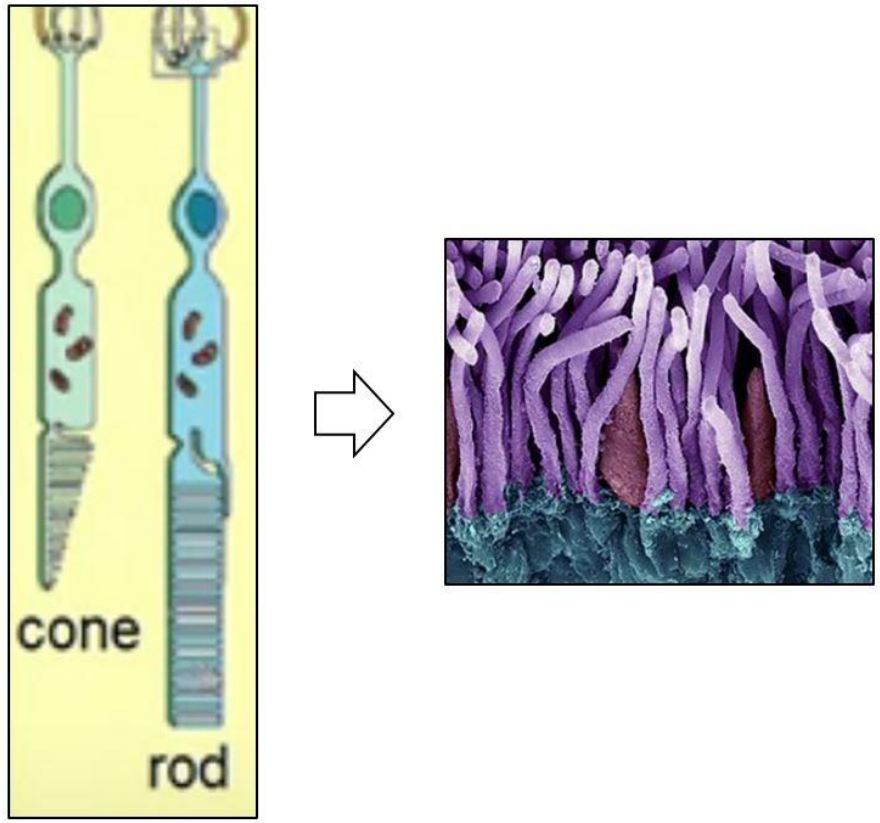
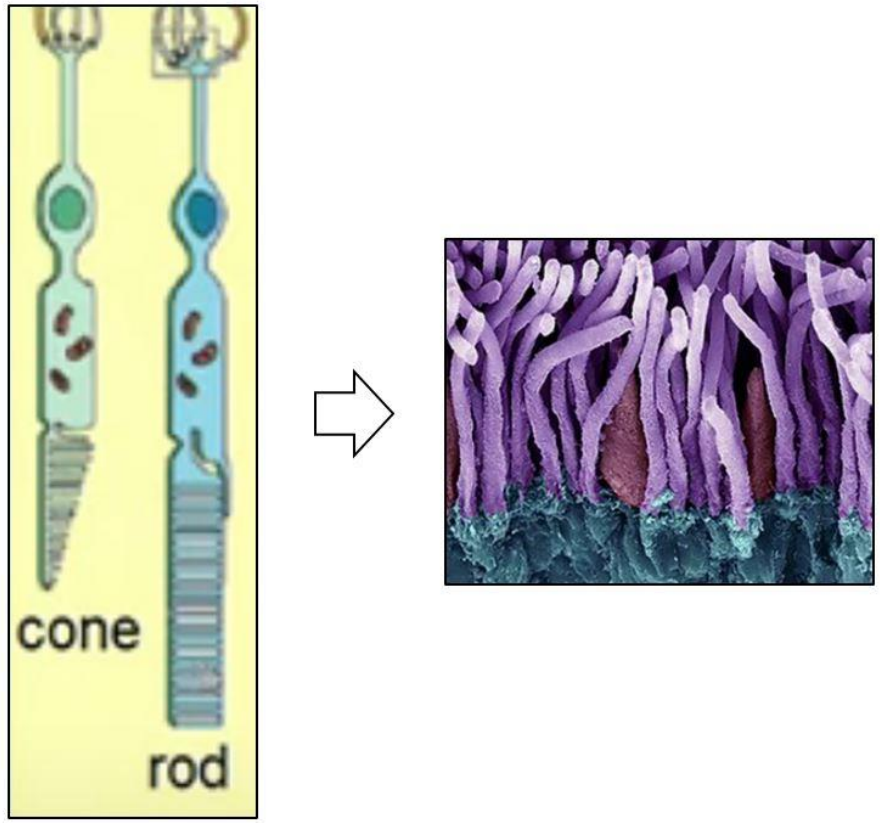


Color

- Light spectrum is continuous, then why are images RGB?

- Evolutionary cones (6 million)

- Characterization of cone cells & understanding visual process in the eye.
  - Ragnar Granit, Haldan Keffer Hartline and George Wald
  - Nobel Prize 1967



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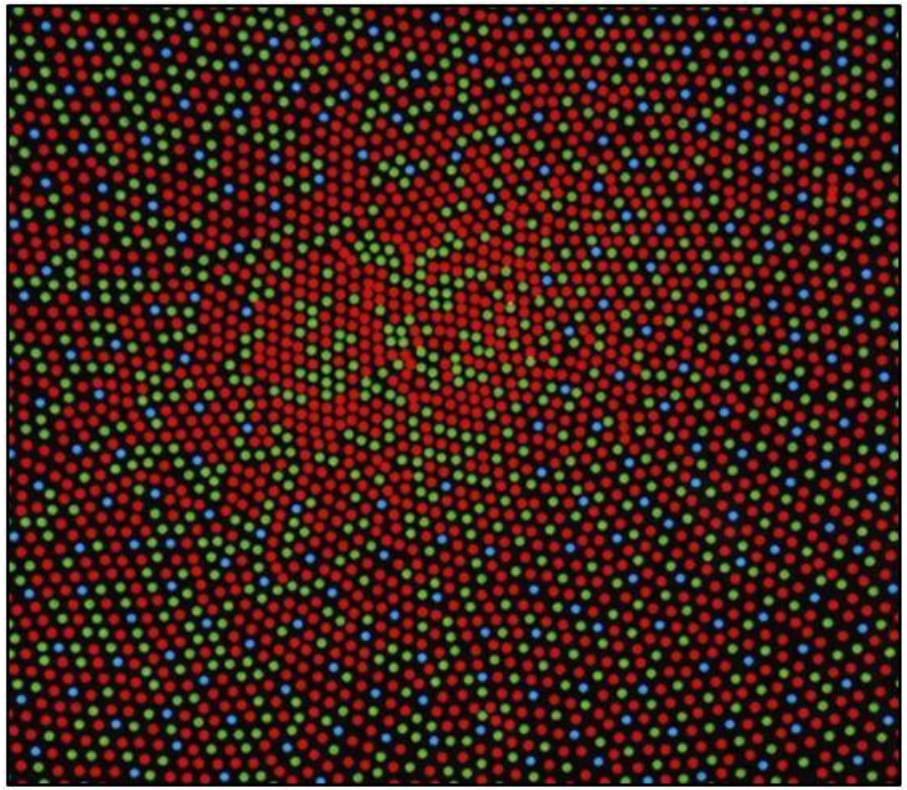

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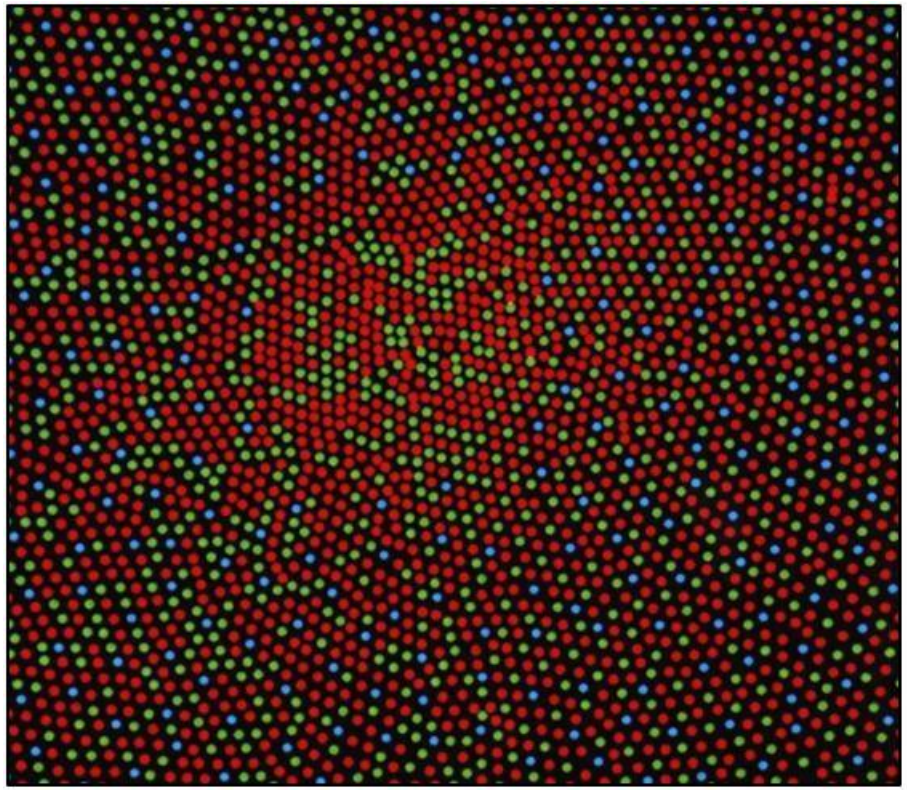

