Unit 5

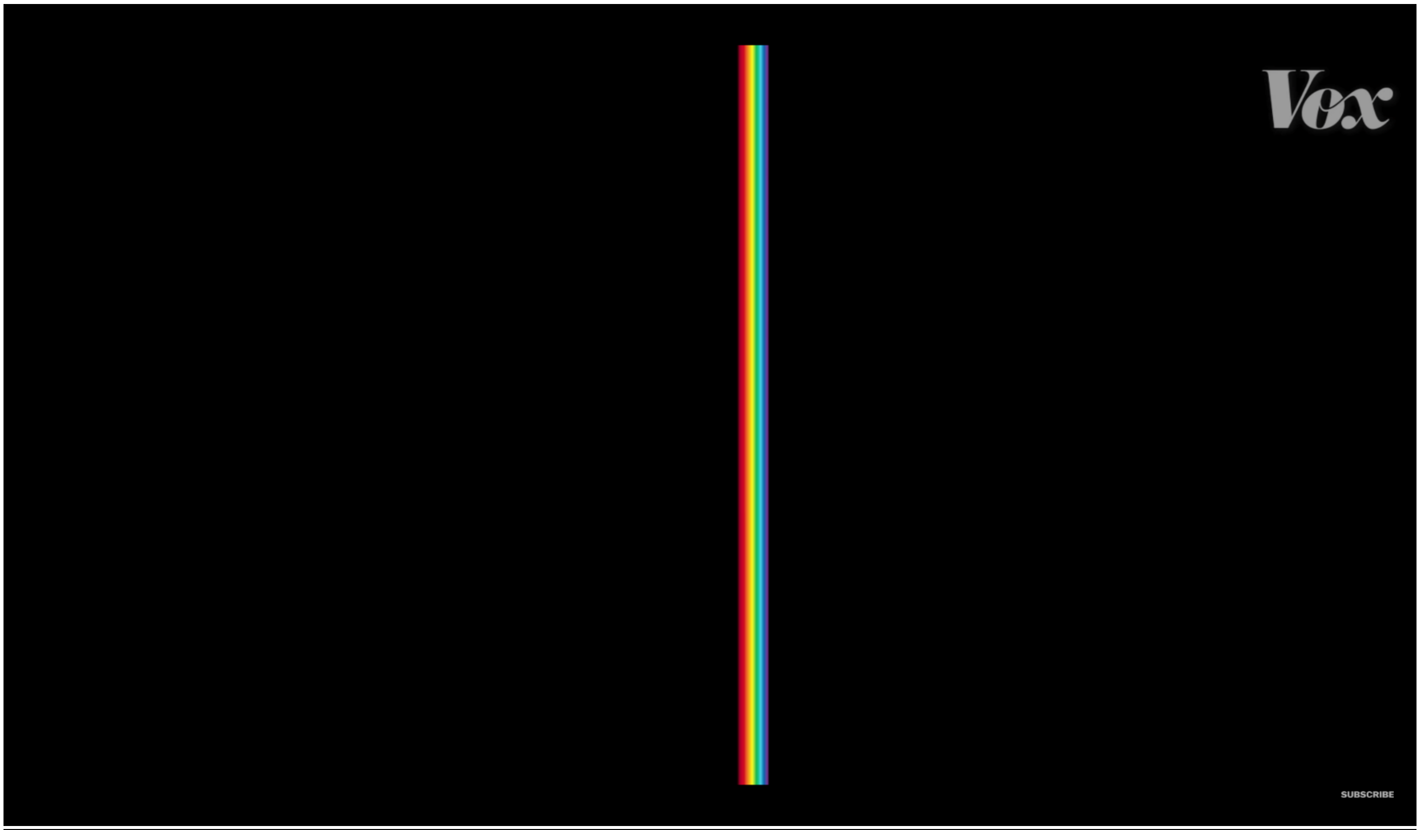
Color Processing

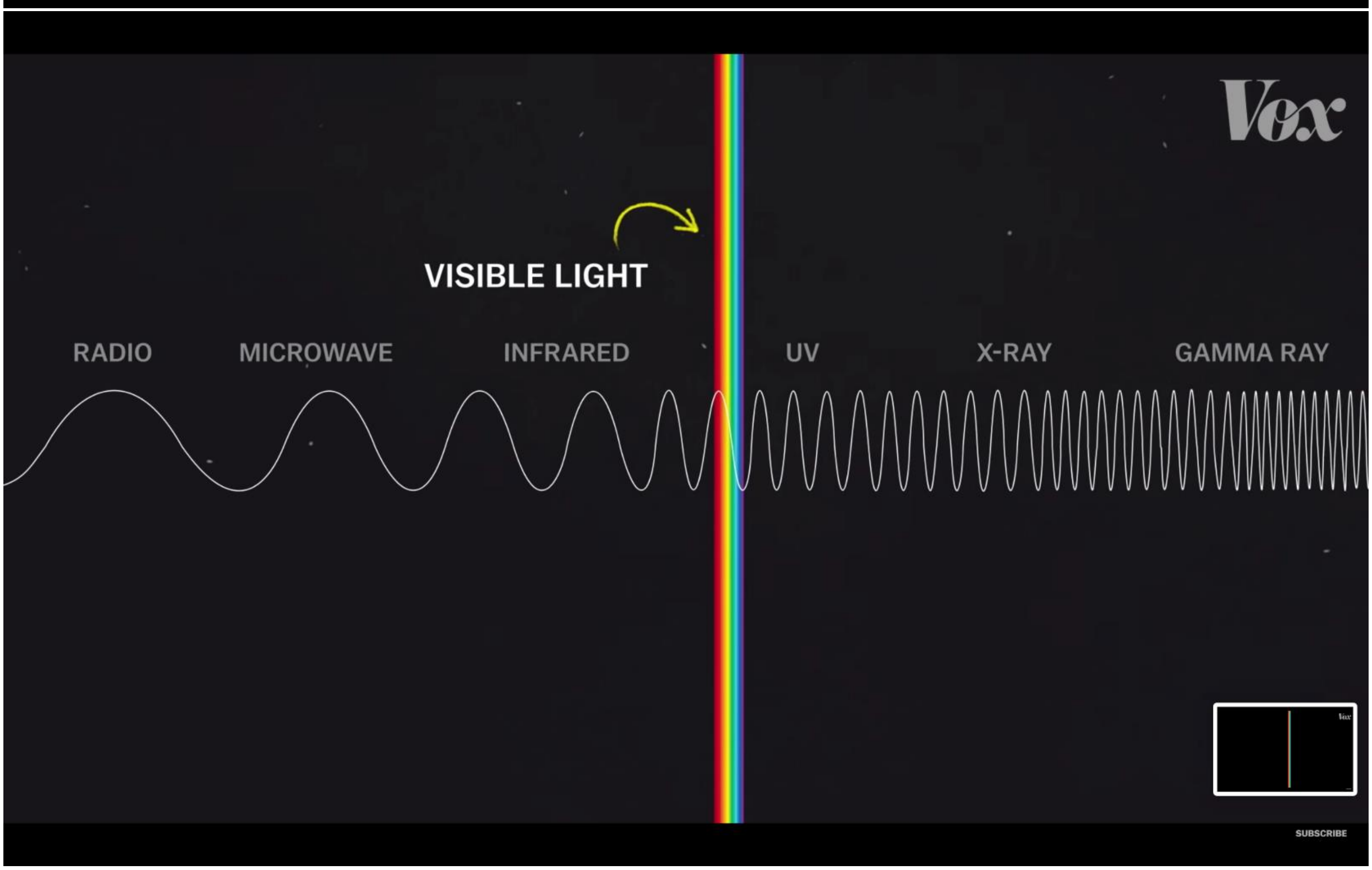
For a long time, I limited myself to one color – as a form of discipline. ***Pablo Picasso***

Outline

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

Let Us Capture Some Points:


