

# **Modelos de Cor**

## **Hughes et al. - Cap. 28**

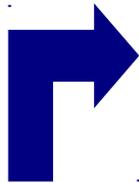
IA725 – Primeiro Semestre de 2016

PE - 22

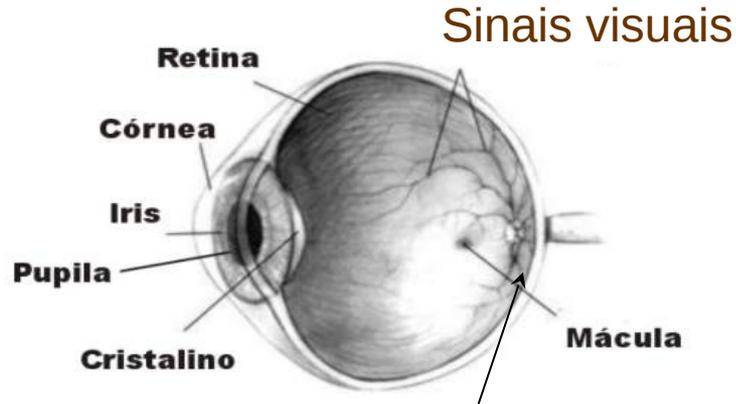
Profa. Ting

# Sistema Visual

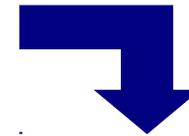
Radiações  
Sinais luminosos



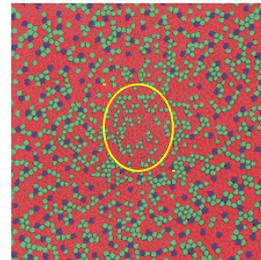
## Sistema Visual



Sinais elétricos



Fóvea ou  
mancha amarela



Cones sensíveis a  
comprimento de onda  
curto, médio e longo

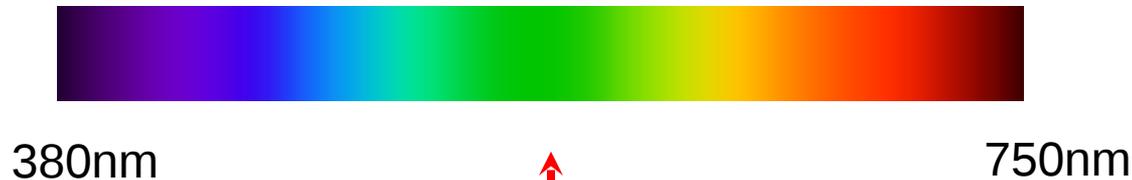
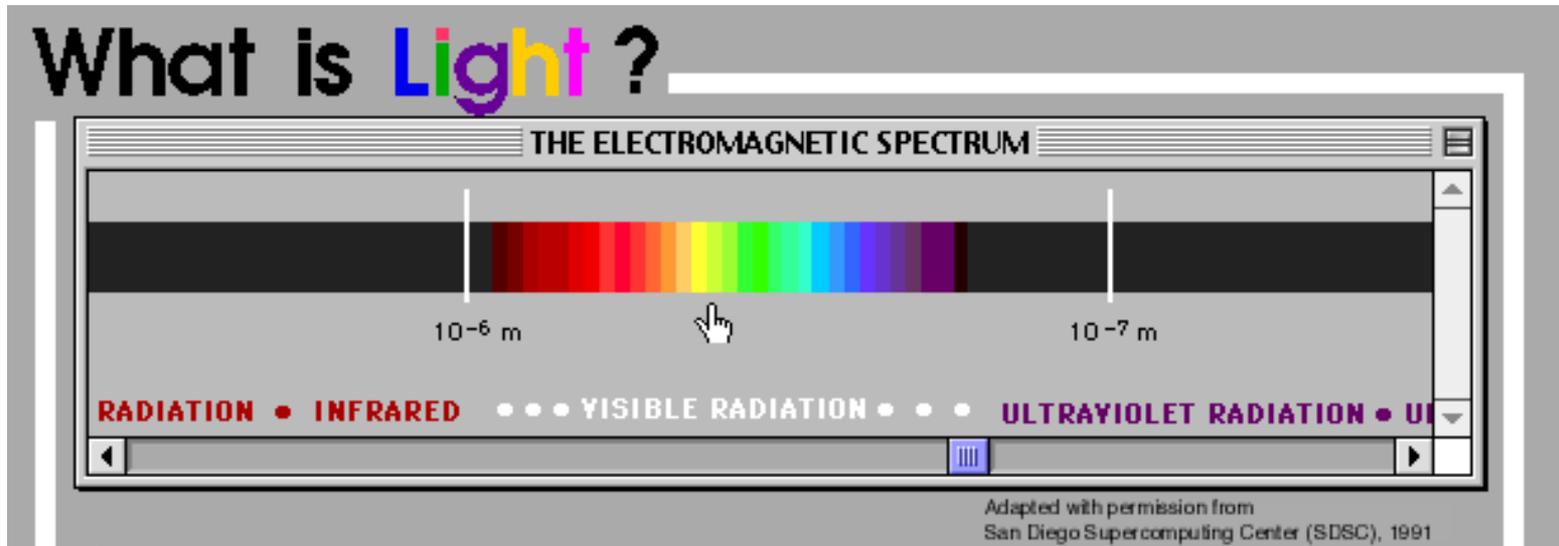