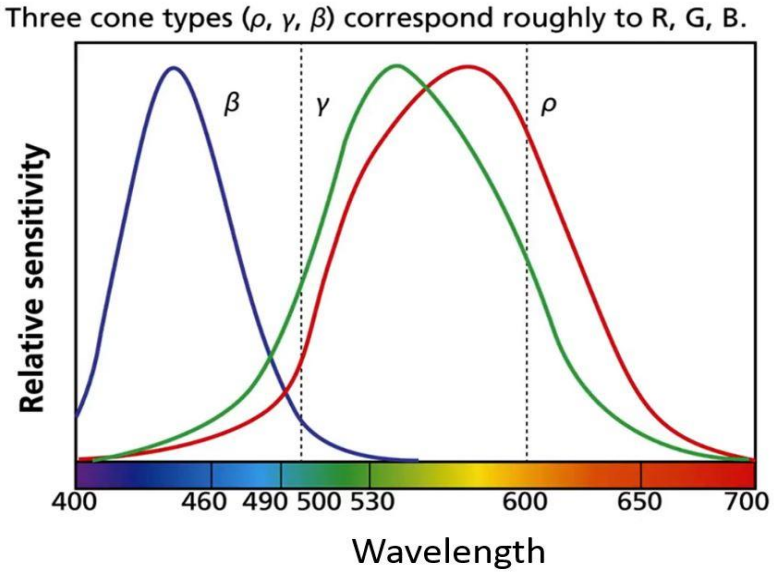

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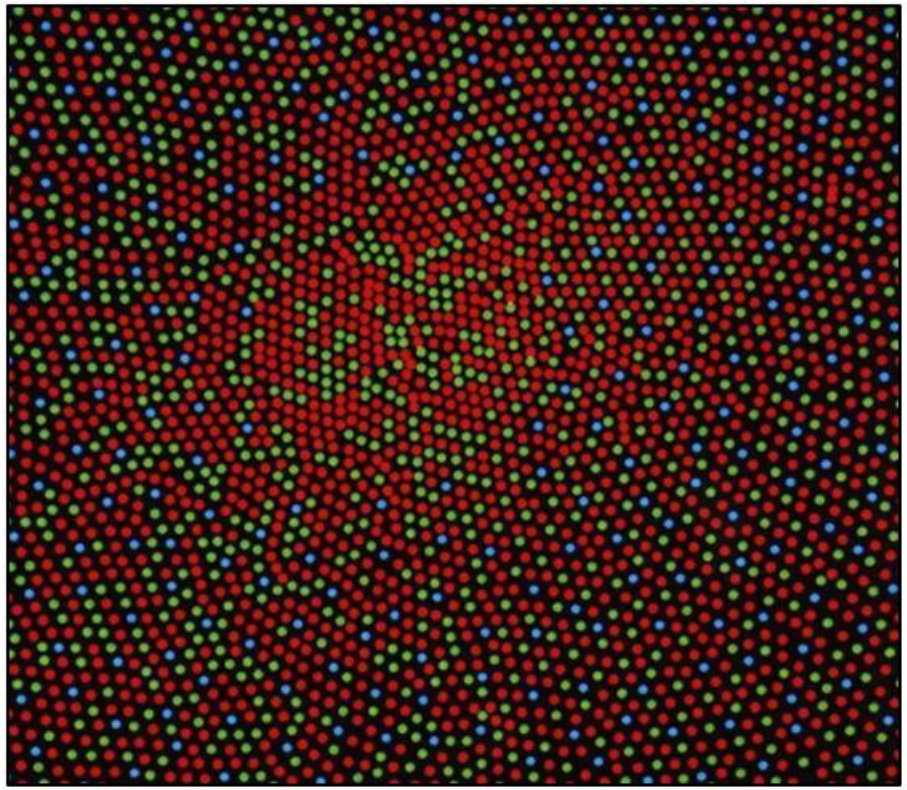
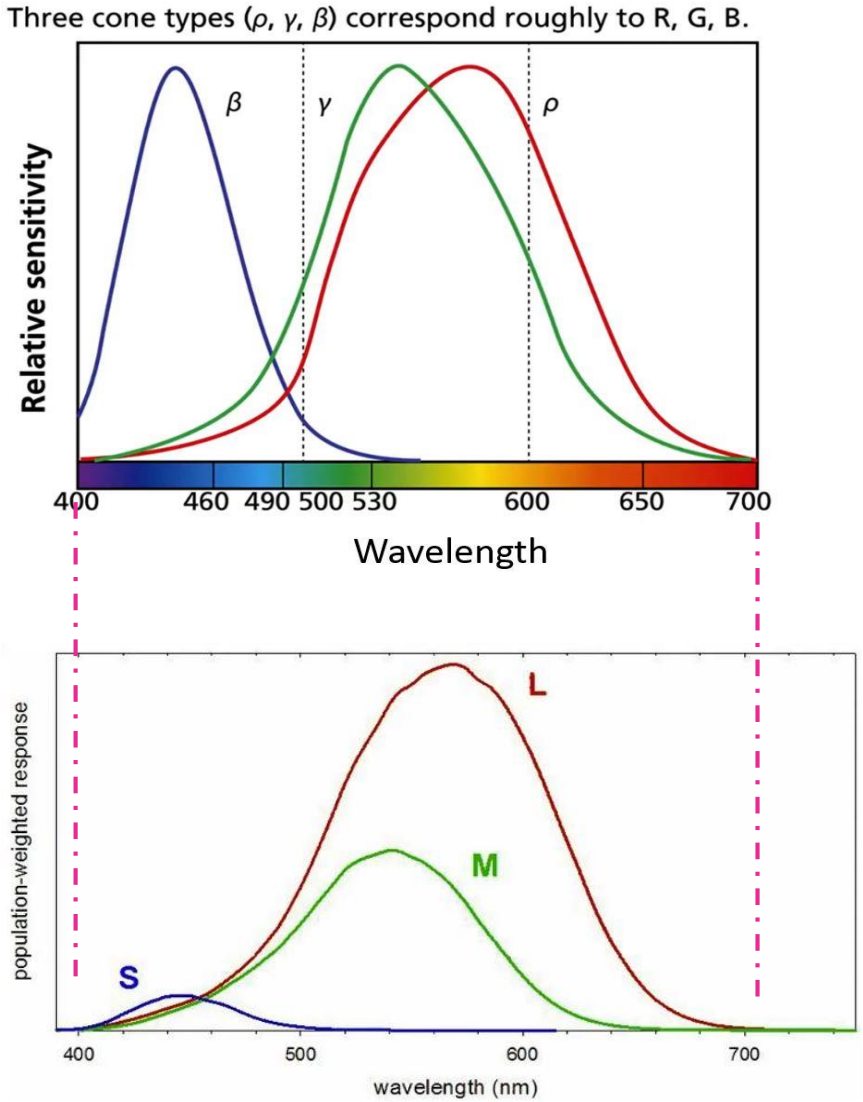
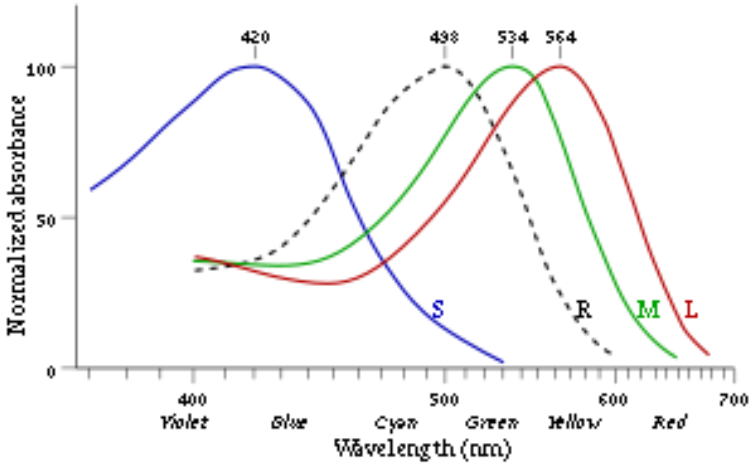




Color

- Cones (Long:L, Medium:M, Short:S) & Rods:R
- S: blue (most sensitive)
- M, L on chromosome X (some women are tetrachromatic)



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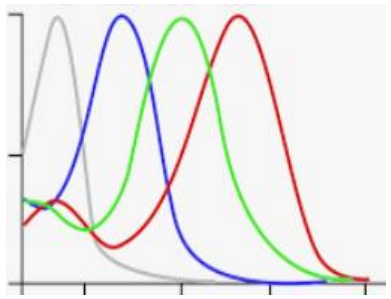

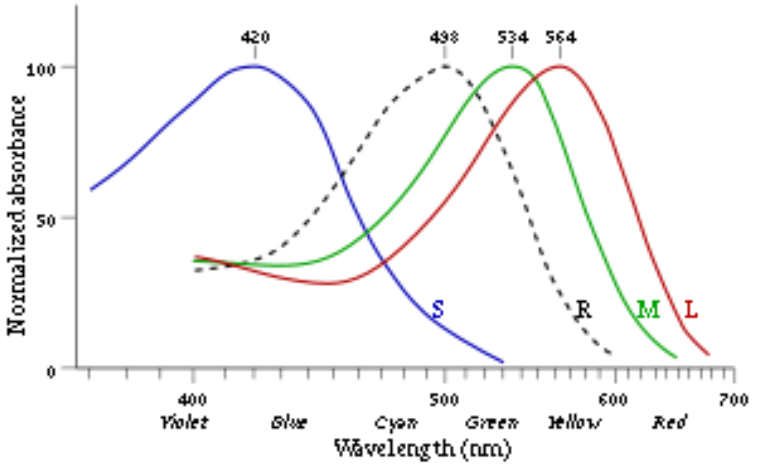

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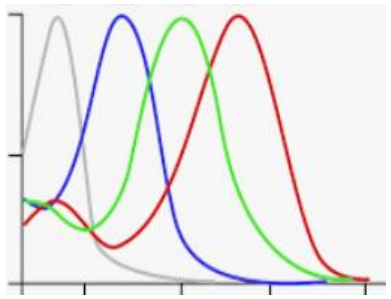

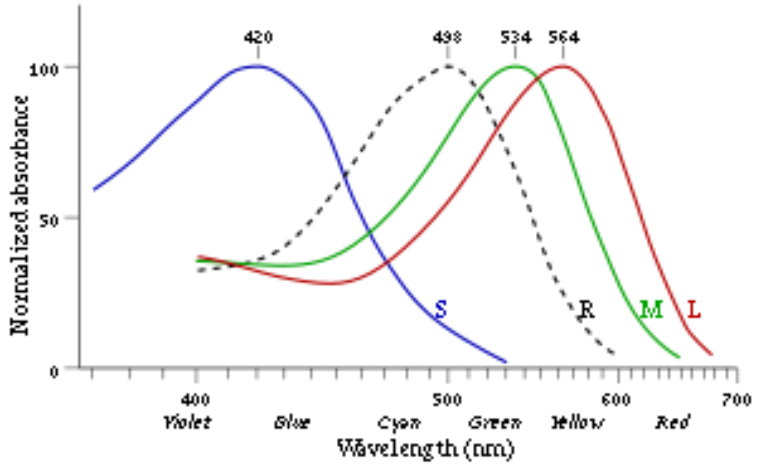

- Reptiles : 5 types of cones
- Mantis shrimp: 12 types of cones

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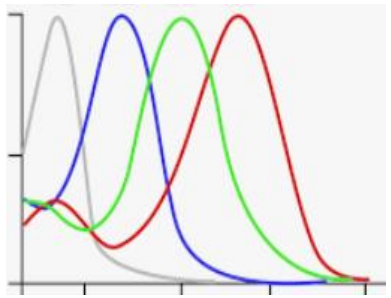

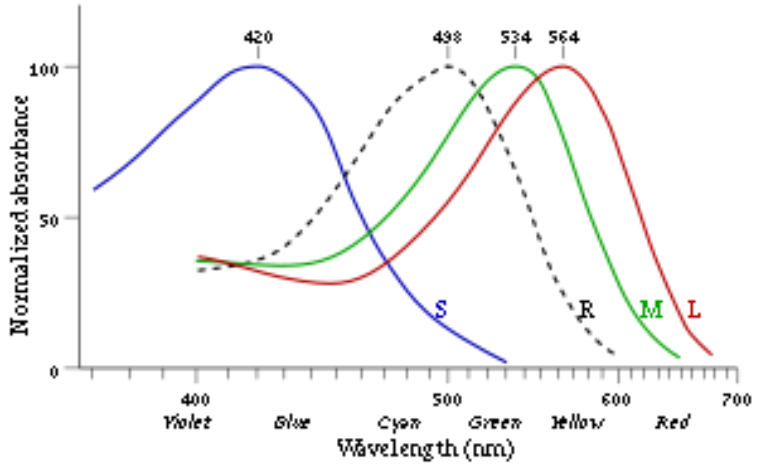

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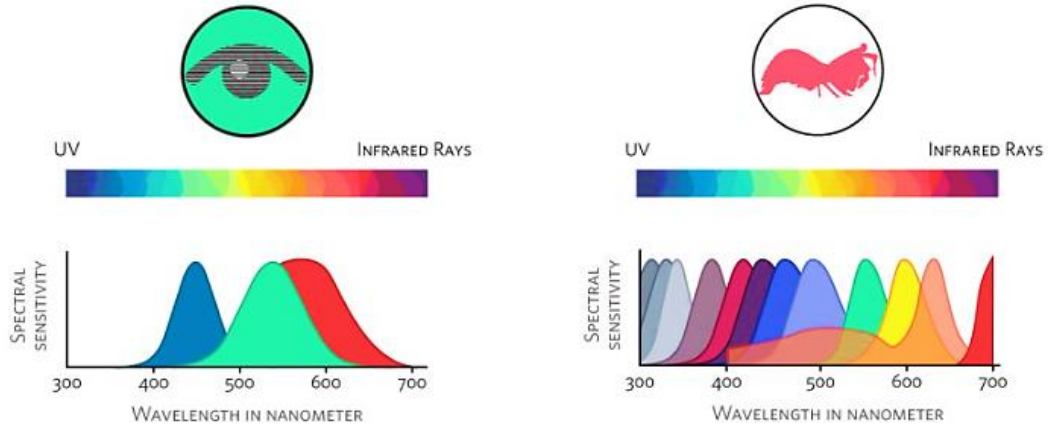

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- psychophysical: physiological sequence of sensory processing
- perceptual: cognitive representation of a physical reality

