Unit 5

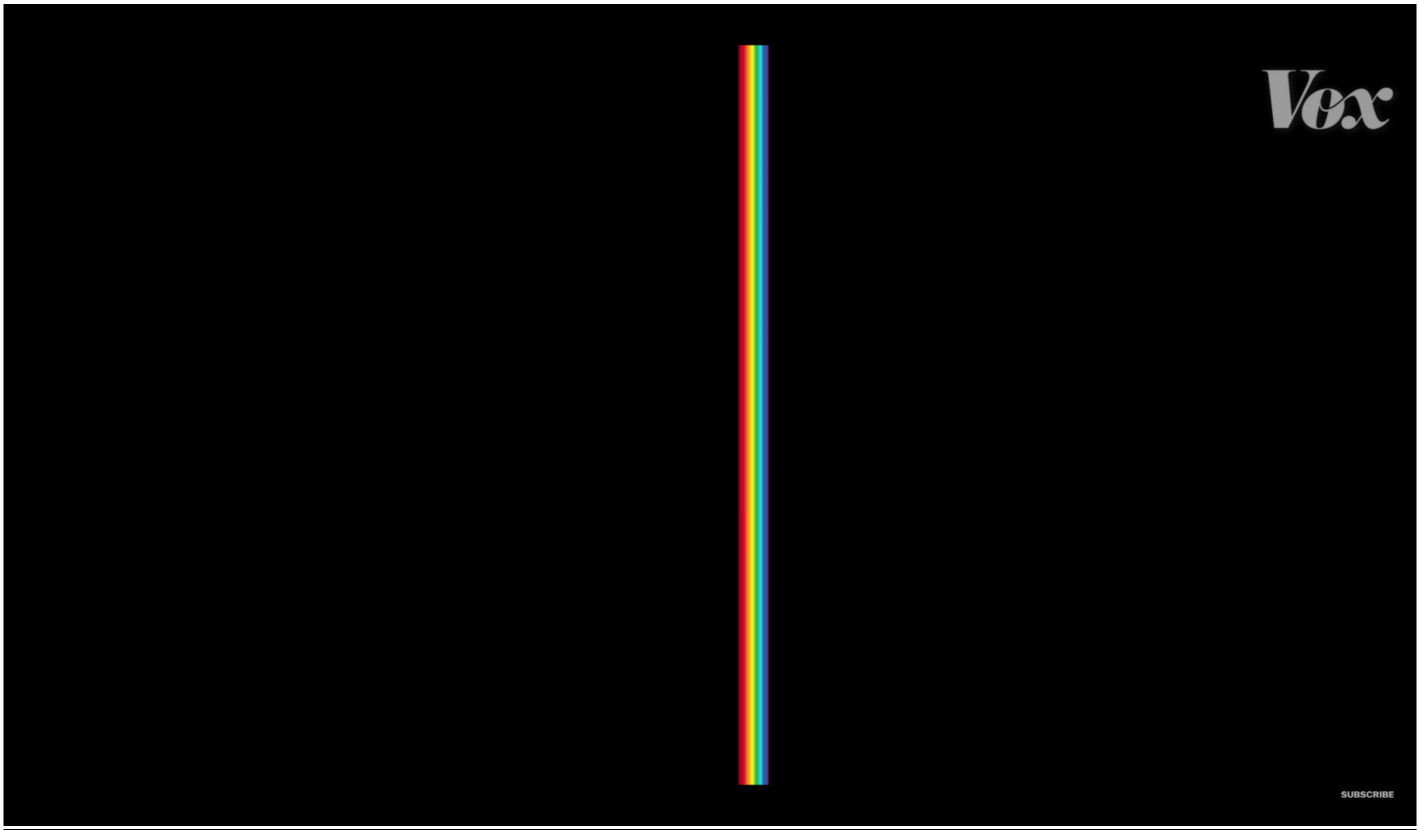
Color Processing

For a long time, I limited myself to one color – as a form of discipline. ***Pablo Picasso***

Outline

- Color Fundamentals,
- Color Models,
- Pseudocolor based Image Processing,
- Color transformations,
- Smoothing and Sharpening operations

