Lecture 3-1 Color Image Processing

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Course piazza link：piazza.com/shanghaitech.edu.cn/spring2021/cs270spring2021

Outline
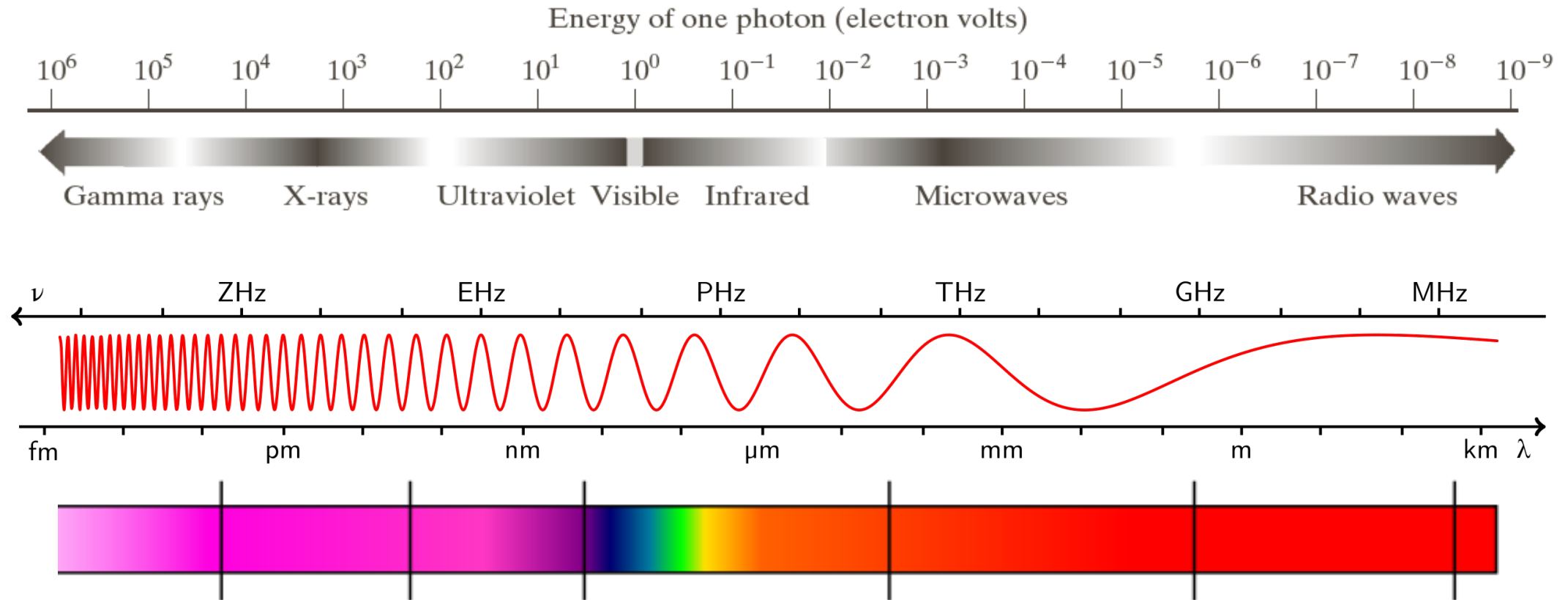
➢ **Standard color spaces**

- RGB
- CMYK
- HSI
- Lab

➢ **Transform between color spaces**

- RGB to gray scale
- RGB to CMY
- RGB to HSI

➢ **Color balance**
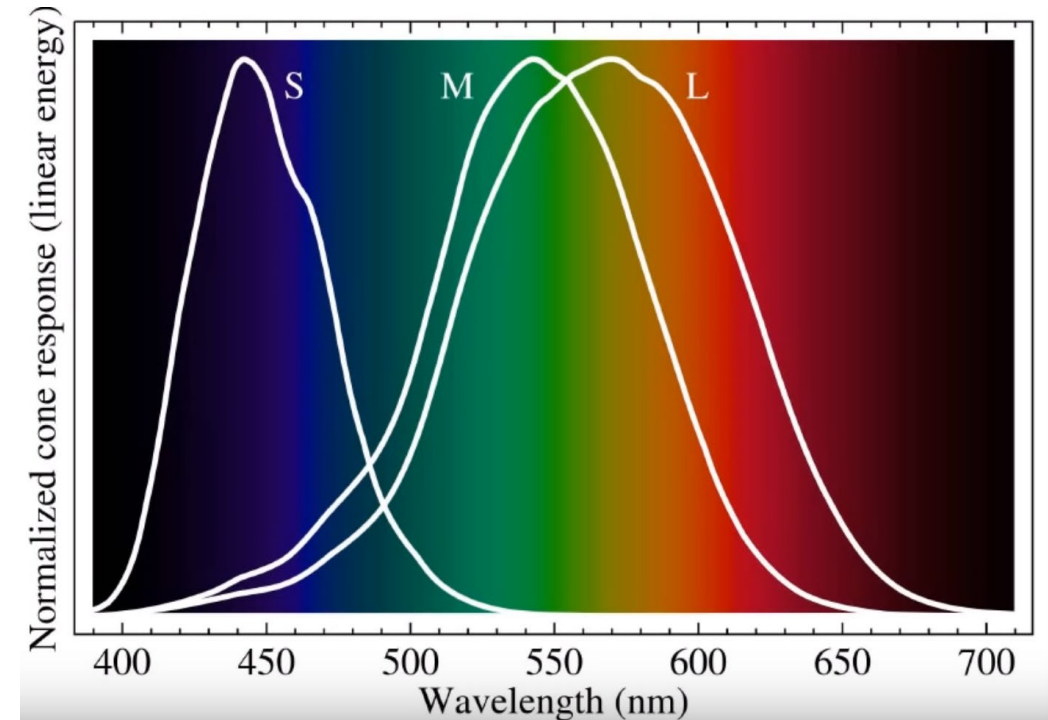
Electromagnetic spectrum