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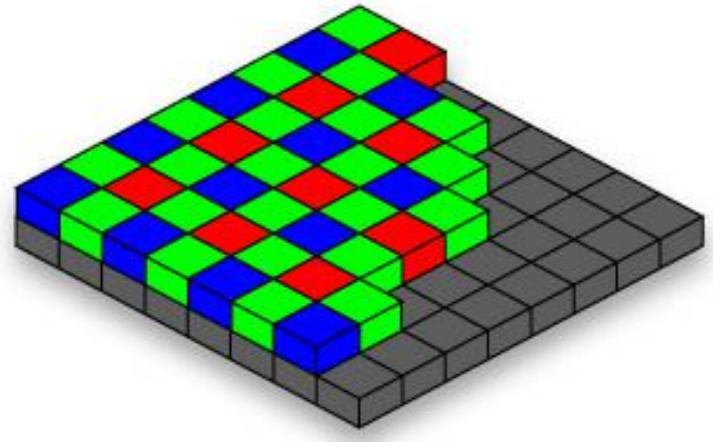
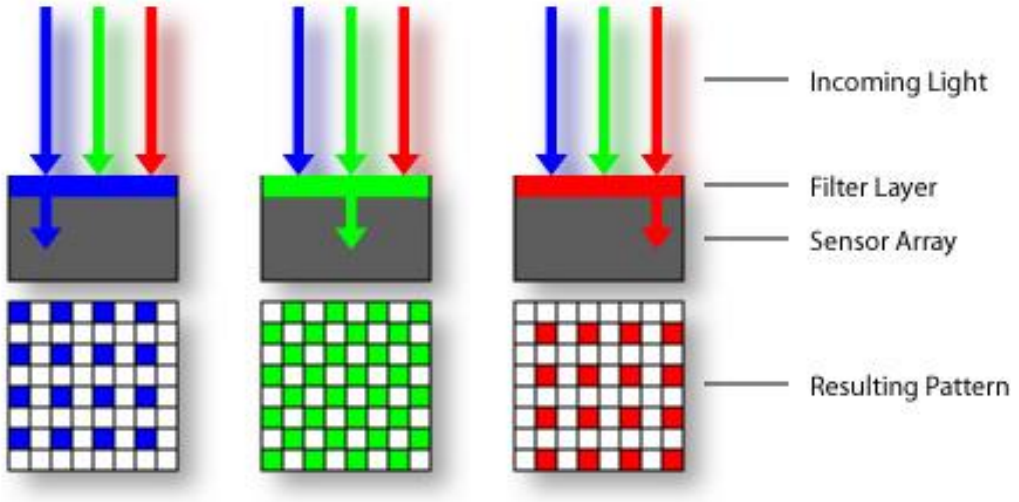
➢ Imagination of the illuminated retina!

Color

- Sensing



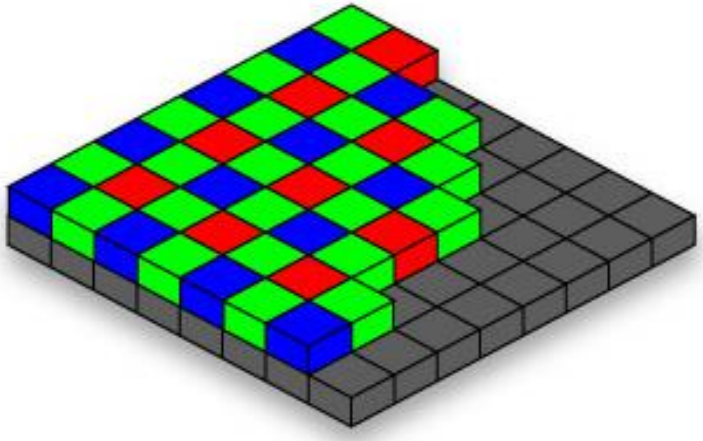
Bayer pattern



Color

- Sensing

Estimate the color



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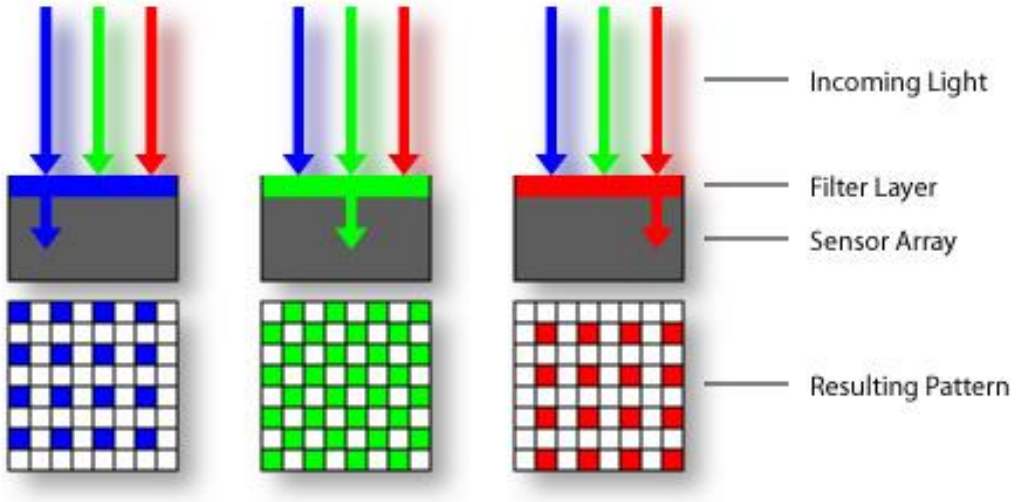

Color

- Representation
  - for graphics & displays
    - CIE chromaticity diagram
    - Commission Internationale de l'éclairage-1931
    - inks, displays, cameras
    - X – mix of RGB
    - Y – illuminance
    - Z – close to blue
  - for computational analysis
    - color spaces
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    - cone responses to XYZ mapping
    - LMS: cone responses of human eye
    - Z ←→ S
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    - X, Z - chromaticity

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$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 1.910\,20 & -1.112\,12 & 0.201\,91 \\ 0.370\,95 & 0.629\,05 & 0 \\ 0 & 0 & 1.000\,00 \end{bmatrix} \begin{bmatrix} L \\ M \\ S \end{bmatrix}_{\text{HPE}}$$

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  - concept of color for computations
    - brightness (white > grey)
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    - normalized function of all tristimulus values
    - Tristimulus: a color is represented by its trichromatic coefficients X, Y, Z

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

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

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

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    - Tristimulus: a color is represented by its trichromatic coefficients X, Y, Z
  - specifies how human eye will experience light with a given spectrum

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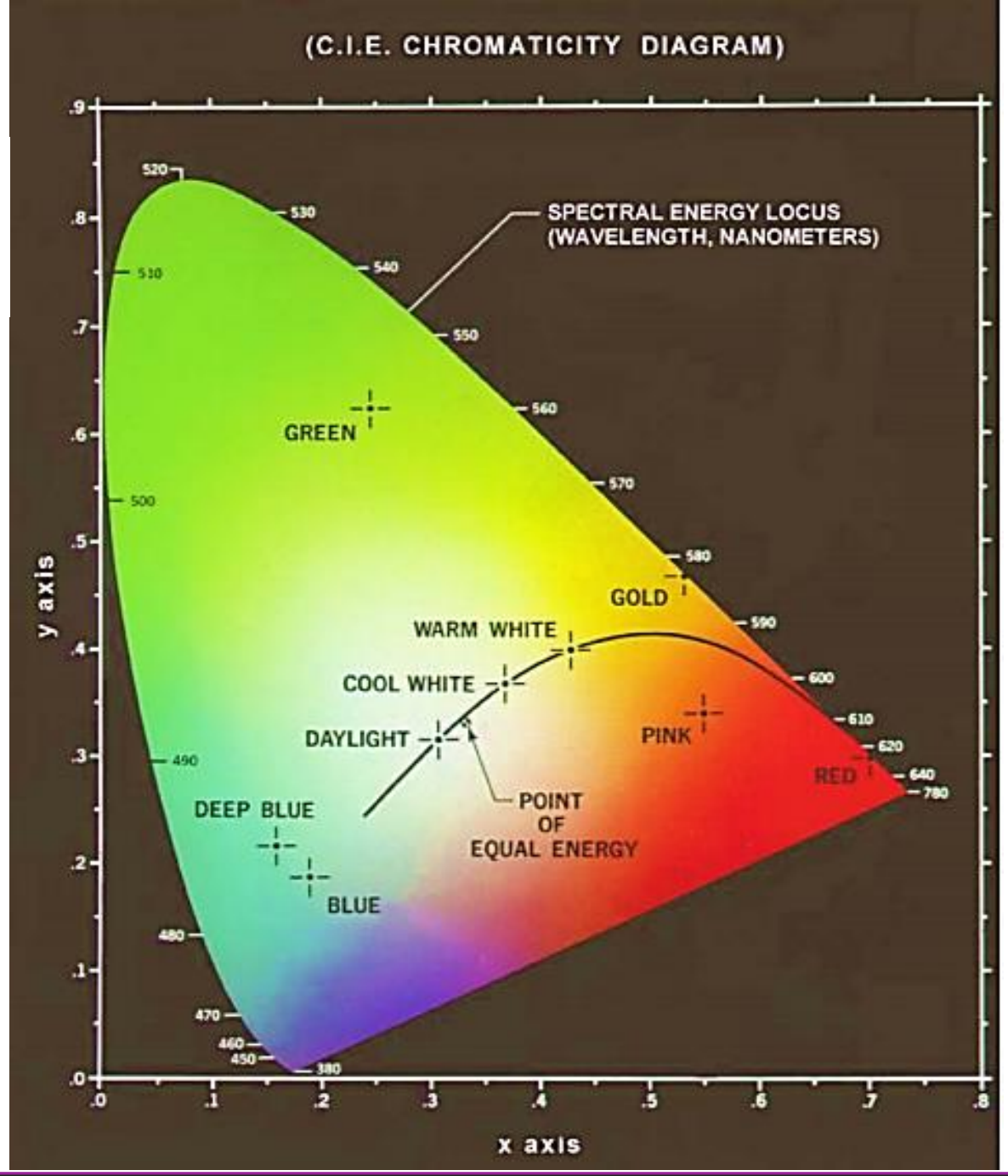
- CIE Chromaticity diagram
  - all the colors that human eye can see, represented as color gamut