Let Us Capture Some Points: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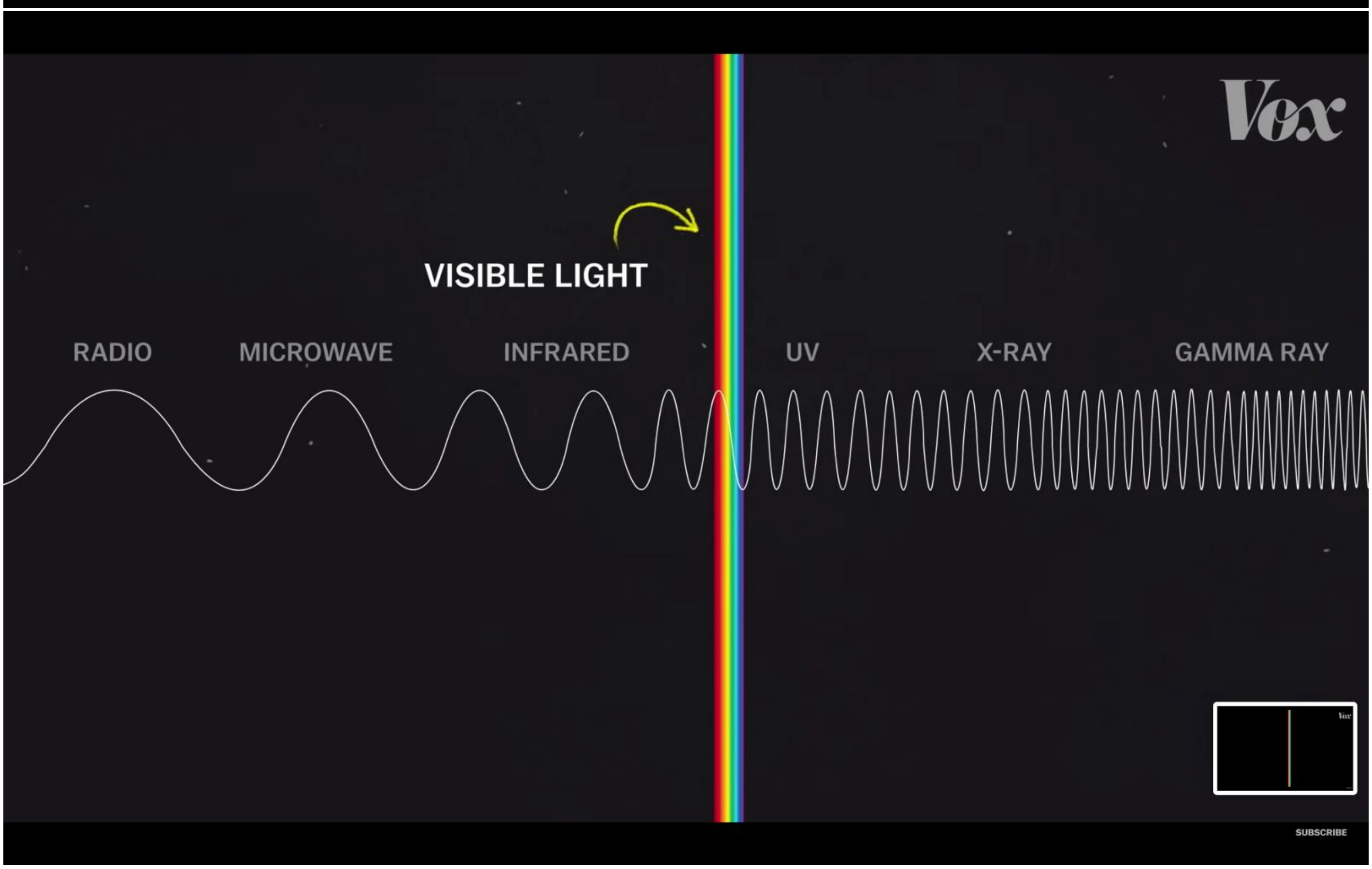
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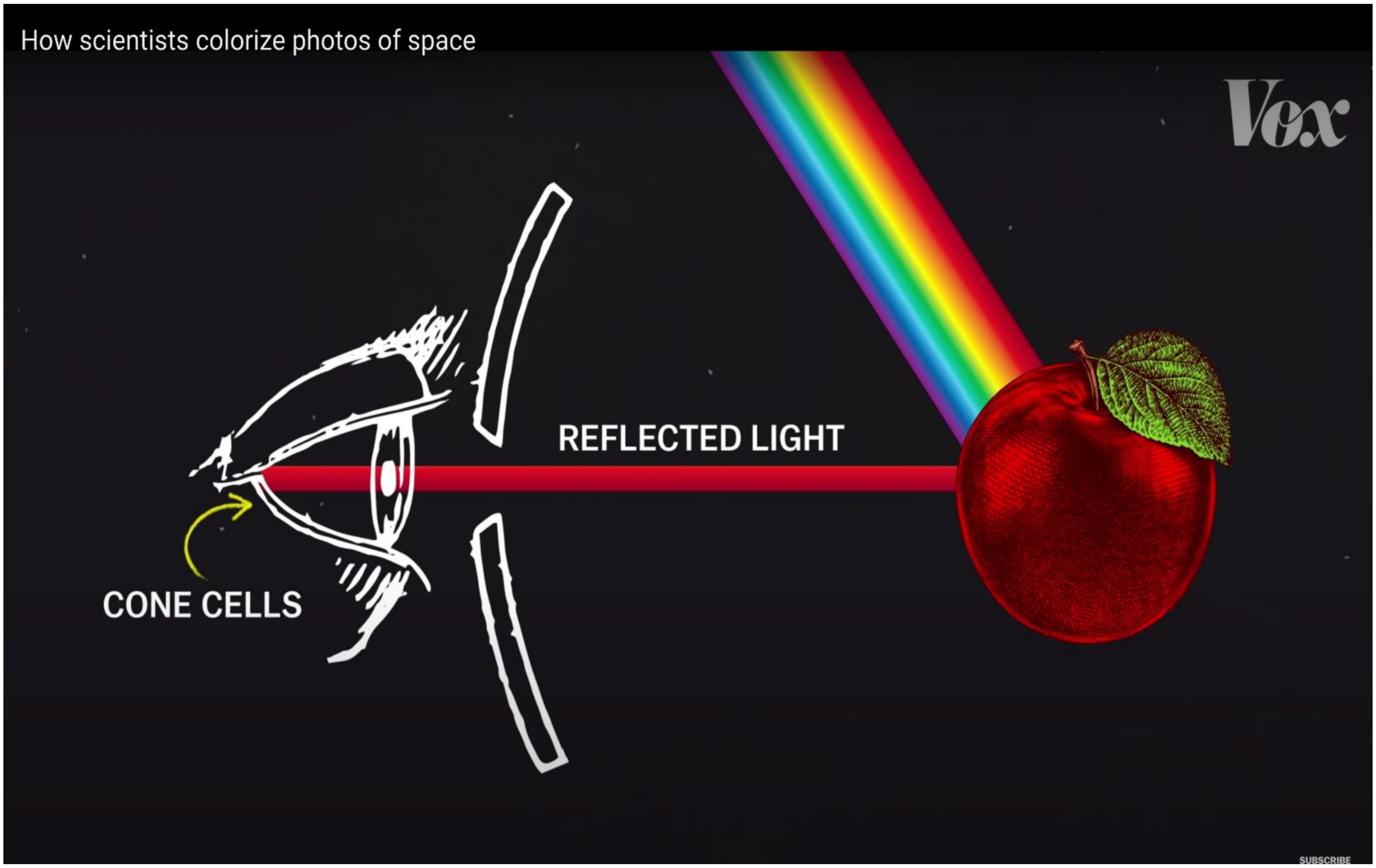
How scientists colorize photos of space
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REFLECTED LIGHT
CONE CELLS
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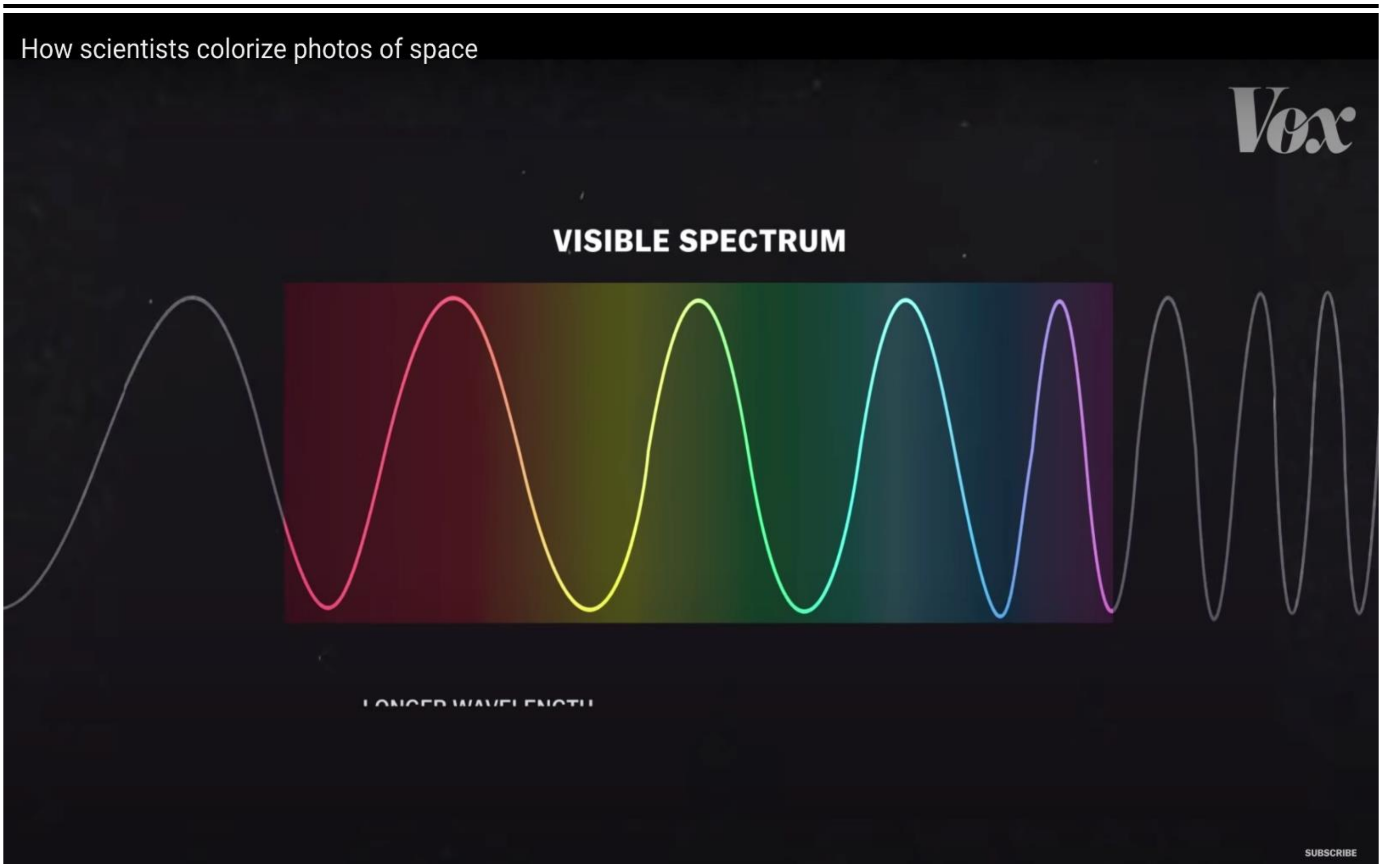
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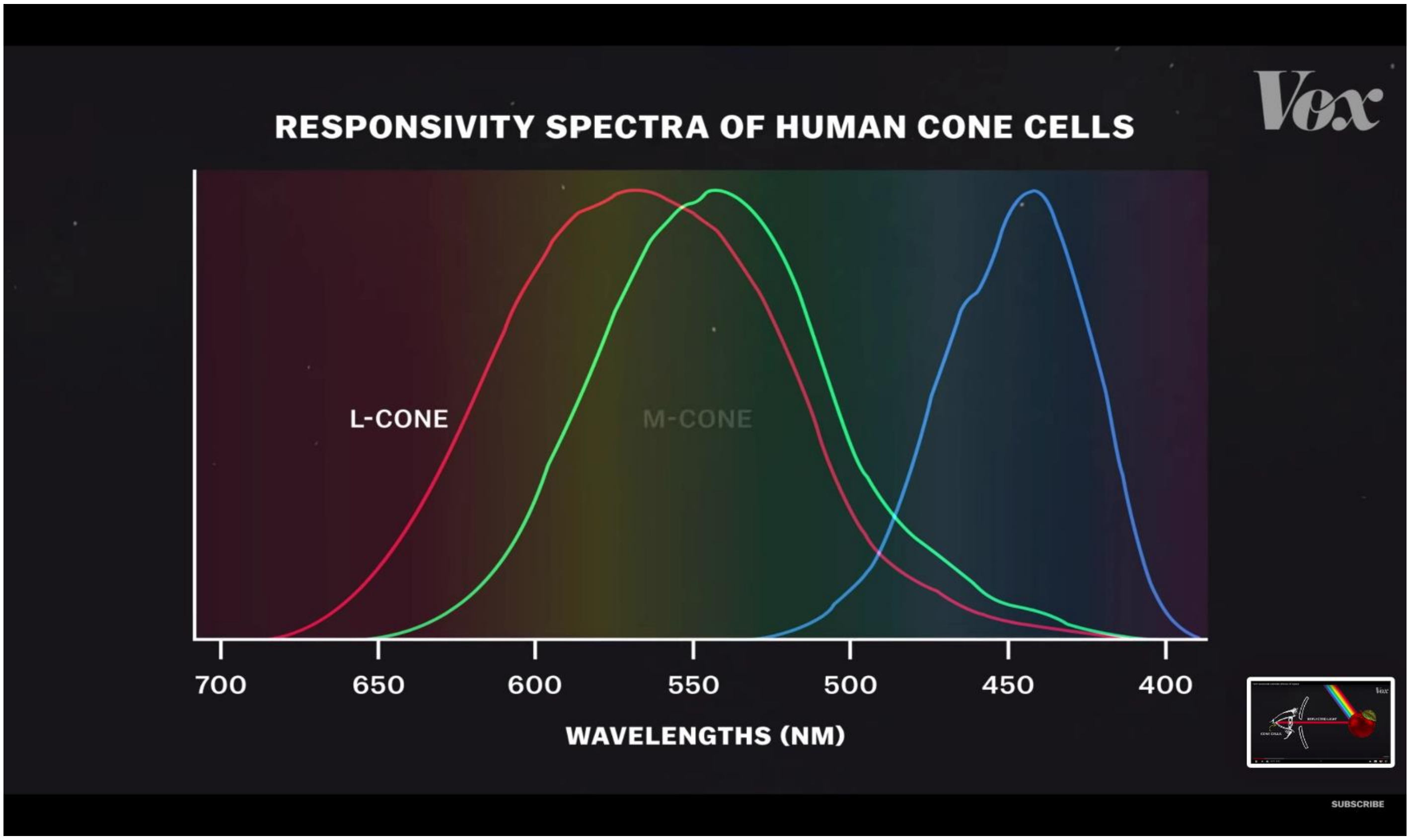
Vox
RESPONSIVITY SPECTRA OF HUMAN CONE CELLS
L-CONE
M-CONE
700
650
600
550
500
450
400
WAVELENGTHS (NM)
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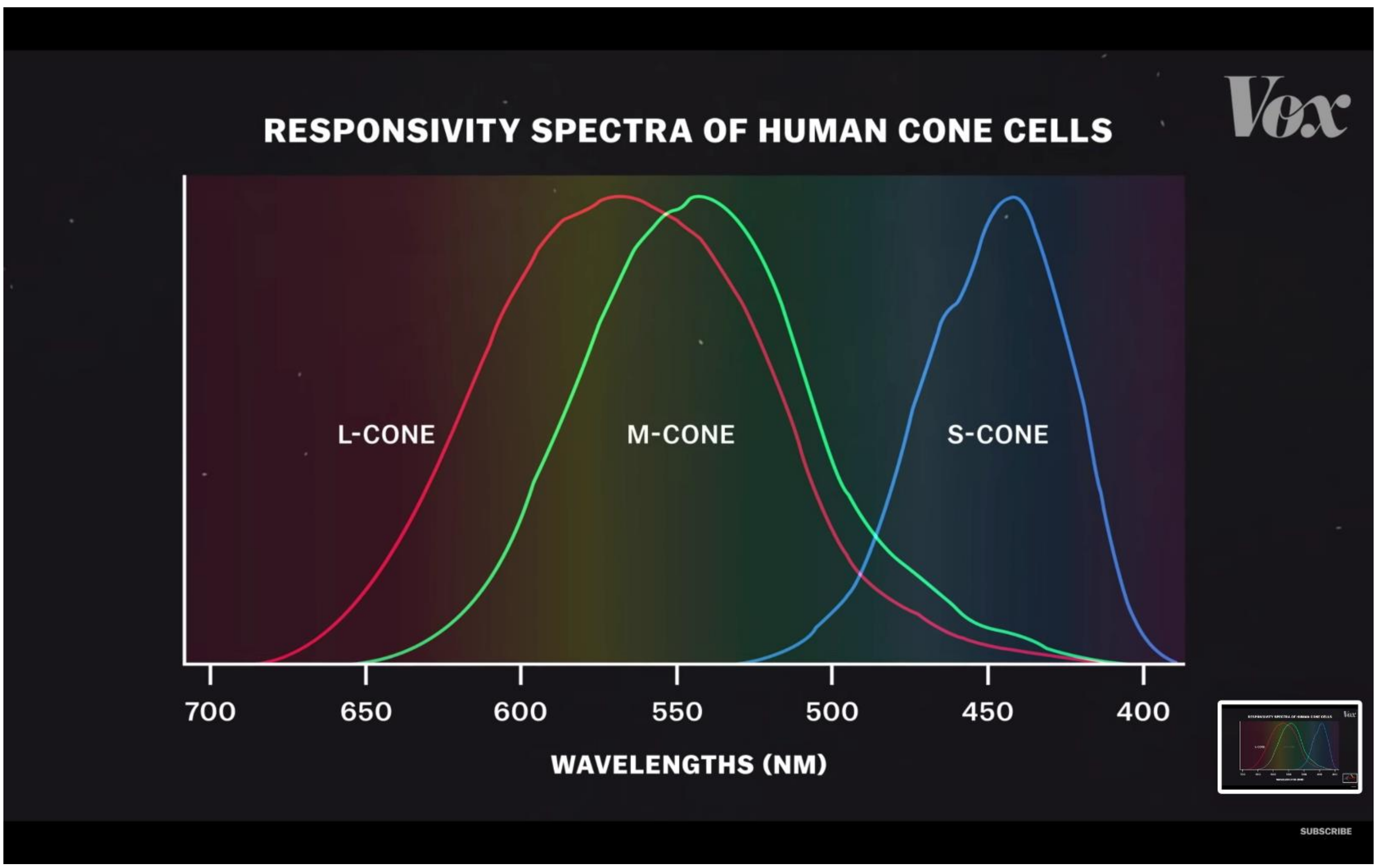
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RESPONSIVITY SPECTRA OF HUMAN CONE CELLS
L-CONE
M-CONE
S-CONE
700
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WAVELENGTHS (NM)
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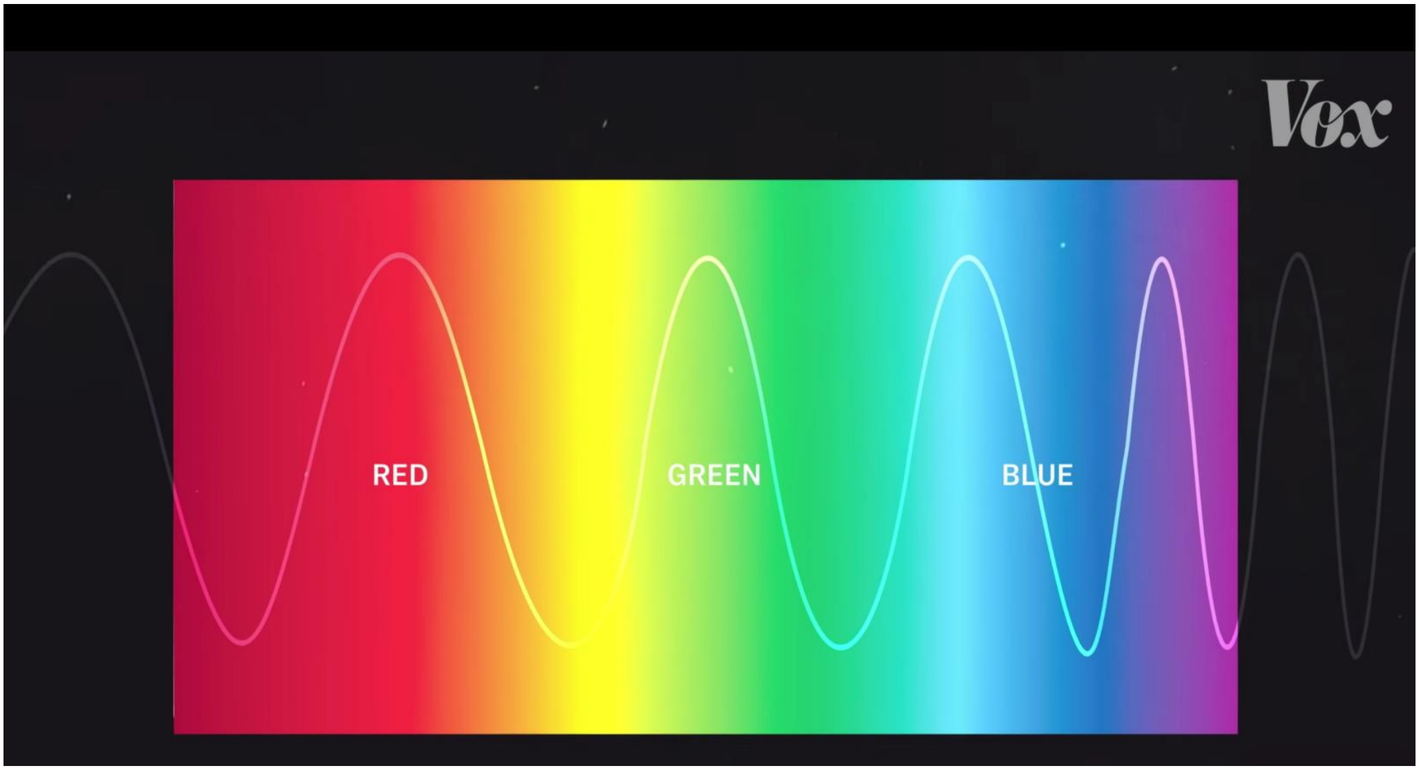
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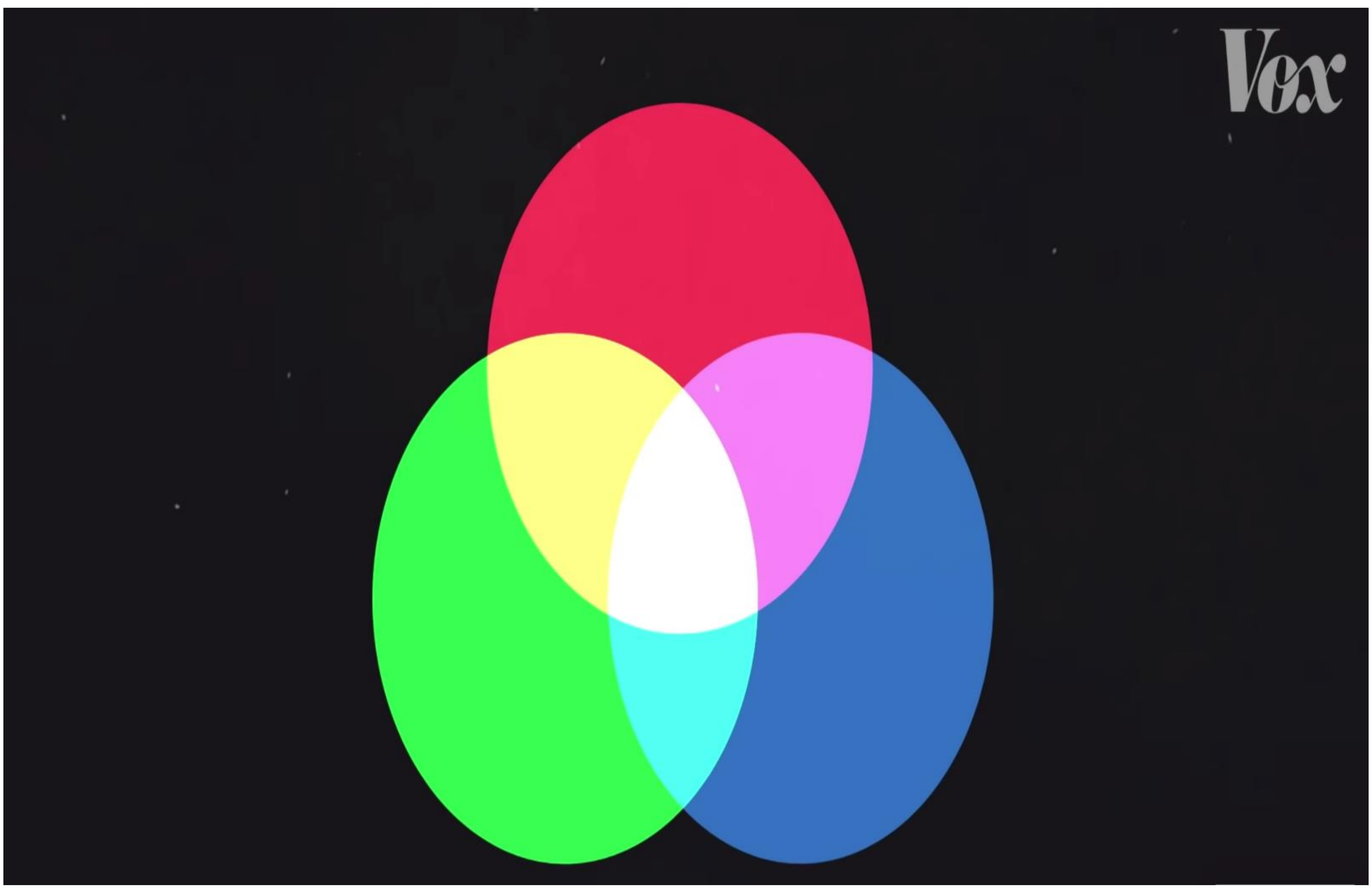
RED
GREEN
BLUE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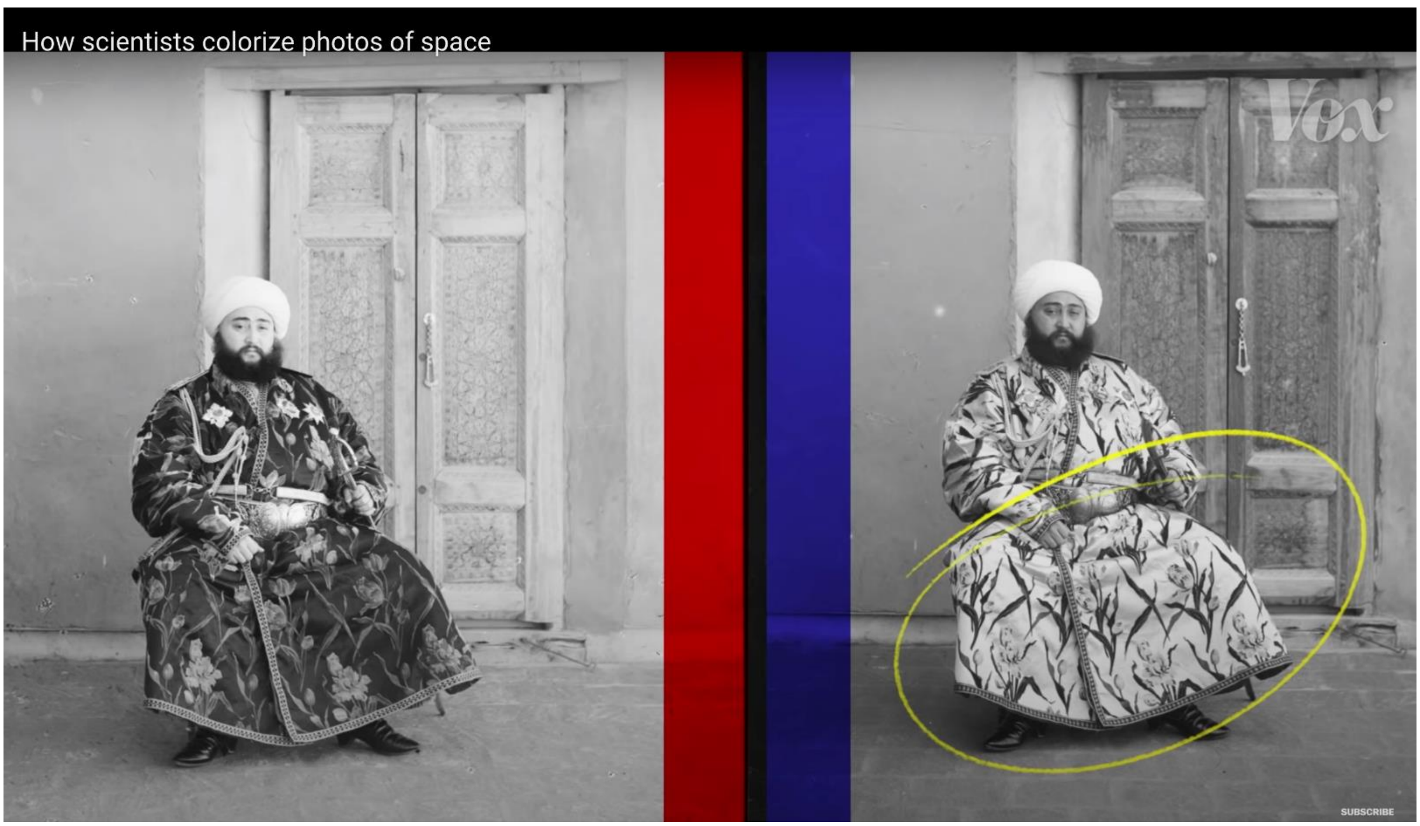
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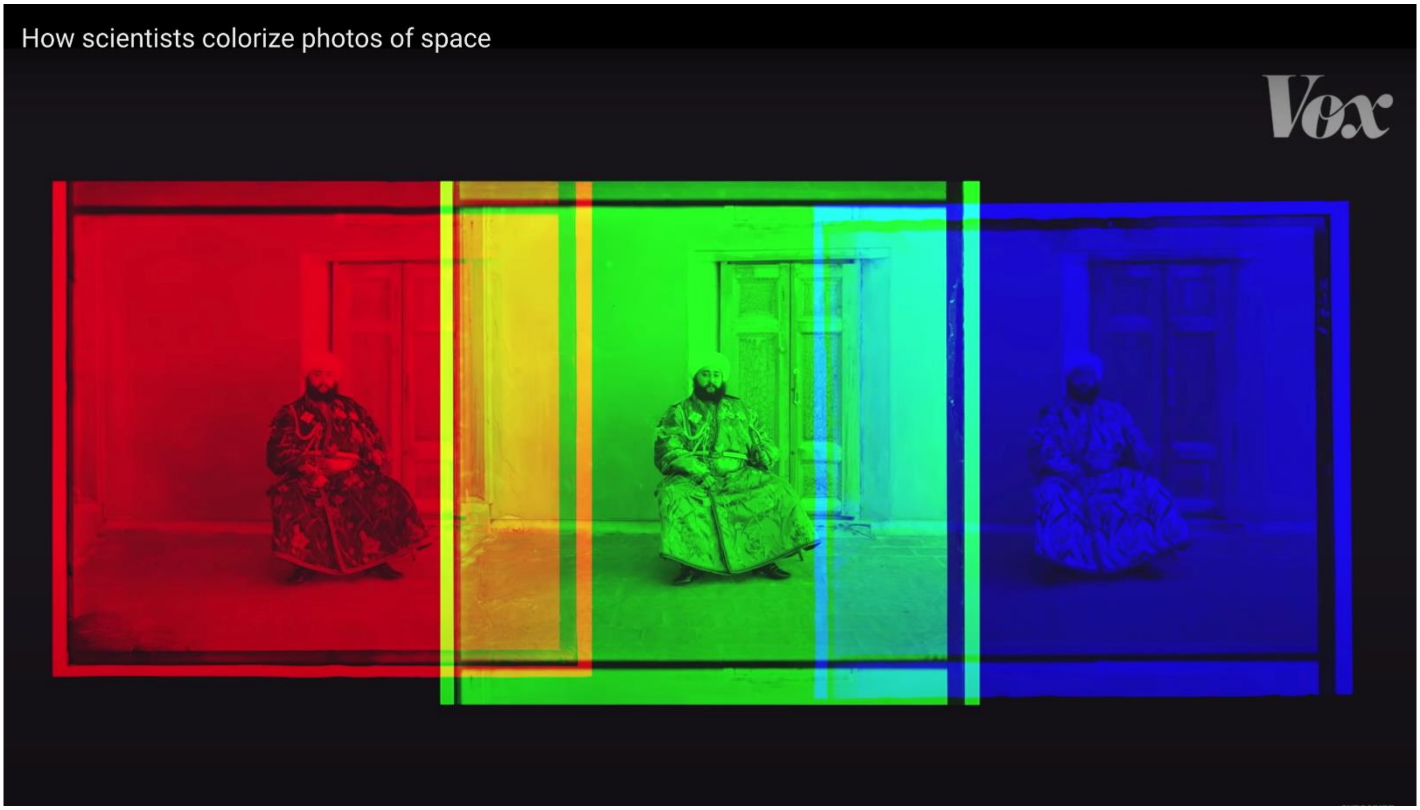
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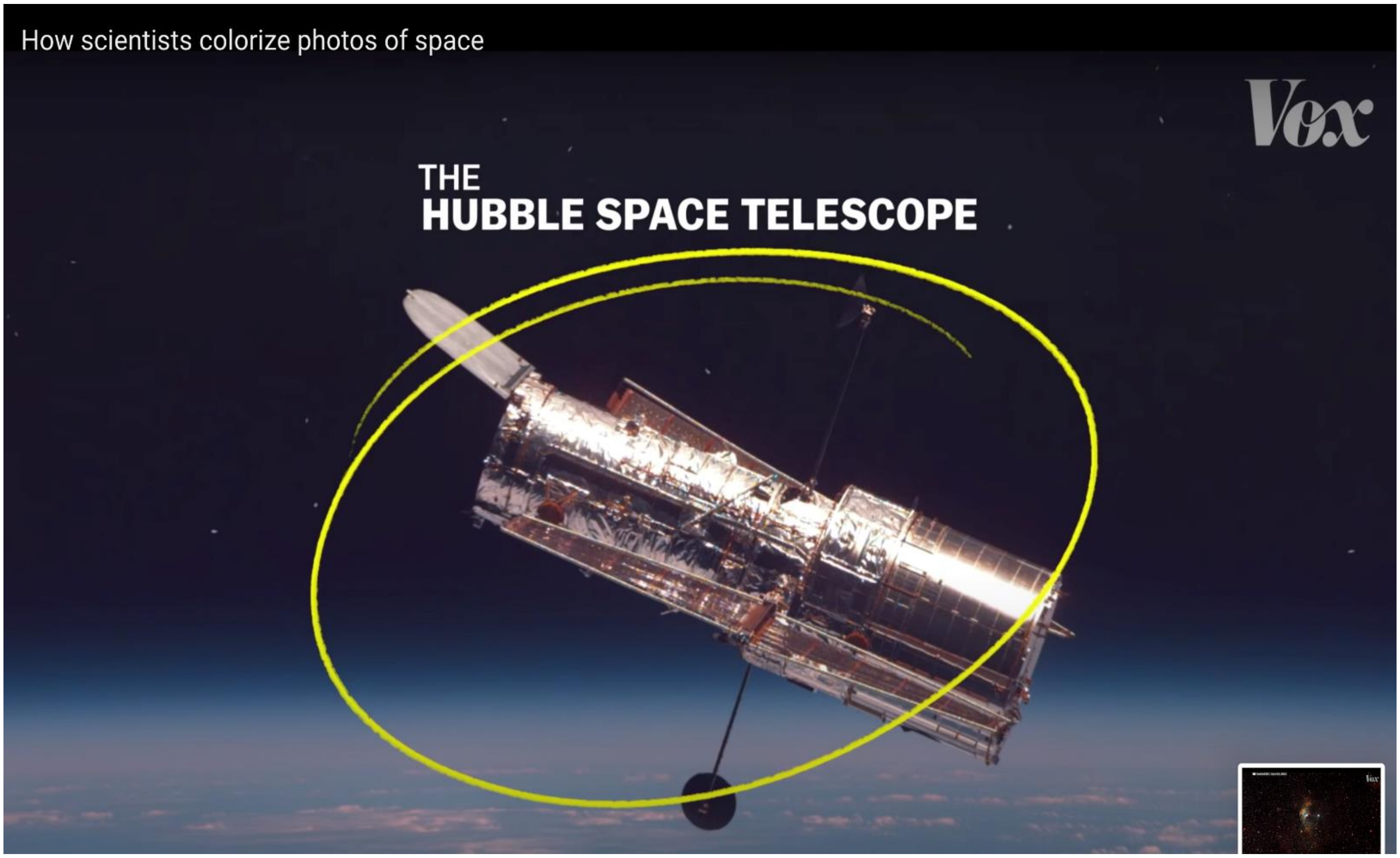
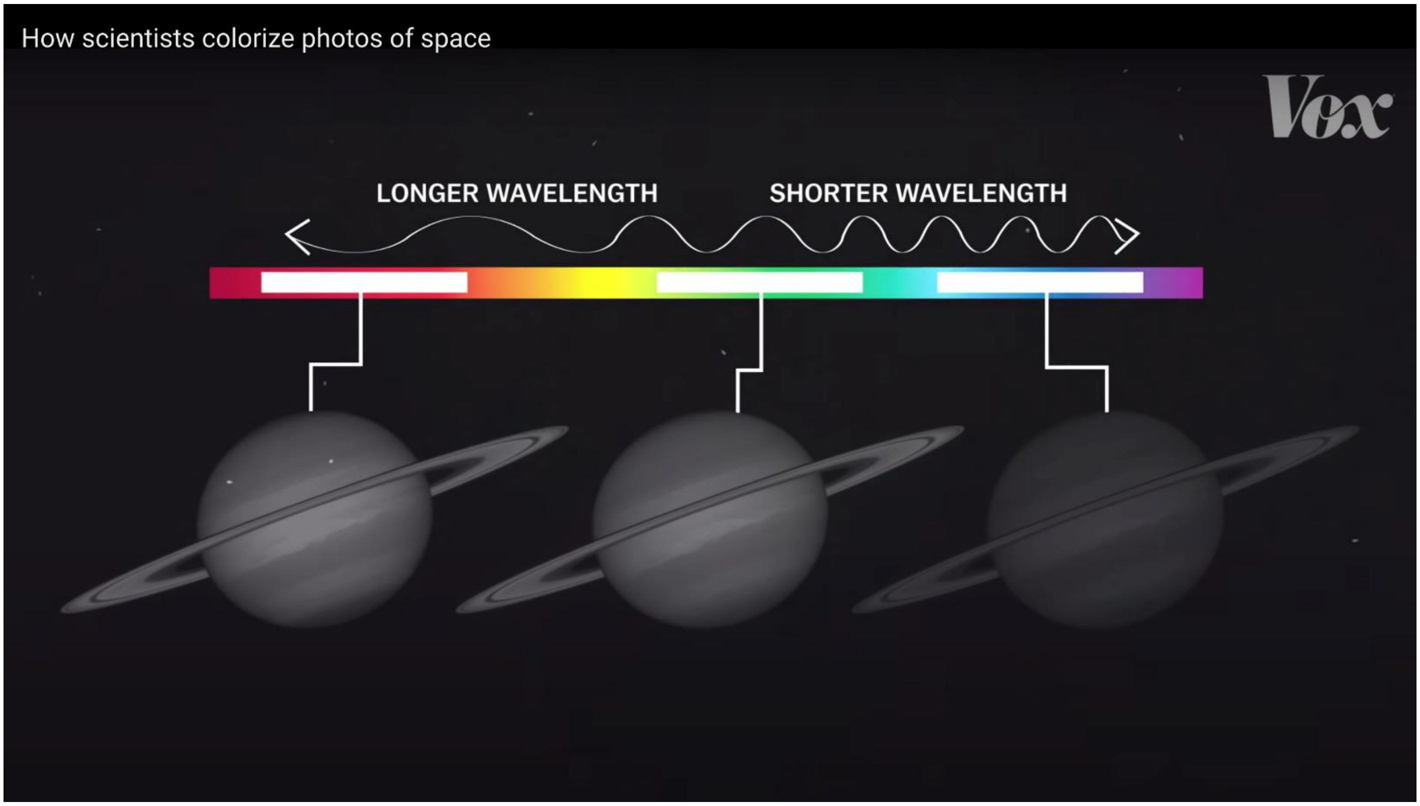