Respostas

Sensação de cores



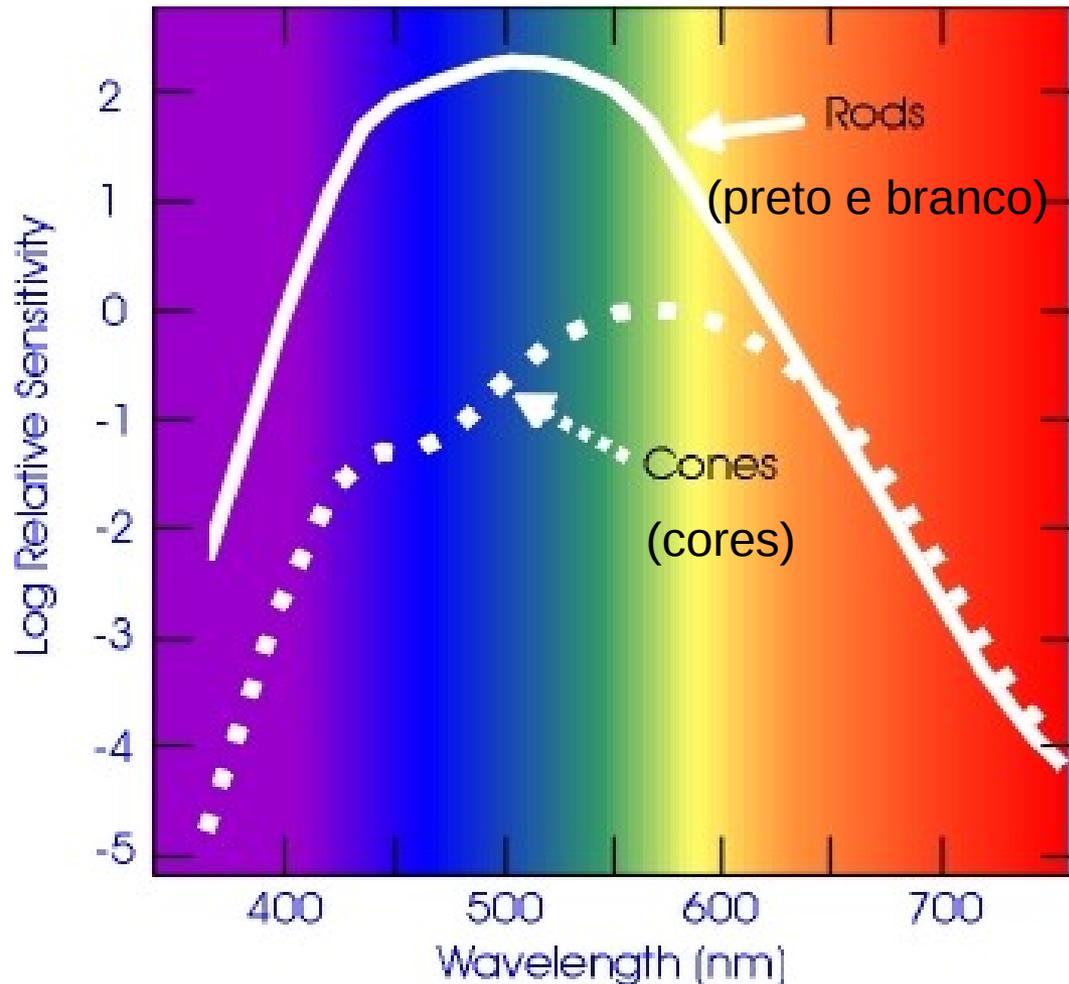
# Ondas Eletromagnéticas Visíveis



**Codificação em cores**

# Células Fotossensíveis

## Cones e Bastonetes



**Visão fotópica (diurna)** : visão adaptada a altos níveis de luminância. Visão colorida.

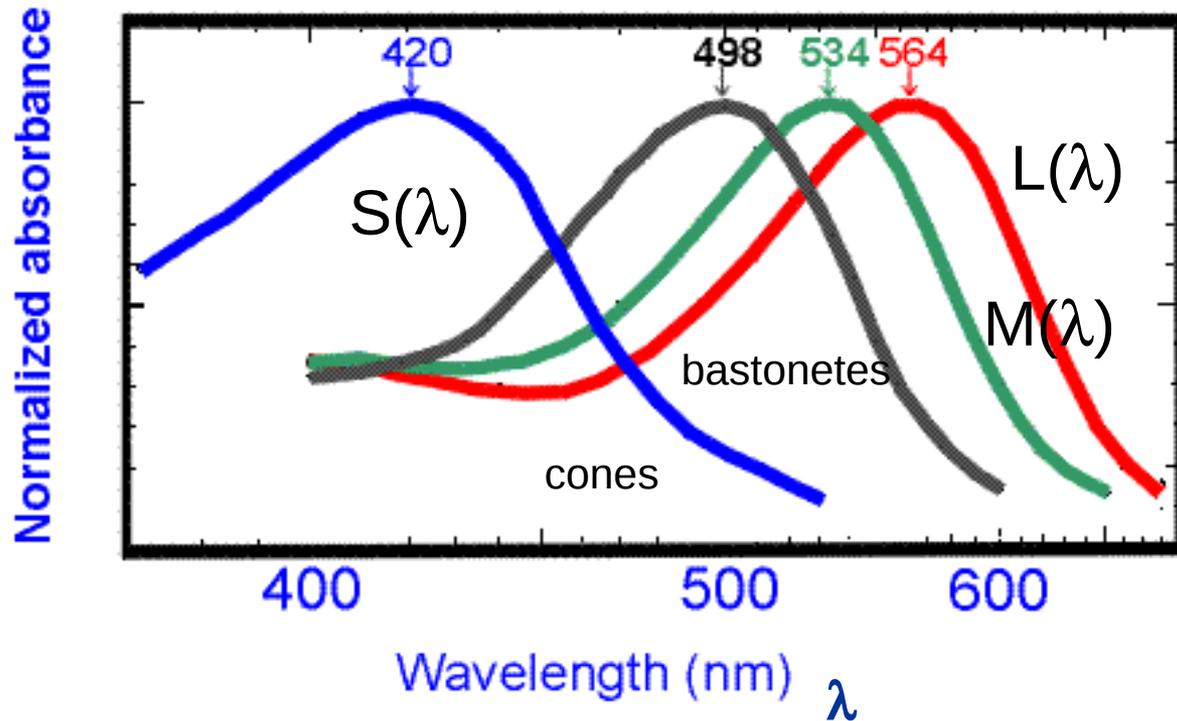
**Visão mesópica**: visão adaptada a regiões de níveis intermediários.