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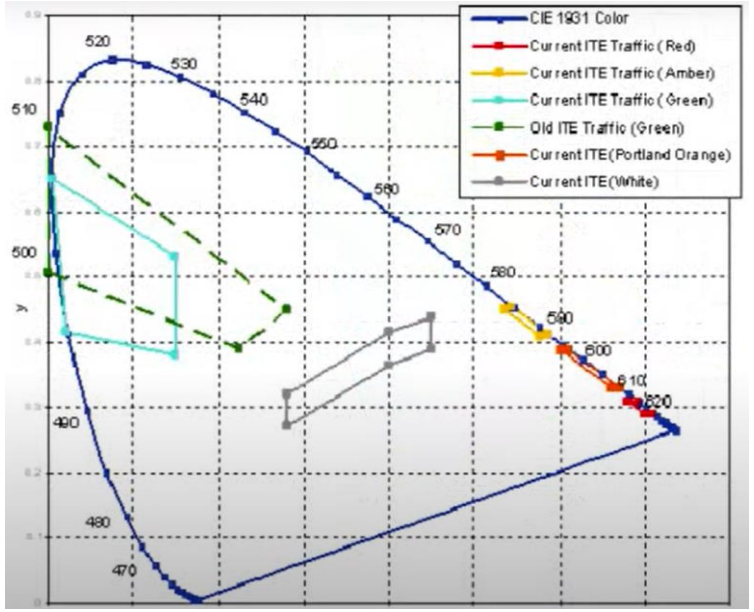
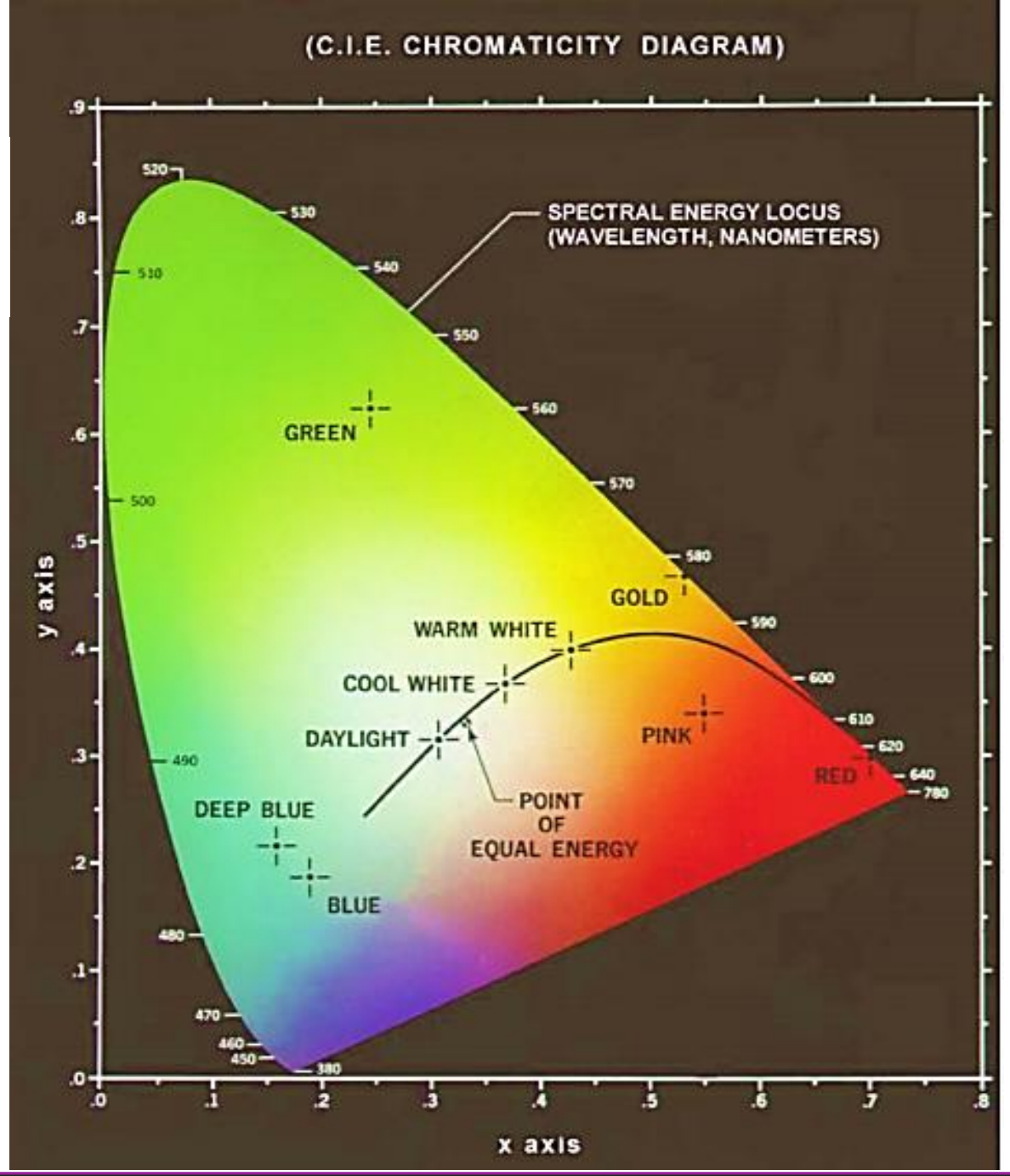
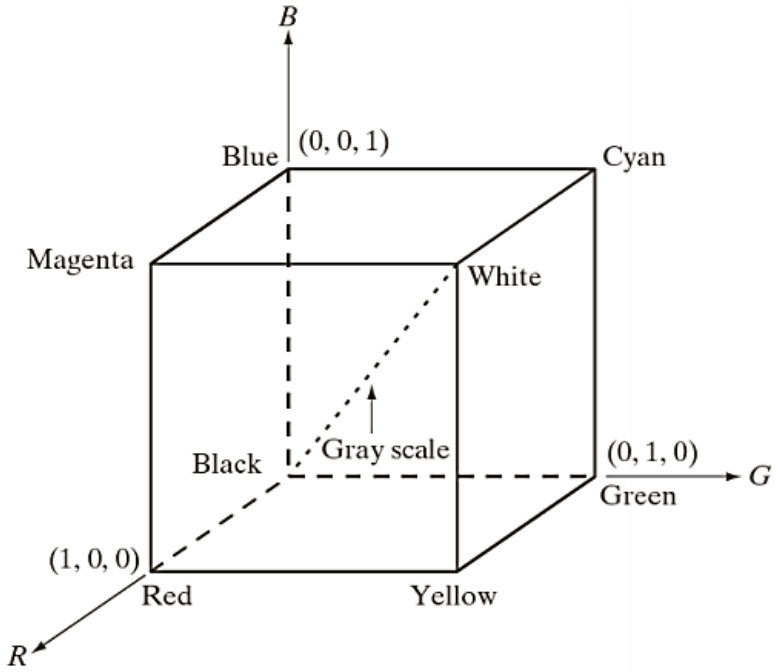
Traffic light specifications





Color spaces: RGB cube

- Normalize to float values (0.0 to 1.0)
- How many possible colors in computer with 3 bytes?
- You can manipulate image inside this cube



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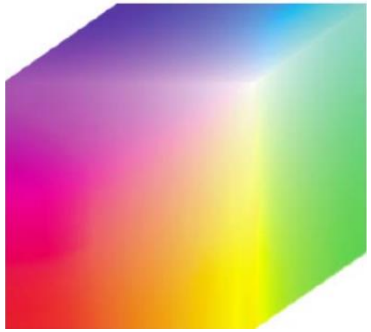
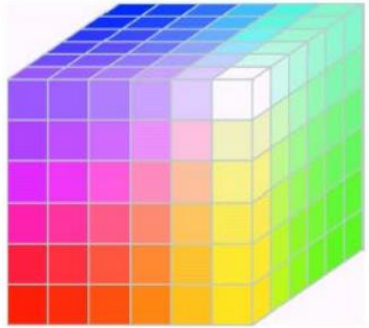
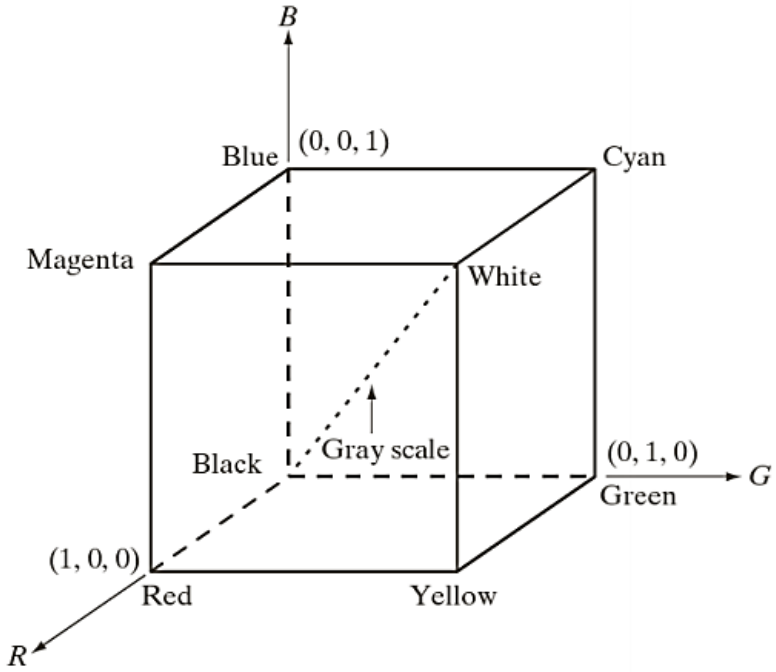
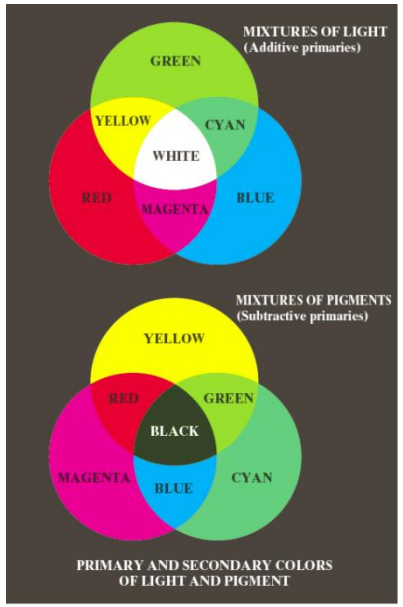






Color spaces: CMYK

- Printer vs display
- CMY = 1 – RGB (vector notation)
- what is C + M + Y = ?
- to compensate muddy black, ‘K’ is added : CMYK
  K = 1 – max(r,g,b)
  find out other components?
- hint: C = (1-r-K)/(1-K)



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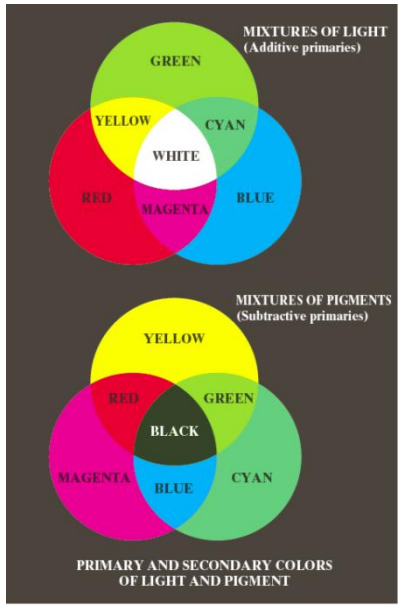
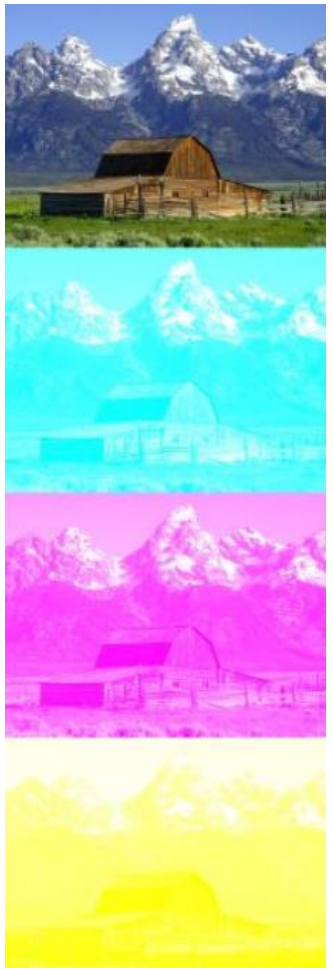


CMY



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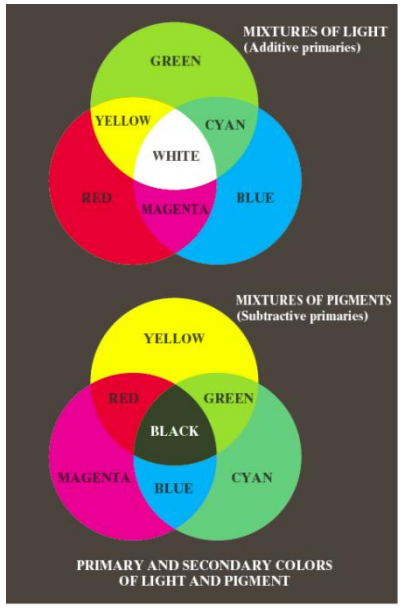

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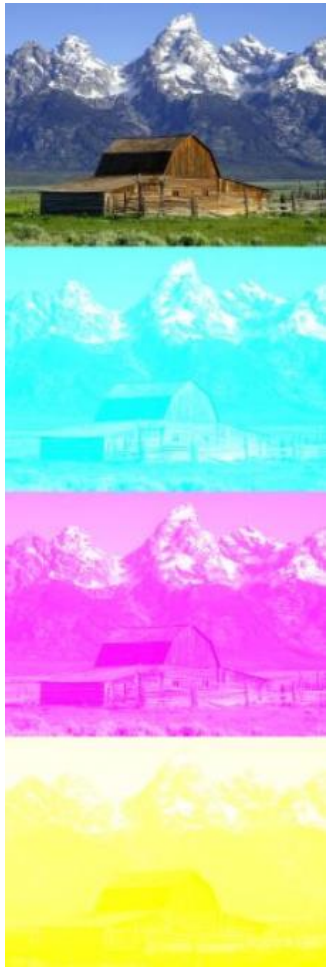
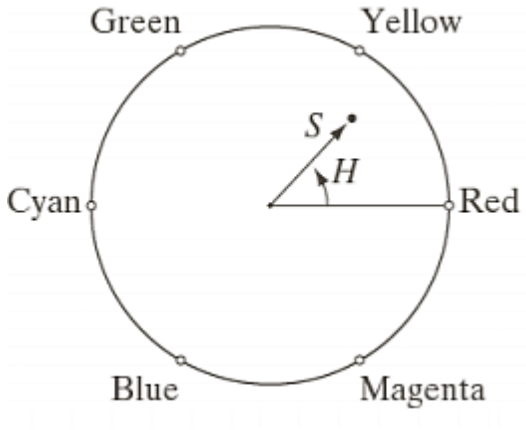