How scientists colorize photos of space
Vox
THE
HUBBLE SPACE TELESCOPE


How scientists colorize photos of space
Vox
BUBBLE NEBULA (NGC 7635)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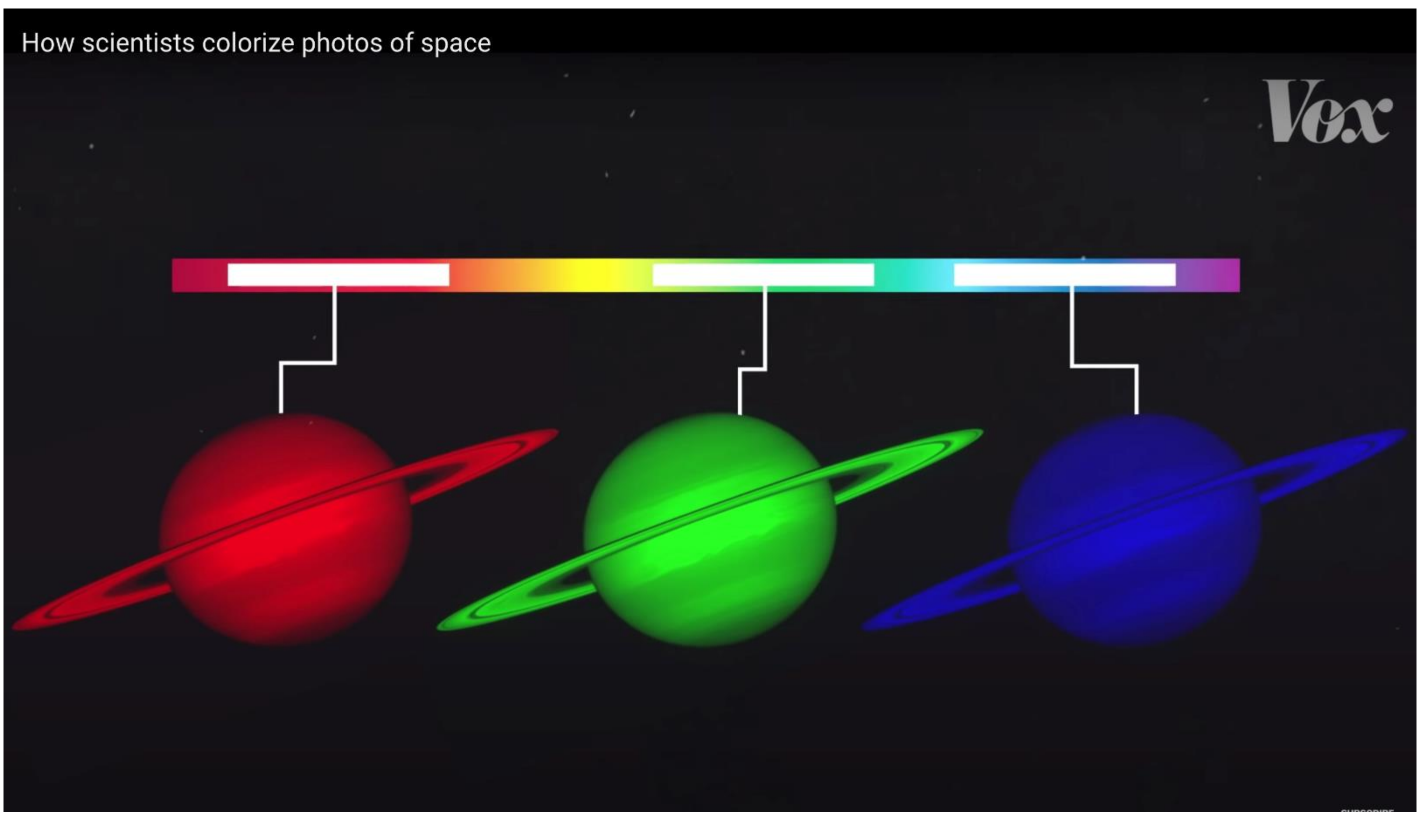
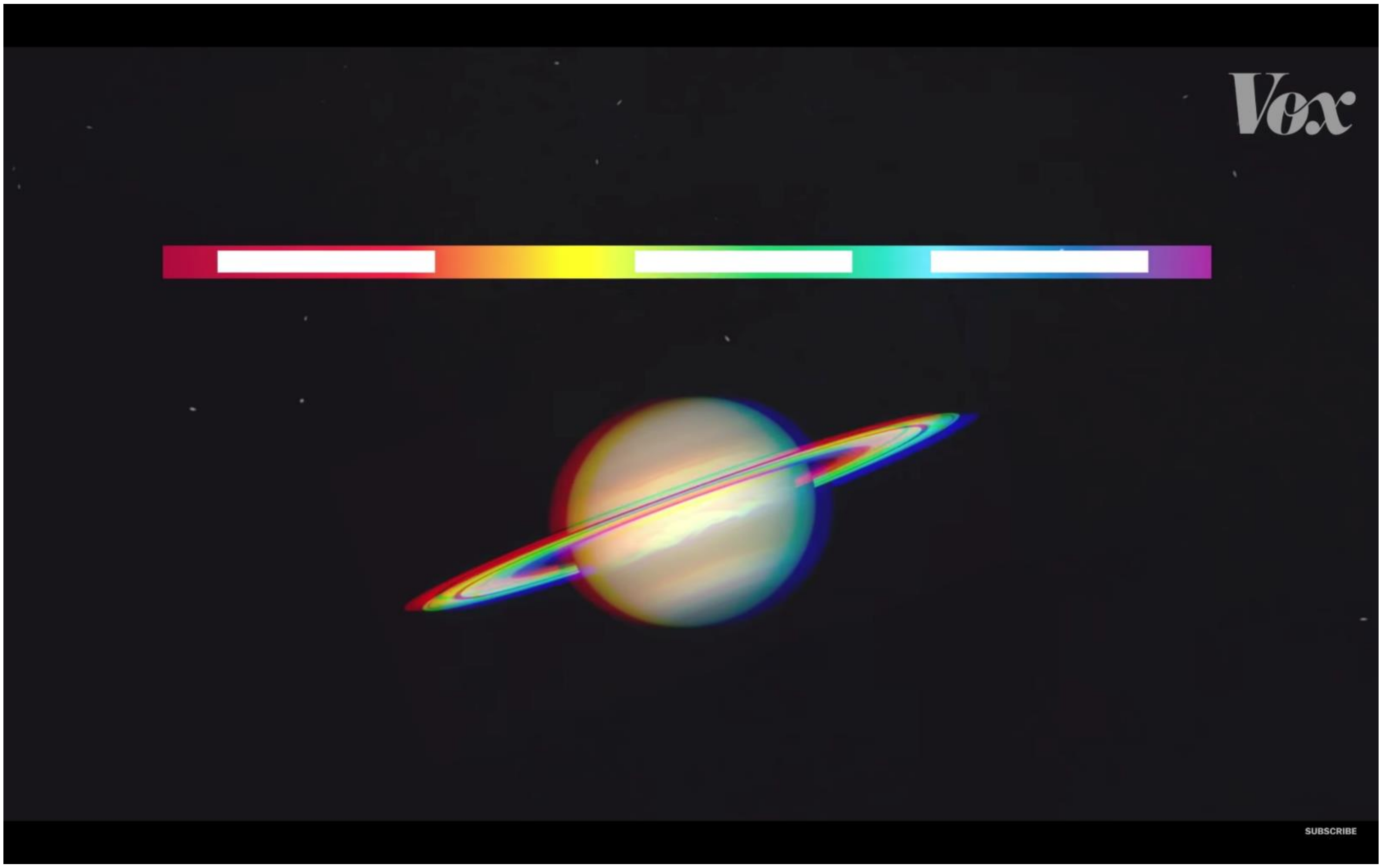
LONGER WAVELENGTH
SHORTER WAVELENGTH


How scientists colorize photos of space
Vox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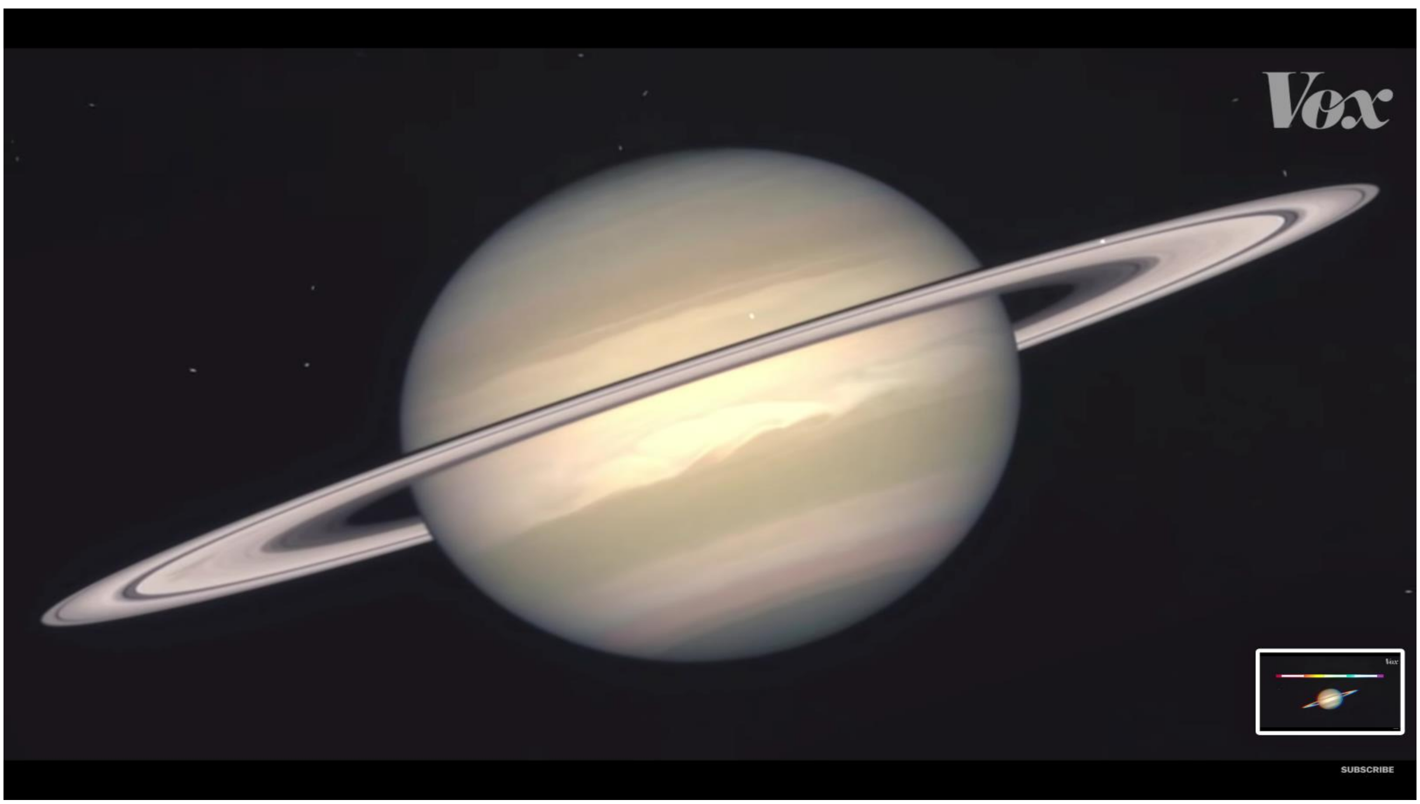
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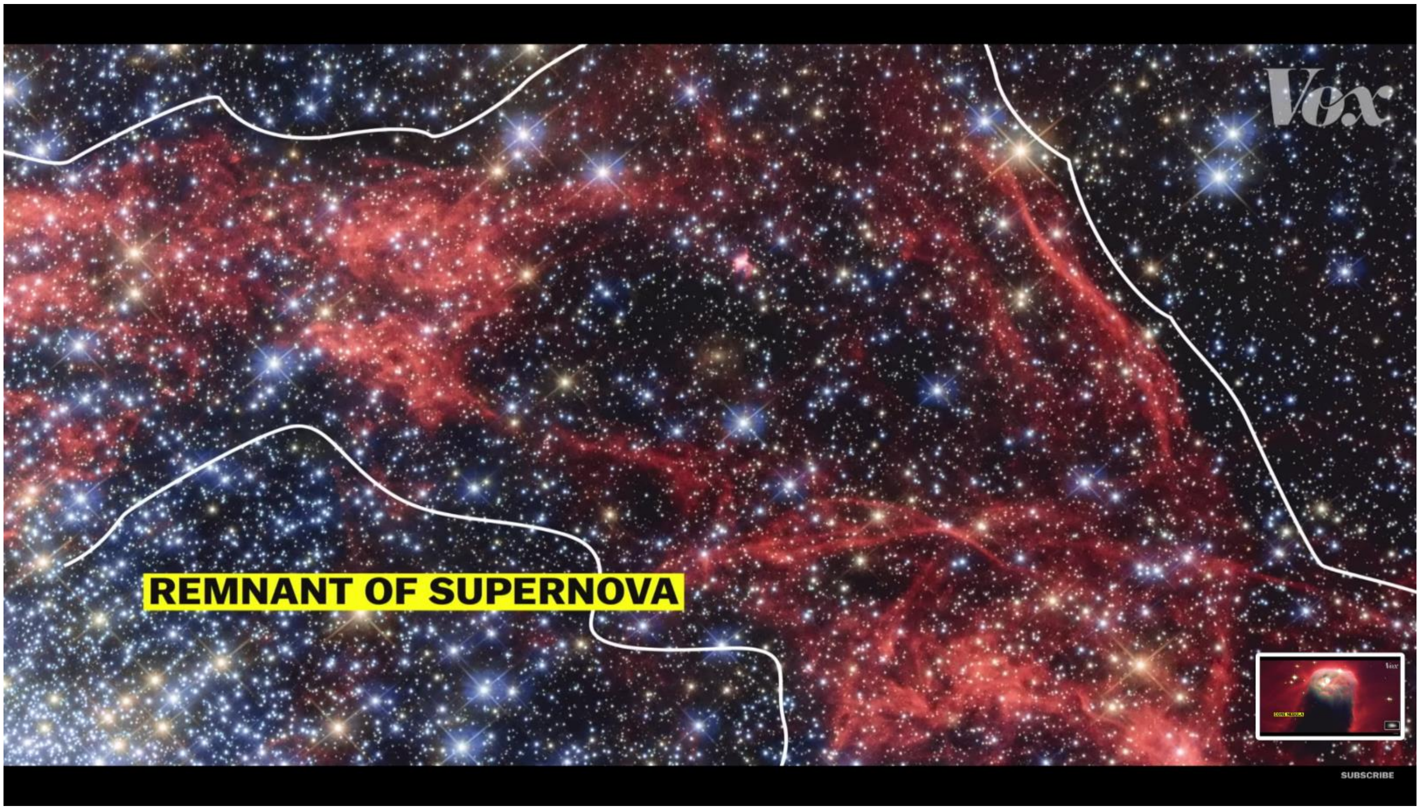
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REMNANT OF SUPERNOVA
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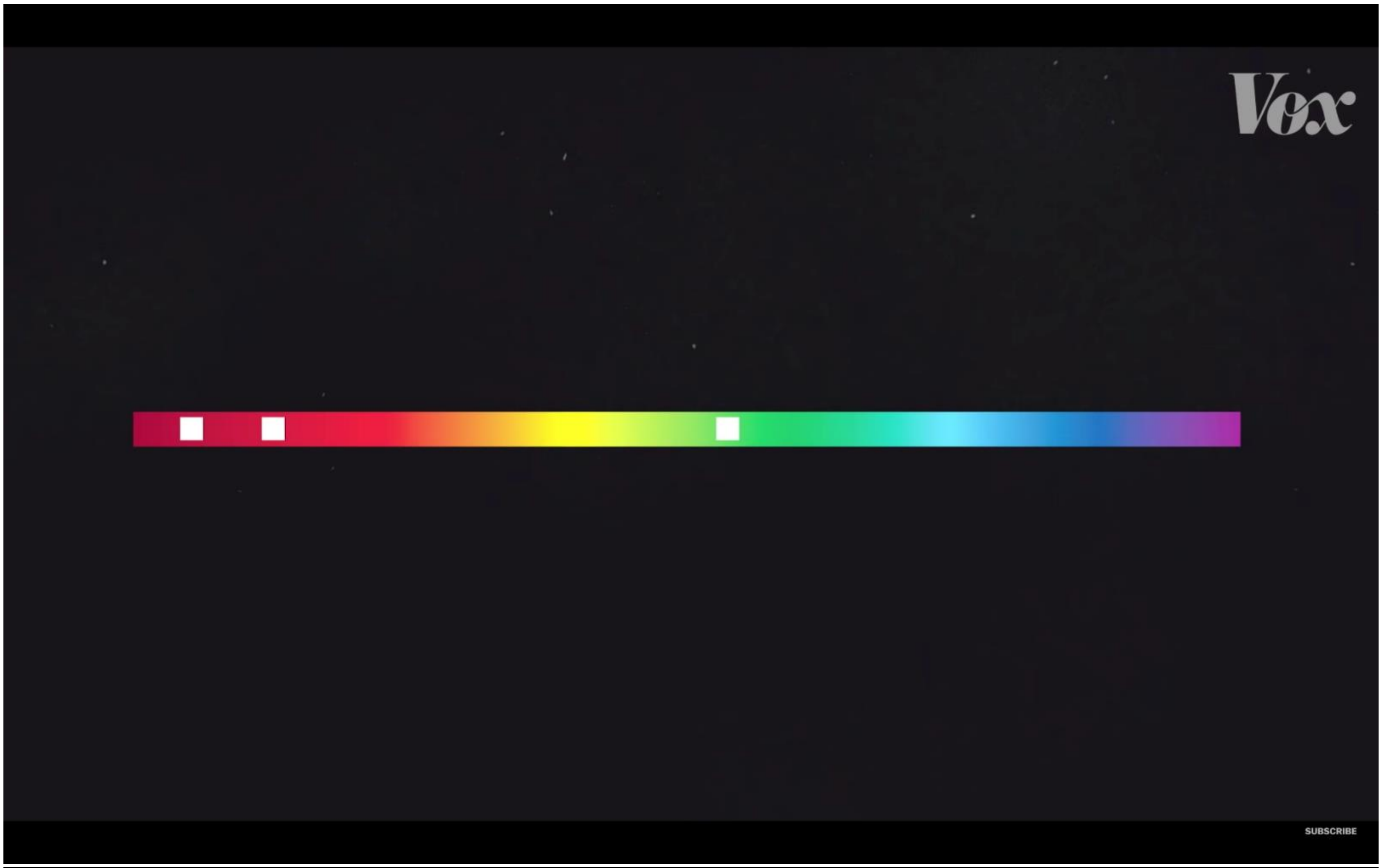
Vox
PILLARS OF CREATION
H-ALPHA NARROWBAND IMAGE
SUBSCRIBE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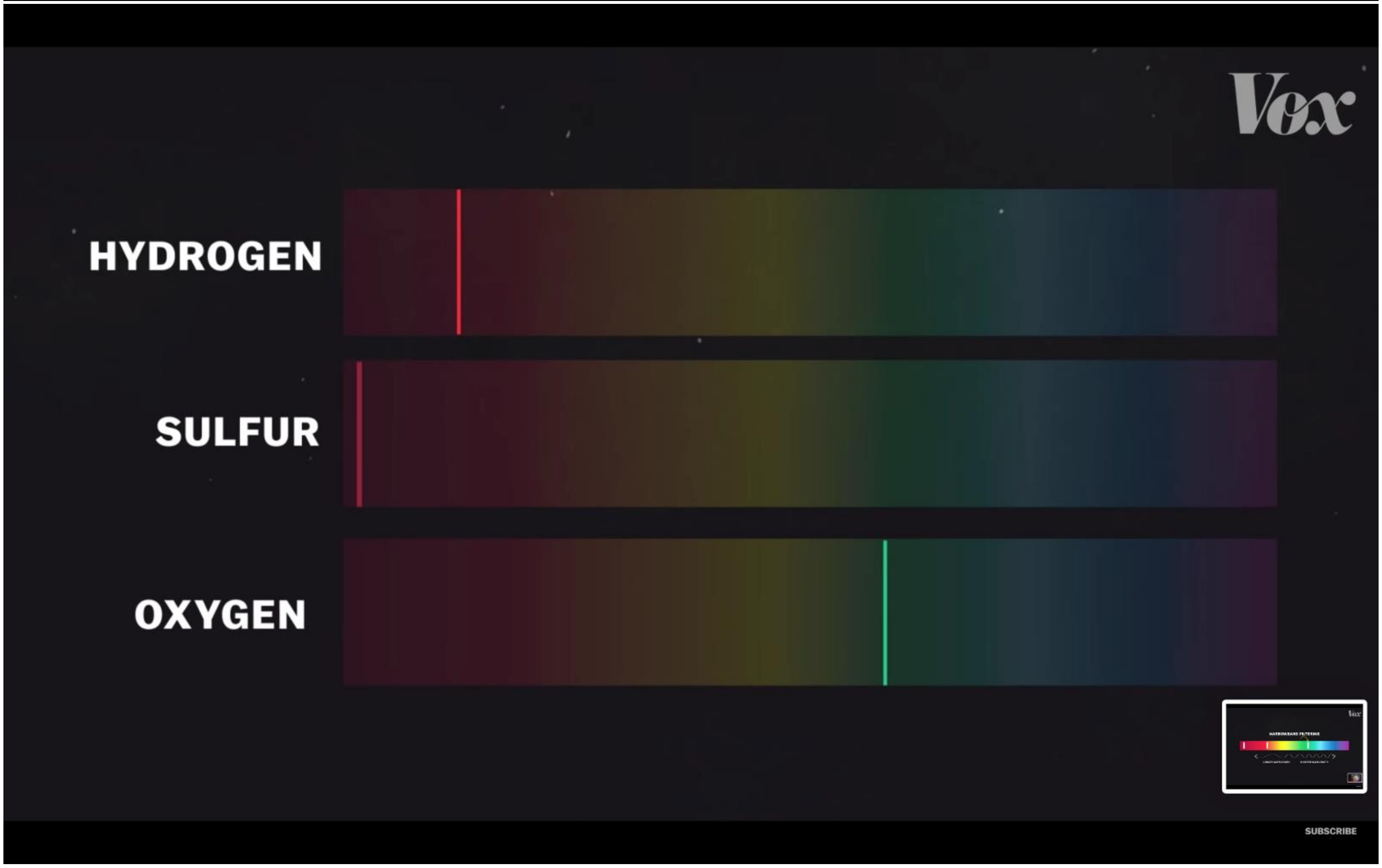
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Color fundamentals