**Visão escotópica (noturna)**: visão adaptada a baixos níveis de luminância. Os bastonetes respondem melhor.

# Teoria Tricromática

Young, Helmholtz, Maxwell

Funções de Sensibilidade Espectral



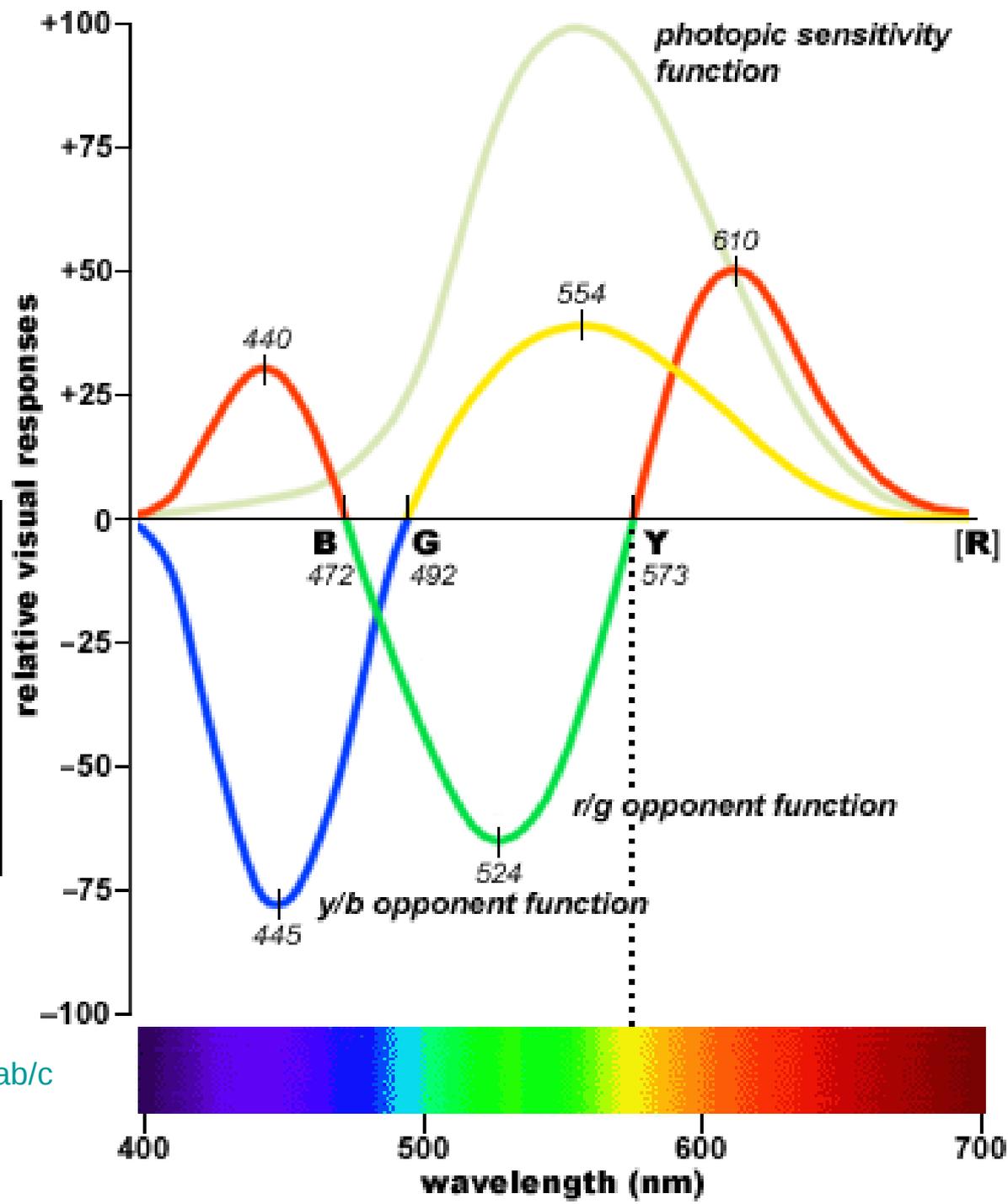
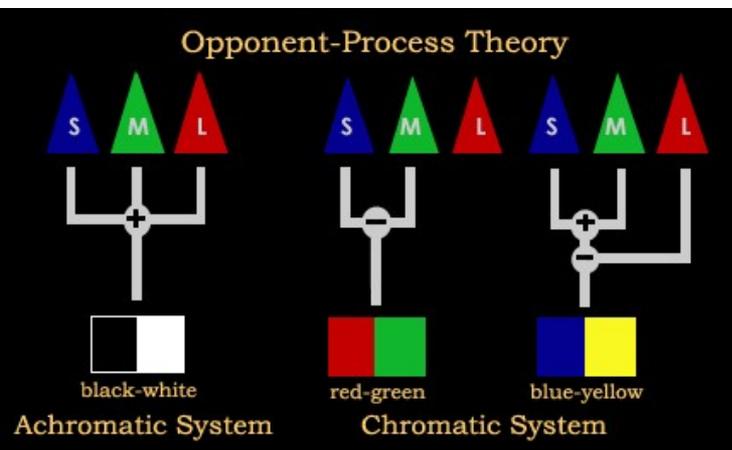
3 tipos de cones