Vox
SUBSCRIBE


Vox
VISIBLE LIGHT
RADIO
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UV
X-RAY
GAMMA RAY
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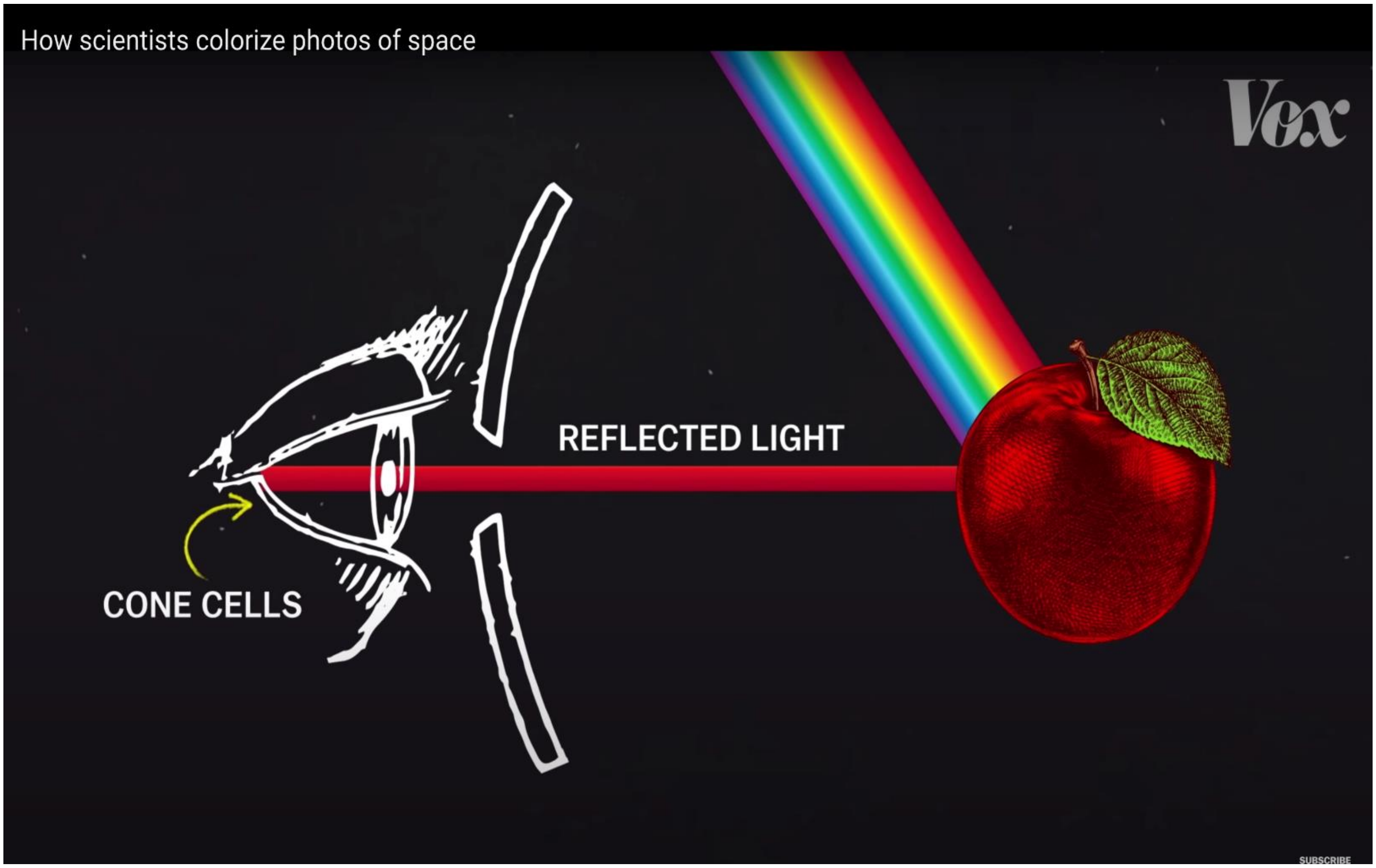
How scientists colorize photos of space
Vox
REFLECTED LIGHT
CONE CELLS
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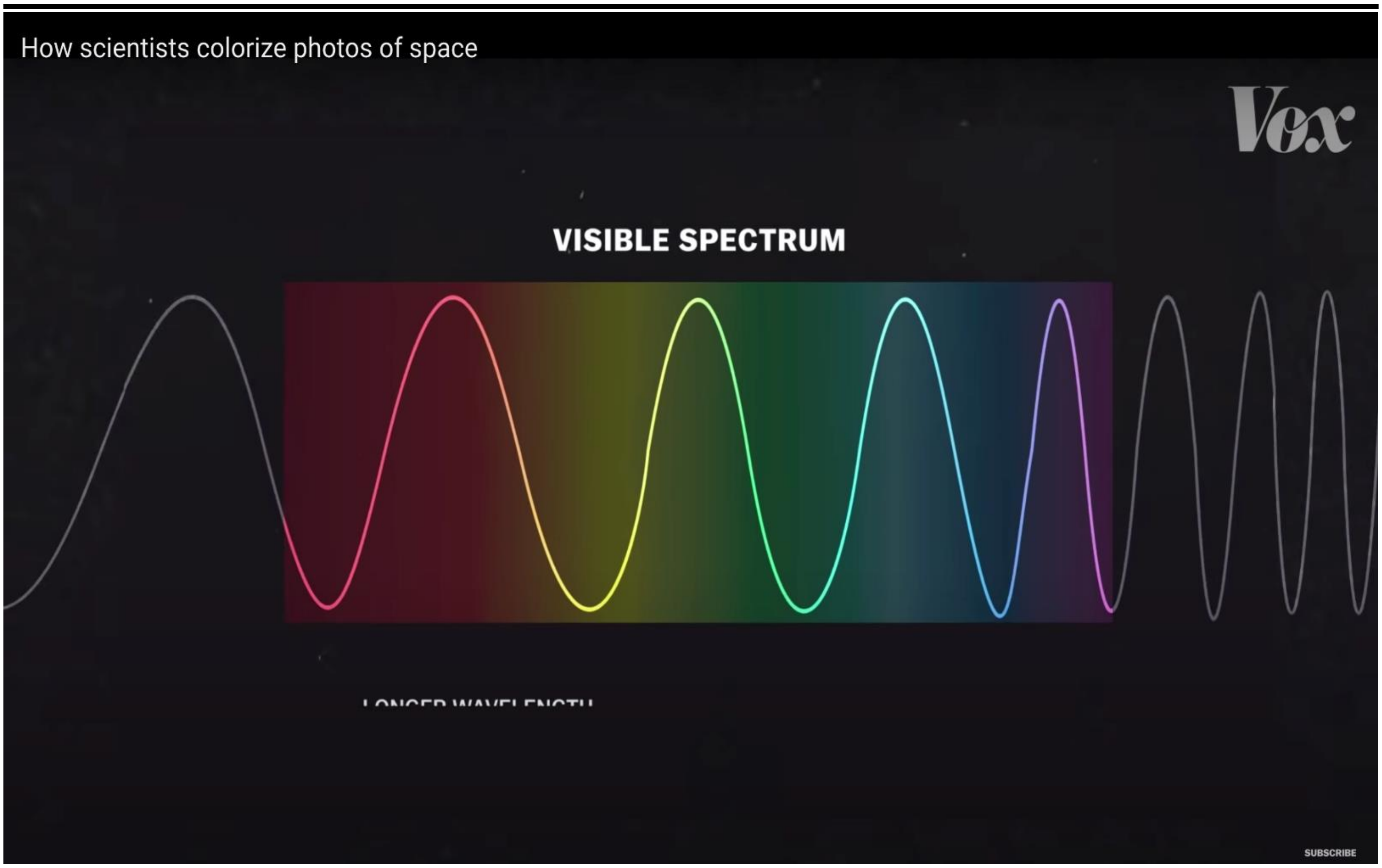
How scientists colorize photos of space
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VISIBLE SPECTRUM
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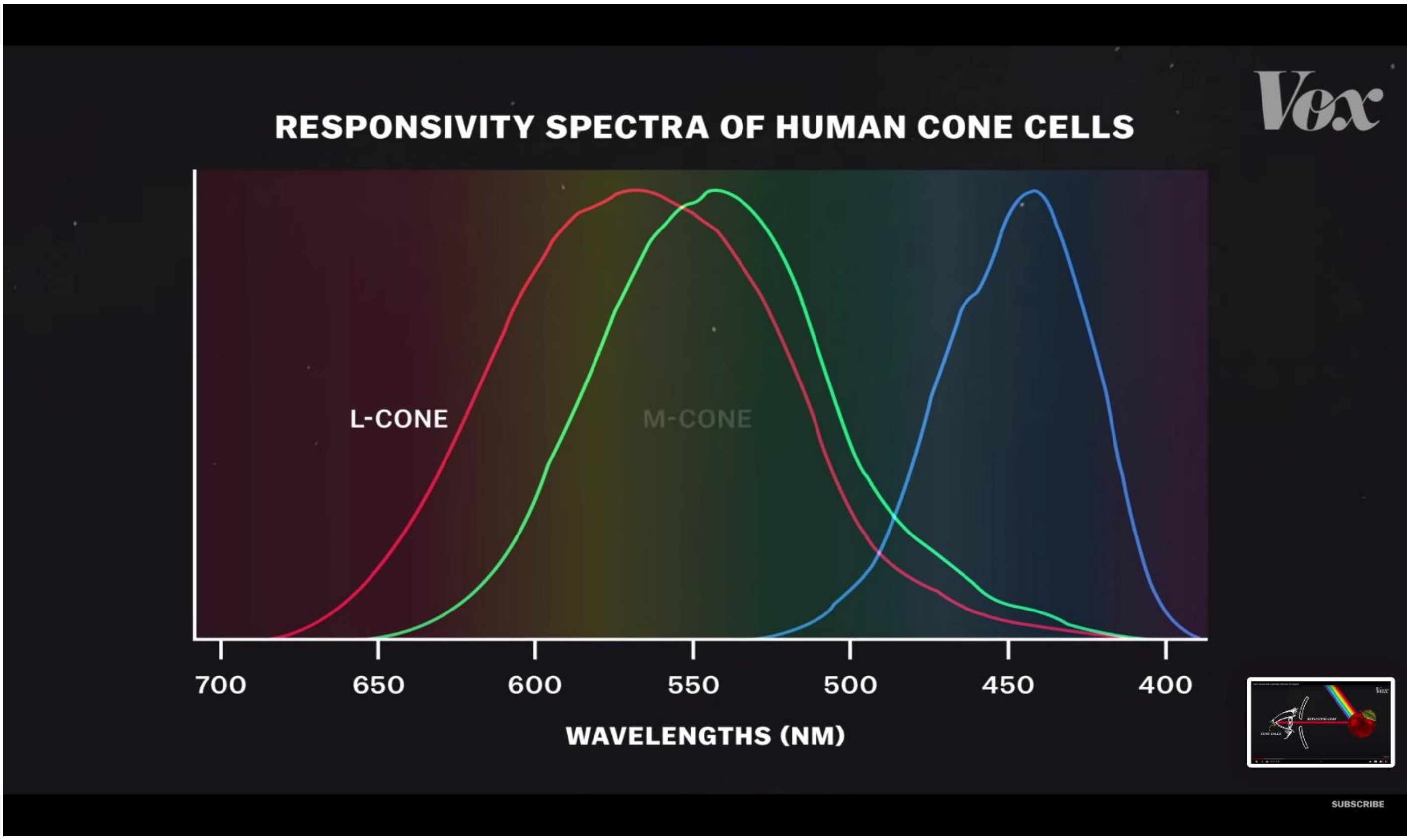
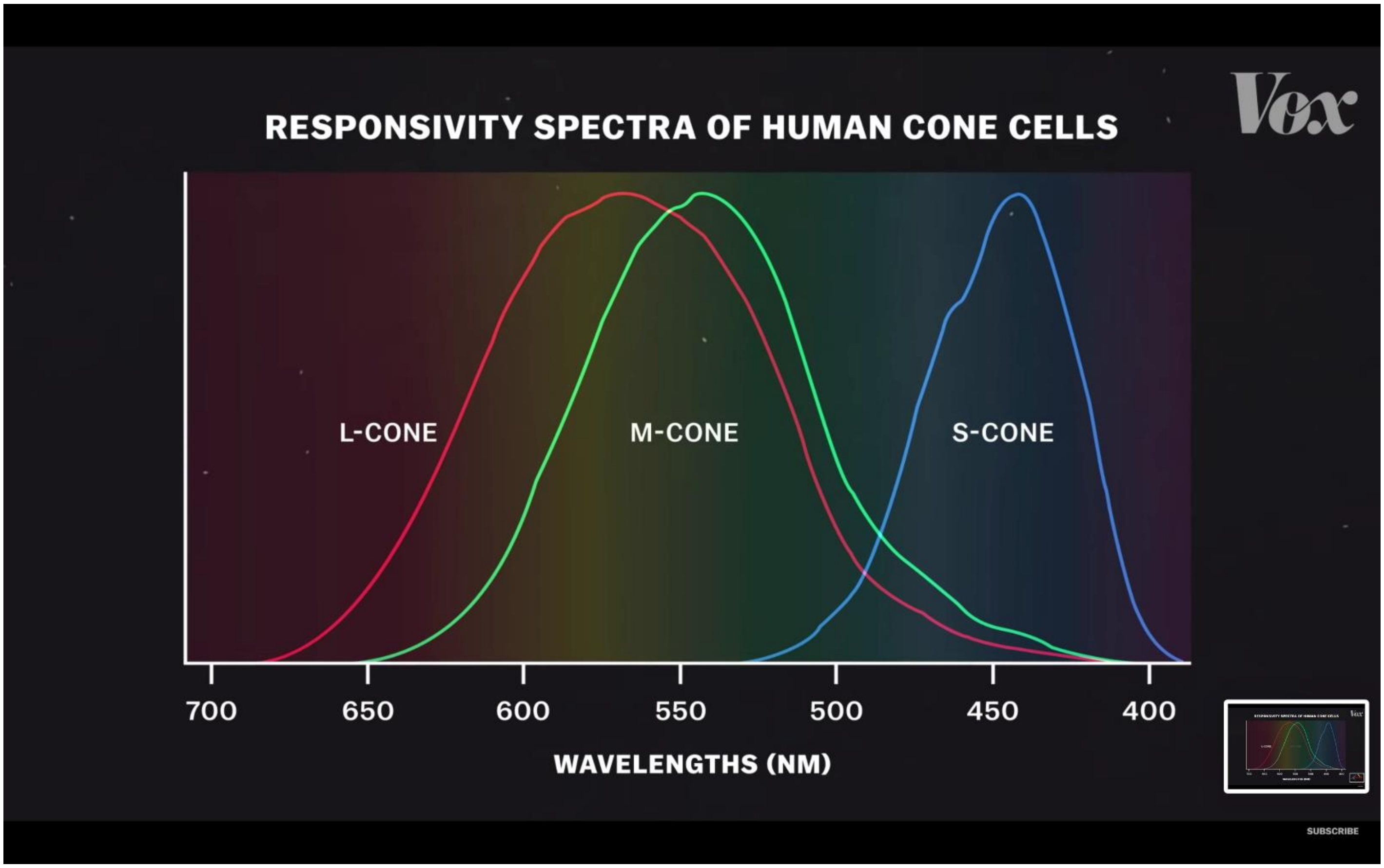