Why use color in image processing?

- ✓ The human visual system can distinguish hundreds of thousands of different color shades and intensities, but only around 100 shades of grey.
- ✓ Therefore, in an image, a great deal of extra information may be contained in the color, and this extra information can then be used to simplify image analysis, e.g. object identification and extraction based on color.
- ✓ Three independent quantities are used to describe any particular color. The *hue* is determined by the dominant wavelength.
- ✓ Visible colors occur between about 400nm (violet) and 700nm (red) on the electromagnetic spectrum, as shown in figure below.

    - Color is a powerful descriptor
    - Object identification and extraction
    - eg. Face detection using skin colors
    - Humans can discern thousands of color shades and intensities
    - Two categories of color image processing.

- ✓ ***Full color processing:***
    - Images are acquired from full-color sensor or equipment's
- ✓ ***Pseudo-color processing:***
    - In the past decade, color sensors and processing hardware are not available.

Colors are assigned to a range of monochrome intensities

Physical phenomenon*:* Physical nature of color is known

Physio-psychological phenomenon*:* How human brain perceive and interpret color?

Sir Isaac Newton(1666) – ***Chromatic light span the electromagnetic spectrum (EM) from 400 to 700 nm***

Developed the prism theory for color of light

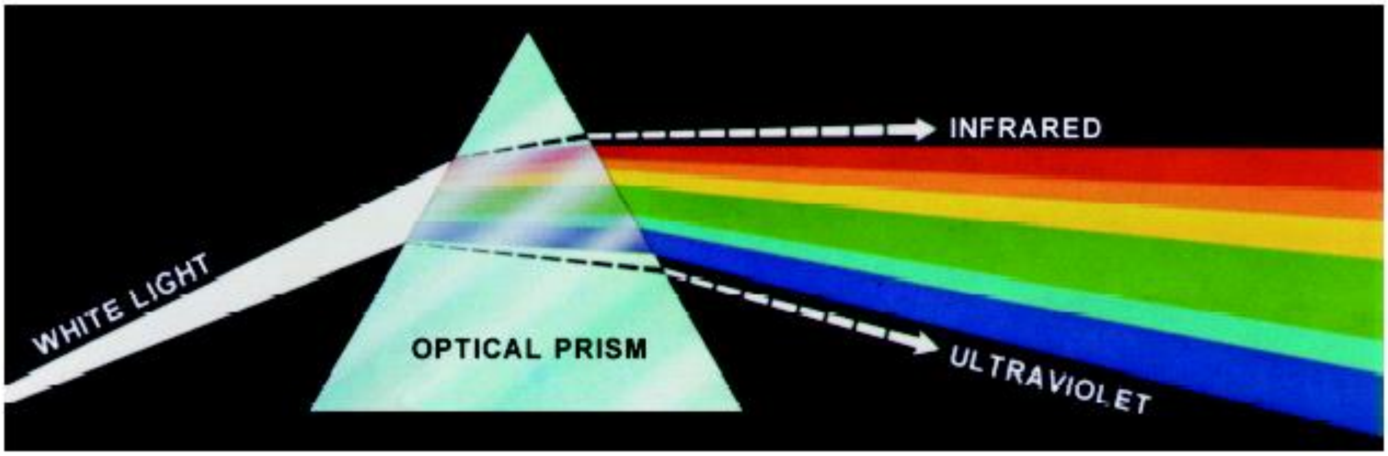


FIGURE 6.1 Color spectrum seen by passing white light through a prism. (Courtesy of the General Electric Co., Lamp Business Division.)

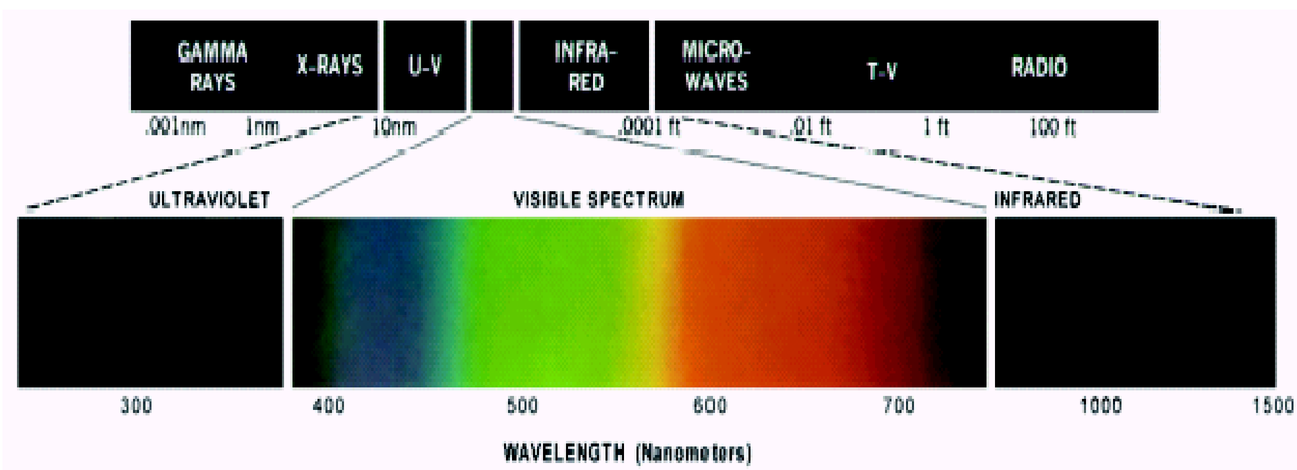
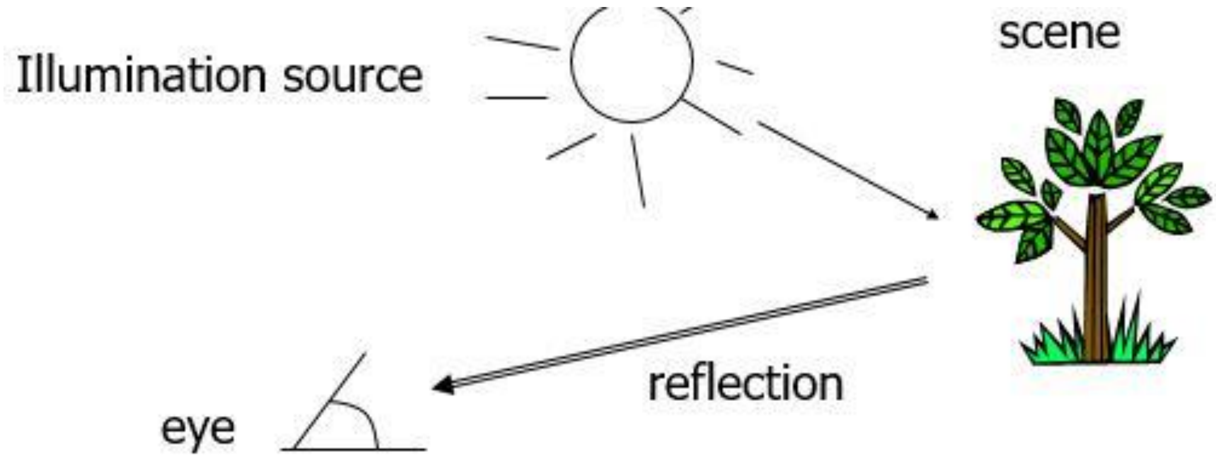


FIGURE 6.2 Wavelengths comprising the visible range of the electromagnetic spectrum. (Courtesy of the General Electric Co., Lamp Business Division.)

Illuminance of Light

- The color that human perceive in an object = the light reflected from the object.
- Physical quantities that decribe light:



- ***Radiance***: total amount of energy that flow from the light source, measured in watts (W)

- ***Luminance*****:** amount of energy an observer *perceives* from a light source, measured in lumens. *Far infrared light*: high radiance, but 0 luminance

- ***Brightness***: subjective descriptor that is hard to measure, similar to the achromatic notion of intensity.

How human eyes sense light?

6~7M Cones are the sensors in the eye

3 principal sensing categories in eyes

Red light 65%,

green light 33%,

blue light 2%

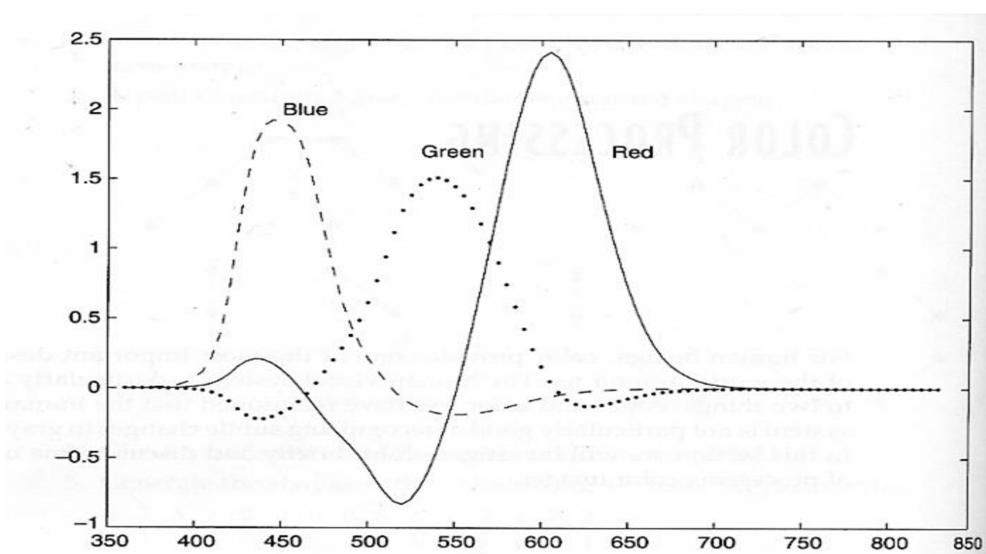
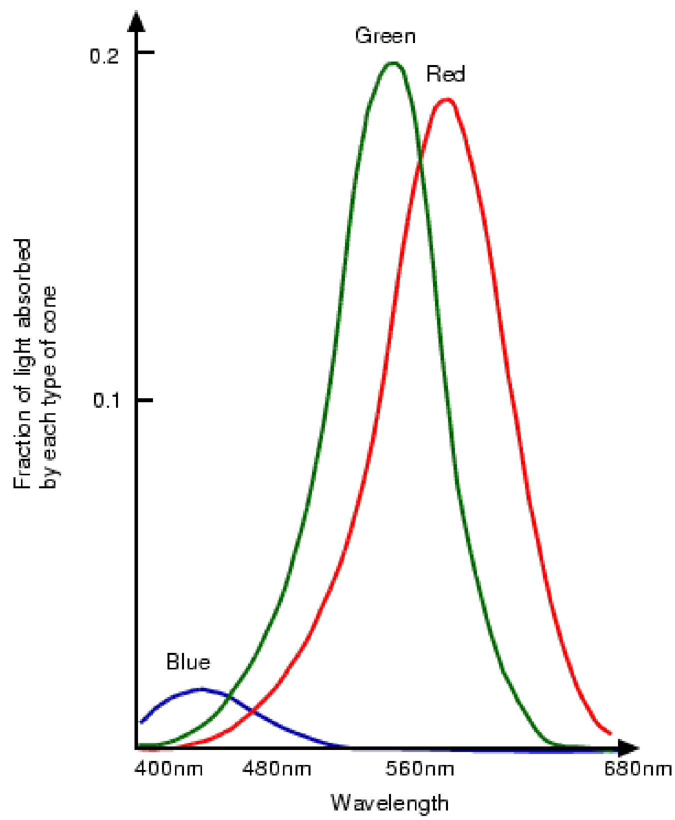


FIGURE B.1 *RGB color-matching functions (CIE, 1931).*

Tristimulus theory of color perception:

- The Tristimulus Theory of color perception is a fundamental concept in the field of color science that explains how humans perceive color.

- This theory is based on the idea that any color can be described by three components corresponding to the three types of cone cells in the human eye, each sensitive to a different range of wavelengths of light.

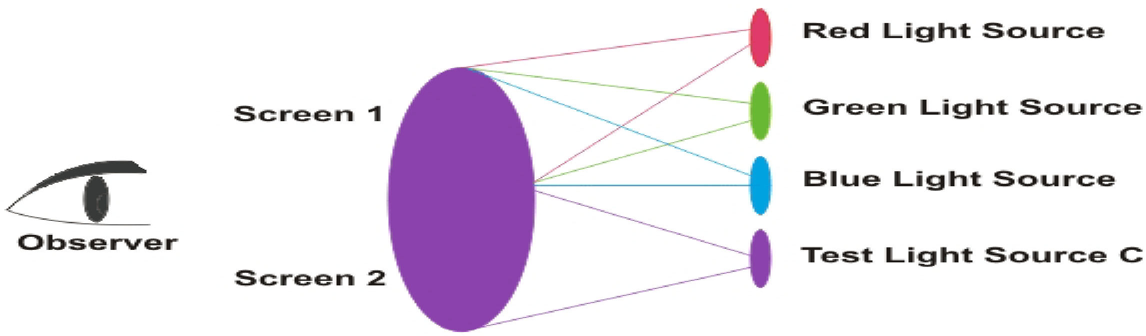


- These components are often referred to as the red, green, and blue (RGB) components, though the exact sensitivities of the cone cells do not correspond exactly to pure red, green, and blue.

- Three Types of Cone Cells: The human retina contains three types of cone cells, each sensitive to a different part of the light spectrum:
  - L Cones (Long-wavelength): These are most sensitive to light that we perceive as red.
  - M Cones (Medium-wavelength): These are most sensitive to light that we perceive as green.
  - S Cones (Short-wavelength): These are most sensitive to light that we perceive as blue.

- Tristimulus Values: The response of each type of cone can be represented as three values (X, Y, and Z) known as tristimulus values. These values are combined in different proportions to reproduce any perceivable color.

- Color Perception: When light enters the eye, it stimulates these cone cells to varying degrees depending on the light's wavelength composition. The brain interprets the combined signals from the three types of cones to produce the sensation of color.



- The peaks for each curve are at 440nm (blue), 545nm (green) and 580nm (red). Note that the last two peak in the yellow part of the spectrum.

- Color Matching Functions: These are mathematical functions that describe how the cones respond to different wavelengths of light. They are used to calculate the tristimulus values for any given color.

- CIE Color Space: The International Commission on Illumination (CIE) developed the CIE 1931 color space, which is based on the tristimulus theory. This color space provides a standardized way to represent colors using three coordinates (X, Y, Z) derived from the tristimulus values.