Dispersion of light

Human visual system color Space

- **The LMS color space:** Cones enable color perceptions;
- 3 Types of cones：
- **Long**： sensitive to

"RED" (more yellow to blue) 65%

- **Middle** **:** sensitive to

"GREEN" (more green to blue) 33%

- **Short** **:** sensitive to

"BLUE" (more blue to purple) 2%

(But most sensitive)

Primary colors

➢ **CIE RGB Standard (**International Commission on Illumination**)**
Commission International d'elairage

- Blue = 435.8 nm

- Green = 546.1 nm

- Red = 700 nm

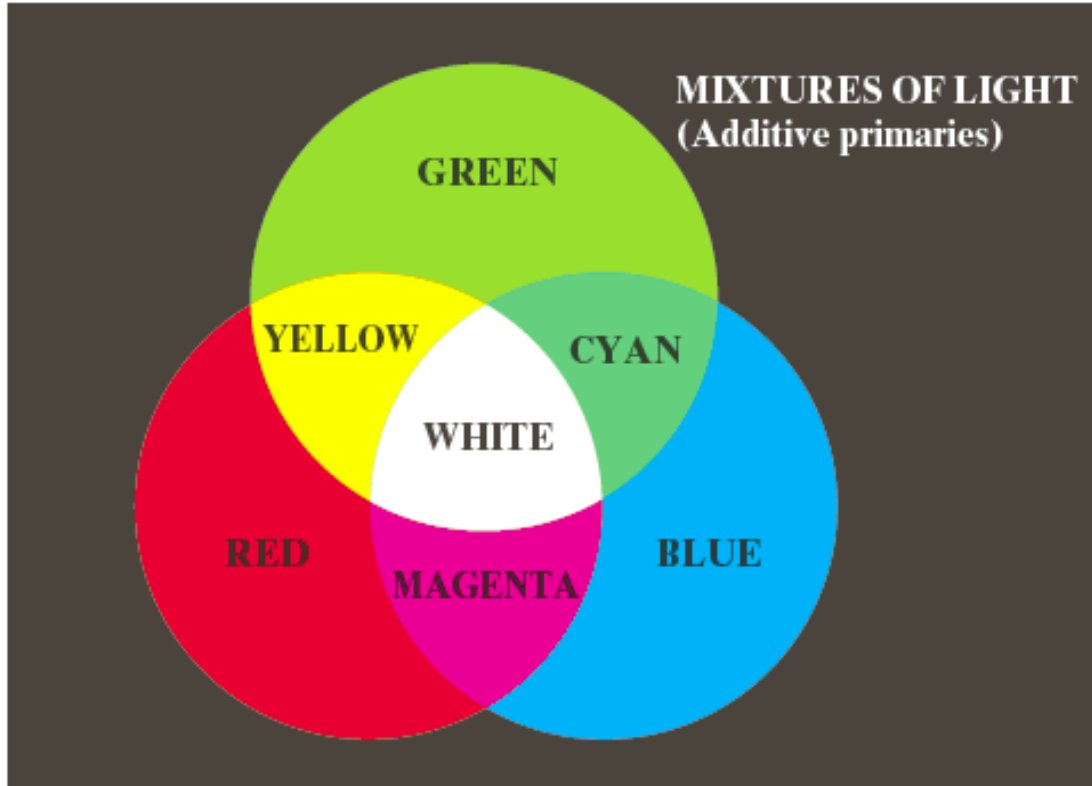➢ **The white light is** achieved with a mixture of RGB light with:

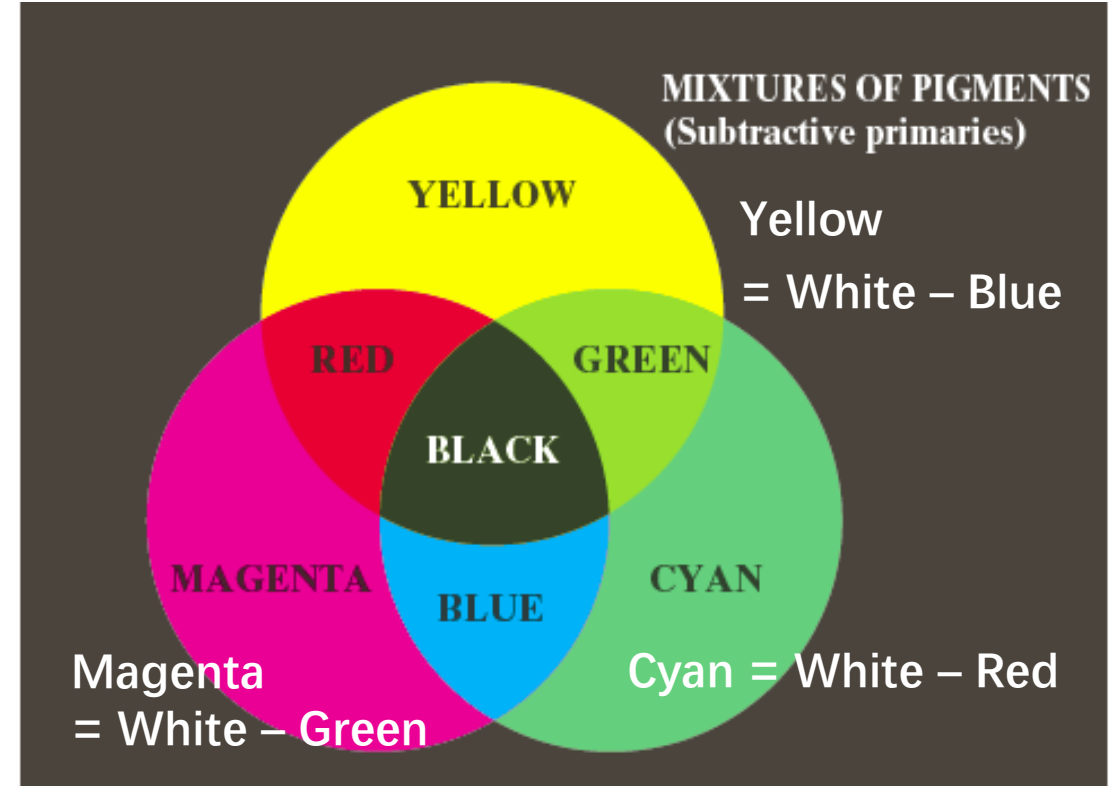- 1.0000 : 4.5907 : 0.0601 of intensity （Luminous intensity）.