CMYK

Color spaces: HSV

- Hue:
  - dominant wavelength in the mixture of light waves
  - dominant color as perceived by us
- Saturation:
  - relative purity
  - amount of white light mixed in hue to get a color
- Value:
  - also called brightness
  - achromatic notion of intensity



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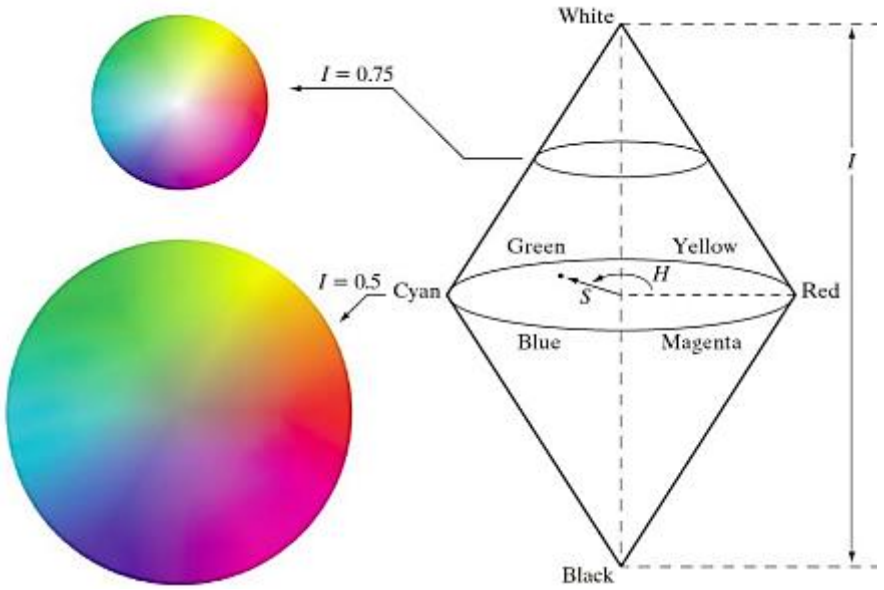

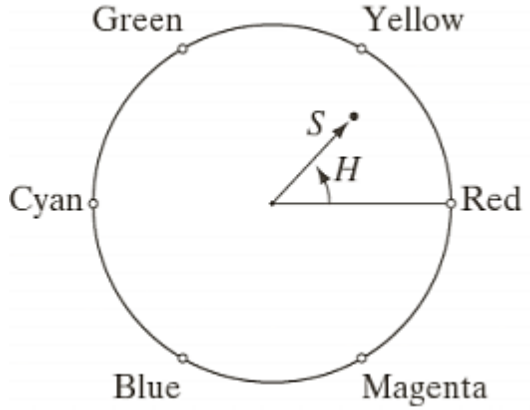

Travelling inter-spaces

- It's nothing but converting image from one space to another

$$I = \tfrac{1}{3}(R+G+B)$$

$$S = 1 - \frac{3}{R+G+B}\min(R,G,B)$$

$$H = \begin{cases} \theta & B \le G \\ 360 - \theta & B > G \end{cases}$$

where

$$\cos\theta = \frac{\tfrac{1}{2}\left[(R-G)+(R-B)\right]}{\left[(R-G)^2+(R-B)(G-B)\right]^{1/2}}$$

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- Online converter
  https://www.rapidtables.com/convert/color/rgb-to-hsv.html

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- It's nothing but converting image from one space to another

$$I = \tfrac{1}{3}(R+G+B)$$

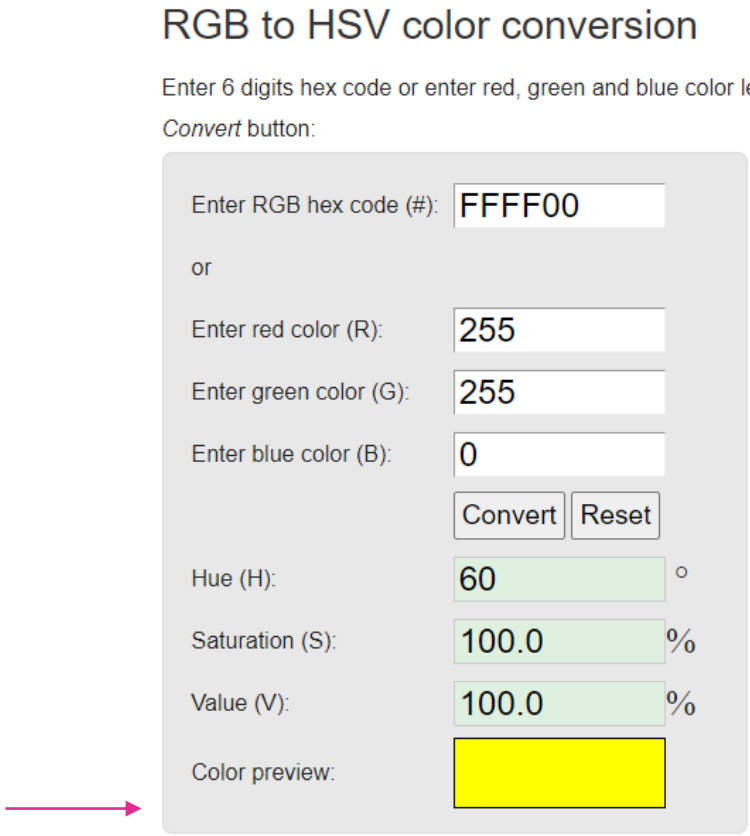
$$S = 1 - \frac{3}{R+G+B}\min(R,G,B)$$

$$H = \begin{cases} \theta & B \le G \\ 360-\theta & B > G \end{cases}$$

where

$$\cos\theta = \frac{\tfrac{1}{2}[(R-G)+(R-B)]}{\left[(R-G)^2+(R-B)(G-B)\right]^{1/2}}$$

- Online converter
  https://www.rapidtables.com/convert/color/rgb-to-hsv.html



Color correction

- Acquired image might be in different illumination or in shadow

$$\begin{bmatrix} \tilde{r} \\ \tilde{g} \\ \tilde{b} \end{bmatrix} = \begin{bmatrix} \alpha_r & 0 & 0 \\ 0 & \alpha_g & 0 \\ 0 & 0 & \alpha_b \end{bmatrix} \begin{bmatrix} r \\ g \\ b \end{bmatrix}$$

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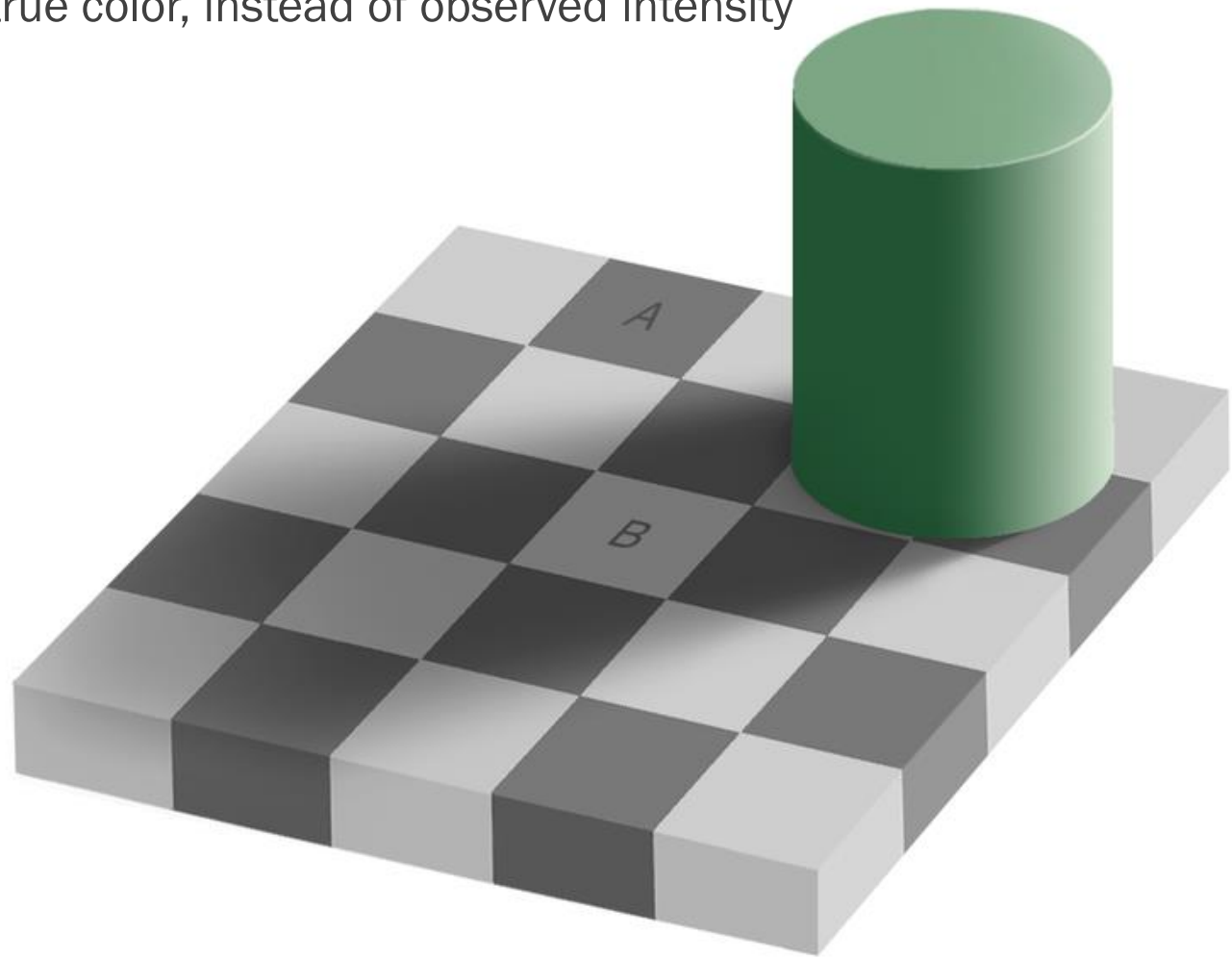
- White world assumption: brightest pixel should be white
  - divide by max value
- Gray world assumption: average value should look like grey
  - m = avg over image[(r+g+b)/3]
  - $\tilde{r} = r * \text{avg(r)/m}$
- Histogram equalization on color channels

Color constancy

- Interpret object surface in terms of albedo or true color, instead of observed intensity
- Contextual phenomenon
- e.g. banana appears yellow even in blue light