Primary and secondary colors

In 1931, CIE(International Commission on Illumination) defines specific wavelength values to the

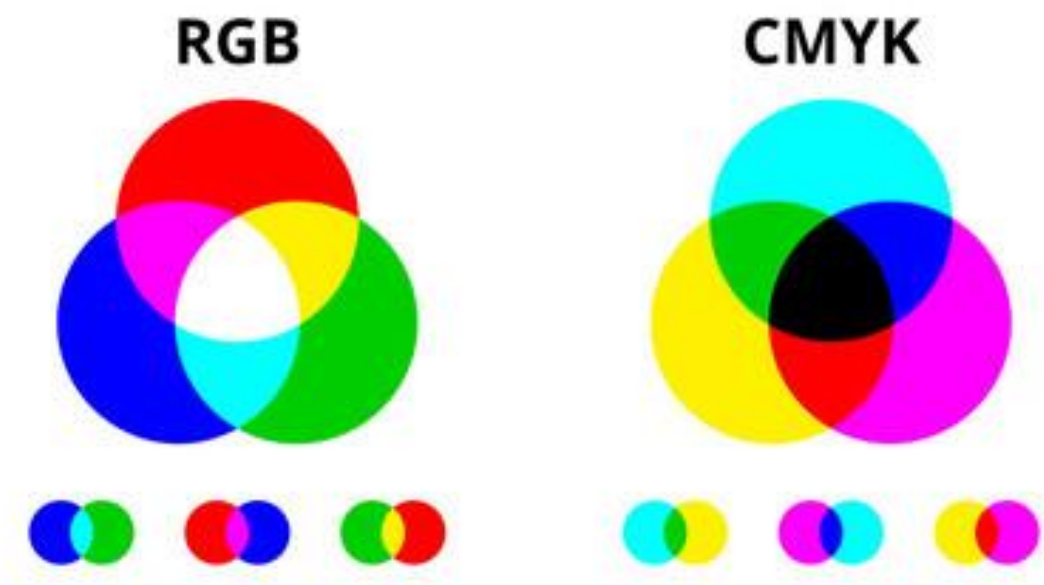
Primary colors

B = 435.8 nm **G = 546.1 nm** **R = 700 nm**

However, we know that no single color may be called red, green, or blue

Secondary colors:

G+B=Cyan, **R+G=Yellow** **R+B=Magenta**



Primary colors of light v.s. primary colors of pigments

The concepts of primary colors differ between light and pigments due to the different ways colors are created and perceived. Here's a comparison:

Primary Colors of Light

- **Additive Color Mixing** : Involves direct light, adding wavelengths together.
- **Primary Colors**: Red, Green, Blue (RGB)
- **Mechanism:** Light colors combine to form other colors. When red, green, and blue light are mixed together in different intensities, they produce the full spectrum of colors, including white when combined at full intensity.
- **Applications**: Used in digital screens, lighting, and anything that emits light. Common examples include computer monitors, televisions, and stage lighting.

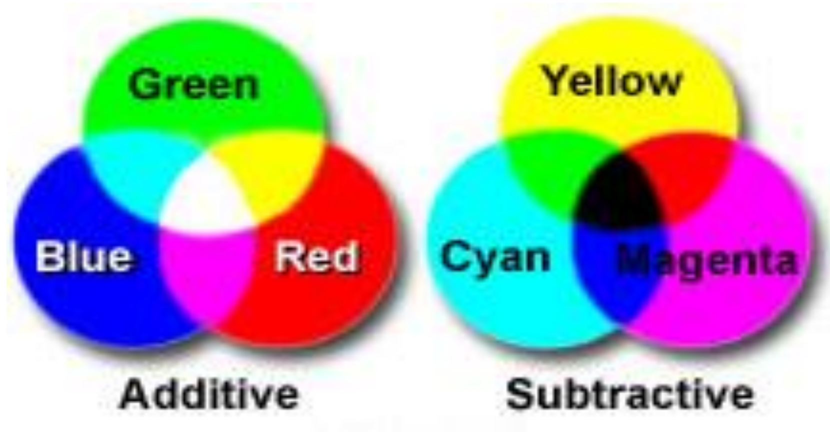
- How it Works:

  Red + Green = Yellow

  Red + Blue = Magenta

  Green + Blue = Cyan

  Red + Green + Blue = White



Primary Colors of Pigments

- **Subtractive Color Mixing:** Involves pigments or dyes, removing (subtracting) wavelengths from white light.

- **Primary Colors**: Cyan, Magenta, Yellow (CMY)

- **Mechanism**: Pigments absorb (subtract) certain wavelengths of light and reflect others. When cyan, magenta, and yellow pigments are mixed together, they absorb all colors and ideally produce black (in practice, they often produce a dark brown, so black (K) is added in printing to form the CMYK model).

- **Applications**: Used in printing, painting, and any medium involving dyes or pigments. Common examples include printers, paints, and textiles.

- How it Works:

  Cyan + Magenta = Blue

  Cyan + Yellow = Green

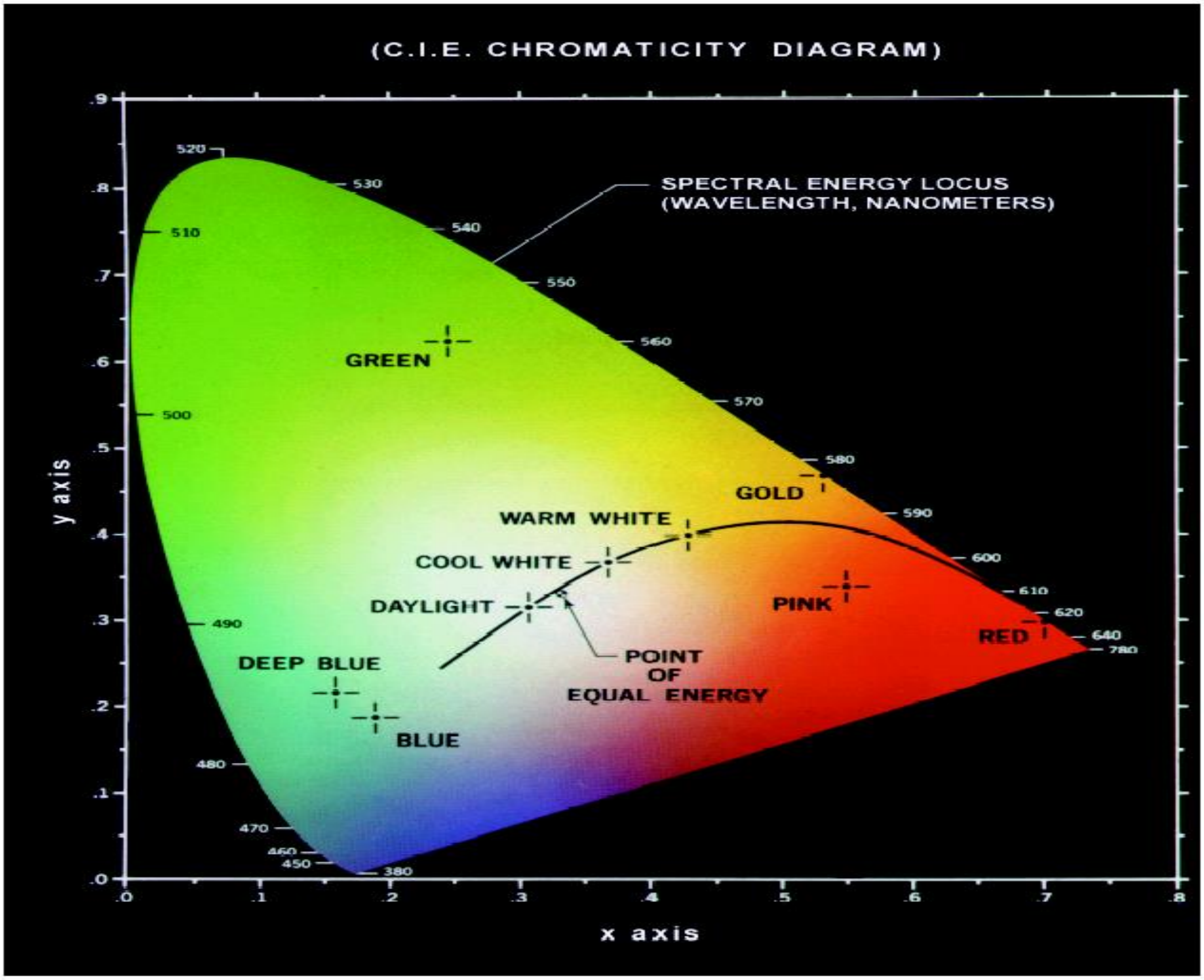
  Magenta + Yellow = Red

  Cyan + Magenta + Yellow = Black (or dark brown)

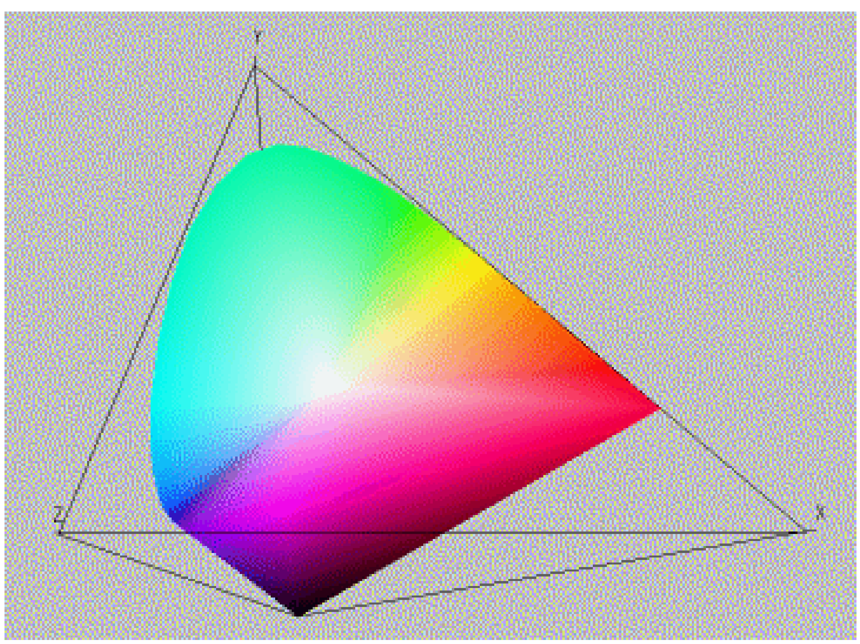
CIE primaries

- The CIE (Commission Internationale de l'Éclairage or International Commission on Illumination) primaries are fundamental to the CIE color space, which is a mathematical model to describe all perceivable colors.

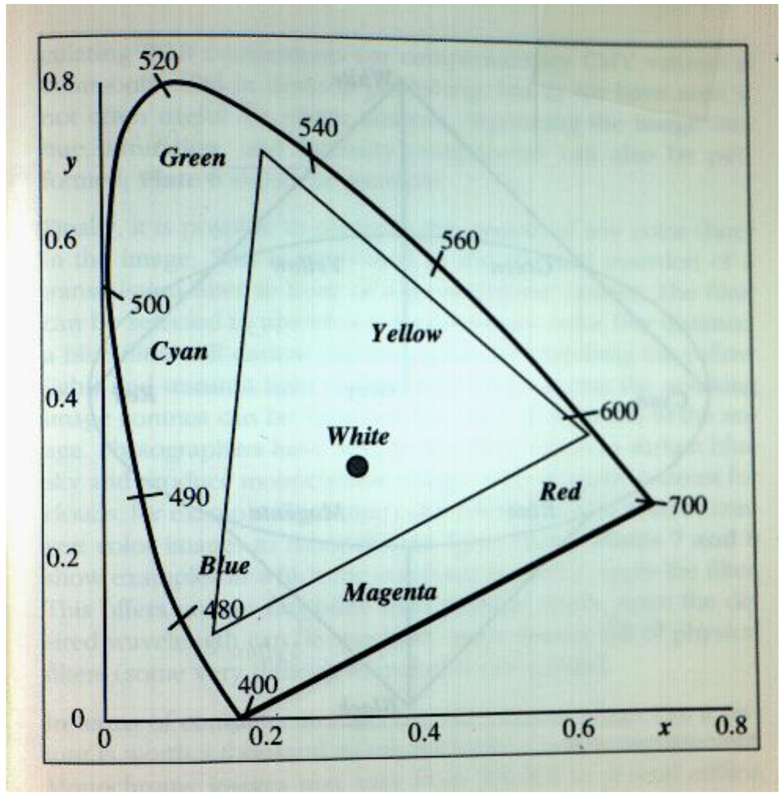
- The most well-known CIE color space is the CIE 1931 XYZ color space, which uses theoretical primary colors that are not **physically realizable but serve as a useful tool for color measurement and comparison.**



➢ **Purpose**: The CIE 1931 XYZ color space was designed to be a device-independent model, meaning it can describe any color perceivable by the human eye without relying on the specific characteristics of physical devices like monitors or printers.



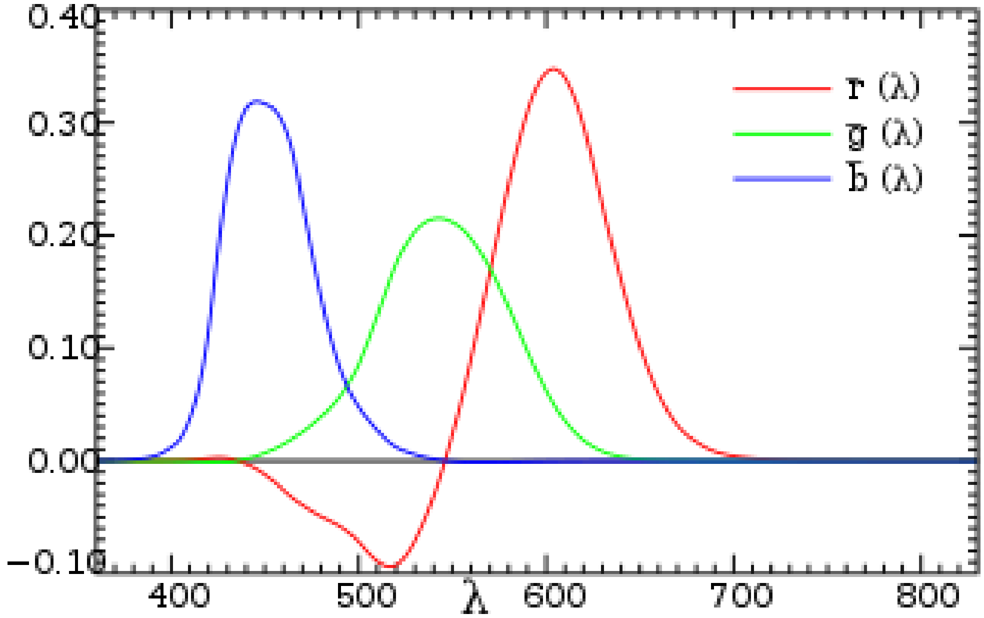
- **Tristimulus Values**:
  - **X**: Represents the mix of the three primary colors with a peak sensitivity similar to the human eye's response to the long-wavelength part of the spectrum (red).
  - **Y**: Corresponds to the brightness or luminance of the color, closely matching the human eye's sensitivity to brightness, with a peak in the green region.
  - **Z**: Relates to the short-wavelength part of the spectrum (blue).



- **CIE Primaries**:
  - The CIE primaries (often denoted as X, Y, and Z) are not real colors but are mathematical constructs.
  - They were chosen such that all physically realizable colors (visible to the human eye) can be represented as positive values of X, Y, and Z.

- **Chromaticity Diagram:** The CIE 1931 color space can be visualized using the chromaticity diagram, where colors are represented by their chromaticity coordinates (x, y), derived from the XYZ tristimulus values:
  - **x = X / (X + Y + Z)**
  - **y = Y / (X + Y + Z)**
  - The chromaticity diagram is a 2D representation where each point corresponds to a color, regardless of its luminance.

- **Standard Observer:** The CIE defined a "standard observer," which is a model of human color vision based on experiments with human subjects. The standard observer's color matching functions, $\bar{x}(\lambda)$ $\bar{y}(\lambda)$ $\bar{z}(\lambda)$ are used to derive the XYZ values from the spectral power distribution of a light source.



- **Applications of CIE Color Space**
  - **Color Measurement**: The CIE XYZ color space is used to measure and describe colors in a standardized way. Colorimeters and spectrophotometers often output colors in terms of their XYZ values.
  - **Color Conversion**: Converting between different color spaces (like RGB to CMYK) often involves an intermediate conversion to the CIE XYZ color space because it is device-independent.
  - **Color Research**: It serves as a foundation for various studies in color science, including color difference measurement and color appearance models.

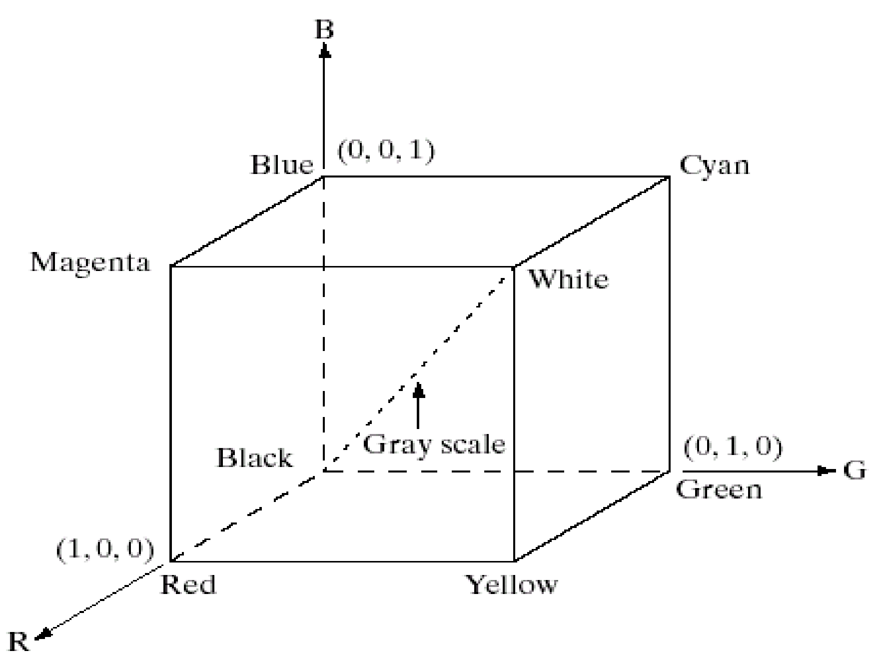
Color Models

- Color model, color space, color system
- Specify colors in a standard way
- A coordinate system that each color is represented by a single point
- Color models provide a standard way to specify a particular color, by defining a 3D coordinate system, and a subspace that contains all constructible colors within a particular model.
- Any color that can be specified using a model will correspond to a single point within the subspace it defines.
- Each color model is oriented towards either specific hardware (RGB, CMY, YIQ), or image processing applications (HSI).