➢ **CMY and CMYK color**

- Cyan = White – Red

- Magenta = White – Green

- Yellow = White – Blue

- Black = White – Red - Green - Blue
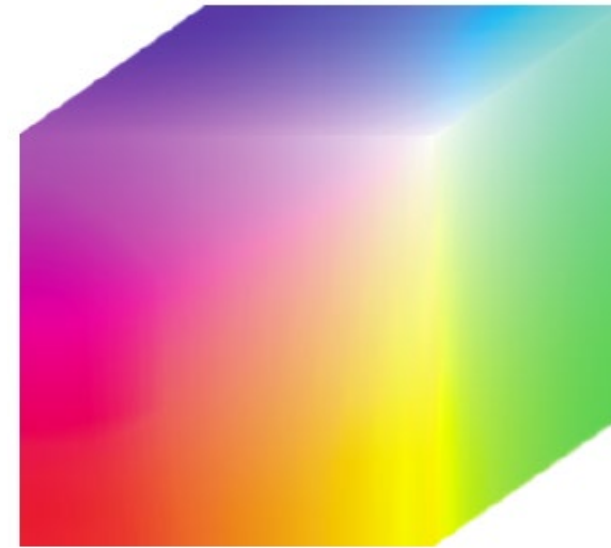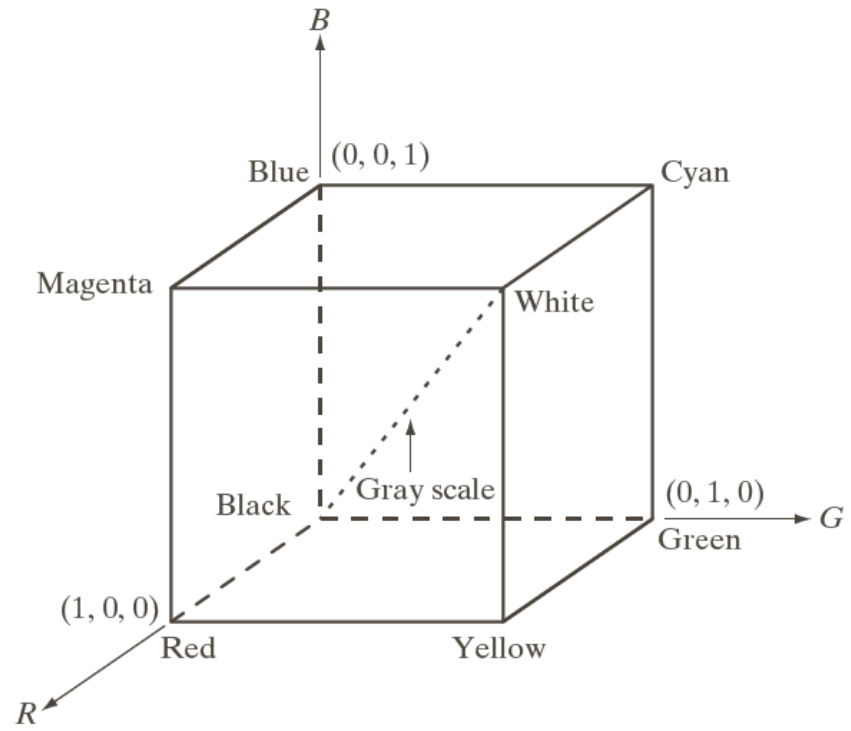
Secondary colors

RGB color

MIXTURES OF LIGHT
(Additive primaries)

GREEN

YELLOW   CYAN

WHITE

RED   MAGENTA   BLUE

CMY and CMYK color

MIXTURES OF PIGMENTS
(Subtractive primaries)