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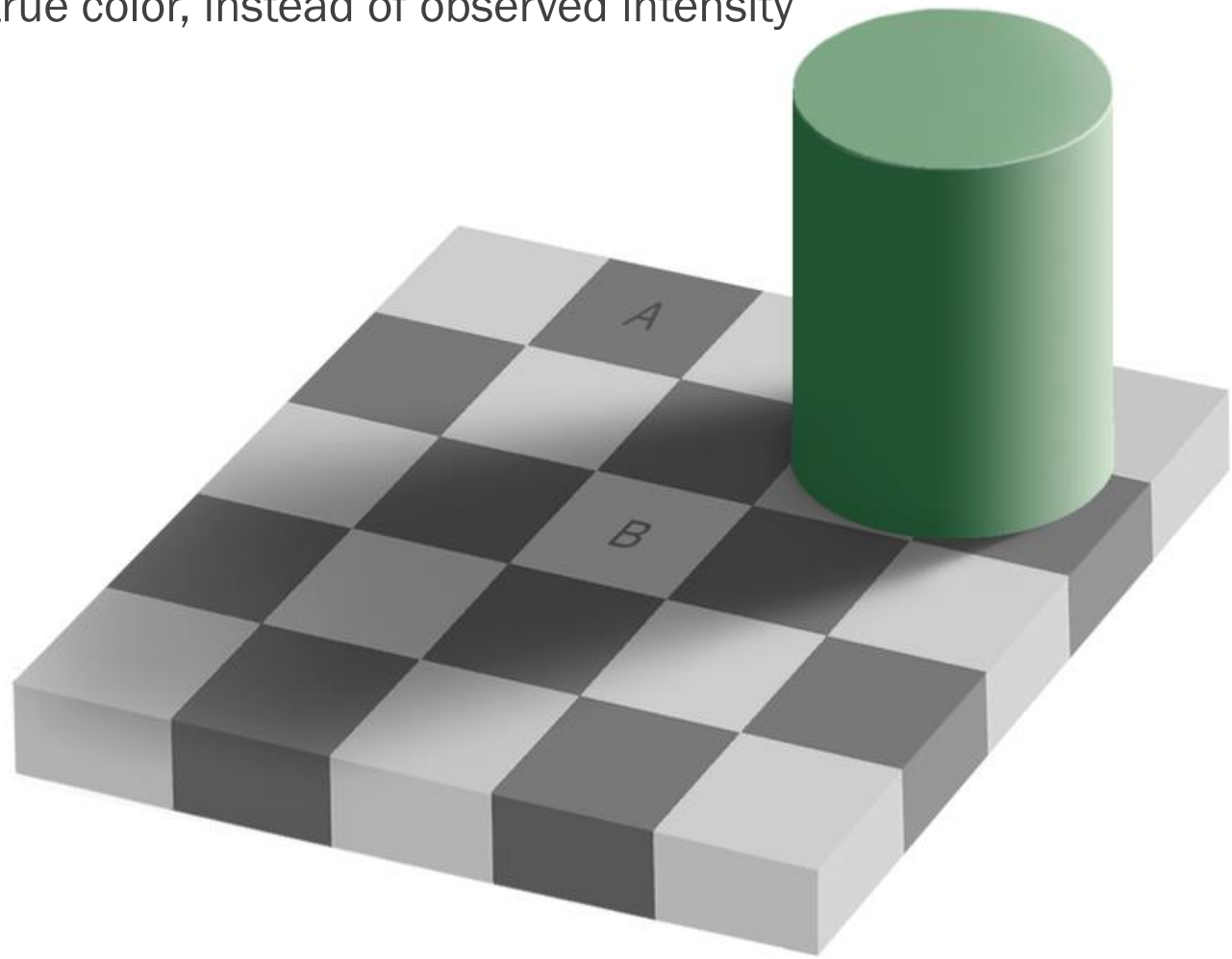

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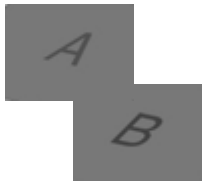
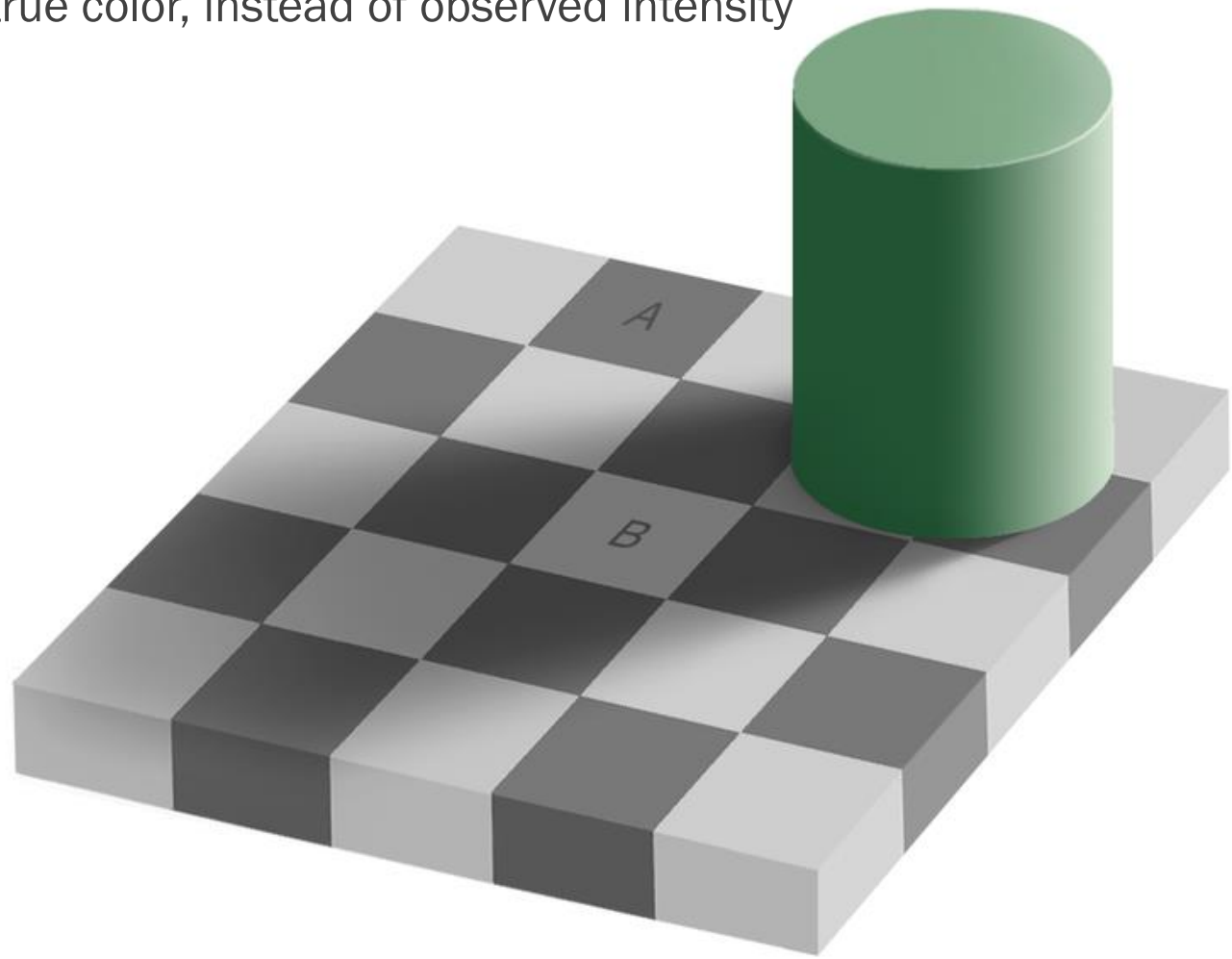
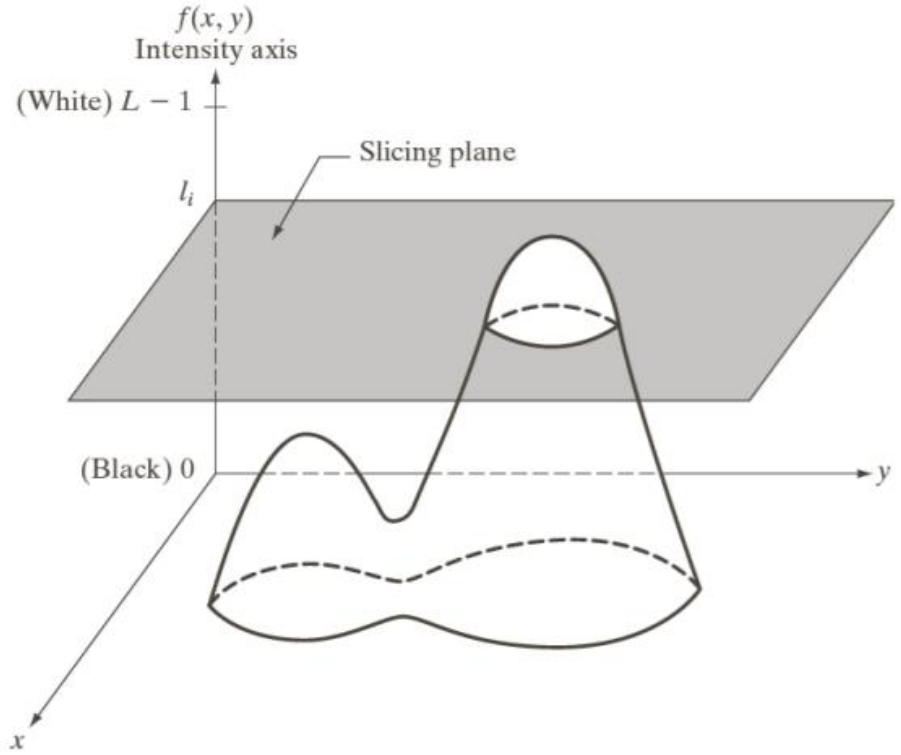




Pseudocolor image processing

- assign colors to grey values (e.g. via intensity slicing)
- Note: different from image colorization

  (estimate underlying true color for a given grey image)



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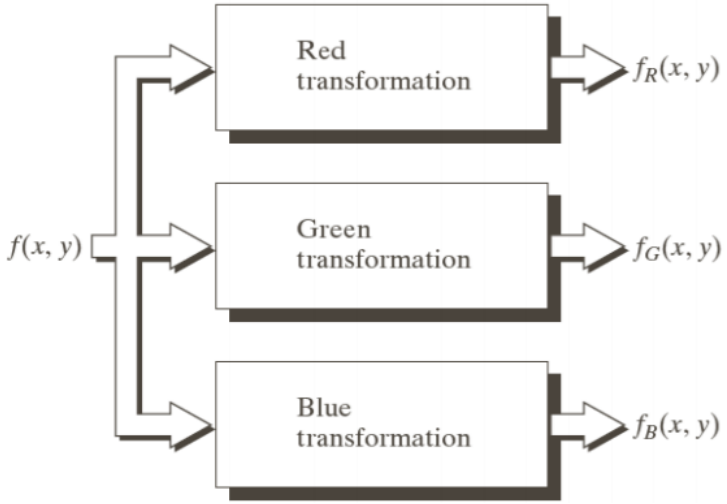
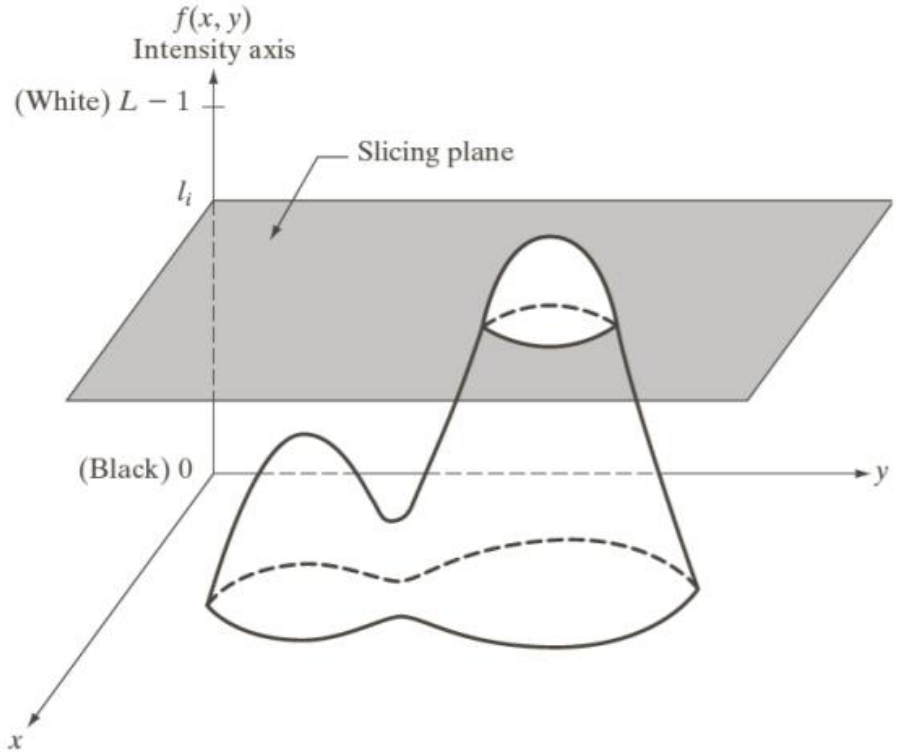
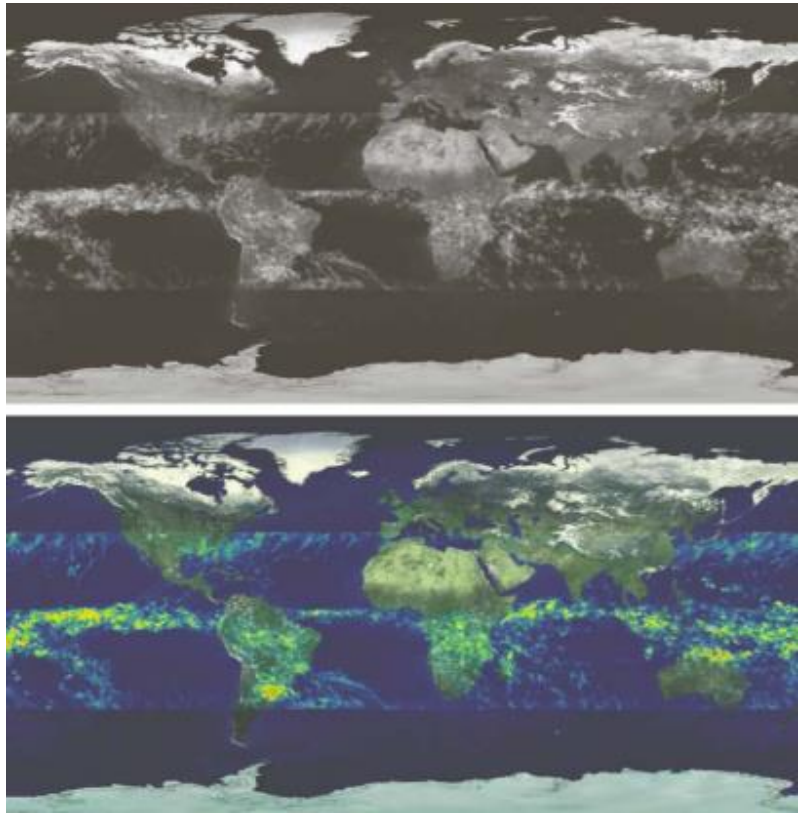