RESPONSIVITY SPECTRA OF HUMAN CONE CELLS
Vox
L-CONE
M-CONE
700
650
600
550
500
450
400
WAVELENGTHS (NM)
SUBSCRIBE


RESPONSIVITY SPECTRA OF HUMAN CONE CELLS
Vox
L-CONE
M-CONE
S-CONE
700
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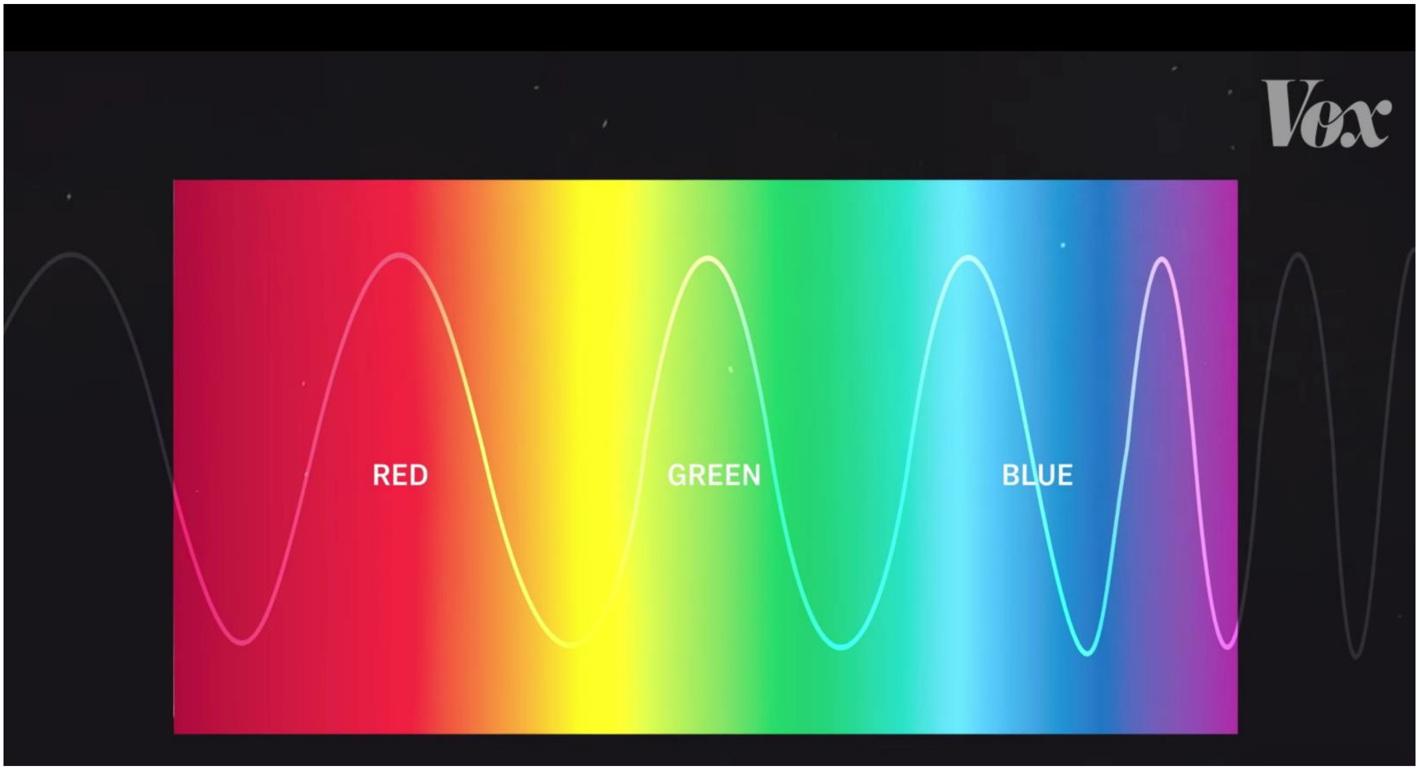
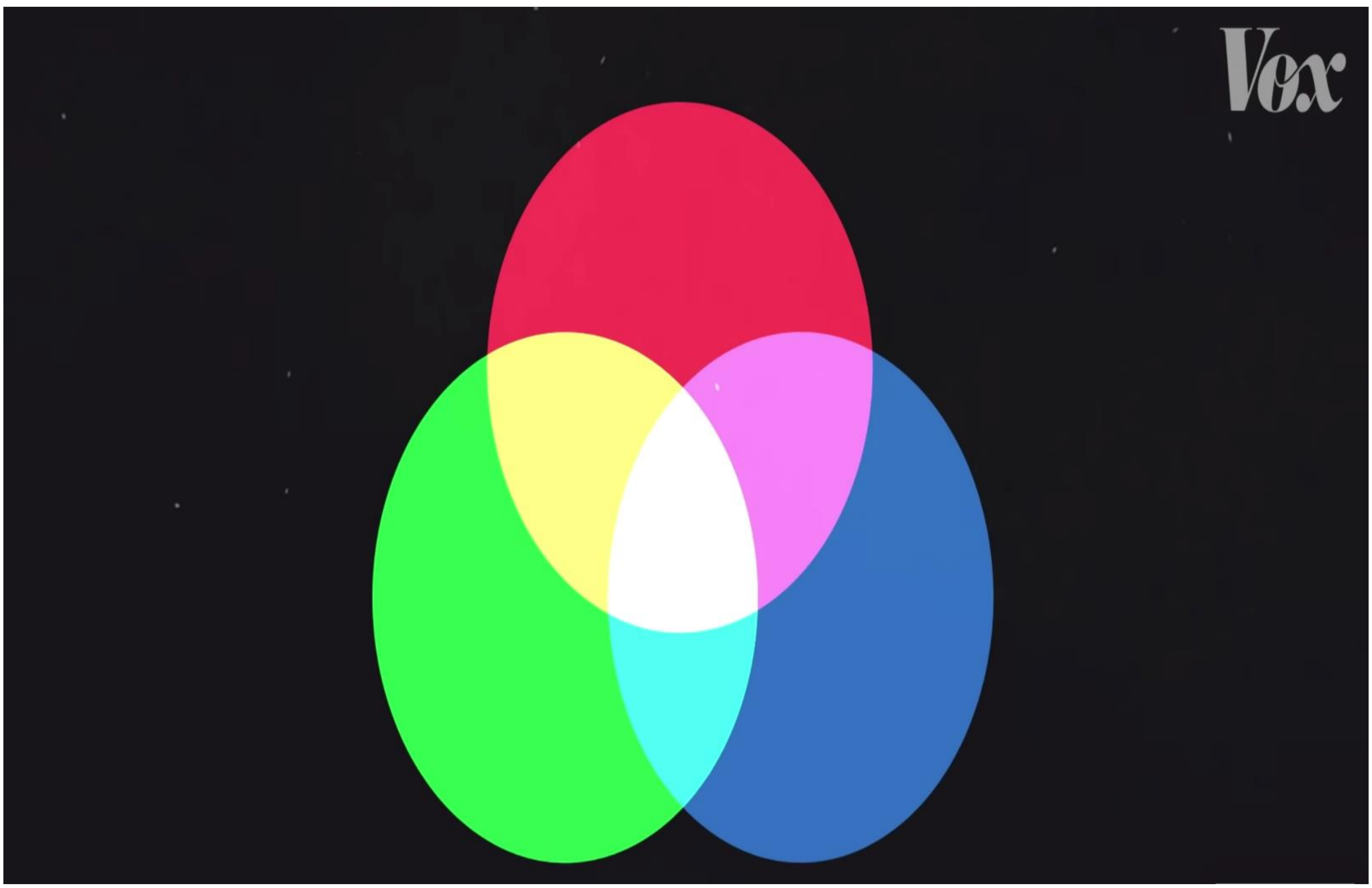
WAVELENGTHS (NM)
SUBSCRIBE


Vox
RED
GREEN
BLUE


Vox


How scientists colorize photos of space
Vox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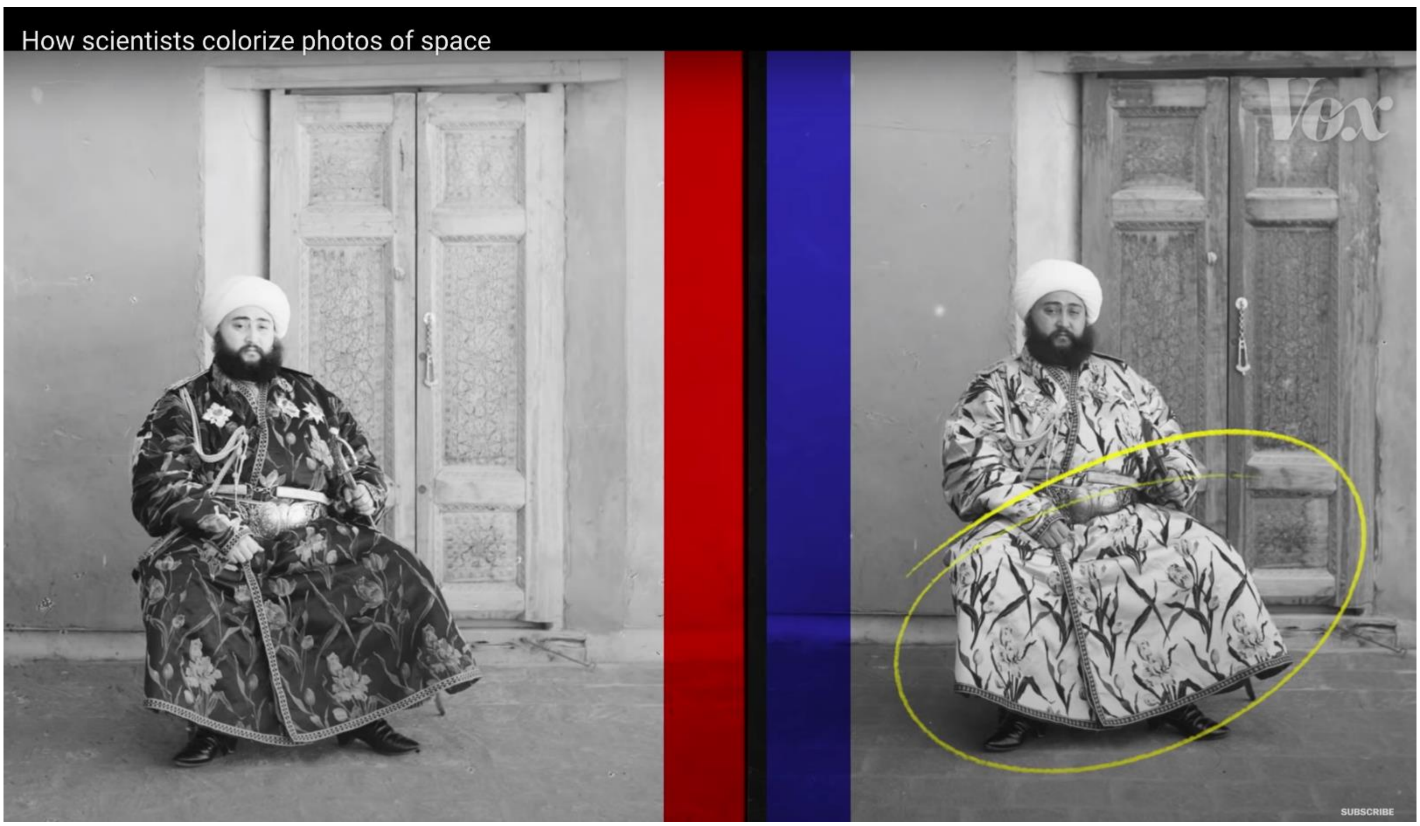
How scientists colorize photos of space
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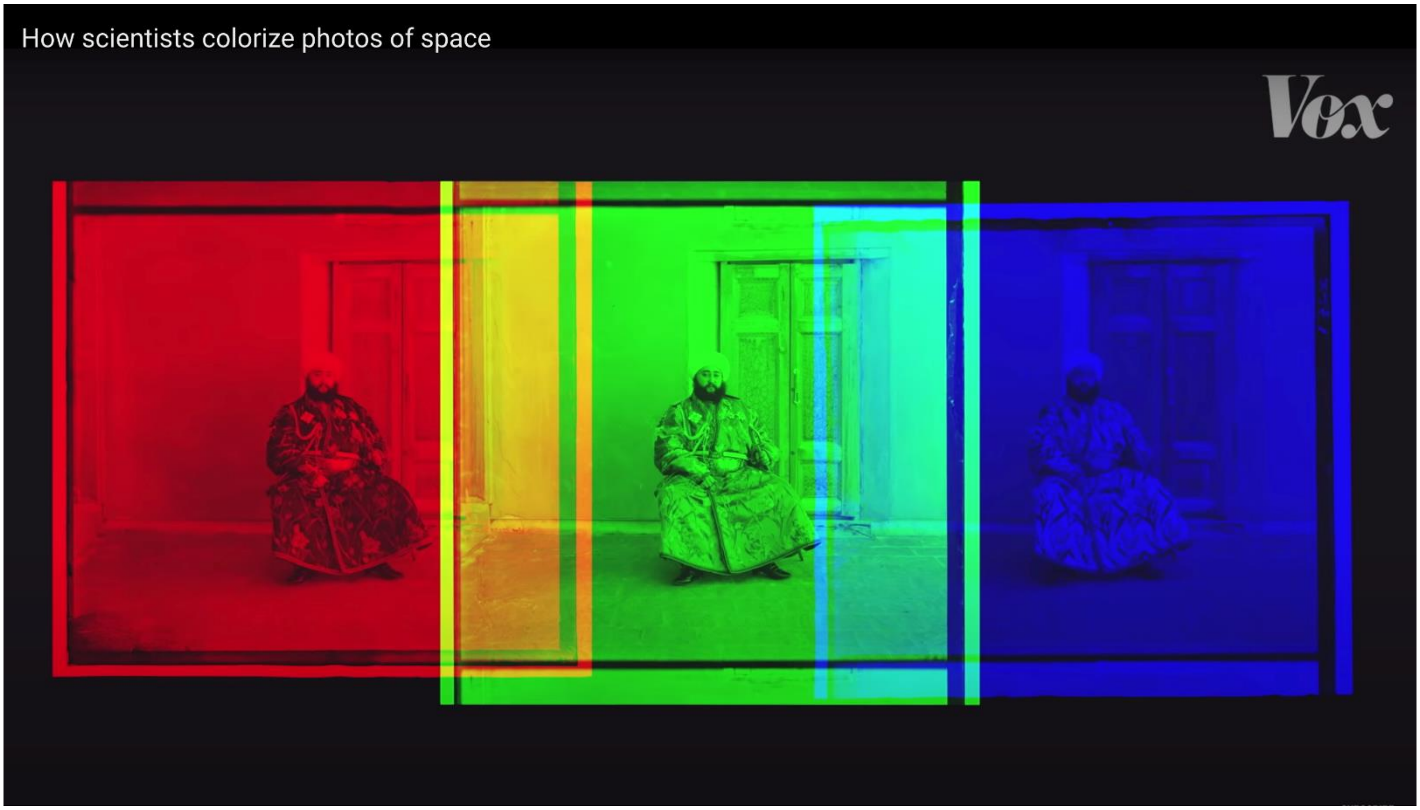
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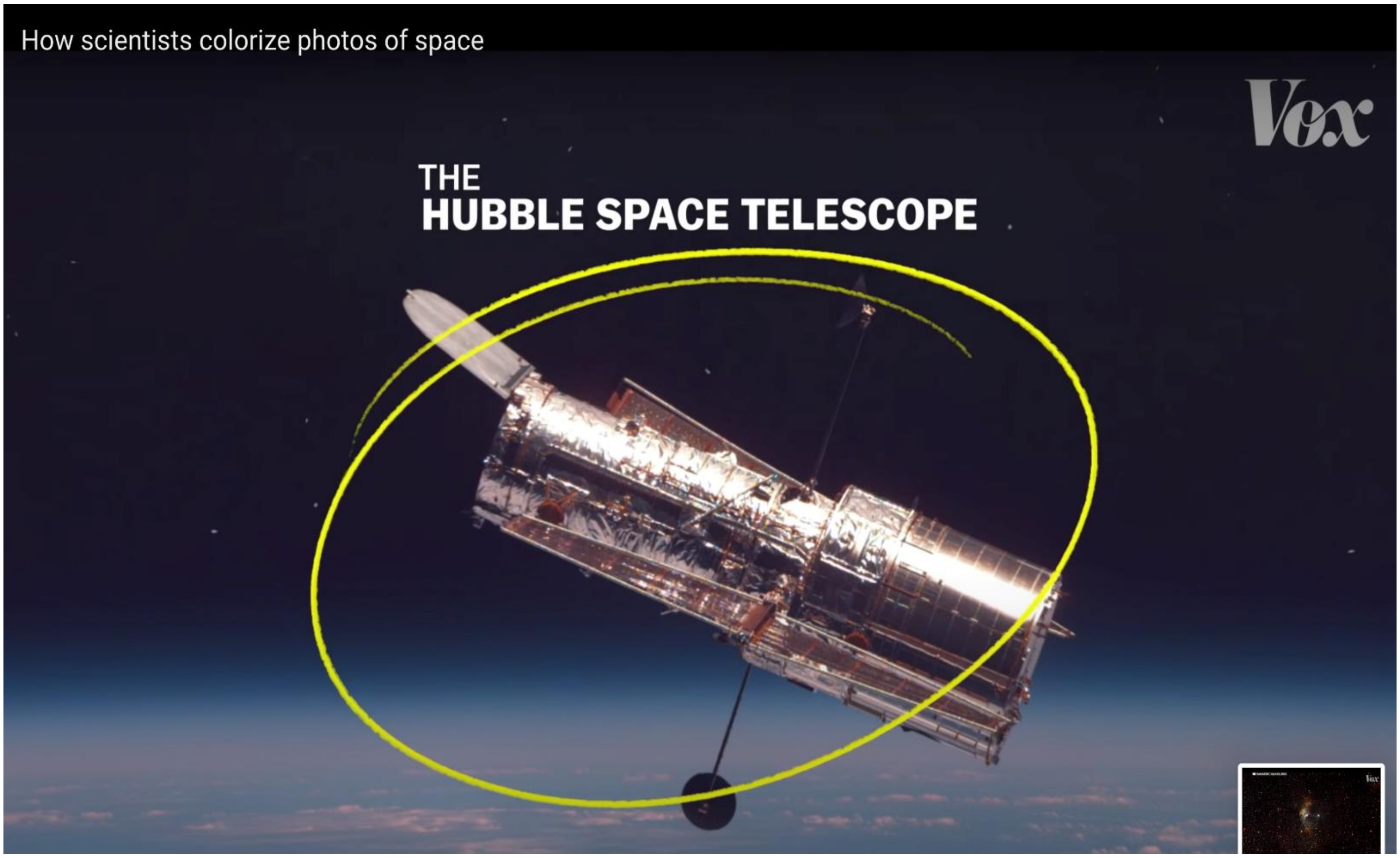
How scientists colorize photos of space
Vox
THE
HUBBLE SPACE TELESCOPE