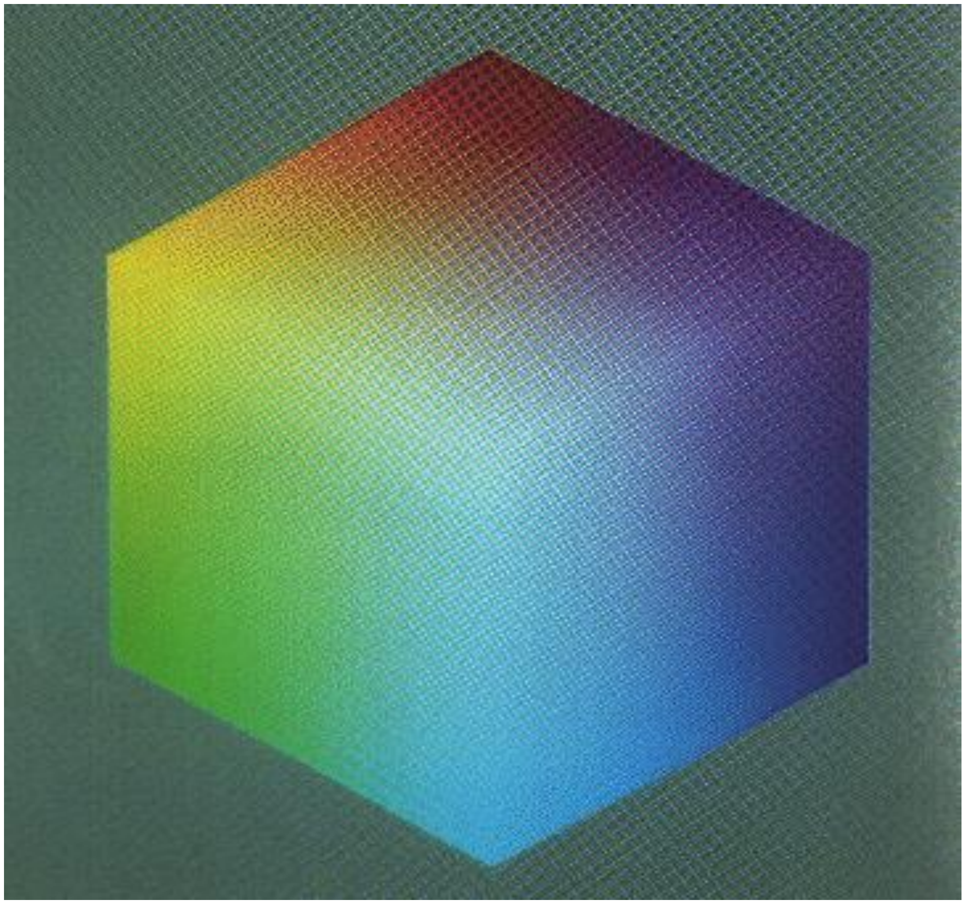
- **RGB model**
- **CYM model**
- **CYMK model**
- **HSI model**

RGB color model

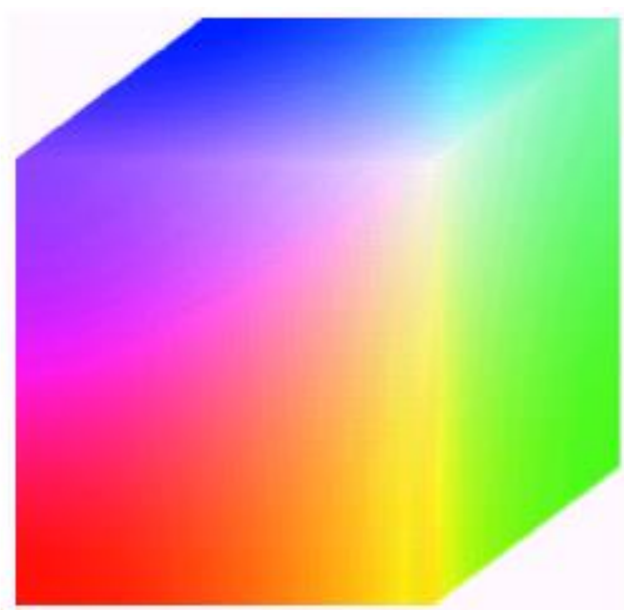
- The RGB color model is composed of the primary colors Red, Green, and Blue.
- This system defines the color model that is used in most color CRT monitors and color raster graphics.
- They are considered the "additive primaries" since the colors are added together to produce the desired color.



- The RGB model uses the cartesian coordinate system as shown in Figure XX. Notice the diagonal from (0,0,0) black to (1,1,1) white which represents the grey-scale.



<u>Here is a view of the RGB color model looking down the gray scale line.</u>



- Pixel depth: the number of bits used to represent each pixel in RGB space

  Full-color image: 24-bit RGB color image

  (R, G, B) = (8 bits, 8 bits, 8 bits)

- In the RGB model, an image consists of three independent image planes, one in each of the primary colors: red, green and blue.

- (The standard wavelengths for the three primaries are as shown in above figure. Specifying a particular color is by specifying the amount of each of the primary components present.

- It shows geometry of the RGB color model for specifying colors using a Cartesian coordinate system.

- The greyscale spectrum, i.e. those colors made from equal amounts of each primary, lies on the line joining the black and white vertices.

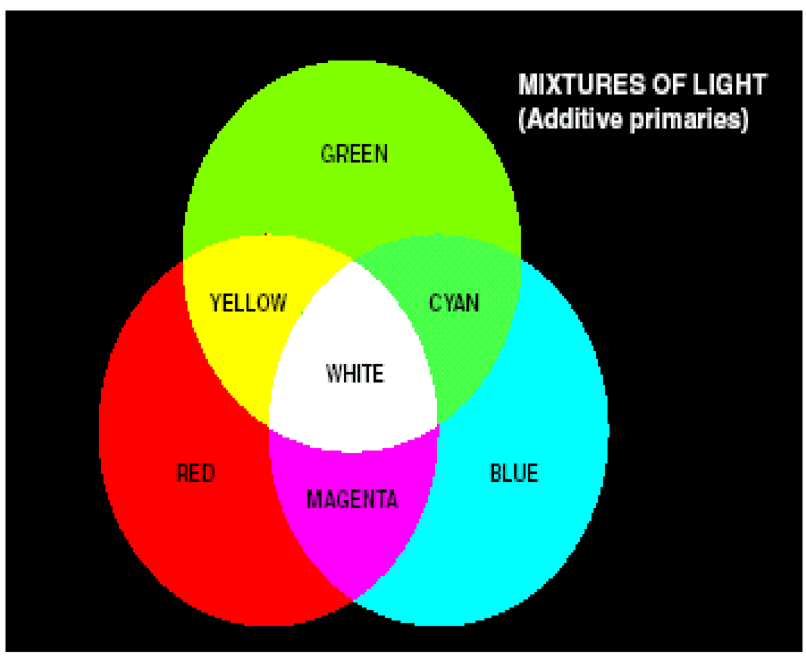
- This is an *additive* model, i.e. the colors present in the light add to form new colors, and is appropriate for the mixing of colored light for example. The image on the left of figure shows the additive mixing of red, green and blue primaries to form the three secondary colors yellow (red + green), cyan (blue + green) and magenta (red + blue), and white ((red + green + blue).

- The RGB model is used for color monitors and most video cameras.

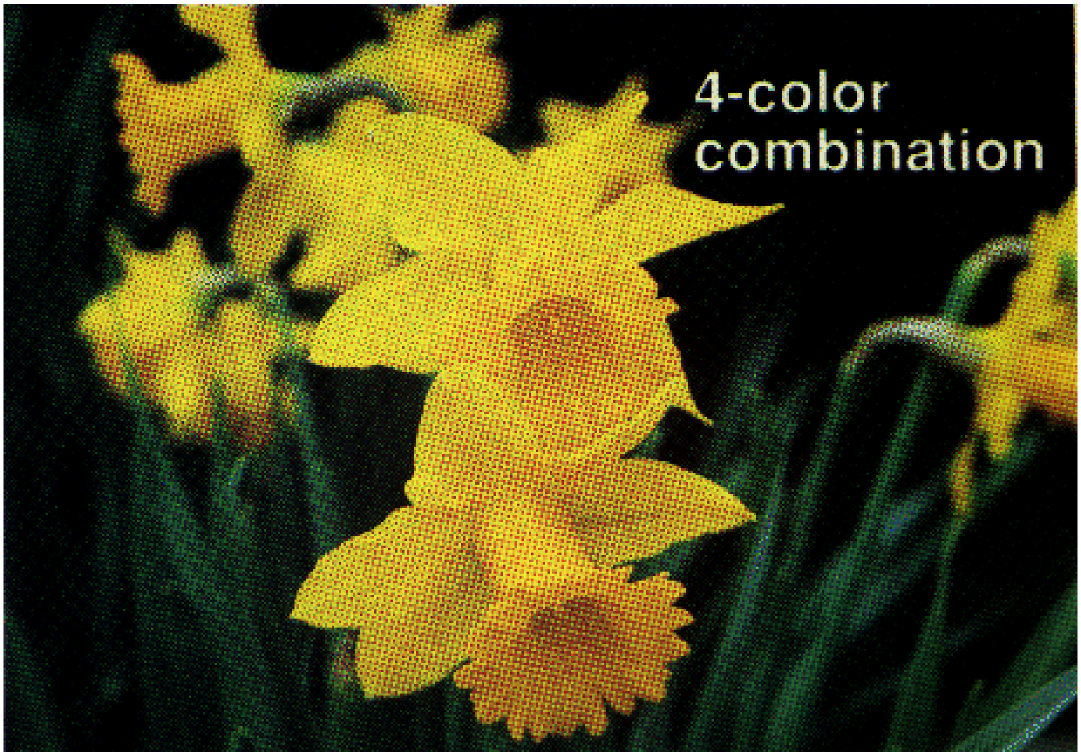
CMY model (+Black = CMYK)

- The CMY color model stands for Cyan, Magenta and Yellow which are the complements of red, green and blue respectively.

- This system is used primary for printing. The CMY colors are called the "subtractive primaries" since the color specified is obtained from by what is removed from white light not added.



- Paper is coated with cyan ink which absorbs the red light, therefore cyan is white - red or blue + green. Similarly, Magenta is White-Green or Red + Blue and Yellow is White-Blue or Red + Green



- CMY: secondary colors of light, or primary colors of pigments
- Used to generate hardcopy output
- The CMY (cyan-magenta-yellow) model is a *subtractive* model appropriate to absorption of colors, for example due to pigments in paints.

$$\begin{bmatrix} C \\ M \\ Y \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

- Whereas the RGB model asks what is added to black to get a particular color, the CMY model asks what is subtracted from white. In this case, the primaries are cyan, magenta and yellow, with red, green and blue as secondary colors.
- When a surface coated with cyan pigment is illuminated by white light, no red light is reflected, and similarly for magenta and green, and yellow and blue. The relationship between the RGB and CMY models is given above:

Example: Why does blue paint plus yellow paint give green?

When blue paint and yellow paint are mixed together, each pigment absorbs certain wavelengths of light and reflects others:

- ✓ Blue paint absorbs the red and green wavelengths but reflects blue.
- ✓ Yellow paint absorbs the blue wavelengths but reflects red and green.

When these two paints are combined, the blue pigment from the blue paint mixes with the green and red wavelengths reflected by the yellow paint. This results in both blue and green wavelengths being reflected back to our eyes, creating the perception of green.

Question: Convert the RGB color (120, 180, 220) to the CMYK color model.

Solution:

Normalize the RGB values to the range [0, 1].

(C): 1 - (R) / 255 = 1 - 120 / 255 = 0.533
(M): 1 - (G) / 255 = 1 - 180 / 255 = 0.294
(Y): 1 - (B) / 255 = 1 - 220 / 255 = 0.137

Find the black component (K) by taking the minimum of the CMY values:

K = min(C, M, Y) = min(0.533, 0.294, 0.137) = 0.137

Calculate the CMYK values:

C' = (C - K) / (1 - K) = (0.533 - 0.137) / (1 - 0.137) = 0.396 / 0.863 ≈ 0.46

M' = (M - K) / (1 - K) = (0.294 - 0.137) / (1 - 0.137) = 0.157 / 0.863 ≈ 0.18

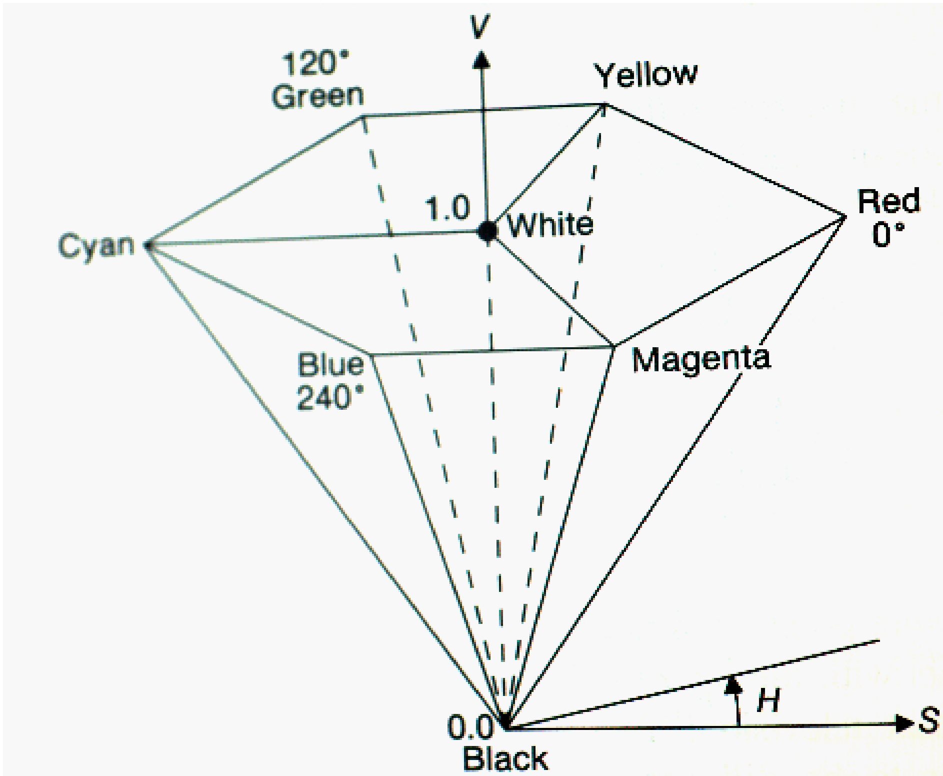
Y' = (Y - K) / (1 - K) = (0.137 - 0.137) / (1 - 0.137) = 0.000 / 0.863 = 0.00

CMYK representation of the RGB color (120, 180, 220)
is approximately (0.46,0.18,0.0).

Cyan (C'): 0.46
Magenta (M'): 0.18
Yellow (Y'): 0.00
Key (K): 0.137 (unchanged)

HSI color model

- Humans describe a color by its hue, saturation, and brightness.



- **Hue:** color attribute.

  Represents the dominant wavelength of the color. It corresponds to the pure color without any white light added. Hue is represented as an angle around a color wheel, with red at 0°, green at 120°, and blue at 240°.

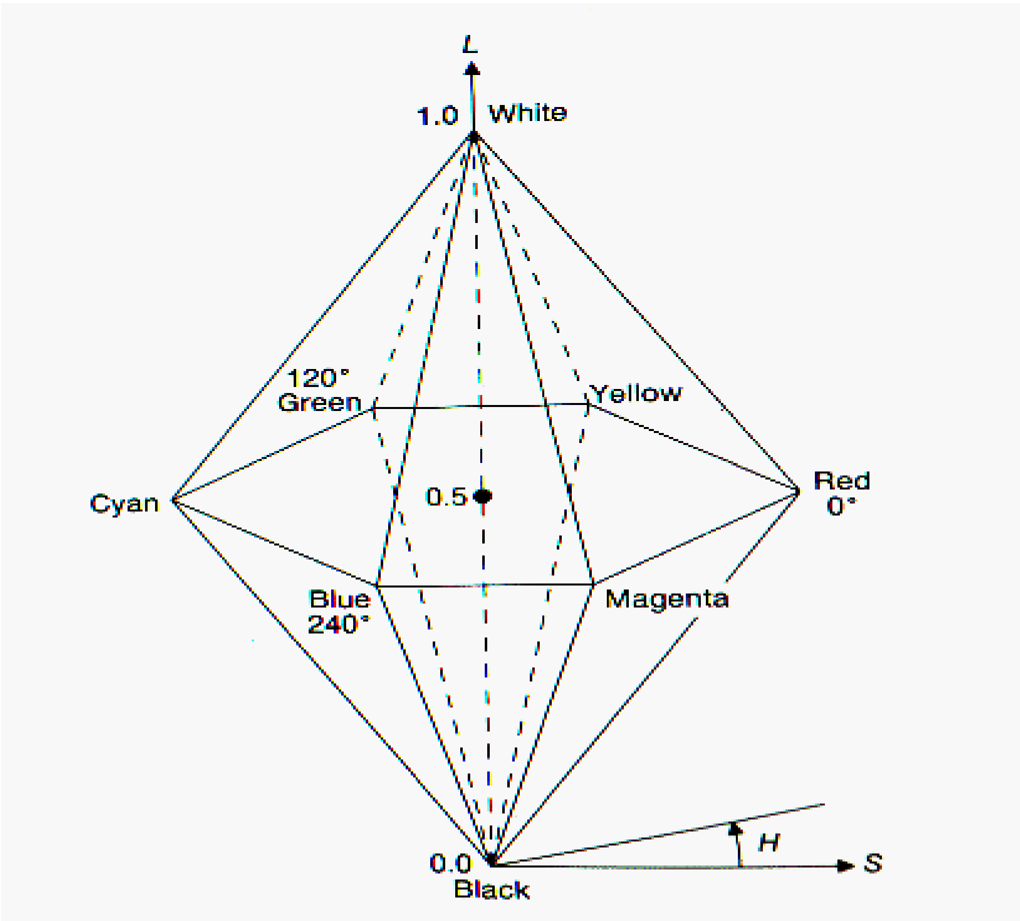
- **Saturation:** purity of color (white->0, primary color->1)

  Represents the purity or vividness of the color. It indicates how much white light is mixed with the pure color. Saturation ranges from 0 (gray) to 1 (fully saturated).

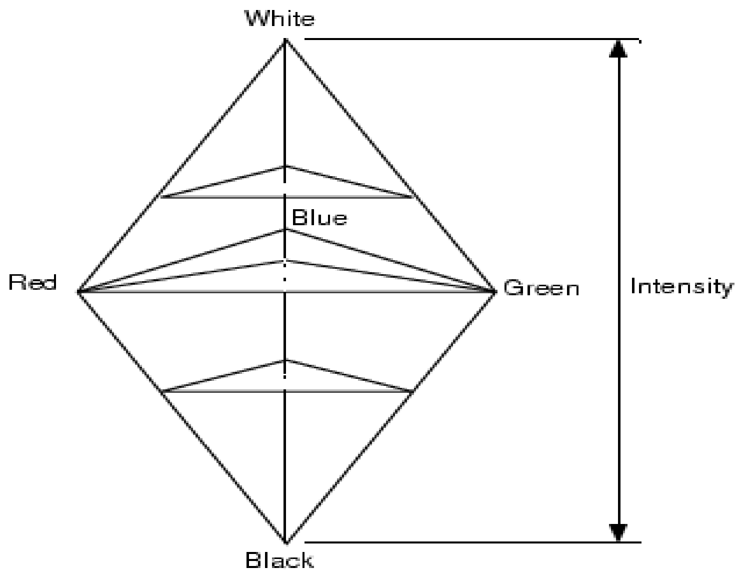
- **Intensity (I) or Brightness (B):** achromatic notion of intensity.

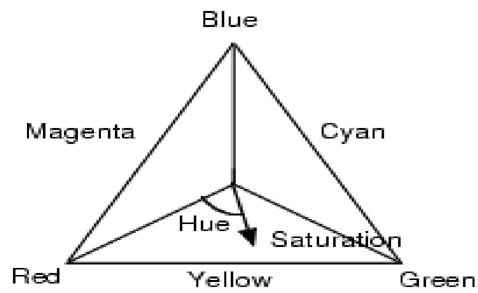
  Represents the overall lightness or darkness of the color. It indicates the amount of light emitted or reflected by the color. Intensity ranges from 0 (black) to 1 (full intensity), while brightness typically ranges from 0 (black) to 100 (full intensity).

- As mentioned above, color may be specified by the three quantities hue, saturation and intensity.
- This is the HSI model, and the entire space of colors that may be specified in this way is shown in figure
- The HSI model, showing the HSI solid on the left, and the HSI triangle on the right, formed by taking a horizontal slice through the HSI solid at a particular intensity.



- Hue is measured from red, and saturation is given by distance from the axis. Colors on the surface of the solid are fully saturated, i.e. pure colors, and the greyscale spectrum is on the axis of the solid. For these colors, hue is undefined.





<u>Conversion between the RGB model and the HSI model is quite complicated. The intensity is given by.</u>

The Intensity is given by:

$$I = \frac{R+G+B}{3},$$

The saturation is given by:

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

The hue is given by:

- $\theta = \arccos\left(\frac{\frac{1}{2}\times((R'-G')+(R'-B'))}{\sqrt{(R'-G')^2+(R'-B')(G'-B')}}\right)$
- $\text{Hue} = \begin{cases} \theta & \text{if } B' \leq G' \\ 360-\theta & \text{otherwise} \end{cases}$

- where the quantities R, G and B are the amounts of the red, green and blue components, normalized to the range [0,1]. The intensity is therefore just the average of the red, green and blue components.

- where the min(R,G,B) term is really just indicating the amount of white present. If any of R, G or B are zero, there is no white and we have a pure color. The expression for the hue, and details of the derivation may be found in reference.

Numerical Question: Conversion between RGB and HSI Models

Question: Convert the RGB color (120, 180, 220) to the HSI color model. Provide the values of hue, saturation, and intensity.