After Bowmaker & Dartnall, 1980



# Processo Oponente

## Hering



<http://www.psych.ucalgary.ca/PACE/VA-Lab/colourperceptionweb/theories.htm>

# Modelo de Processamento Visual

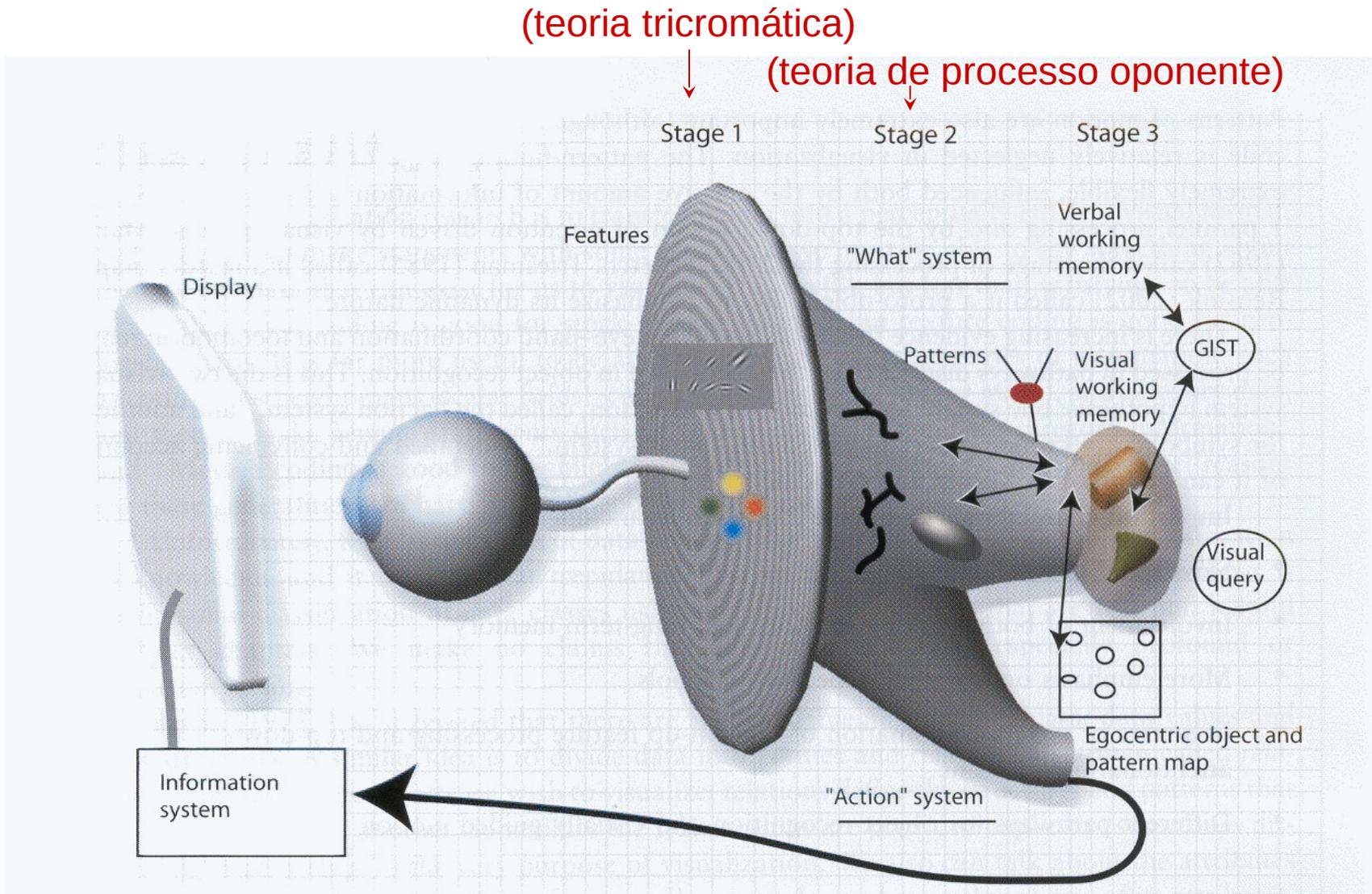
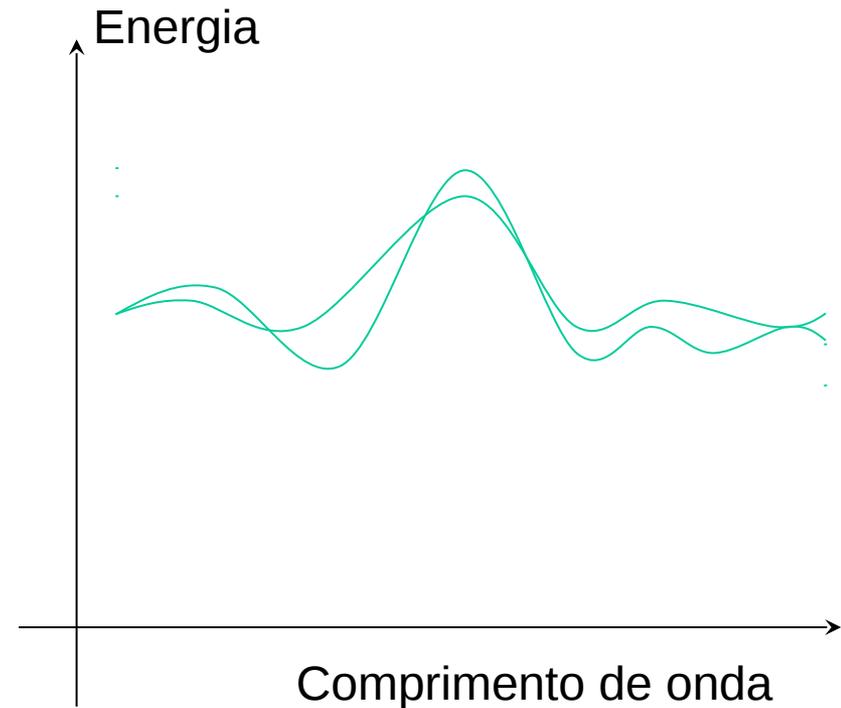
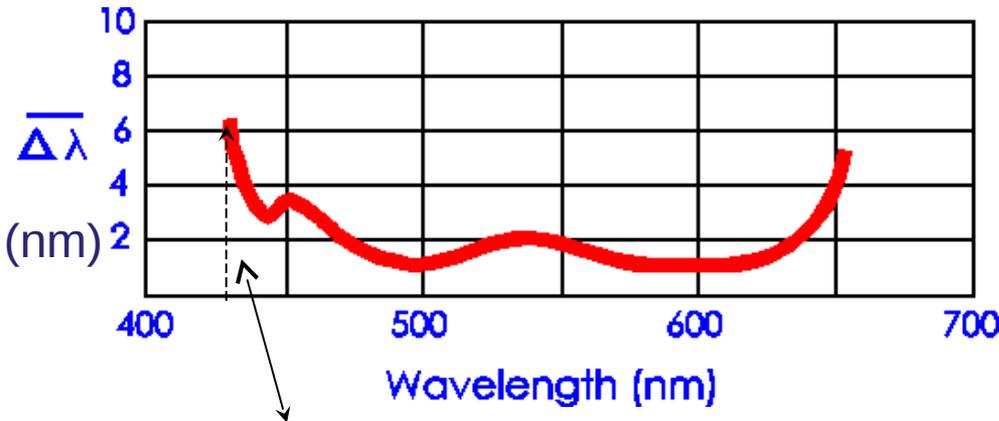
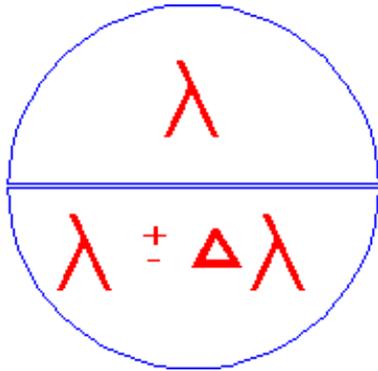


Figure 1.11 A three-stage model of human visual information processing.