How scientists colorize photos of space
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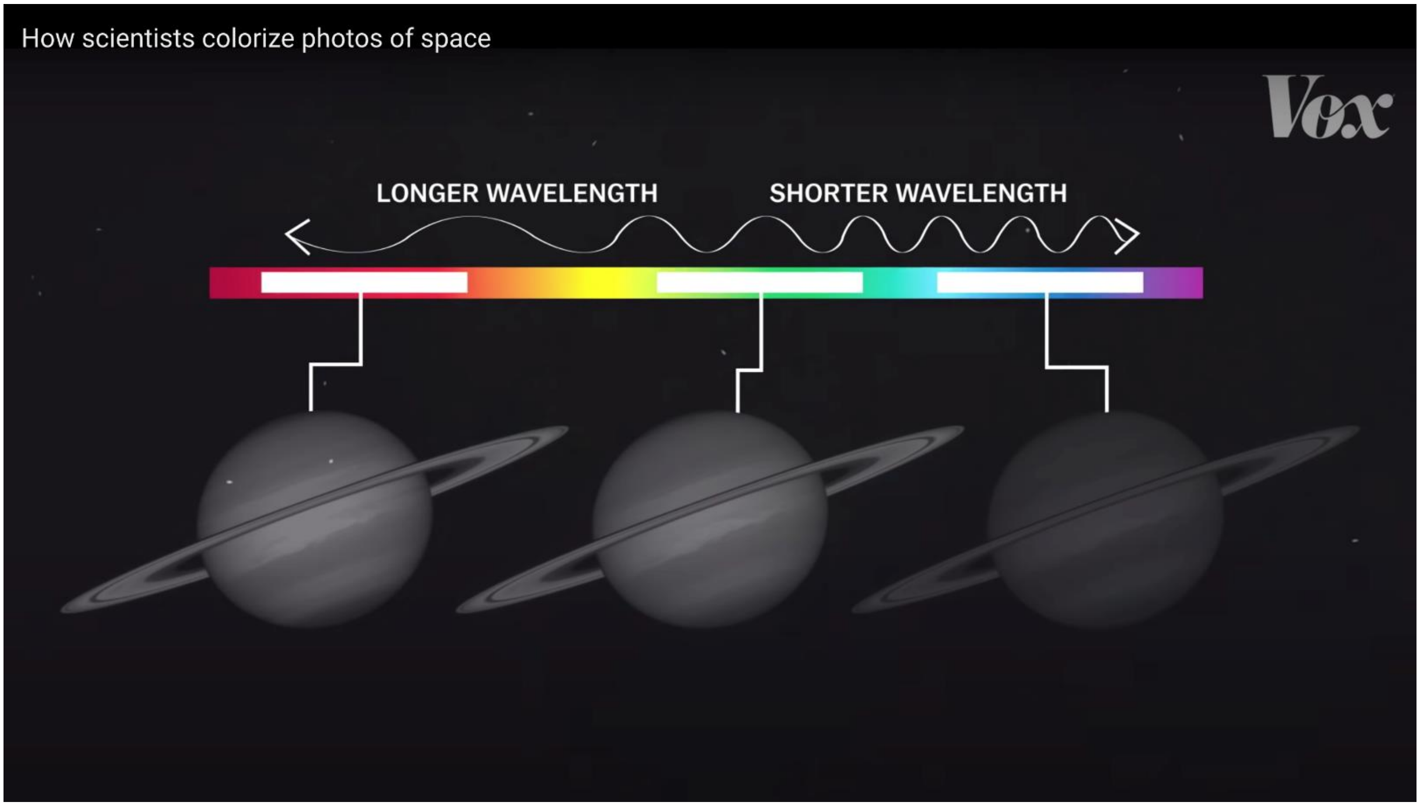
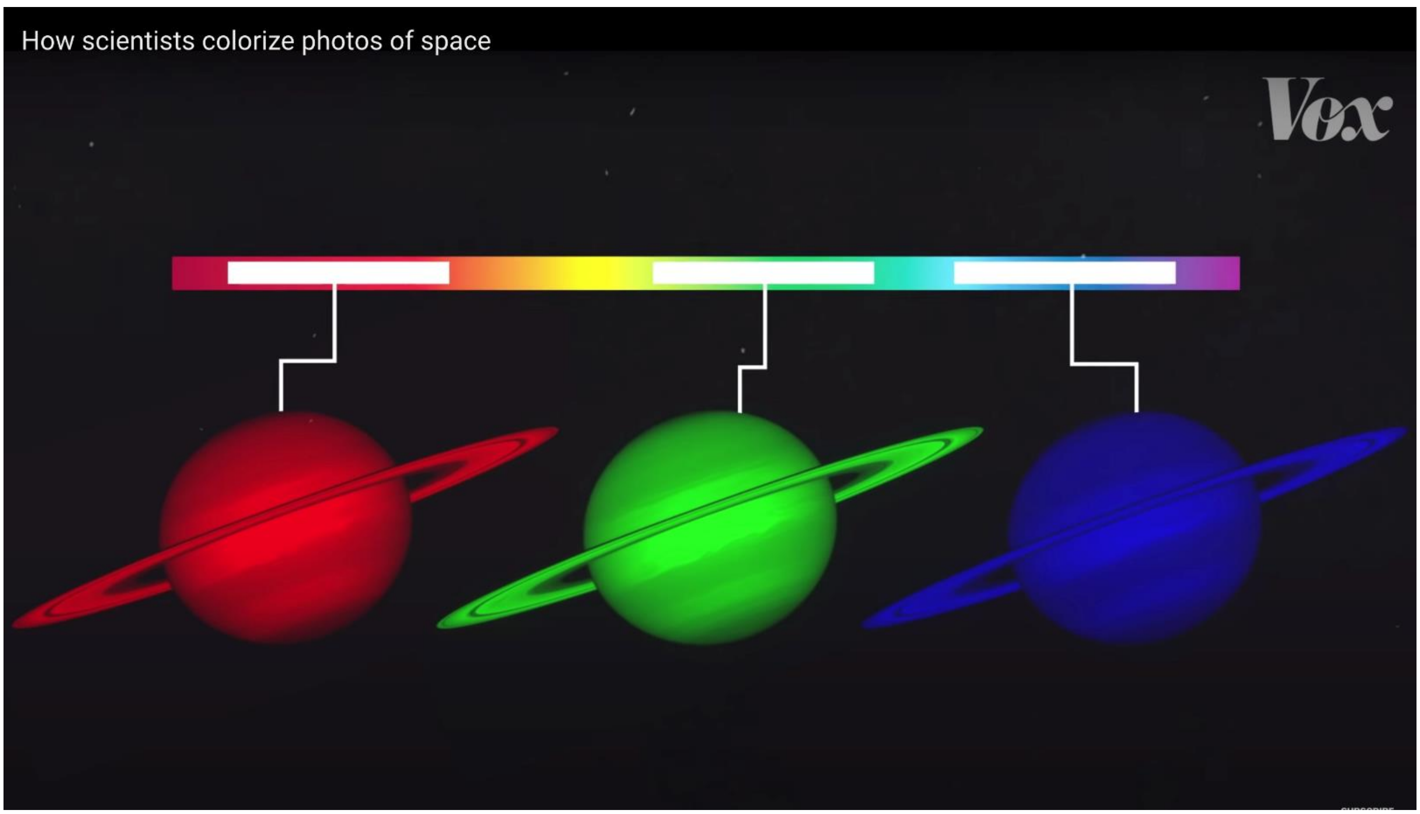
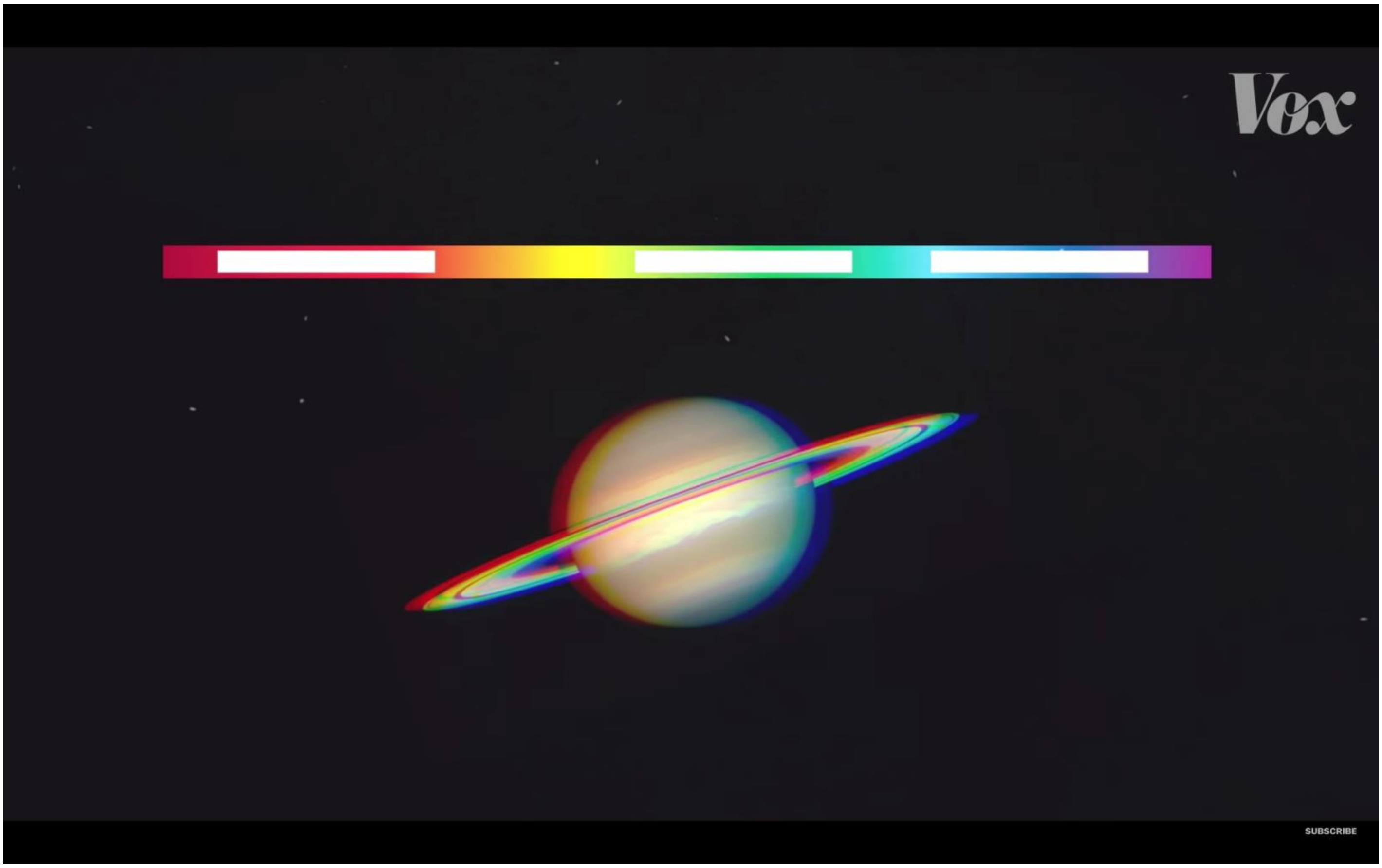
BUBBLE NEBULA (NGC 7635)
SUBSCRIBE