YELLOW

Yellow
= White – Blue

RED   GREEN

BLACK

MAGENTA   BLUE   CYAN
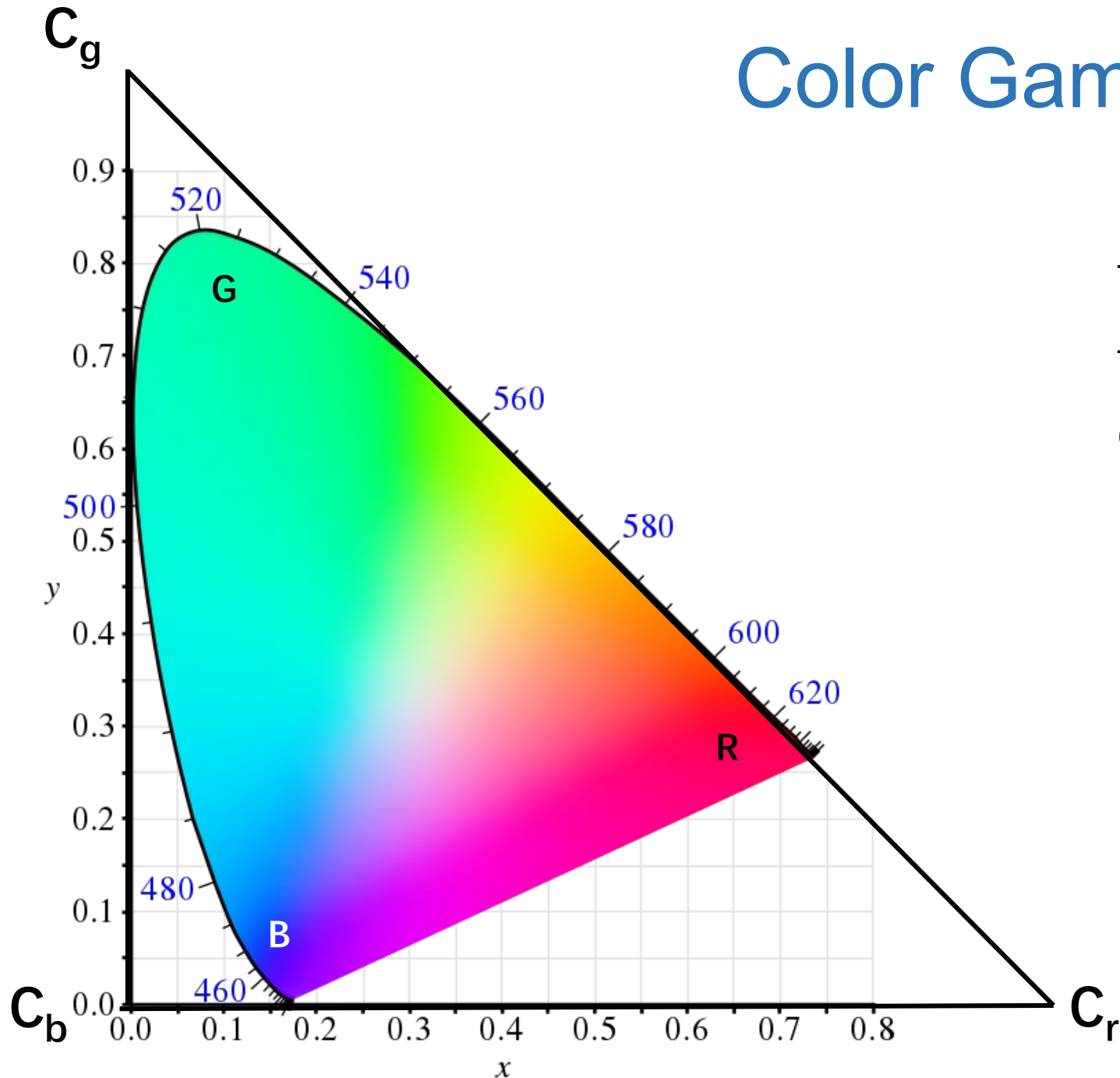
Magenta
= White – Green

Cyan = White – Red

Black = White – Red - Green - Blue

RGB Color Model

Color Gamut

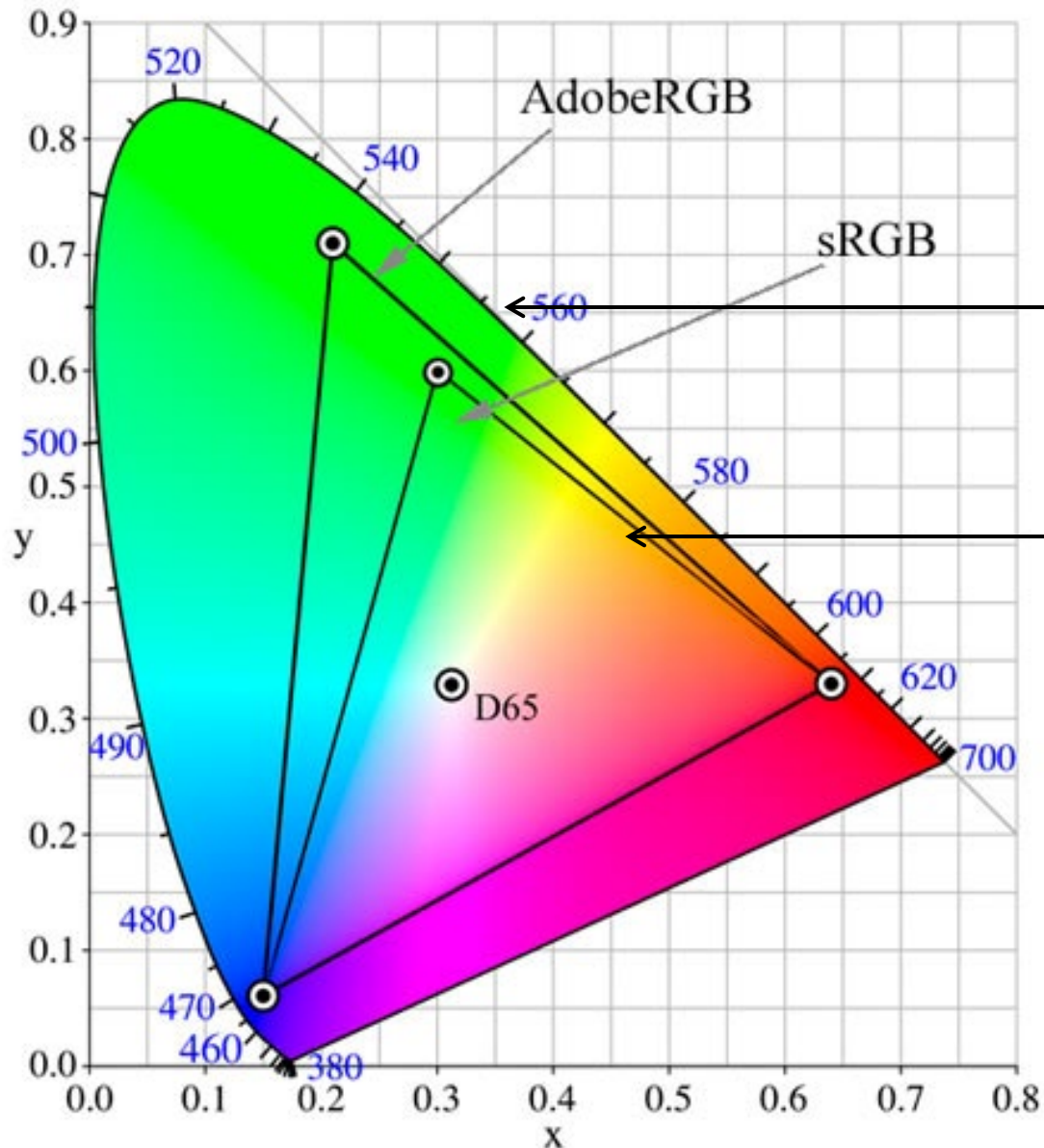
$$x = \frac{R}{R+G+B}, \ y = \frac{G}{R+G+B}, \ z = \frac{B}{R+G+B}$$

Then $z = 1 - x - y$.