# Percepção Visual

## Metâmeras

Distintas distribuições espectrais, porém  
mesma percepção colorida



Diferença mínima para  
que duas cores sejam  
perceptualmente distintas  
IA725– 1s2016 - Ting

# Cores

Respostas neurais aos estímulos das células fotoreceptoras pelas radiações eletromagnéticas refletidas pela superfície dos materiais físicos.

Fenômeno psicofisiológico  
Fenômeno psicofísico

# Lei de Weber

- JND - *Just Noticeable Difference*

$$k = \frac{\Delta I}{I}$$

- Para gerar a mesma diferença na percepção, a variação da intensidade é proporcional à intensidade do estímulo.

# Especificação

## Grandezas colorimétricas

Comprimento de onda dominante

Pureza na excitação

Luminância

## Grandezas fisiológicas

↔ **Matiz**: cor

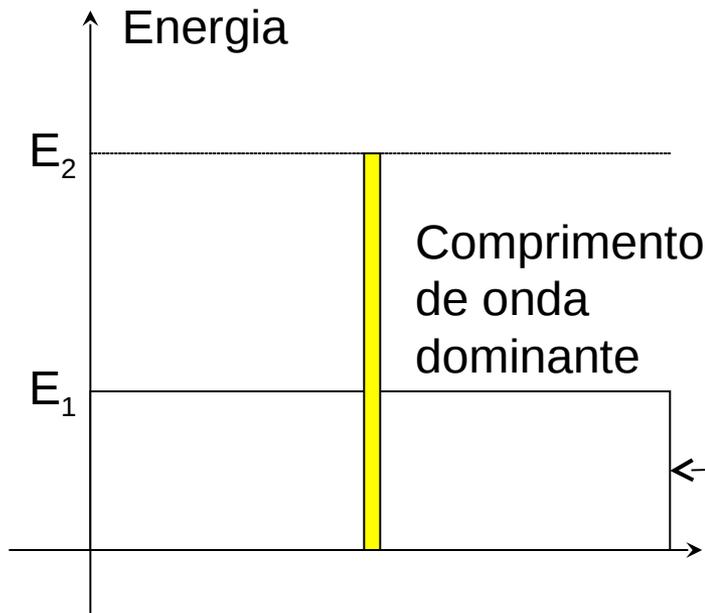
↔ **Saturação**: tonalidade da cor

↔ **Brilho**: brilho da cor

Distribuição de energia de uma cor “monocromática”: só há um comprimento dominante

$$\text{Pureza} = \frac{E_2 - E_1}{E_2}$$

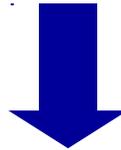
Luminância  $\propto$  Energia



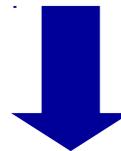
BRANCO = radiações de todos os comprimentos com a mesma energia