How scientists colorize photos of space
Vox
LONGER WAVELENGTH
SHORTER WAVELENGTH


How scientists colorize photos of space
Vox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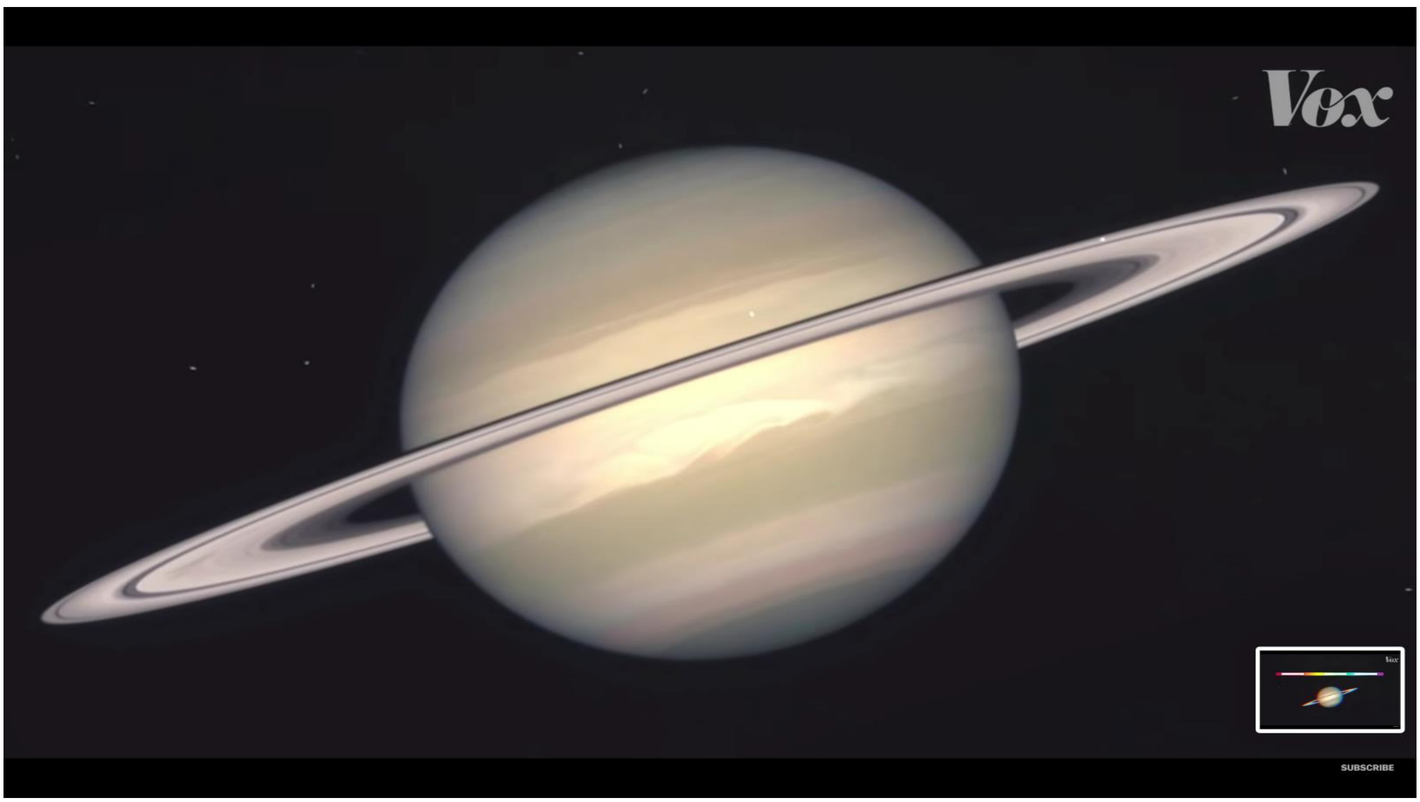
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SOMBRERO GALAXY
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CONE NEBULA
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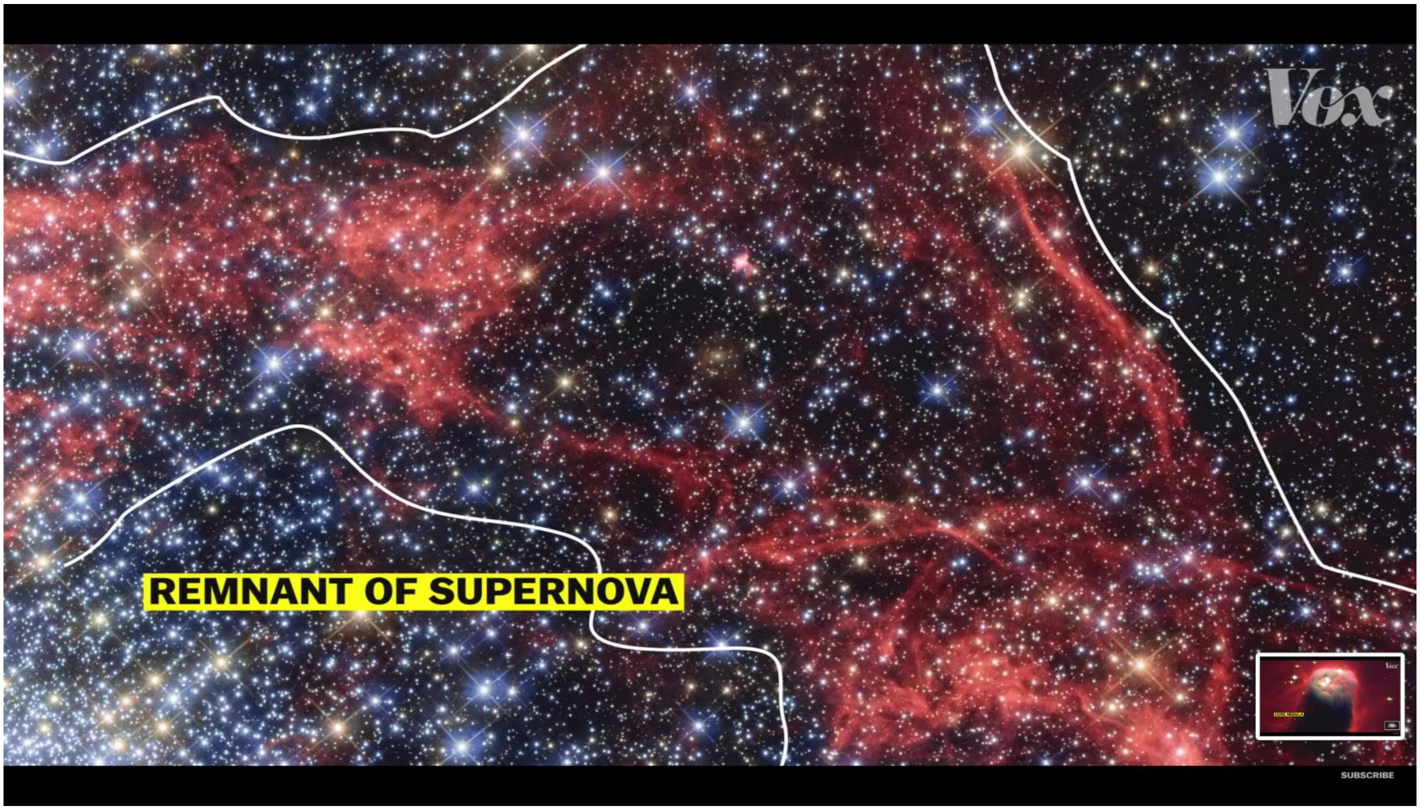
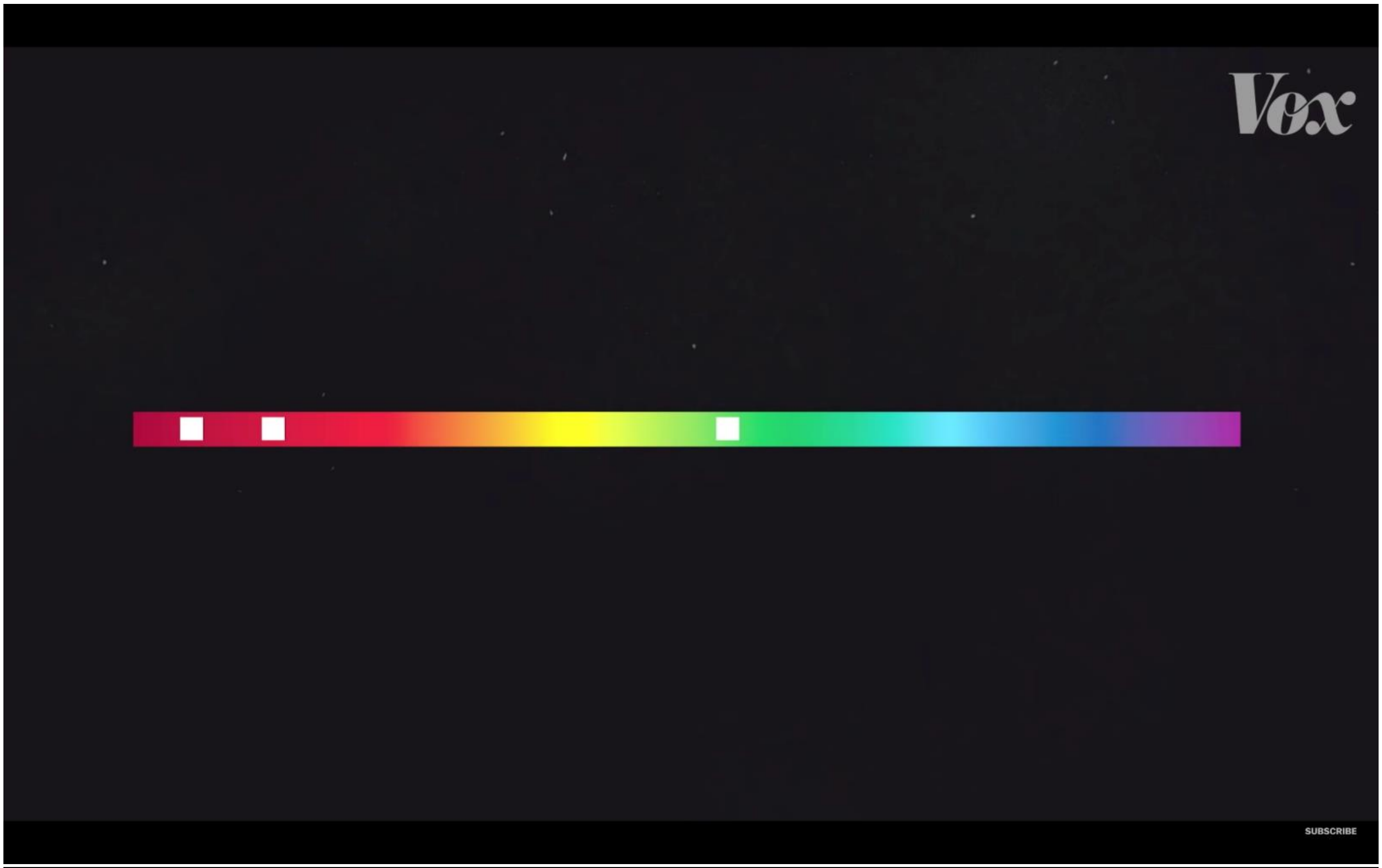