The color cube is turns to a 2-D color gamut.

➢ It is seen that all visible chromaticities correspond to non-negative values of x, y, and z.

➢ An equal mixture of two equally bright colors will not generally lie on the midpoint of that line.

Color Gamut

White：D65 [0.3127,0.3290]
Red：[0.6400, 0.3300]
Green：[0.3000, 0.6000]
Blue: [0.1500, 0.0600]

CIE Chromaticity diagram

Color gamut for monitor

- **sRGB** (**standard Red Green Blue**) is an RGB color space and Microsoft created cooperatively in 1996 to use on monitors, printers, and the Internet.

- The **Adobe RGB (1998) color space** is an RGB color space developed by Adobe System, Inc. in 1998.

CMY Color Model

➢ **RGB to CMY conversion**

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

In order to produce true black in printing, a fourth color, black, is added into the CMYK color model

Outline

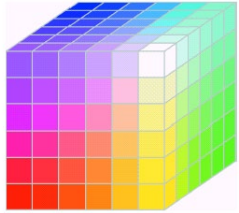➢ **Standard color spaces**

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- HSI
- Lab

➢ **Transform between color spaces**
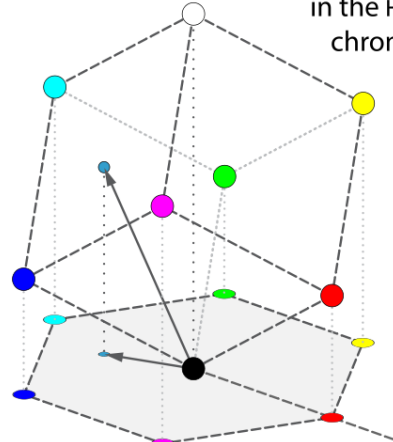
- RGB to gray scale
- RGB to CMY
- RGB to HSI

➢ **Color balance**
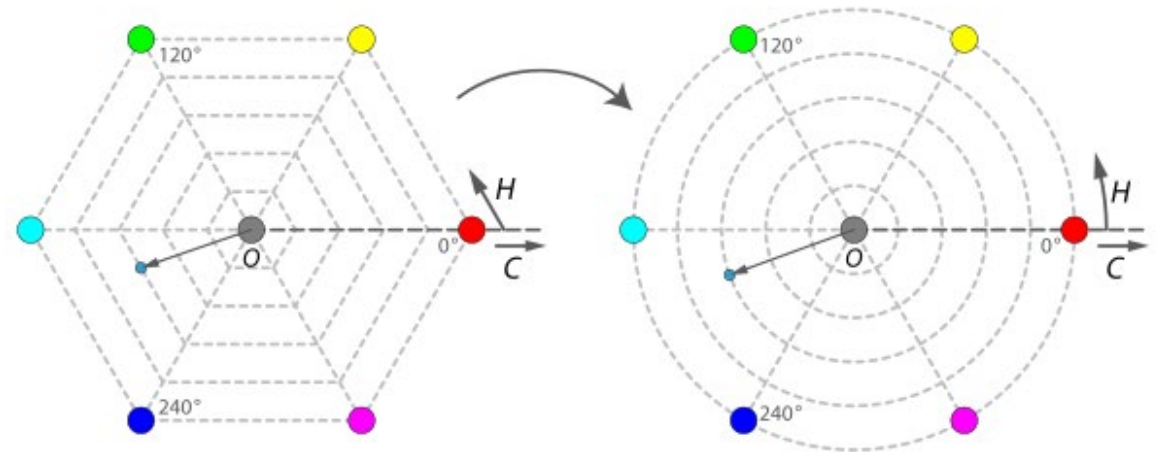
HSI/HSV Color Model

RGB color cube
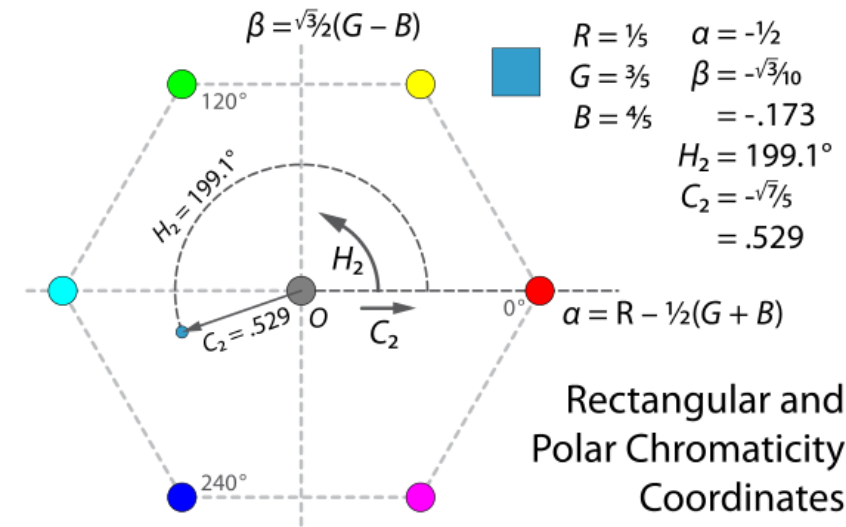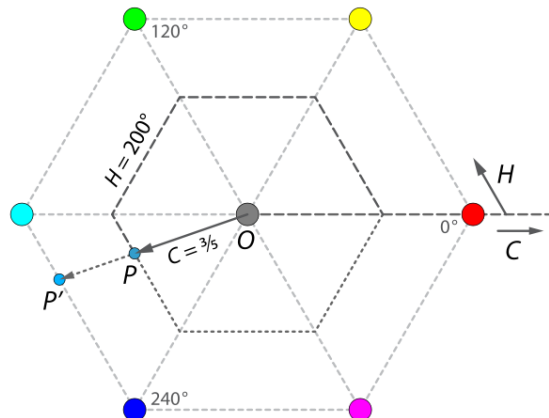
Hue and chroma in the HSL/HSV chromaticity plane