# “Algebrizar” cores

Funções de Reconstrução Espectral com 3 cores



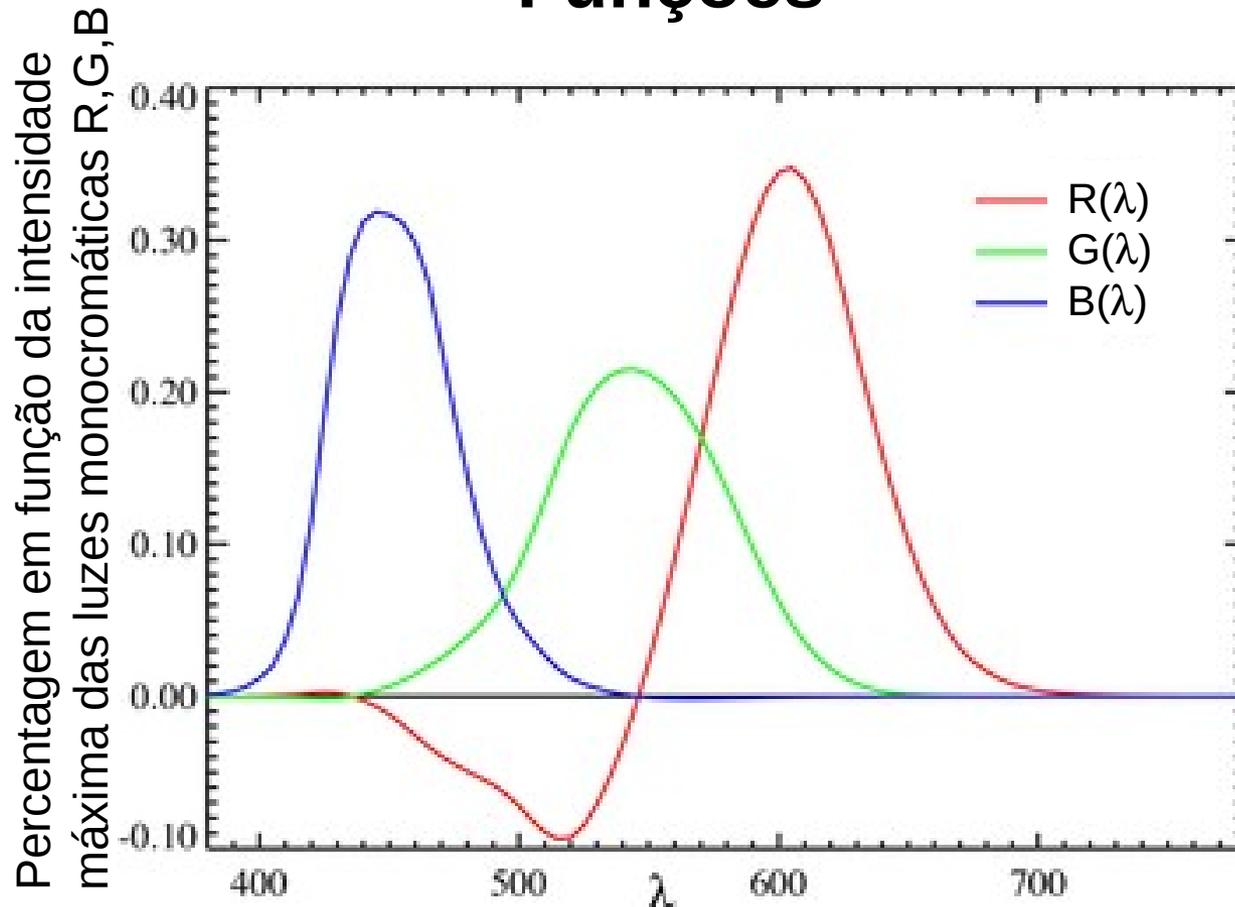
Leis de Grassman



Espaço Vetorial de Cores

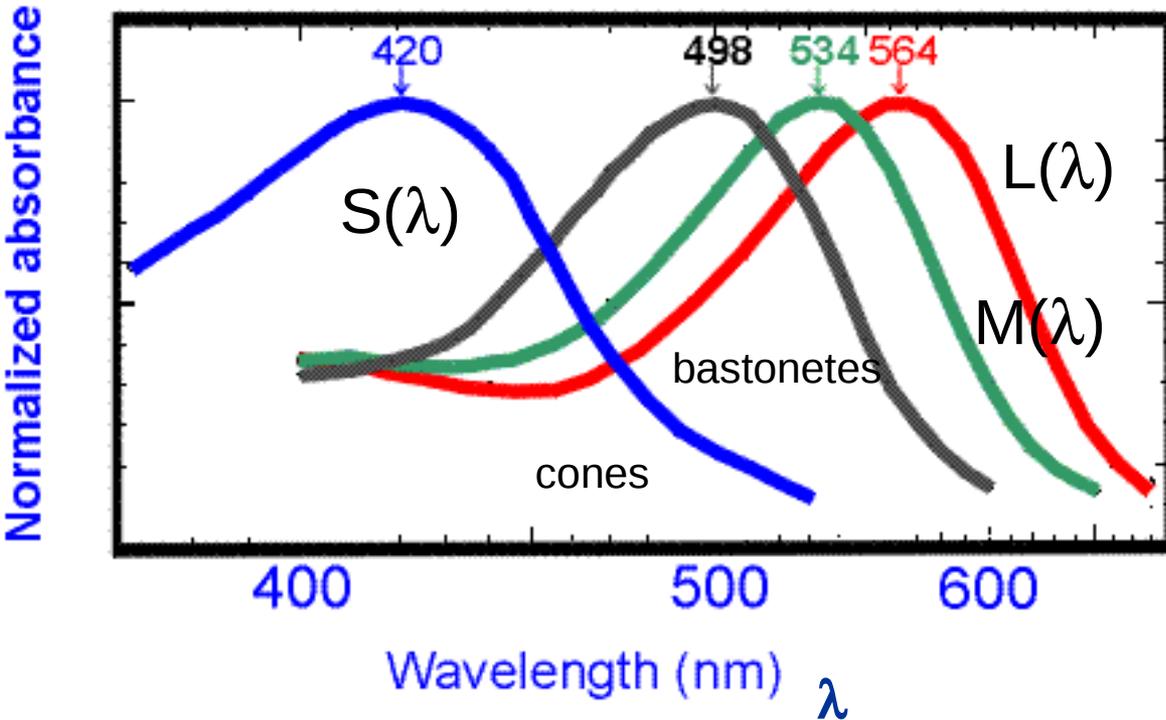
# Reconstrução Espectral

## Funções



$$A(\lambda) = rR(\lambda) + gG(\lambda) + bB(\lambda)$$

# Unicidade



$$S_C = rS_R + gS_G + bS_B$$

$$M_C = rM_R + gM_G + bM_B$$

$$L_C = rL_R + gL_G + bL_B$$

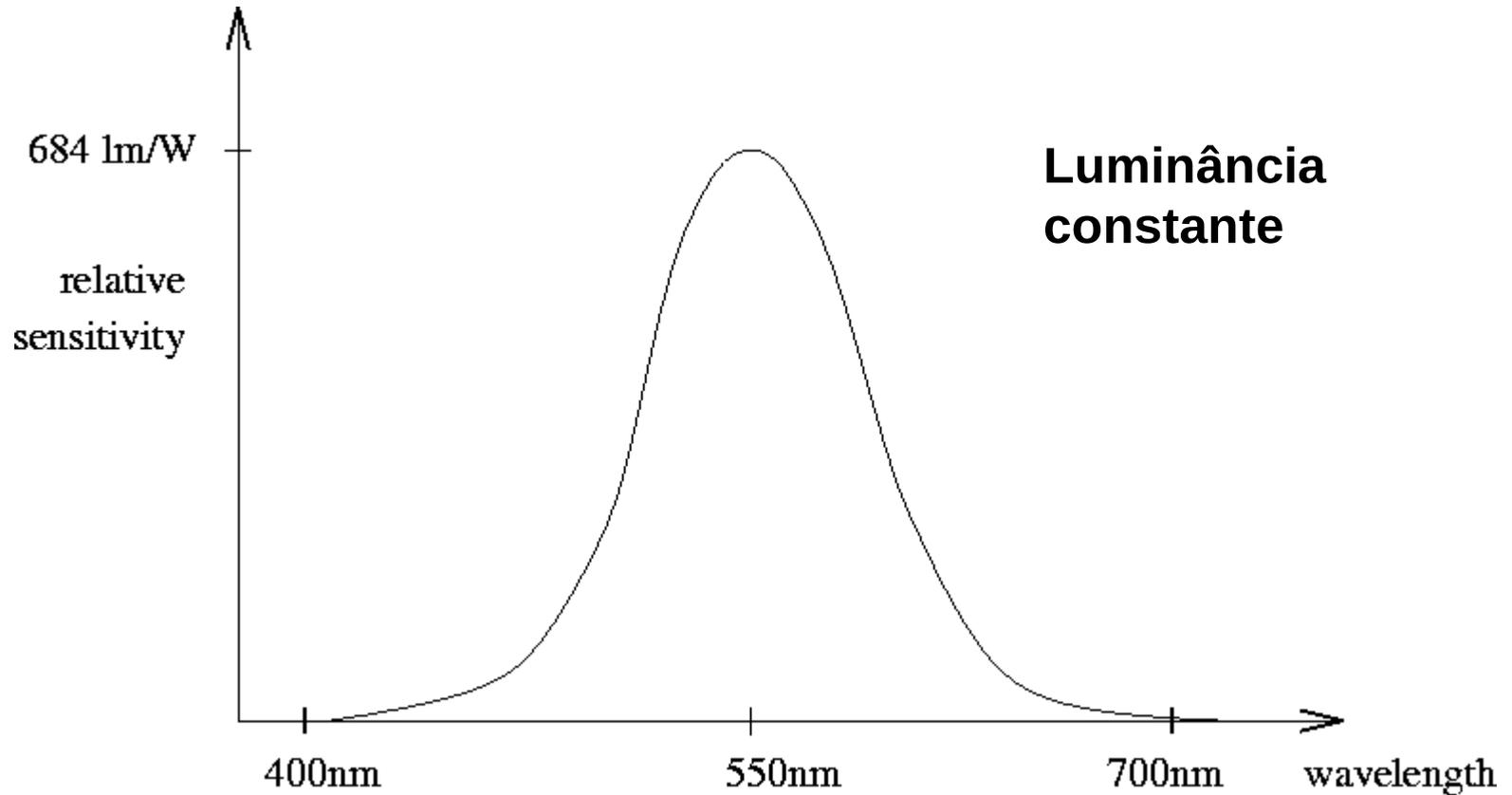
After Bowmaker & Dartnall, 1980

$$C = \alpha \mathbf{R} + \beta \mathbf{G} + \gamma \mathbf{B} = \alpha S_c + \beta M_c + \gamma L_c$$