Vox
REMNANT OF SUPERNOVA
SUBSCRIBE


Vox
PILLARS OF CREATION
H-ALPHA NARROWBAND IMAGE
SUBSCRIBE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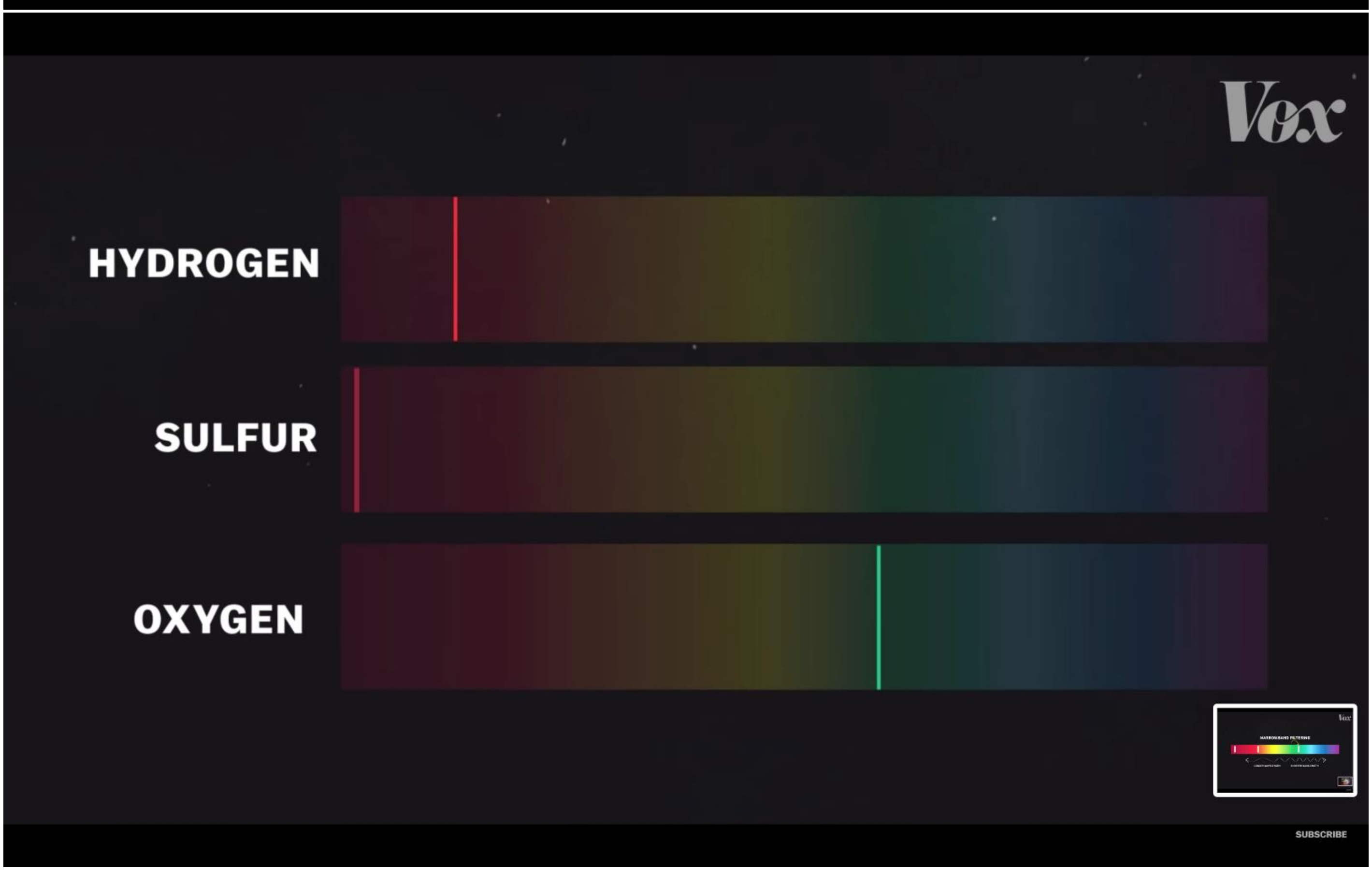
Vox
HYDROGEN
SULFUR
OXYGEN
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Color fundamentals

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) –

Developed the prism theory for color of light

Chromatic light span the electromagnetic spectrum (EM) from 400 to 700 nm

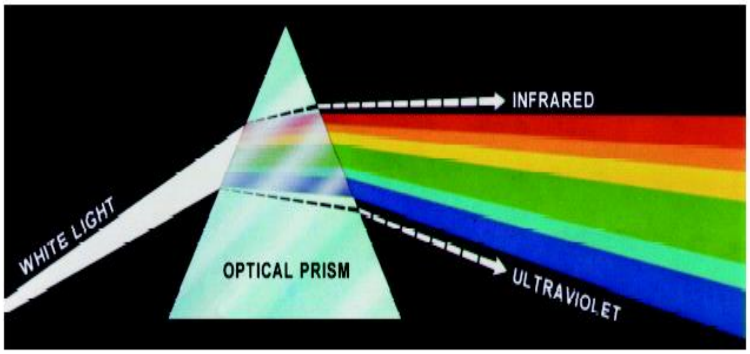


FIGURE 6.1 Color spectrum seen by passing white light through a prism. (Courtesy of the General Electric Co., Lamp Business Division.)

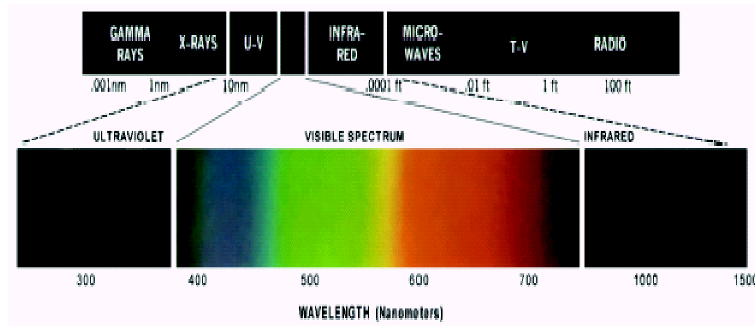
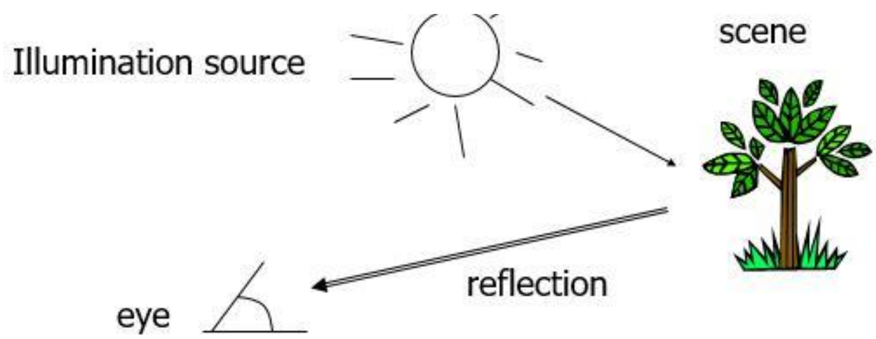


FIGURE 6.2 Wavelengths comprising the visible range of the electromagnetic spectrum. (Courtesy of the General Electric Co., Lamp Business Division.)

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?

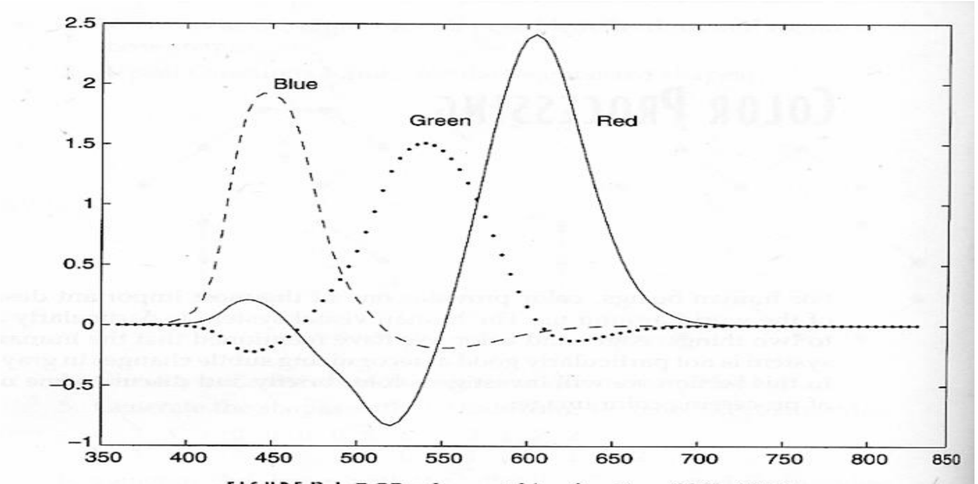


FIGURE B.1 *RGB color-matching functions (CIE, 1931).*

6~7M Cones are the sensors in the eye

3 principal sensing categories in eyes

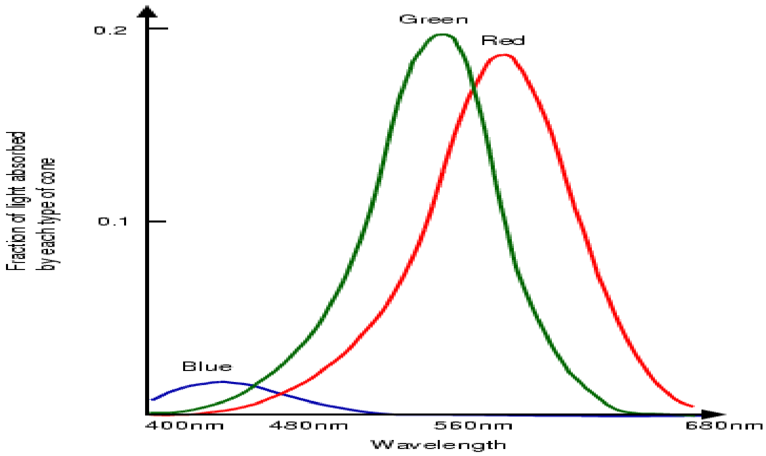
Red light 65%,

green light 33%,

blue light 2%

Tristimulus theory of colour perception:

- ✓ As



discussed in lecture 1, the human retina has 3 kinds of cones.

- ✓ The response of each type of cone as a function of the wavelength of the incident light is shown in figure 2.
- ✓ 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[2].

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

Primary color of pigments: Color that subtracts or absorbs a primary color of light and reflects or transmits the other two

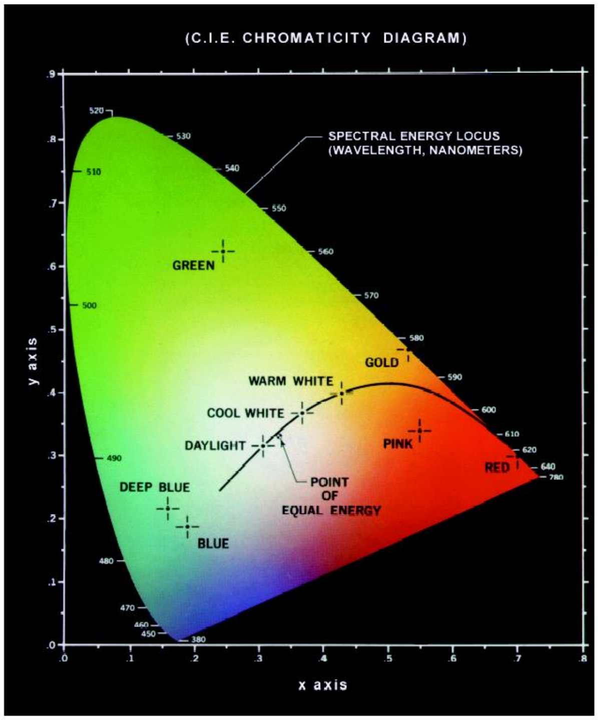
Color of light:	**R**	**G**	**B**
Color of pigments:	**absorb R**	**absorb G**	**absorb B**
	Cyan	**Magenta**	**Yellow**

CIE primaries

- ★ The tristimulus theory of colour perception seems to imply that any colour can be obtained from a mix of the three primaries, red, green and blue, but although nearly all visible colours can be matched in this way, some cannot.
- ★ However, if one of the primaries is added to one of these unmatchable colours, it can be matched by a mixture of the other two, and so the colour may be considered to have a negative weighting of that particular primary.