$$\beta = {}^{\sqrt{3}}\!/_{2}(G - B)$$

$R = \tfrac{1}{5}$ $\alpha = -\tfrac{1}{2}$
$G = \tfrac{3}{5}$ $\beta = -\sqrt{3}/_{10}$
$B = \tfrac{4}{5}$ $= -.173$
$H_2 = 199.1°$
$C_2 = -\sqrt{7}/_{5}$
    $= .529$

$H_2 = 199.1°$

$C_2 = .529$

$\alpha = R - \tfrac{1}{2}(G + B)$

Rectangular and Polar Chromaticity Coordinates

$$C = \frac{OP}{OP'} = B - R = \tfrac{4}{5} - \tfrac{1}{5} = \tfrac{3}{5} = .6$$

$R = \tfrac{1}{5}$
$G = \tfrac{3}{5}$ $H = 60° \times \left(4 + \frac{R - G}{C}\right) = 60° \times (4 - \tfrac{2}{3}) = 200°$
$B = \tfrac{4}{5}$

$H = 200°$

$C = \tfrac{3}{5}$

HSI/HSL Color Model
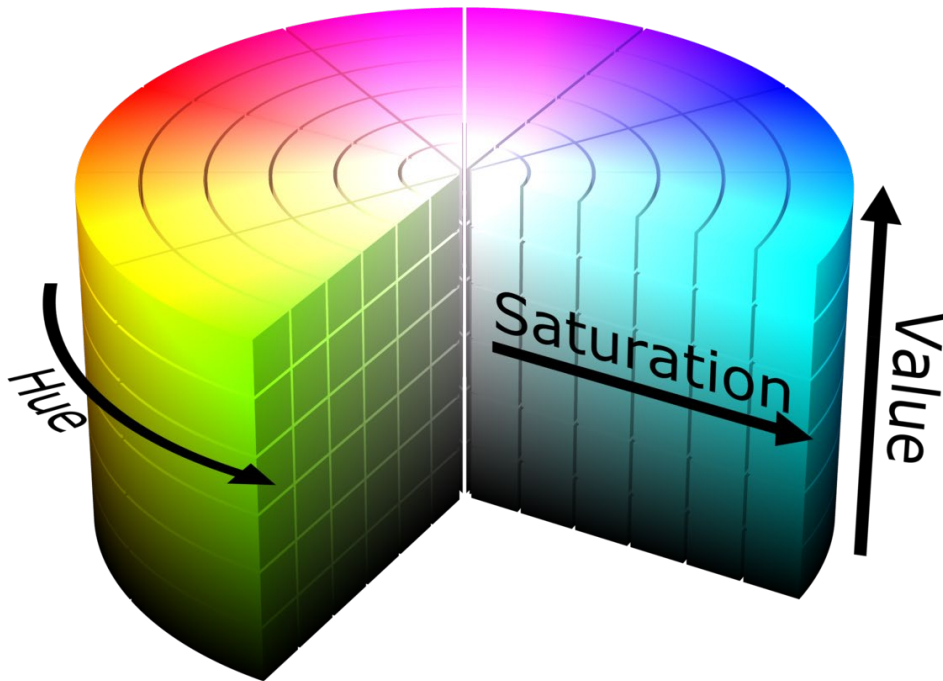
➢ **HSI Color Model**

- **Hue:** Dominant color associated with wavelength.