SOLUTION

Normalize the RGB values:

(R') : 120 / 255 = 0.4706
(G') : 180 / 255 = 0.7078
(B') : 220 / 255 = 0.8627

Calculate the intensity:

I = (R + G + B) / 3 = (120 + 180 + 220) / 3 = 173.33

Find the maximum (Max) and minimum (Min) normalized values:

Max = max(R, G, B) = 0.8627
Min = min(R, G, B) = 0.4706

Calculate the saturation:

S = 1 – 3* min (R',G',B') / (R + G + B)

= 1 – 3 * 0.4706 / (120 + 180 + 220)

= 0.9973

Calculate the hue:

- $\theta = \arccos\left(\frac{\frac{1}{2}\times((R'-G')+(R'-B'))}{\sqrt{(R'-G')^2+(R'-B')(G'-B')}}\right)$
- $\text{Hue} = \begin{cases}\theta & \text{if } B' \leq G' \\ 360-\theta & \text{otherwise}\end{cases}$

Substitute the normalized RGB values:

- $\theta = \arccos\left(\frac{\frac{1}{2}\times((0.4706-0.7059)+(0.4706-0.8627))}{\sqrt{(0.4706-0.7059)^2+(0.4706-0.8627)(0.7059-0.8627)}}\right)$
- $\theta = \arccos\left(\frac{\frac{1}{2}\times(-0.2353+(-0.3921))}{\sqrt{(-0.2353)^2+(-0.3918)(-0.1568)}}\right)$
- $\theta = \arccos\left(\frac{\frac{1}{2}\times-0.6274}{\sqrt{0.0554+0.0614}}\right)$
- $\theta = \arccos\left(\frac{-0.3137}{\sqrt{0.1168}}\right)$
- $\theta = \arccos\left(\frac{-0.3137}{0.3419}\right)$
- $\theta = \arccos(-0.9174)$
- $\theta \approx 156.3652$

Since $B' > G'$, $\text{Hue} = 360-\theta$

- $\text{Hue} \approx 360-156.3652$
- $\text{Hue} \approx 203.6348$

Therefore, the HSI representation of the RGB color (120, 180, 220) is approximately (203.6348°, 0.9973, 173.3333).

Interpretations:

Hue (203.6348°): *This represents the type of color or the dominant wavelength of the color. It is usually expressed in degrees (0° to 360°) on the color wheel, where 0°*

corresponds to red, 120° to green, and 240° to blue. A hue of 203.6348° falls between blue and cyan.

Saturation (0.9973)*: This represents the purity or vividness of the color, ranging from 0 to 1. A saturation of 0 means the color is a shade of gray, while a saturation of 1 means the color is fully saturated (vivid). A value of 0.9973 indicates a highly saturated color, very close to its pure form.*

Intensity (173.3333)*: This represents the brightness of the color, which can range from 0 (black) to 255 (white) in an 8-bit representation. An intensity of 173.3333 means the color is relatively bright but not at its maximum brightness.*

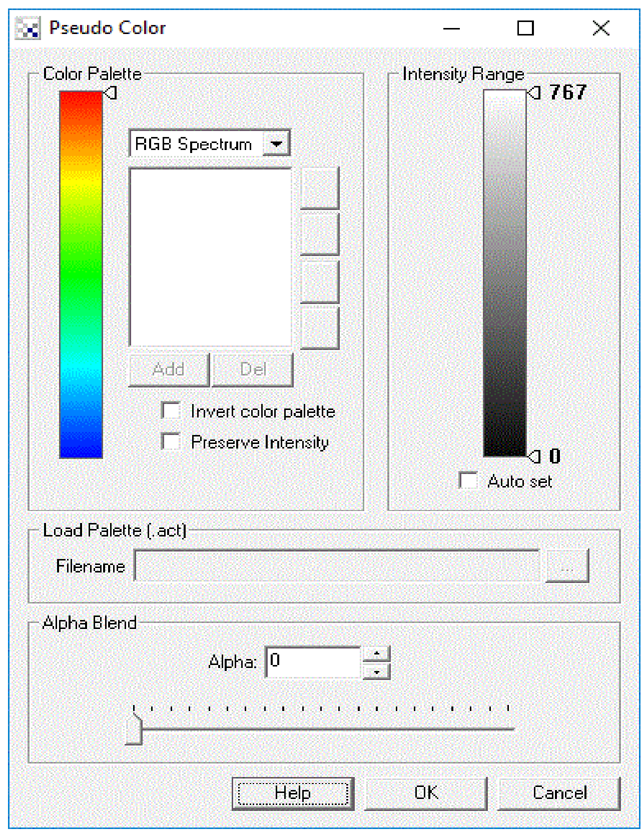
YIQ Color Model

- This is the color model used by the U.S. Commercial Color Television Broadcasting.
- It is a recording of RGB for transmission efficiency and for downward compatibility for black & white television.
- It is transmitted using the NTSC (National Television System Committee) system.
- To convert between RGB and YIQ the following matrix should be used

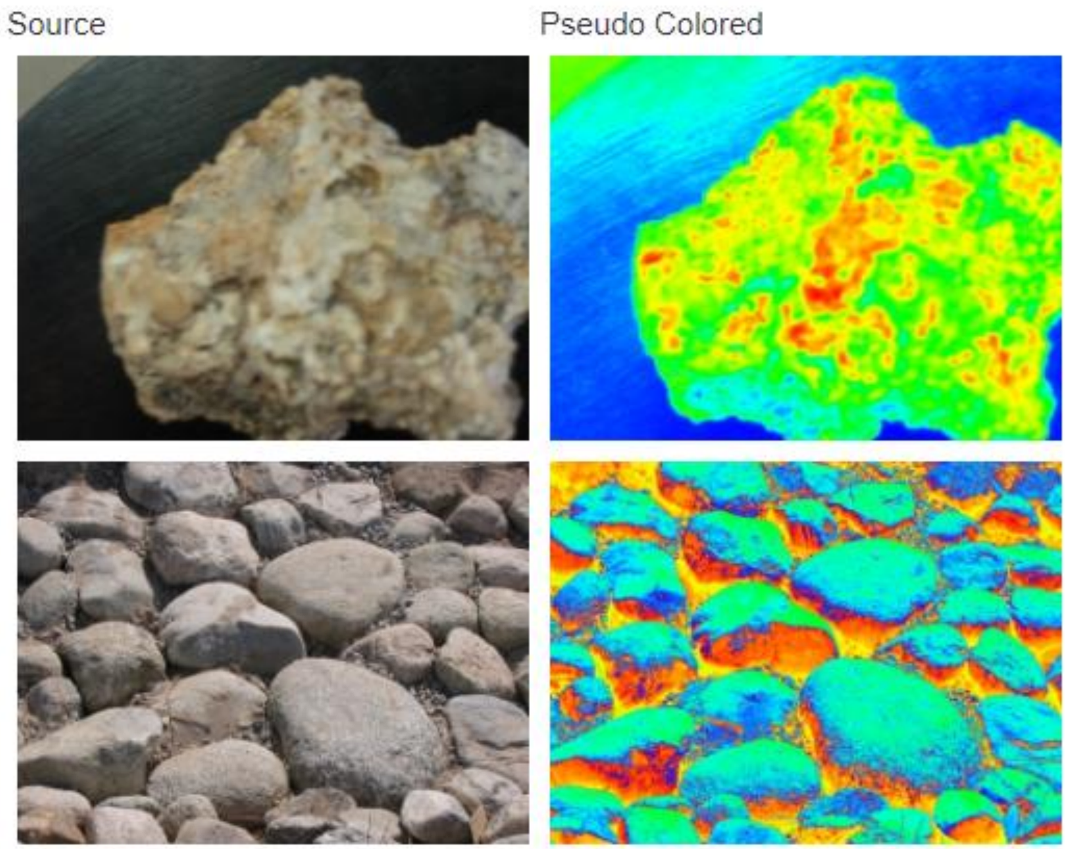
Pseudo-color image processing

- Pseudocolor-based image processing is a technique used to enhance the visualization of grayscale images by mapping the intensity values to a specific color.
- This method is particularly useful in scientific imaging, medical imaging, and data visualization where the goal is to improve the interpretability of images.
- **Pseudocolor Mapping:**
    - Involves assigning colors to different intensity levels of a grayscale image.
    - Commonly used color maps include rainbow, hot, cool, and jet.

- **Purpose of Pseudocolor:**
  - Enhance visual contrast and detail.
  - Facilitate the identification of patterns, structures, or anomalies.
  - Improve the interpretability of complex data.



- **Applications:**
  - Medical Imaging: Enhancing X-rays, MRI, and CT scans.
  - Thermal Imaging: Visualizing temperature distributions.
  - Scientific Imaging: Visualizing data from various sensors (e.g., satellite images).



Numerical Example:

Apply pseudocolor mapping to the following 3x3 grayscale image segment using a simple colormap where:

Intensity values 0-63 are mapped to blue.
Intensity values 64-127 are mapped to green.
Intensity values 128-191 are mapped to yellow.
Intensity values 192-255 are mapped to red.

Grayscale Image Segment:

45	**70**	**130**
180	**200**	**220**
90	**150**	**240**

Solution:

Using the provided colormap:

Intensity 0-63 → Blue (0, 0, 255)

Intensity 64-127 → Green (0, 255, 0)
Intensity 128-191 → Yellow (255, 255, 0)
Intensity 192-255 → Red (255, 0, 0)

Map each pixel intensity to the corresponding color:

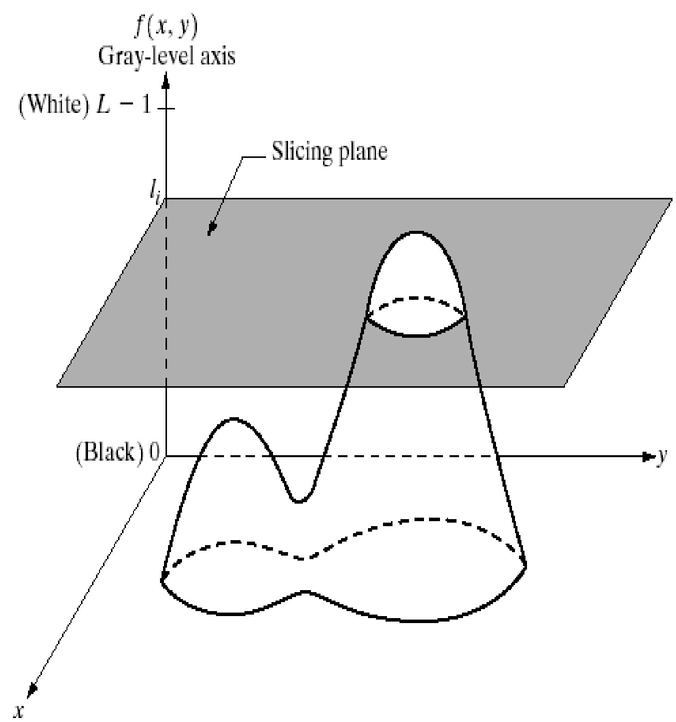
45 B	**70 G**	**130 Y**
180 Y	**200 R**	**220 R**
90 G	**150 Y**	**240 R**

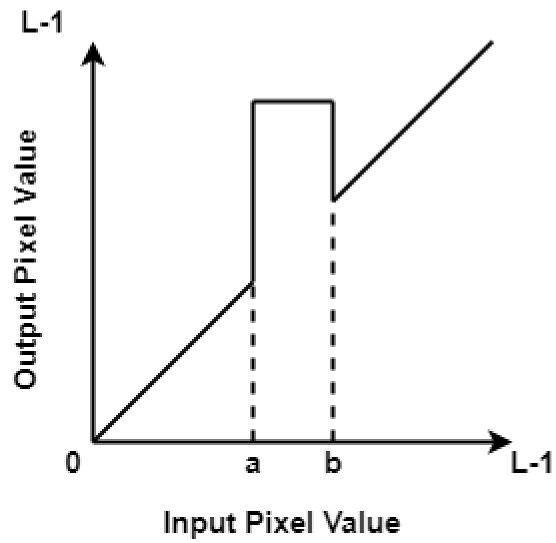
Pseudo colored Image Segment:

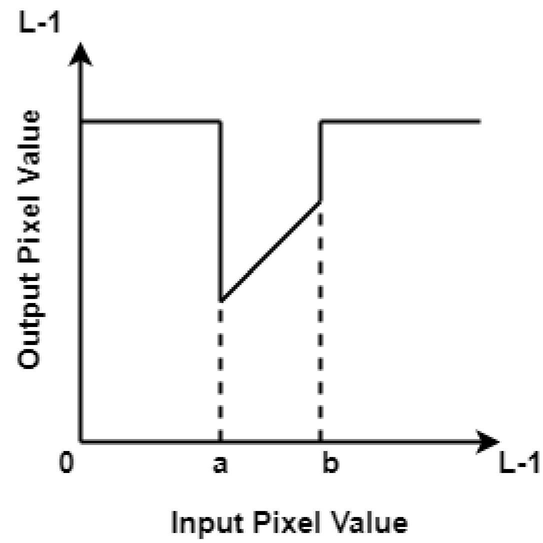
(0, 0, 255)	**(0, 255, 0)**	**(255, 255, 0)**
(255, 255, 0)	**(255, 0, 0)**	**(255, 0, 0)**
(0, 255, 0)	**(255, 255, 0)**	**(255, 0, 0)**

Intensity Slicing:

- Assign colors to gray values based on a specified criterion.
- For human visualization and interpretation of gray-scale events.
- **Intensity Slicing** is a technique used in image processing to enhance the visualization of grayscale images by mapping specific ranges of intensity values to different colors.
- This method helps in highlighting specific features or regions within an image, making it easier to analyze and interpret.







Applications of Intensity Slicing:

1. **Medical Imaging:** Highlighting different tissues or structures in MRI and CT scans based on intensity values.
2. **Remote Sensing:** Enhancing satellite images to identify land use patterns, vegetation, and water bodies.
3. **Geological Surveys:** Mapping mineral deposits or other geological features based on their intensity in survey images.

Question:

Apply intensity slicing to the following 4x4 grayscale image using the specified intensity ranges and corresponding colors:

0-63: Blue (0, 0, 255)
64-127: Green (0, 255, 0)
128-191: Yellow (255, 255, 0)
192-255: Red (255, 0, 0)

Grayscale Image:

45	70	130	200
30	90	160	210
50	110	170	220
60	140	180	230

Solution:

Define Intensity Ranges and Colors:

0-63: Blue (0, 0, 255)
64-127: Green (0, 255, 0)
128-191: Yellow (255, 255, 0)
192-255: Red (255, 0, 0)

Map Intensities to Colors:

45 → Blue (0, 0, 255) 70 → Green (0, 255, 0) 130 → Yellow (255, 255, 0) 200 → Red (255, 0, 0) 30 → Blue (0, 0, 255) 90 → Green (0, 255, 0) 160 → Yellow (255, 255, 0) 210 → Red (255, 0, 0)	50 → Blue (0, 0, 255) 110 → Green (0, 255, 0) 170 → Yellow (255, 255, 0) 220 → Red (255, 0, 0) 60 → Blue (0, 0, 255) 140 → Yellow (255, 255, 0) 180 → Yellow (255, 255, 0) 230 → Red (255, 0, 0)

Construct the Pseudocolored Image

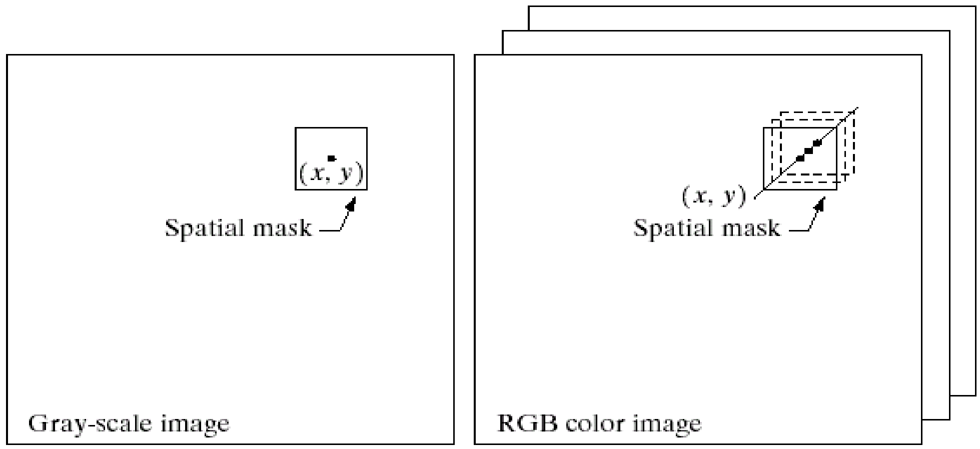
(0, 0, 255)	(0, 255, 0)	(255, 255, 0)	(255, 0, 0)
30	90	160	210
50	110	170	220
60	140	180	(255, 0, 0)

DO REST...........

Color transformations

$$\mathbf{g\ (x, y) = T\ [\ f(x, y\ )\ ]}$$

- The expression g(x, y) = T[f(x, y)] represents a transformation applied to a function f(x,y) to produce a new function g(x, y).
- T is an operator on f over a spatial neighborhood of (x , y)
- A pixel at (x, y) is a vector in the color space



- Color transformations are crucial in image processing for tasks like
    - color correction,
    - image enhancement,
    - and converting images between different color spaces.
- RGB color space $\mathbf{c}(x, y) = \begin{bmatrix} R(x, y) \\ G(x, y) \\ B(x, y) \end{bmatrix}$

.

- General Form of Color Transformation

$$S_i = T_i\,(r_1, r_2, \ldots, r_n) \qquad\qquad i = 1, 2, \ldots, n$$

- si component of the output color
- Ti of all components of the input color *r1*, *r2*,…, *rn* .

- *Where…………….*

- *f(x,y) is the input image function with components f1,f2,…,fn (e.g., RGB components).*
- *g(x,y) is the output image function with components s1,s2,…,sn (e.g., components in another color space like XYZ).*
- *Ti are the transformation functions that map the input color components to the output color components.*

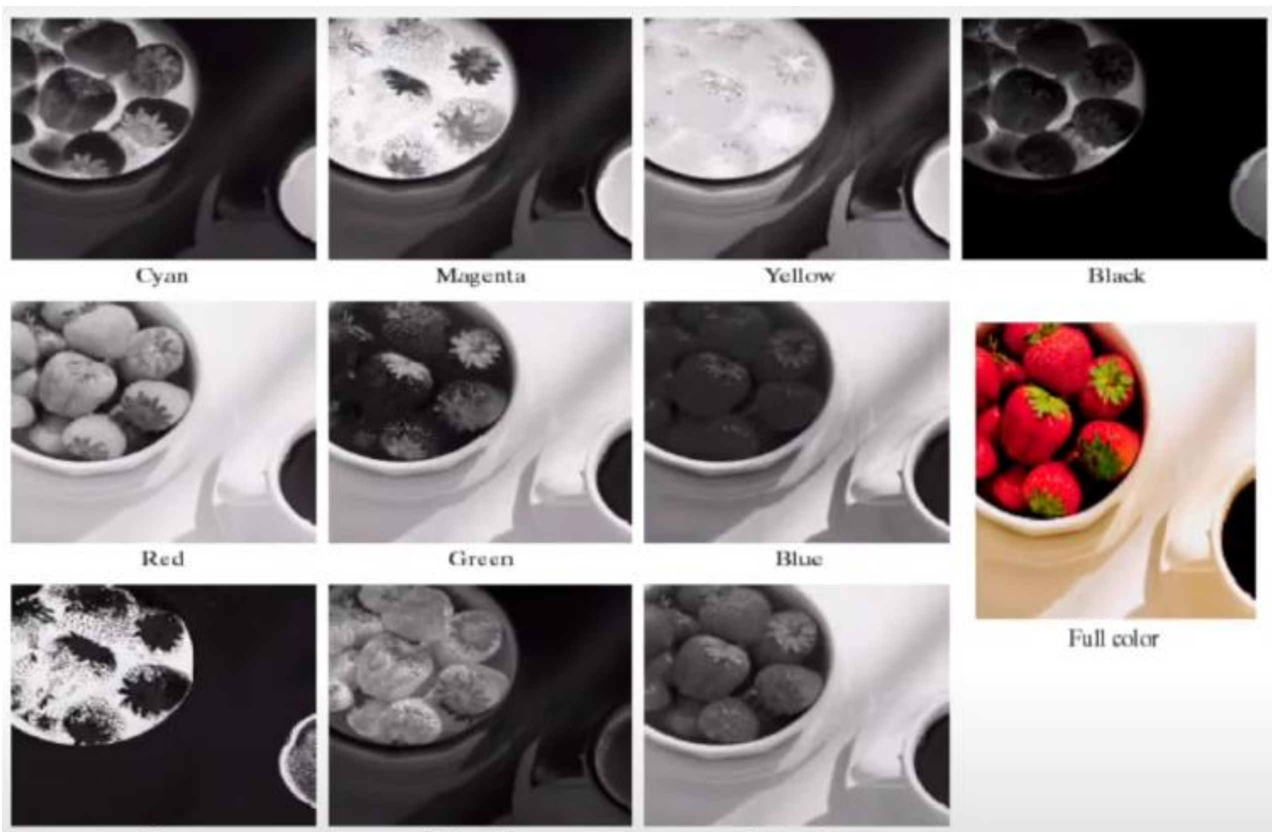
- Simplicity, ri = color components of f (x, y) , and si = color component of g(x, y)

- n = no of color components,
- ti = transformation mapping as operate on ri to produce si

- color space chosen describe the pixels of f and g determines the value of n

- For RGB color space, e.g. n = 3, r1, r2, r3 then red ,green, blue components for input

- For CMYK or HSI color space are chosen as n = 4 or n = 3



- This is a general form of color transformation, applicable in various contexts such as image processing and color space conversion.