★ In 1931, the *Commission Internationale de l'Éclairage (CIE) / (*International Commission on Illumination) defined three standard primaries, called *X*, *Y* and *Z*, that can be added to form all visible colours.

★ The primary *Y* was chosen so that its colour matching function exactly matches the luminous-efficiency function for the human eye, given by the sum of the three curves in figure



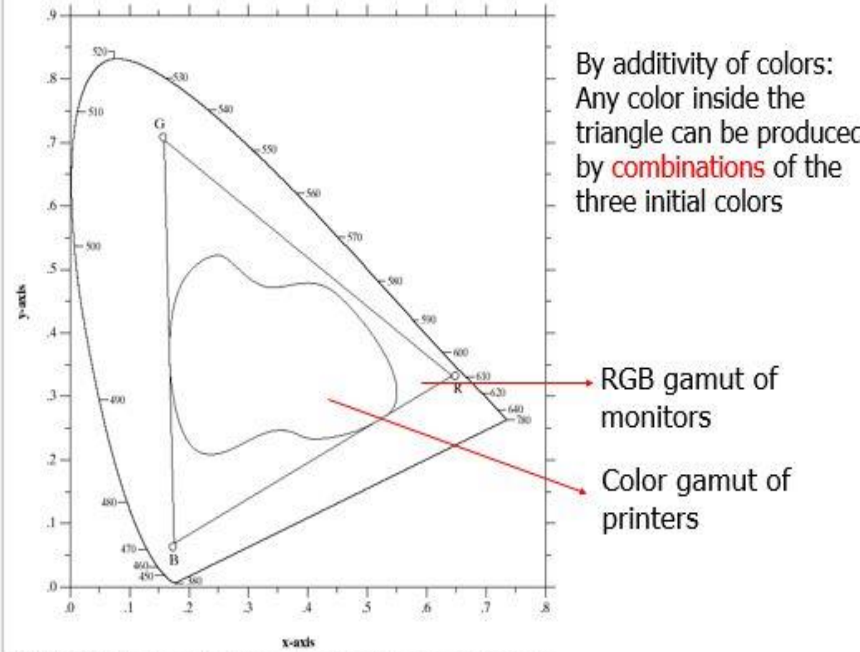


FIGURE 6.6 Typical color gamut of color monitors (triangle) and color printing devices (irregular region).

Color Models

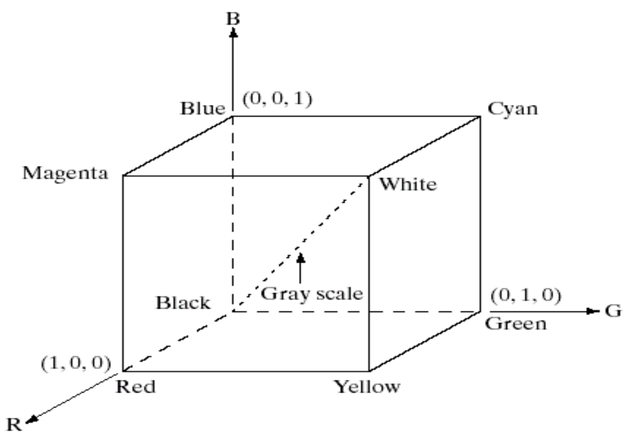
✓ Color model, color space, color system

✓ Specify colors in a standard way

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

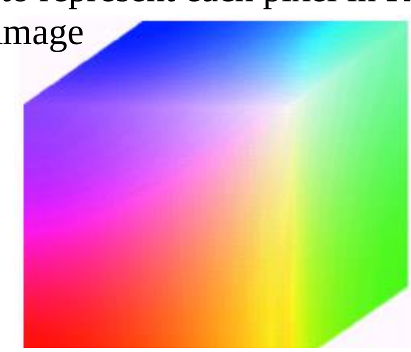
- **RGB model**
- **CYM model** — ***Suitable for hardware or applications***
- **CYMK model**
- **HSI model** — **match the human description**

B.1 RGB color model



- 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.

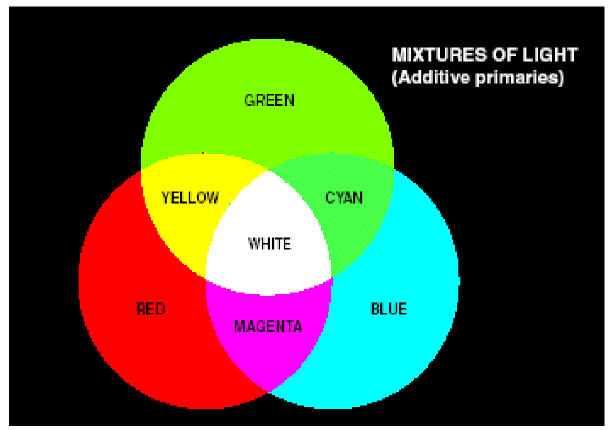
- ✓ This is an *additive* model, i.e. the colors present in the light add to form new colors, and is appropriate for the mixing of colored light for example. The image on the left of figure shows the additive mixing of red, green and blue primaries to form the three secondary colors yellow (red + green),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

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

B.2 CMY model (+Black = CMYK)

CMY: secondary colors of light, or primary colors of pigments

Used to generate hardcopy output



- ➢ The $$\begin{bmatrix} C \\ M \\ Y \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$ CMY (cyan-magenta-yellow) model is a *subtractive* model appropriate to absorption of colours, for example due to pigments in paints.
- ➢ Whereas the RGB model asks what is added to black to get a particular colour, 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 colours .
- ➢ 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

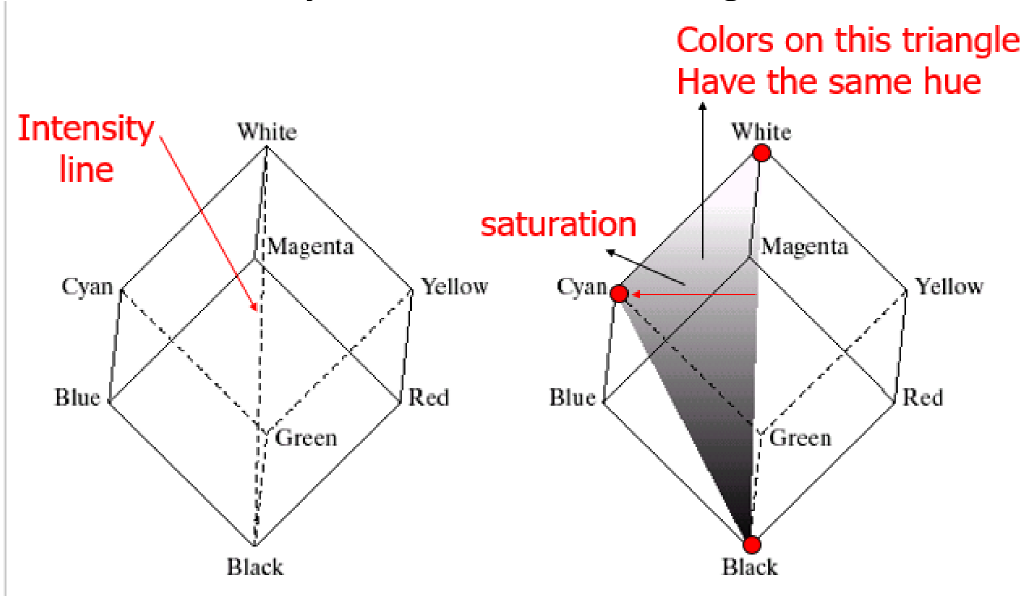
Y' = (Y - K) / (1 - K) = (0.137 - 0.137) / (1 - 0.137) = 0.000 / 0.863 = 0.00

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)

B.3 HSI color model

- Will you describe a color using its R, G, B components?
- Humans describe a color by its hue, saturation, and brightness

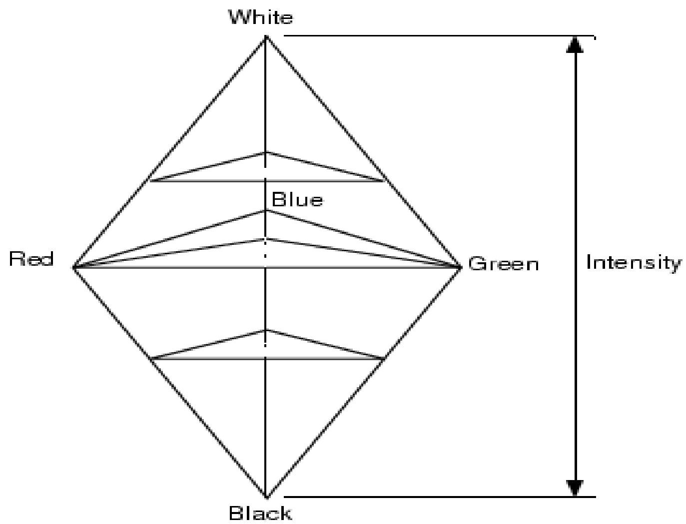


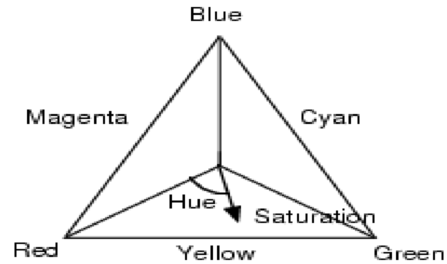
Hue: color attribute.

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, colour may be specified by the three quantities hue, saturation and intensity. This is the HSI model, and the entire space of colours 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. Colours on the surface of the solid are fully saturated, i.e. pure colours, and the greyscale spectrum is on the axis of the solid. For these colours, hue is undefined.

Conversion between the RGB model and the HSI model is quite complicated. The intensity is given by.

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, normalised 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 colour. 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 $B' > G'$, $\mathrm{Hue} = 360 - \theta$

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

Therefore, the HSI representation of the RGB color (120, 180, 220)

is approximately (203.6348°, 0.9973, 173.3333).

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.

Pseudo-color image processing

Introduction:

- ★ 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:

Question:

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**

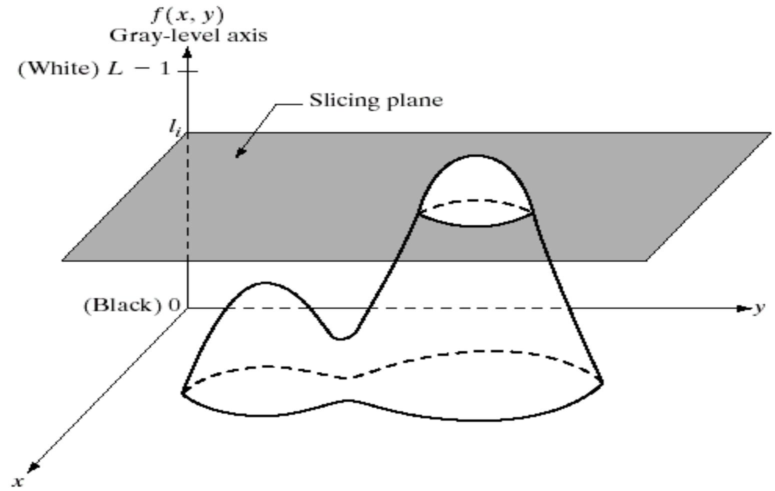
Pseudocolored Image Segment:

(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.