Pseudocolor image processing

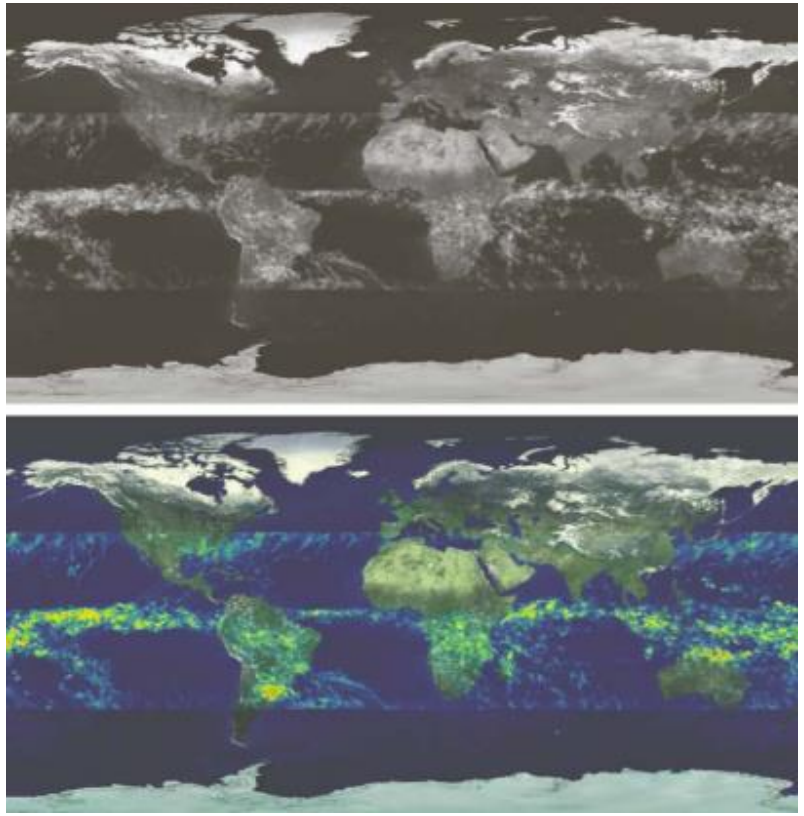
satellite



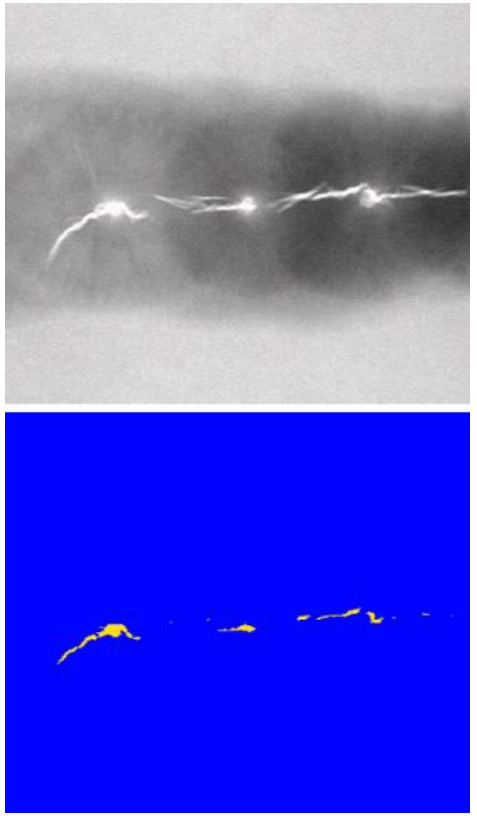
Credit: U. Berkeley & NASA

Pseudocolor image processing

satellite



X-ray



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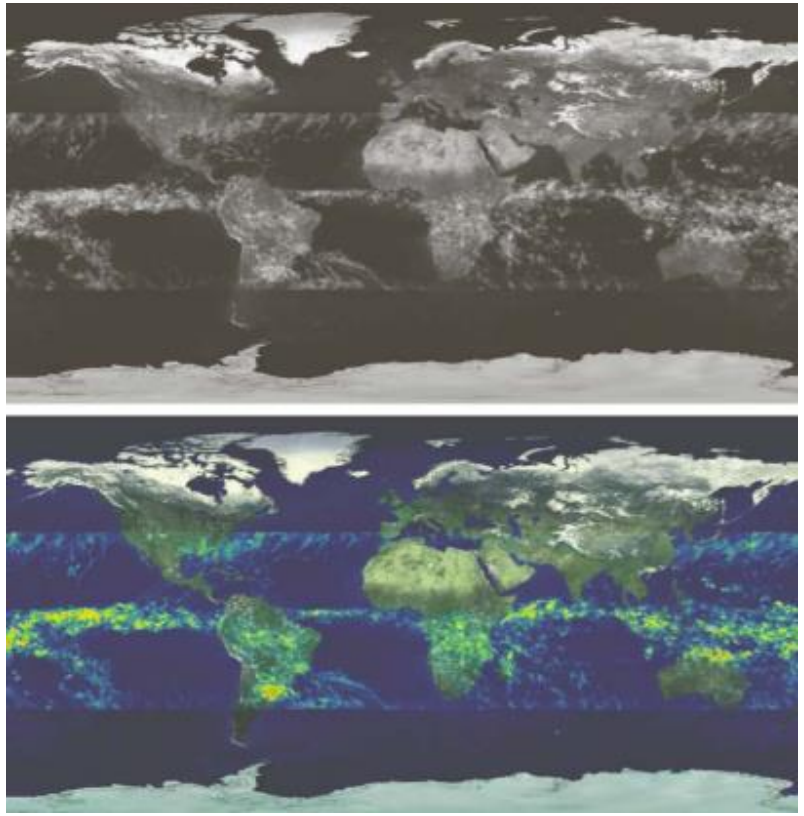
Pseudocolor image processing

satellite



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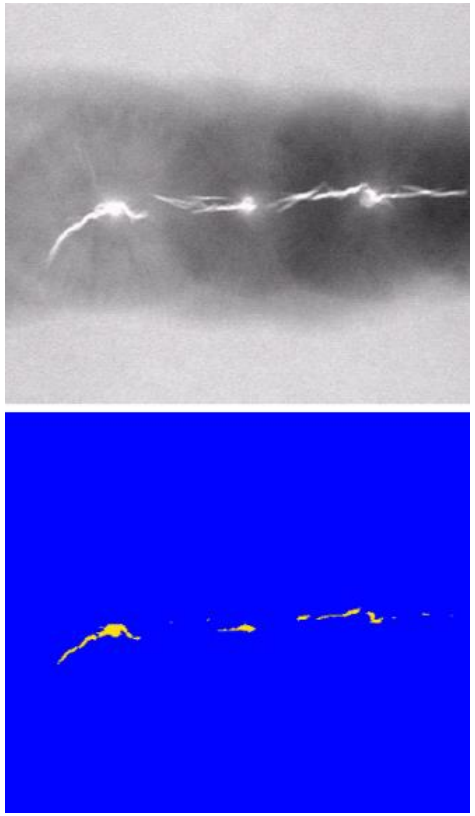
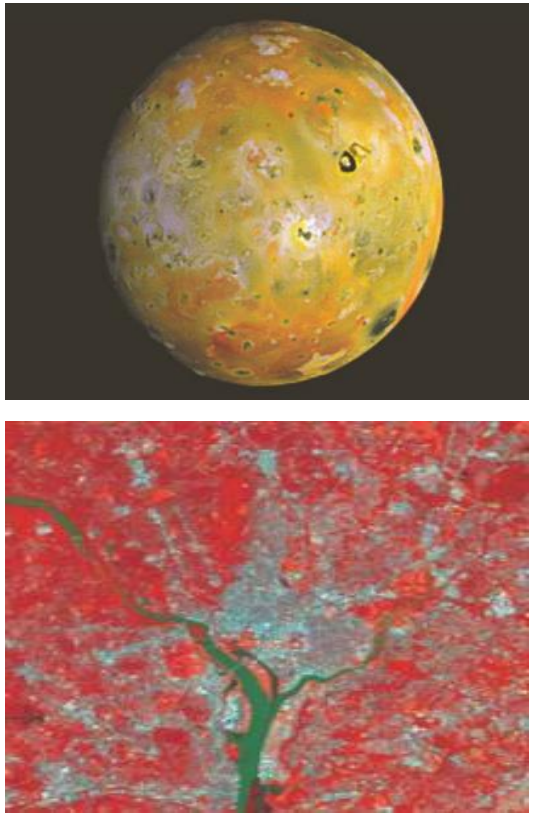