- **Saturation:** relative purity, the amount of white light mixed with a hue

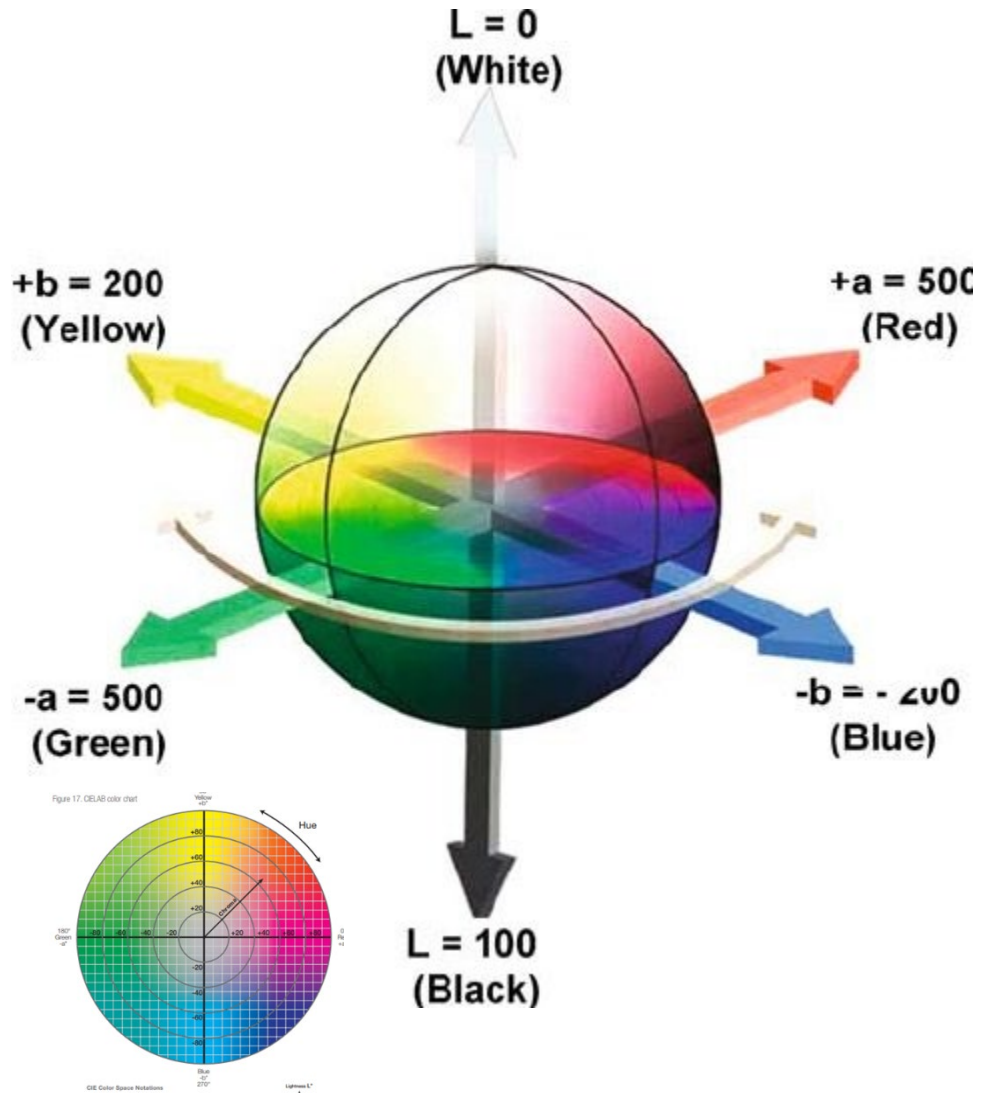- **Intensity/Lightness.** $I = (r + g + b) / 3$
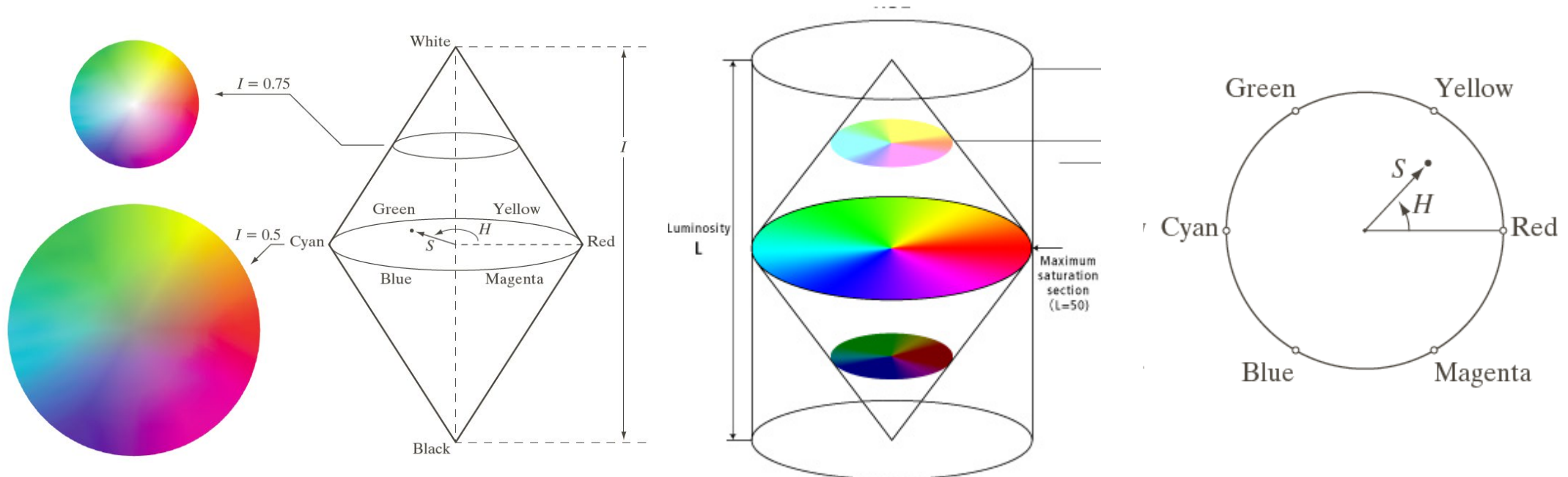
HSV Color Model

➢ **HSI Color Model**

- **Hue:** Dominant color associated with wavelength.

- **Saturation:** relative purity, the amount of white light mixed with a hue

- **Value.** $v = \max(r, g, b);$

Lab Color Model

- **L∗: Lightness**

- **a∗: Red/Green Value**

- **b∗: Blue/Yellow Value**

- The a∗ axis runs from left to right. A color measurement movement in the +a direction depicts a shift toward red.

- Along the b∗ axis, +b movement represents a shift toward yellow.

- The center L∗ axis shows L = 0 (black or total absorption) at the bottom.

- At the center of this plane is neutral or gray.

Outline

➢ **Standard color spaces**

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➢ **Transform between color spaces**

- RGB to gray scale
- RGB to CMY
- RGB to HSI/HSV

➢ **Color balance**

RGB to Gray scale

➢ **Maximum value:**

$$g_R(x,y) = g_G(x,y) = g_B(x,y) = \max[f_R(x,y), f_G(x,y), f_B(x,y)]$$

➢ **Average value**

$$g_R(x,y) = g_G(x,y) = g_B(x,y) = [f_R(x,y) + f_G(x,y) + f_B(x,y)]/3$$

➢ **Weighted value**

$$g_R(x,y) = g_G(x,y) = g_B(x,y) = 0.299f_R(x,y) + 0.587f_G(x,y) + 0.114f_B(x,y)$$

Transform to CMY Color Space

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

- $$\begin{bmatrix} g_R(x,y) \\ g_G(x,y) \\ g_B(x,y) \end{bmatrix} = \begin{bmatrix} 255 - f_R(x,y) \\ 255 - f_G(x,y) \\ 255 - f_B(x,y) \end{bmatrix}$$