$$\text{Cor} \Leftrightarrow (\alpha, \beta, \gamma)$$

IA725-15216 Titc Cada cor tem uma proporção de pesos distinta

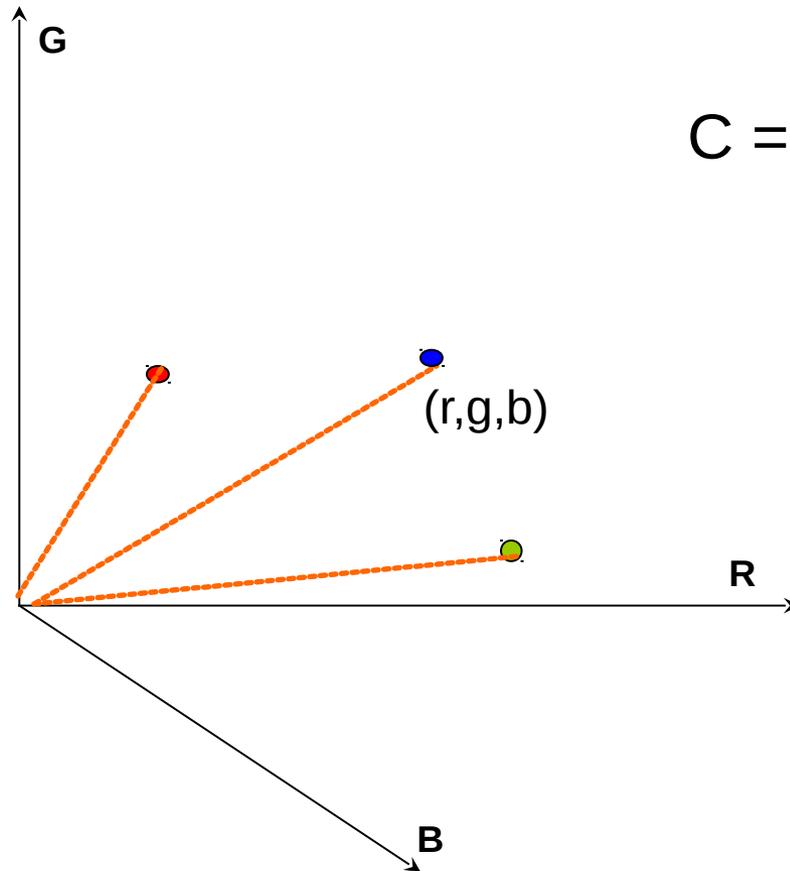
# Função de Eficiência Luminosa



# Leis de Grassman

1. Qualquer cor pode ser especificada como mistura aditiva de **3 cores independentes**.
2. A cor de uma mistura aditiva não se altera quando substituirmos as cores componentes pelas suas metâmeras.
3. Se uma componente de uma mistura aditiva é alterada numa dada proporção **continuamente**, a cor da mistura é modificada na mesma proporção **continuamente**, obedecendo as leis de simetria, transitividade e linearidade.

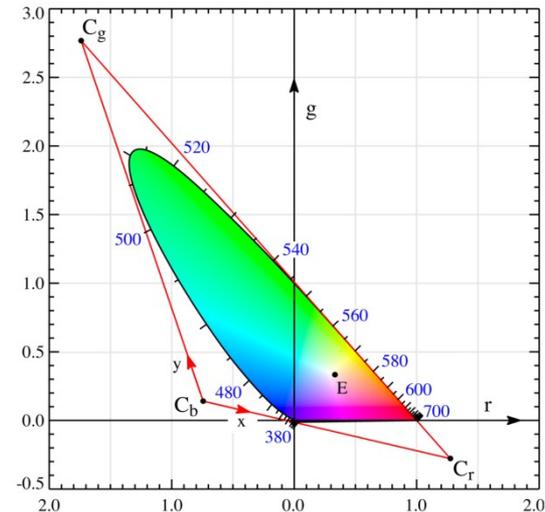
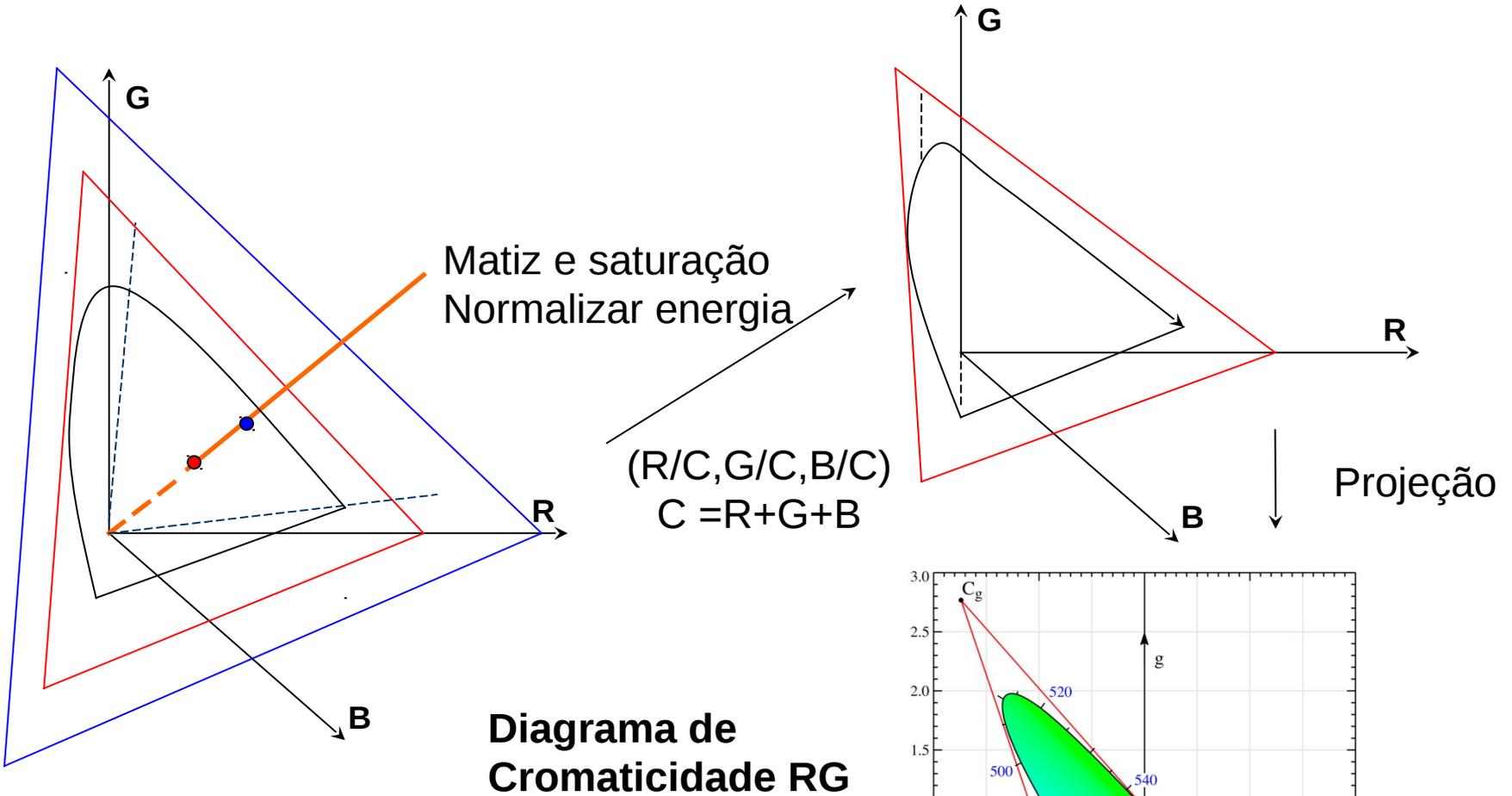
# Espaço de Cores RGB