Multi-sensors



Credit: U. Berkeley & NASA

Pseudocolor image processing

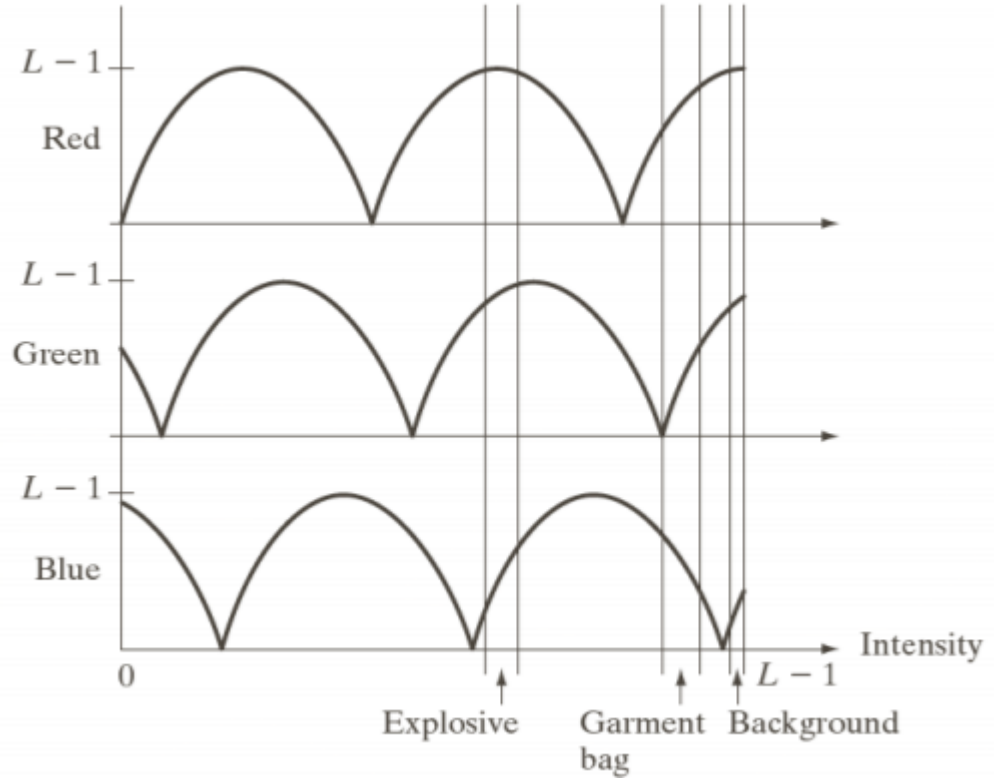
- Transformation functions

Input X-ray image

Pseudocolor image processing

- Transformation functions

Input X-ray image



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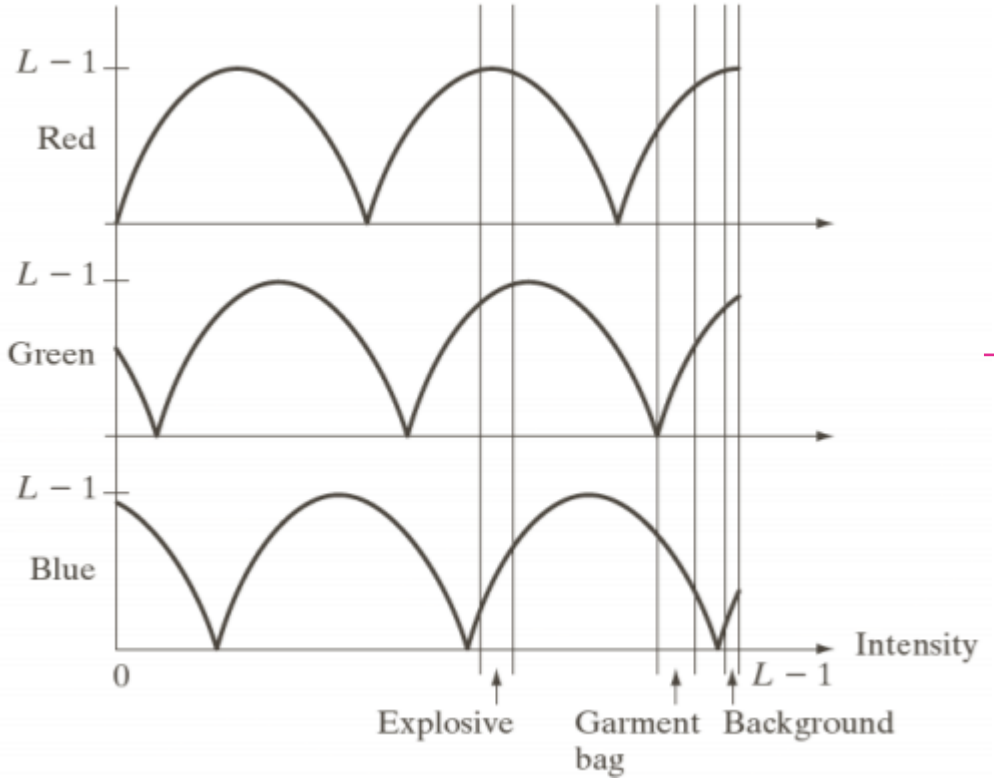
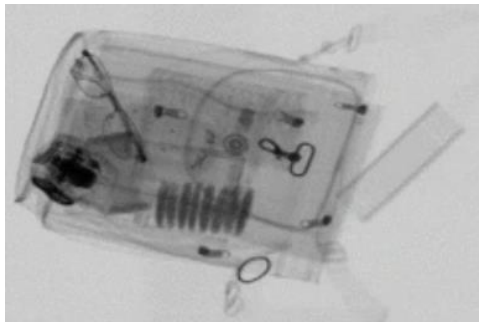
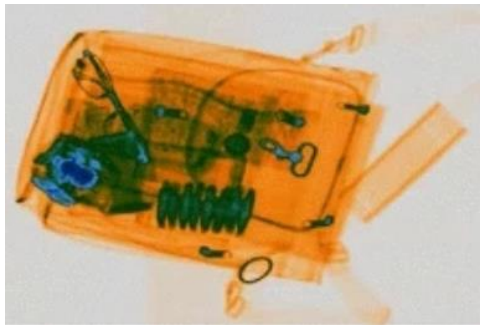


Pseudocolor image processing

- Transformation functions
  - with different transformation functions





Credit: K. Dmitruk et al.

Pseudocolor image processing

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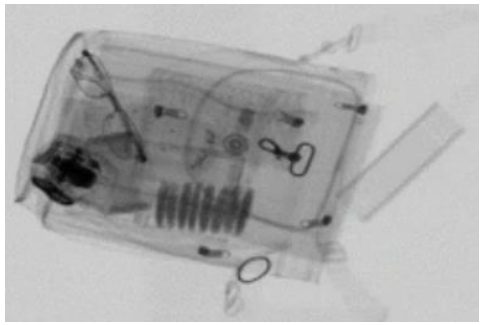
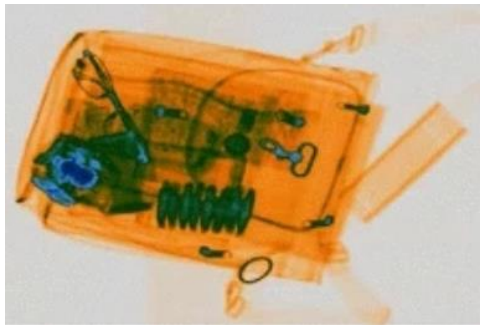
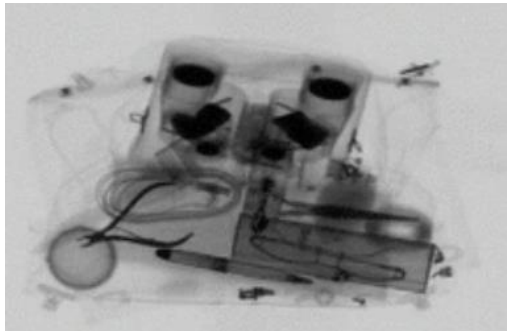
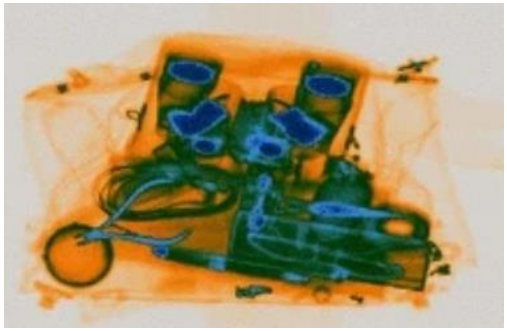

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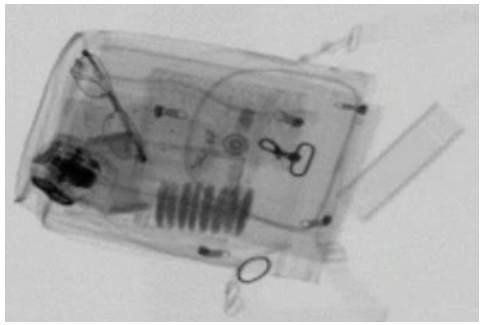
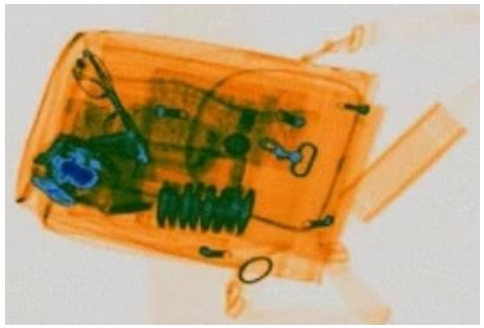
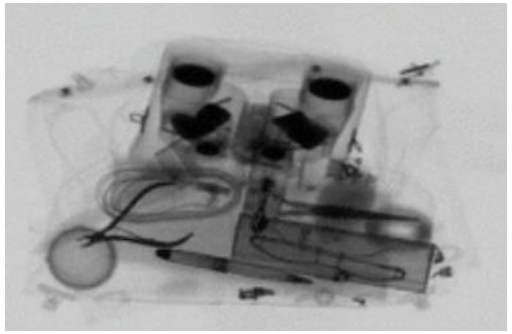
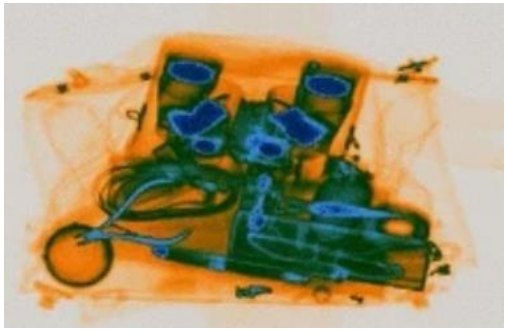

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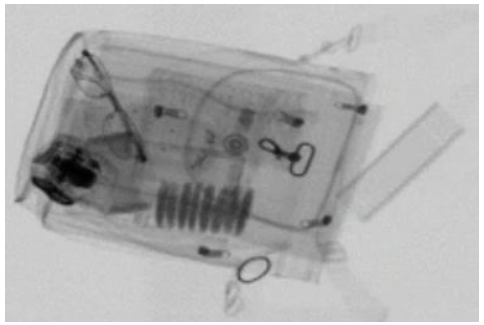
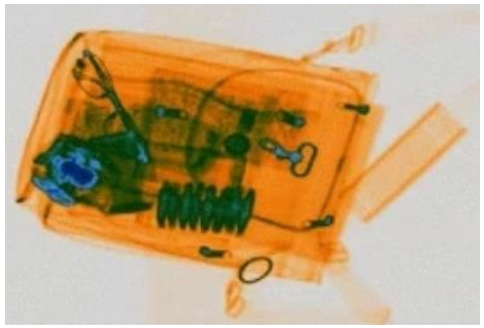
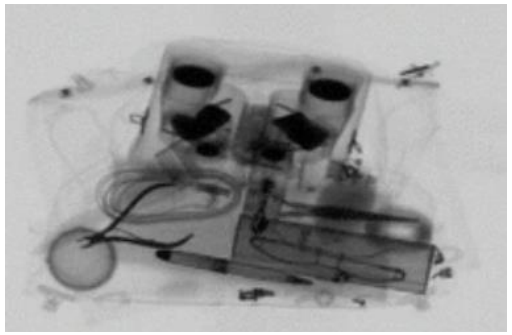
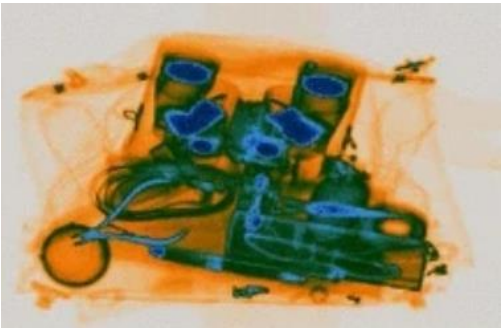


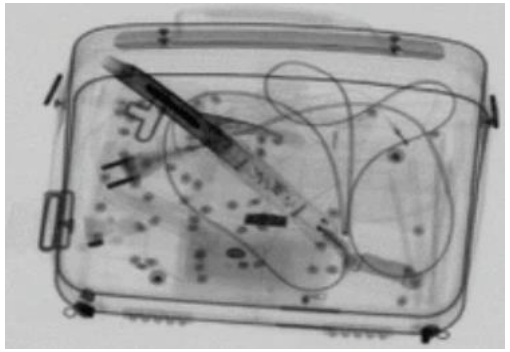


Credit: K. Dmitruk et al.

Conclusion

- Color fundamentals
- Color spaces

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- Light sources
  - Spectra to retina sensing

- Color
  - Cones
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"Blurring the pseudocolors in friendships, reduces the relational spaces & life becomes Colorful."

-TS