Transform from RGB to HSI/HSV

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

$$H = \begin{cases} \theta, & G \geq B \\ 360 - \theta, & G < B \end{cases}$$

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

$$I = \frac{R+G+B}{3} \qquad V = \max(R,G,B);$$

$$S = 0 \rightarrow H = 0, \quad I - 0 \rightarrow S = 0, H = 0$$

Transform from HSI to RGB

➢ $0° \leq H < 120°$

$$B = I(1 - S), \qquad R = I\left[1 + \frac{Scos(H)}{\cos(60° - H)}\right], \qquad G = 3I - (R + B)$$

➢ $120° \leq H < 240°$

$$R = I(1 - S), \qquad G = I\left[1 + \frac{Scos(H - 120°)}{\cos(180° - H)}\right], \qquad B = 3I - (R + G)$$

➢ $240° \leq H < 360°$

$$G = I(1 - S), \qquad B = I\left[1 + \frac{Scos(H - 240°)}{\cos(300° - H)}\right], \qquad R = 3I - (G + B)$$

Color Balance

➢ **White balance:**

$$I(x,y) = 0.299 f_R(x,y) + 0.587 f_G(x,y) + 0.114 f_B(x,y)$$

$$k_R = \frac{\bar{I}}{\bar{f_R}} \quad k_G = \frac{\bar{I}}{\bar{f_G}} \quad k_B = \frac{\bar{I}}{\bar{f_B}}$$

$$\begin{bmatrix} g_R(x,y) \\ g_G(x,y) \\ g_B(x,y) \end{bmatrix} = \begin{bmatrix} k_R & & \\ & k_G & \\ & & k_B \end{bmatrix} \begin{bmatrix} f_R(x,y) \\ f_G(x,y) \\ f_B(x,y) \end{bmatrix}$$

➢ **Maximum value balance**

$$S_{RGB} = \min[R_{max}, G_{max}, B_{max}]$$

$$k_R = \frac{S_{RGB}}{T_R} \quad k_G = \frac{S_{RGB}}{T_G} \quad k_B = \frac{S_{RGB}}{T_B}$$

$$\begin{bmatrix} g_R(x,y) \\ g_G(x,y) \\ g_B(x,y) \end{bmatrix} = \begin{bmatrix} k_R & & \\ & k_G & \\ & & k_B \end{bmatrix} \begin{bmatrix} f_R(x,y) \\ f_G(x,y) \\ f_B(x,y) \end{bmatrix}$$
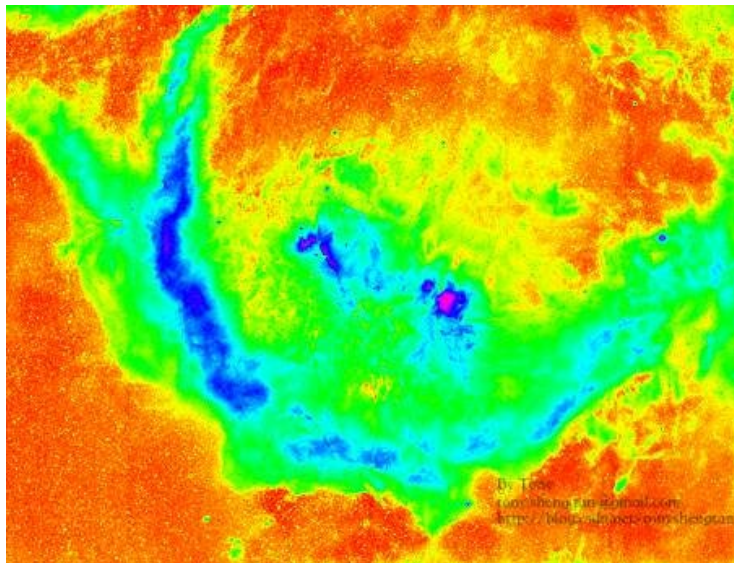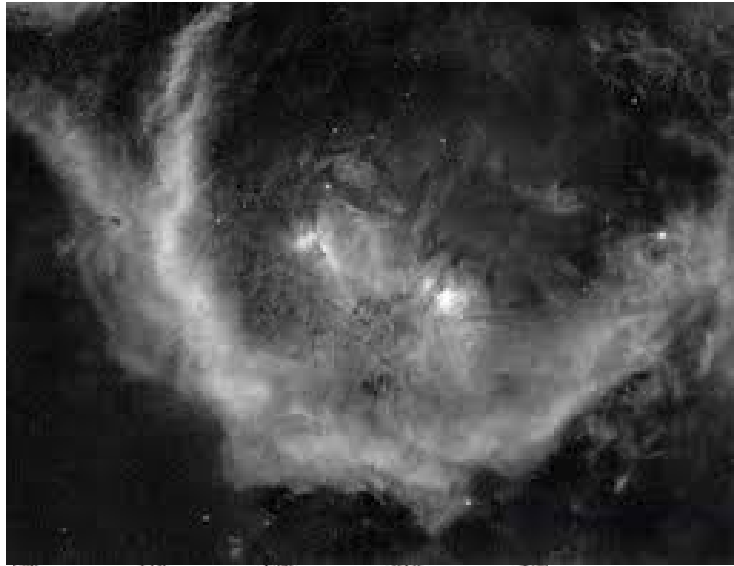
1. Find the smallest max value S_{RGB} in each color channel.

2. Calculate the number of intensities Nr, Ng, Nb that larger than S_{RGB} in each color channel. Then find the largest number Nmax = max[Nr,Ng,Nb].

3. Sort the intensities in each channel and find the the Nmax$_{th}$ intensity value [Tr, Tg, Tb] in each color channel.

Pseudo color enhancement

Take home message

- 1. The color that you perceived depends on the cone cells in your eye.

- 2. There are variety of different color space defined by CIE. Each color space has its unique advantage.

- 3. When the intensity in each color channel is unbalance, the color looks weird. Try to practice color space transform by implementing a color balance correction method.