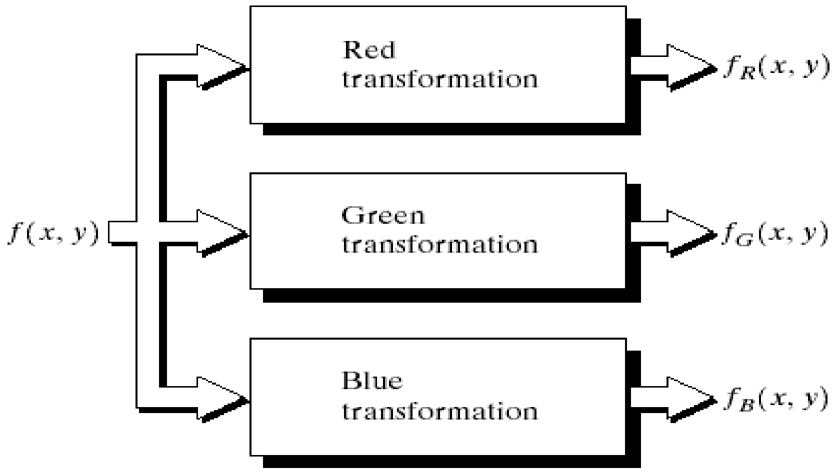
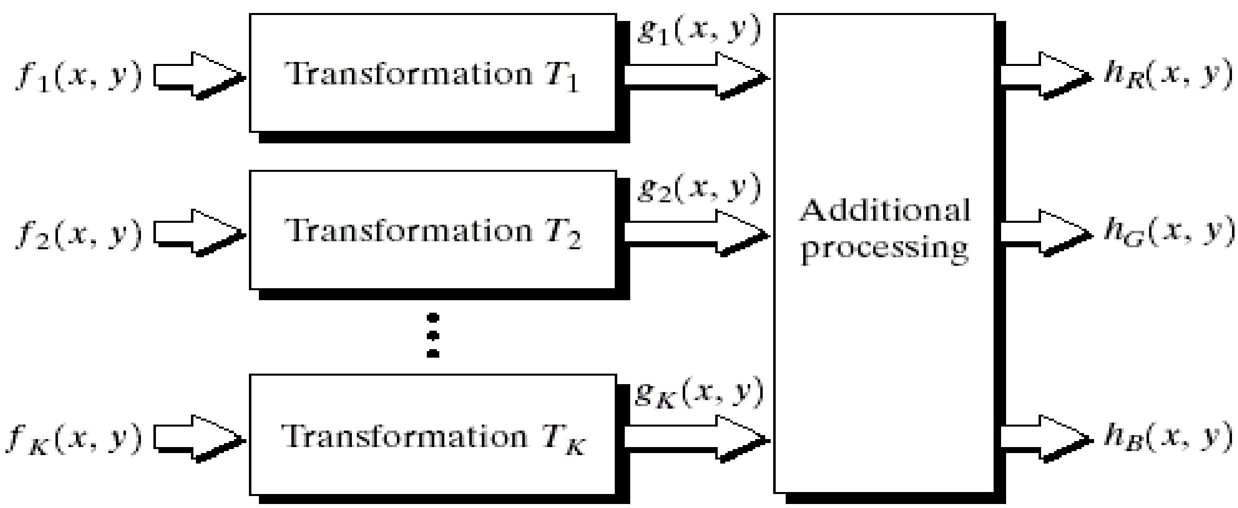


FIGURE 6.23 Functional block diagram for pseudocolor image processing. f_R, f_G, and f_B are fed into the corresponding red, green, and blue inputs of an RGB color monitor.



Color vector:

***Per-color-component processing**:* Process each color component

***Vector-based processing**:* Process the color vector of each pixel

Example: of Per-color-component processing is smoothing an image by smoothing each RGB component separately.

When can the above methods be equivalent?

- Process can be applied to both scalars and vectors
- Operation on each component of a vector must be independent of the other component.

Example of Full Color Image with various Color space components:

- In color transformation, its used to transform color to color.
- Formulation**: g (x, y) = T [f(x , y)]**
    - *Where, **f (x, y)** = input color image,*
    - ***g(x , y)** = output color image*
    - ***T** = operation on f over a spatial neighborhood of **f (x, y).***

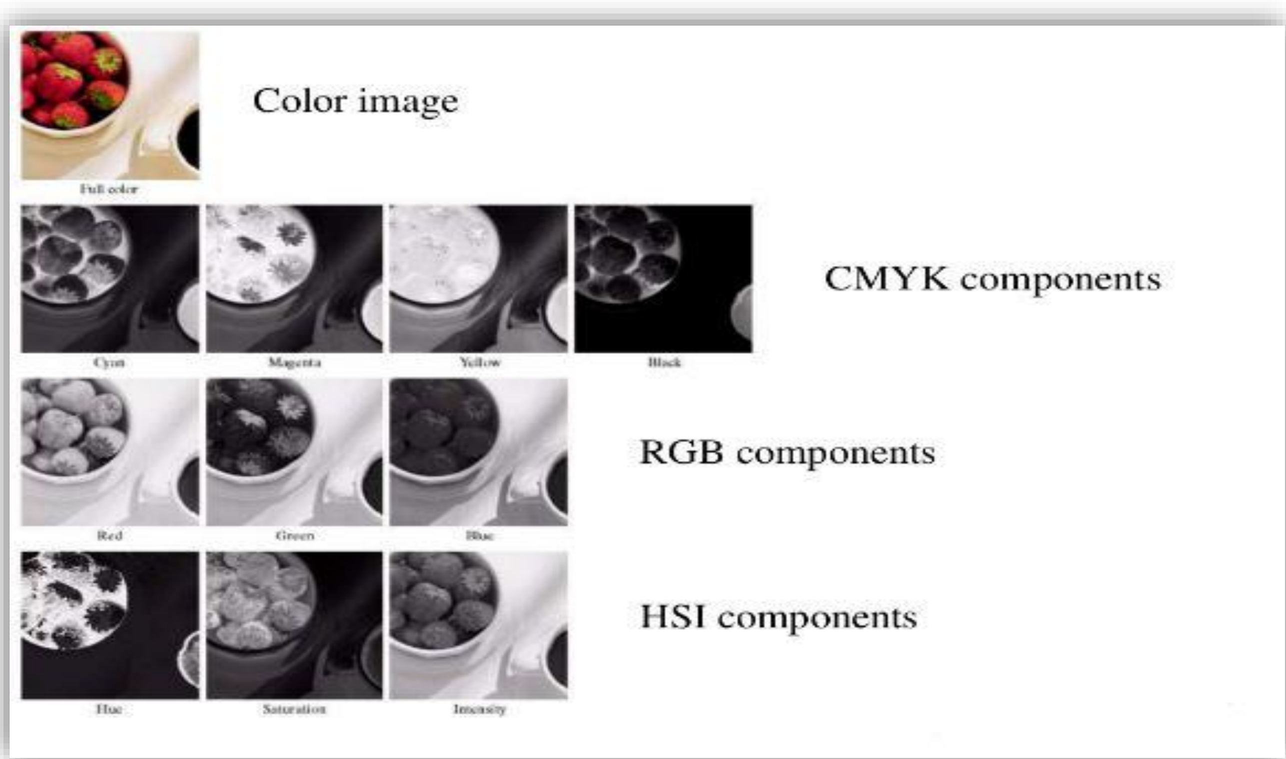
- When only data at one pixel is used in the transformation, we can express the transformation as:

$$s_i = T_i (r_1, r_2, K , r_n) \qquad i=1,2,3 \ldots\ldots\ldots,n$$

where r_i = color component of f(x , y)

For RGB image n=3

s_i = color component of g(x,y)



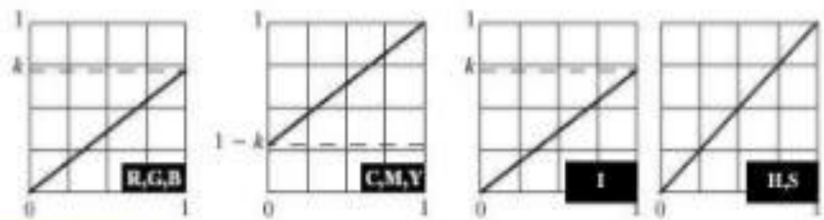
Example: Color Transformation

Formula for RGB:

$$s_R(x,y) = k r_R(x,y)$$
$$s_G(x,y) = k r_G(x,y)$$
$$s_B(x,y) = k r_B(x,y)$$

Formula for HSI:

$$s_I(x,y) = k r_I(x,y)$$



Formula for CMY:

$$s_C(x,y) = k r_C(x,y) + (1-k)$$
$$s_M(x,y) = k r_M(x,y) + (1-k)$$
$$s_Y(x,y) = k r_Y(x,y) + (1-k)$$

These 3 transformations give the same results.

Smoothing and sharpening

Before and after image smoothing transformation(above)

Before and after image sharpening transformation(below)

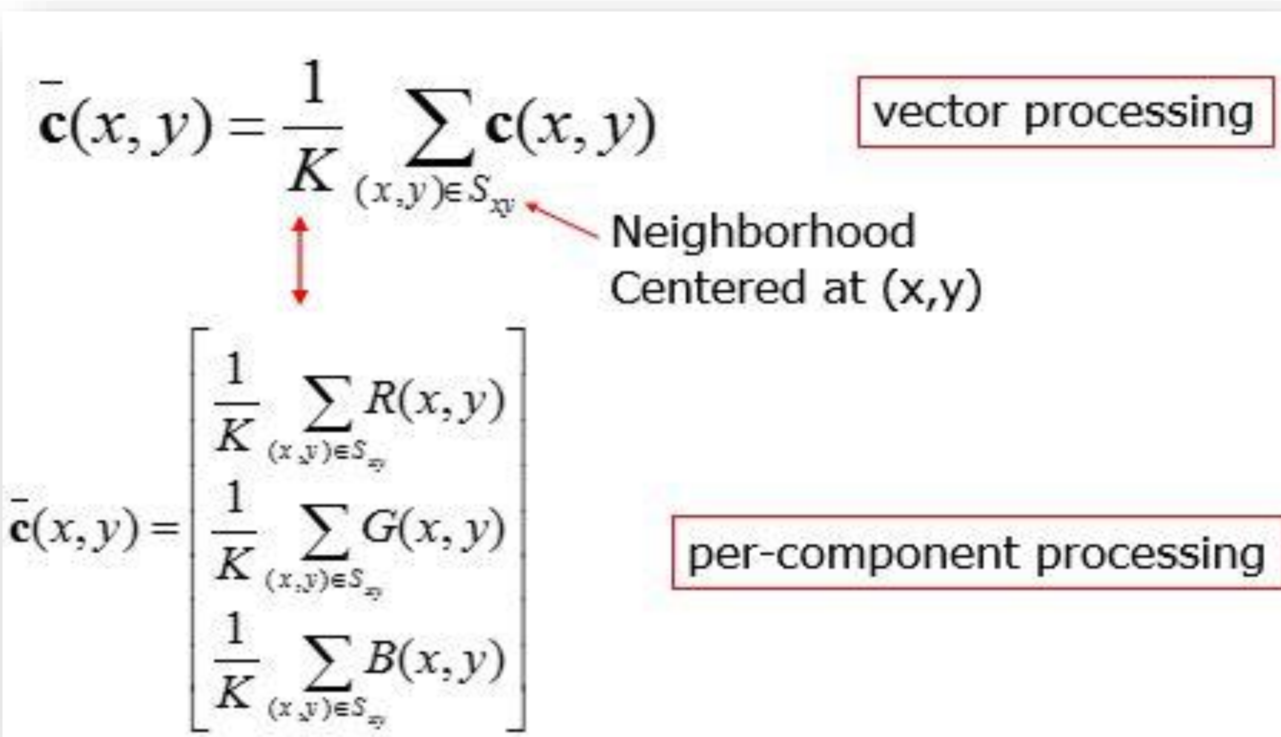
Smoothing	Sharpening
Purpose: Smoothing is used to reduce noise or unwanted variations in an image, resulting in a more uniform appearance	**Purpose:** Sharpening enhances the edges and details in an image, making it appear clearer and more defined.
Smoothing images, it basically means we're going to blur it	Sharpening works quite similarly as smoothing does, as convolution in both cases, but with sharpening
Applications: Smoothing is particularly useful in reducing noise in photographs, improving the appearance of gradients, and preparing images for further processing steps where noise can interfere.	**Applications:** Sharpening is commonly used in photography, digital image processing, and graphics to make images appear more detailed and crisper. However, excessive sharpening can introduce artifacts and noise.

Smoothing

Color image smoothing image is classfied as:

- Per color plane method
- Smooth only intensity component

Per color plane method :



$$\bar{\mathbf{c}}(x,y) = \frac{1}{K}\sum_{(x,y)\in S_{xy}} \mathbf{c}(x,y)$$

$$\bar{\mathbf{c}}(x,y) = \begin{bmatrix} \frac{1}{K}\sum_{(x,y)\in S_{xy}} R(x,y) \\ \frac{1}{K}\sum_{(x,y)\in S_{xy}} G(x,y) \\ \frac{1}{K}\sum_{(x,y)\in S_{xy}} B(x,y) \end{bmatrix}$$

- For RGB, CMY color models Smooth each color plane using moving averaging and combine back to RGB.
- This method involves processing each color channel (such as Red, Green, and Blue in RGB color space) independently to reduce noise or unwanted variations in that particular channel.
- Each color channel is treated separately using techniques like Gaussian blur, median filtering, or bilateral filtering.

Smooth only intensity component

- In HIS image while leving H and S unmodified.

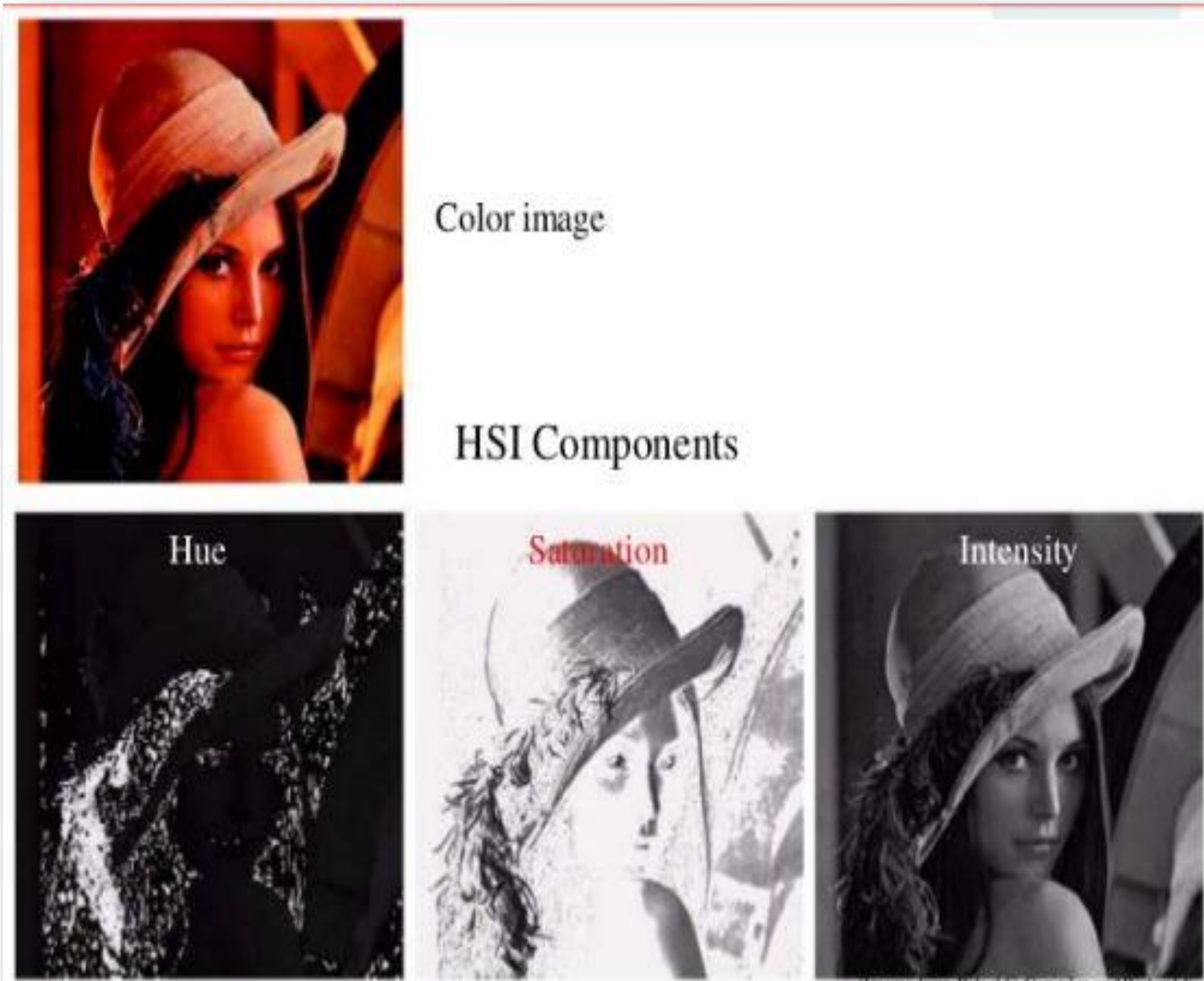
- In some color processing techniques, particularly those that involve color spaces where intensity (or brightness) is separated from color information (like in HSV or YUV color spaces), smoothing is applied only to the intensity component.

- The intensity component represents the perceived brightness of the image and is separated from the color information.

- By smoothing only, the intensity component, the image's overall brightness variations or noise can be reduced without altering the color information as drastically.

- After smoothing the intensity component, it can be combined back with the color information to produce the final smoothed color image.

(Images from Rafael C. Gonzalez and


Color image
HSI Components
Hue
Saturation
Intensity


Smooth all RGB components
Smooth only I component of HSI
(faster)

Sharpening:

Image Sharpening can be done same manner as color image smoothing:

Per-color-plane method for RGB, CMY images

Sharpening only, I component of a HSI image

Sharpening all RGB components

Sharpening only I component of HSI

Difference between sharpened results from 2 methods in the previous slide.

Sharpening

Per-color-plane method for RGB, CMY images	**Sharpening only the (I) component of an HIS image**
➢ **RGB Color Space:** In the RGB color space, an image consists of separate channels for Red, Green, and Blue. Sharpening using the per-color-plane method involves enhancing the edges and details in each color channel independently. ➢ Techniques like unsharp masking or high pass filtering can be applied to each RGB channel separately. These techniques aim to increase the contrast along edges, thereby enhancing perceived sharpness. ➢ After sharpening each channel, they are combined back to form the final sharpened color image. ➢ This method allows for precise control over how sharpening affects each color component, which can be particularly useful for images with distinct color regions or gradients.	➢ **HSI Color Space:** In the HSI color space, colors are separated into three components: ➢ **Hue (H):** The type of color (red, green, blue, etc.) ➢ **Saturation (S):** The intensity or purity of the color ➢ **Intensity (I):** The perceived brightness of the color ➢ Sharpening can be applied specifically to the intensity component (I) of an HSI image. This component represents the brightness variations in the image. ➢ By sharpening only the intensity component, you enhance the perceived sharpness of the image without affecting the hue or saturation, which can help maintain color fidelity. ➢ After sharpening the intensity component, it is combined back with the hue and saturation components to reconstruct the final sharpened color image.

Considerations:

- **Color Fidelity:** When sharpening color images, especially in methods like RGB or HSI, it's crucial to balance sharpening effects to avoid introducing color artifacts or unnatural-looking edges.
- **Application:** The choice between these methods depends on the characteristics of the image, the desired visual effect, and the specifics of the color space being used.
- **Order of Operations:** Similar to smoothing, sharpening is often applied after initial processing steps to enhance details and edges selectively.