★

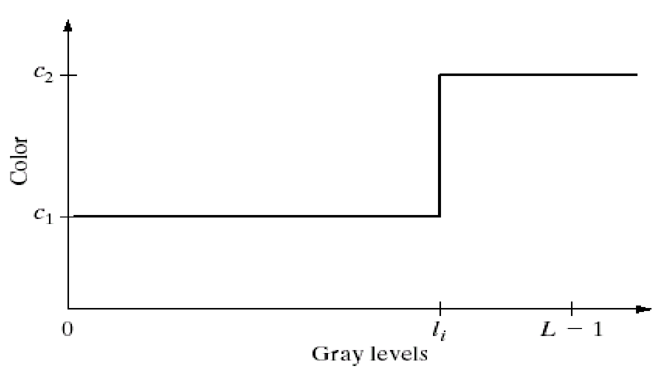


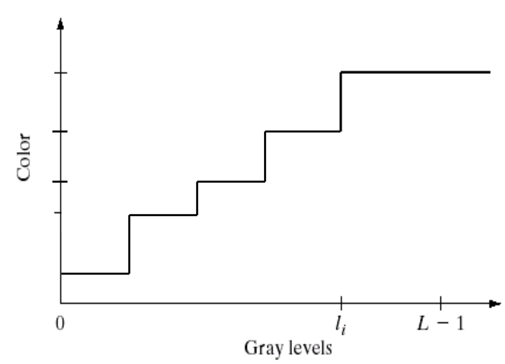
Applications of Intensity Slicing:

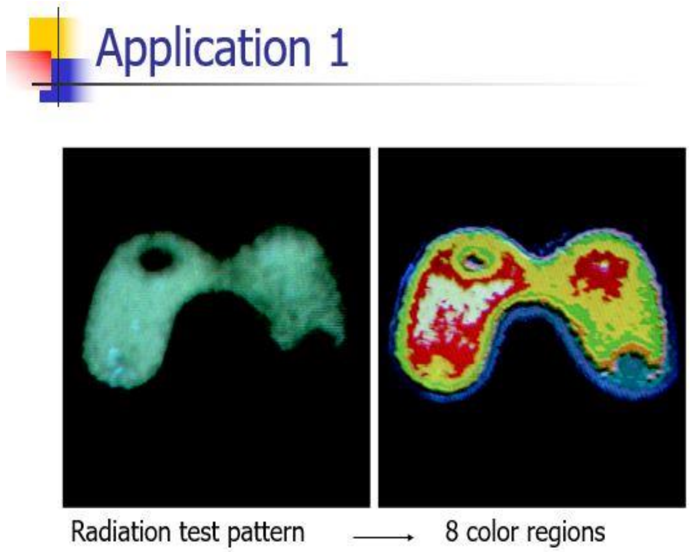
1. **Medical Imaging:** Highlighting different tissues or structures in MRI and CT scans based on intensity values.
2. **Remote Sensing:** Enhancing satellite images to identify land use patterns, vegetation, and water bodies.
3. **Geological Surveys:** Mapping mineral deposits or other geological features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

Piecewise Linear transformation of gray level shown below

The thresholding is used to make such an image binary. The examples of the clipping and thresholding are shown in the following figure. Clipping and thresholding. **Intensity** Level **Slicing**. There are **intensity** level **slicing** without background and with background.







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)	50 → 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)	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...........

Gray level to color transformation: (to color image)

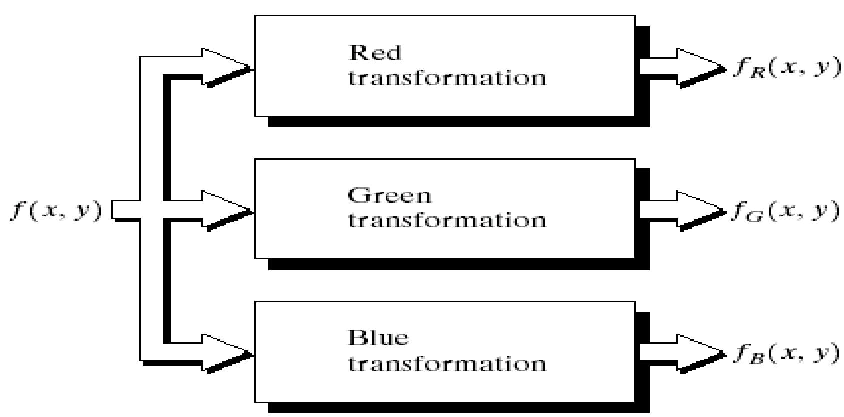


FIGURE 6.23 Functional block diagram for pseudocolor image processing. f_R, f_G, and f_B are fed into the corresponding red, green, and blue inputs of an RGB color monitor.

Assigning colors to gray levels based on specific mappings functions.

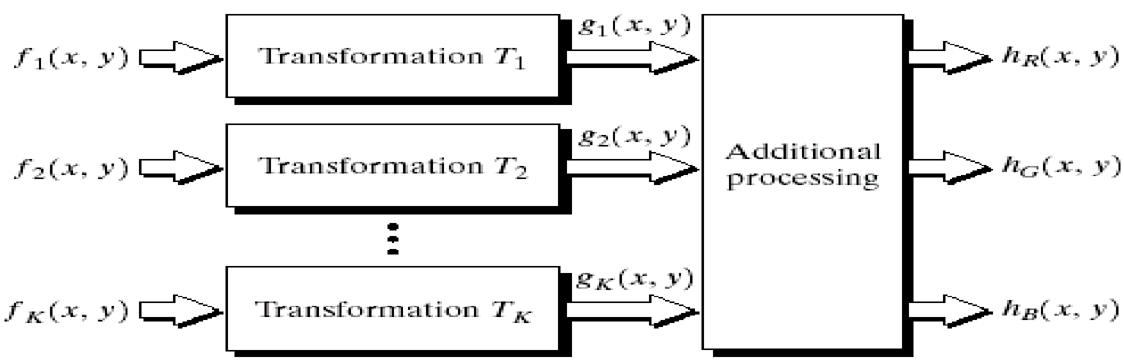
- Given all these different representations of colour, and hence colour images, the question arises as to what is the best way to apply the image processing techniques we have covered so far to these images?
- One possibility is to apply the transformations to each colour plane in an RGB image, but what exactly does this mean?

- If we want to increase the contrast in a dark image by histogram equalisation, can we just equalise each colour independently? This will result in quite different colours in our transformed image.

- In general it is better to apply the transformation to just the intensity component of an HSI image, or the luminance component of a YIQ image, thus leaving the chromaticity unaltered.An example is shown in figure above . When histogram equalisation is applied to each colour plane of the RGB image, the final image is lighter, but also quite differently coloured to the original.
- When histogram equalisation is only applied to the luminance component of the image in YIQ format, the result is more like a lighter version of the original image, as required.

Combine several monochrome images:

Used in the case where there are many monochrome images such as multispectral satellite image.

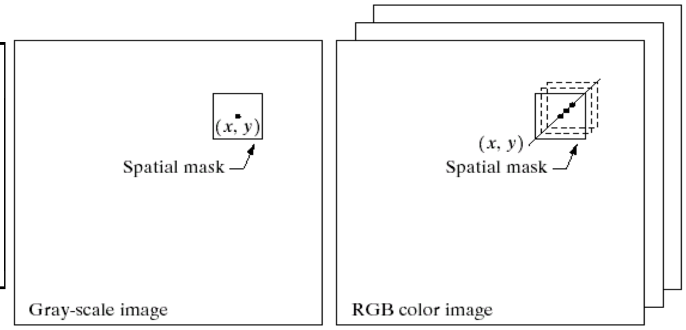


c. <u>Color transformations</u>

A pixel at (x,y) is a vector in the color space

RGB color space

$$\mathbf{c}(x,y) = \begin{bmatrix} R(x,y) \\ G(x,y) \\ B(x,y) \end{bmatrix}$$



c.f. gray-scale image

f(x,y) = I(x,y)

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.

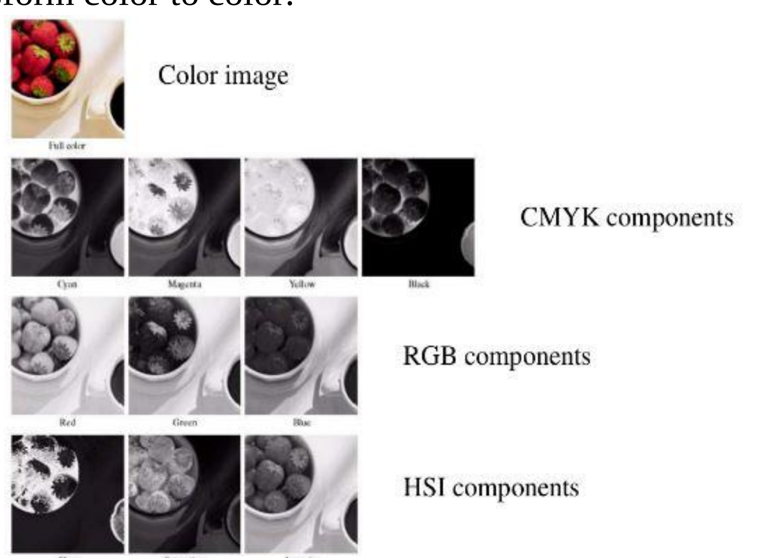
When can the above methods be equivalent?

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).***

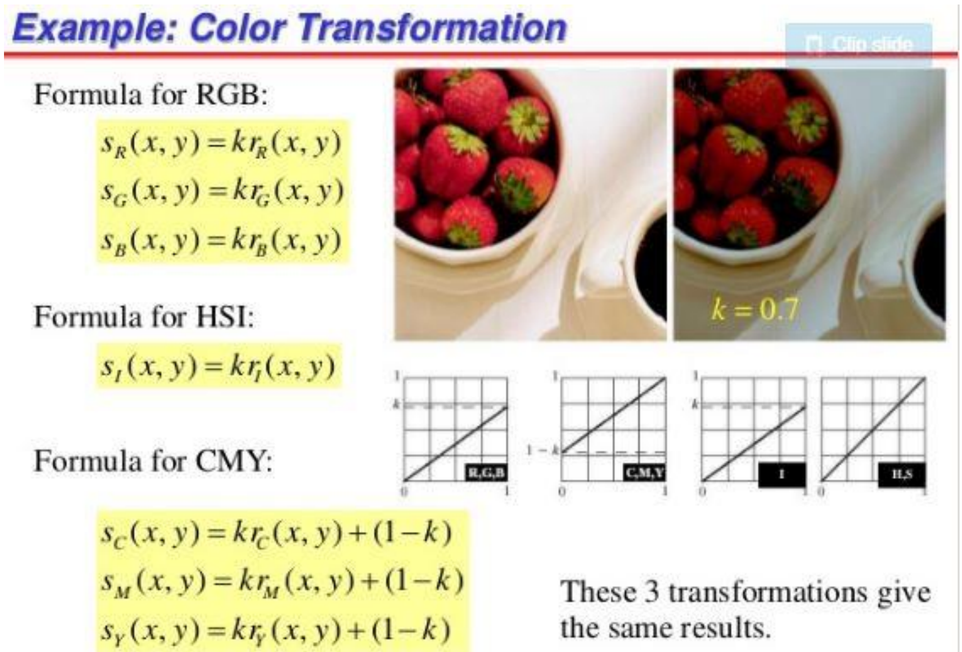
When only data at one pixel is used in the transformation, we can express the transformation as:

$s_i = T_i(r_1, r_2, K, r_n)$ **i=1,2,3 ………,n**

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

For RGB image n=3

s_i = color component of g(x,y)



d. <u>Smoothing and sharpening</u>

Smoothing

Color image smoothing image is classfied as:

1. **Per color plane method**
2. **Smooth only intensity component**

1. **Per color plane method** :
   For RGB, CMY color models Smooth each color plane using moving averaging and combine back to RGB.

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

vector processing

Neighborhood Centered at (x,y)

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

per-component processing

2. **Smooth only intensity component**
   In HIS image while leving H and S unmodified.

Example

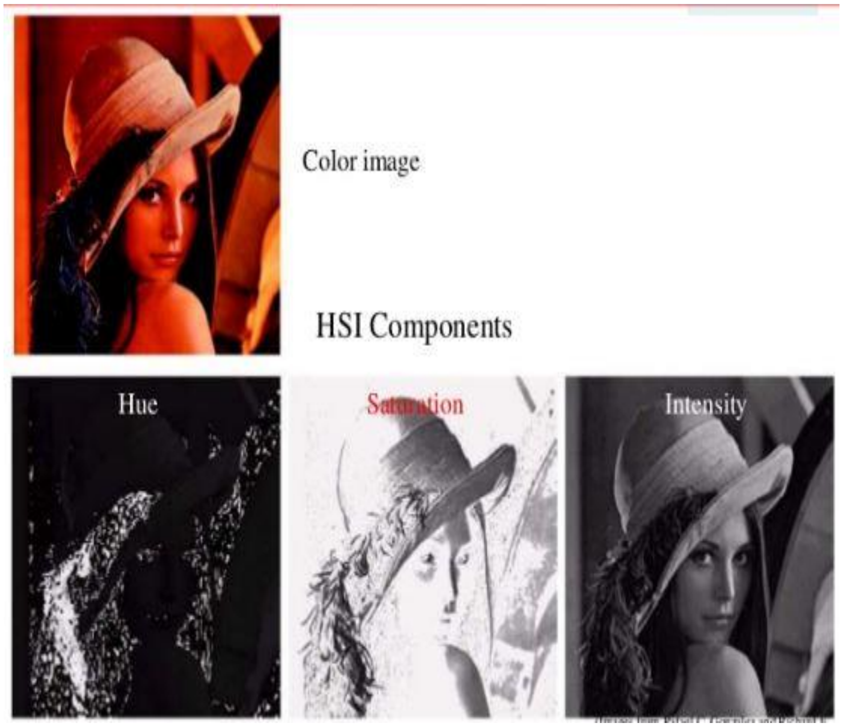
Color image

Red

Green

Blue

(Images from Rafael C. Gonzalez and


Color image
HSI Components
Hue
Saturation
Intensity


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

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

Sharpening:

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

1. **Per-color-plane method for RGB, CMY images**
2. **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.