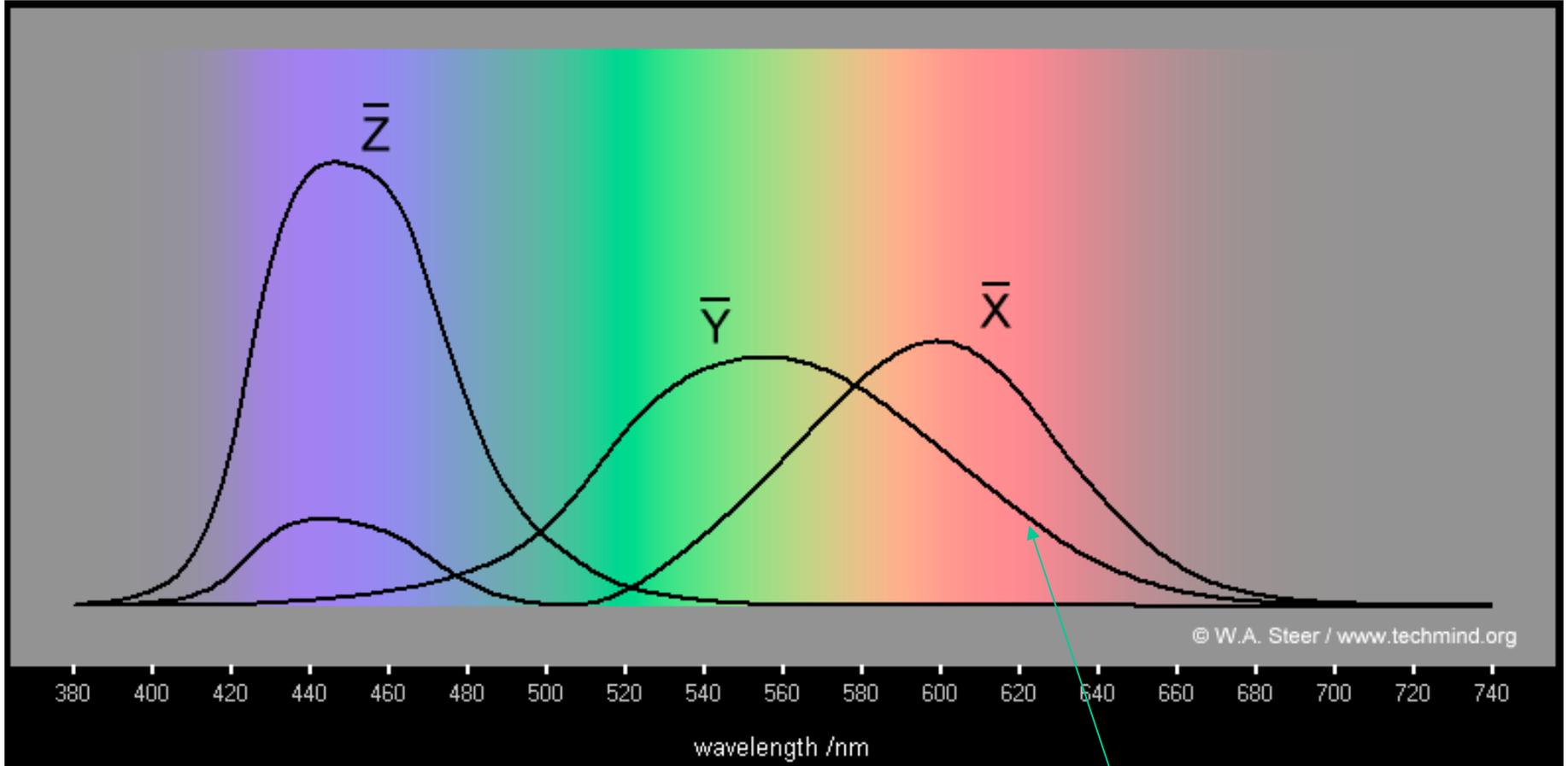
$$C = rR + gG + bB$$

Uma cor pode ser obtida como soma ponderada de somente três tipos de radiações.

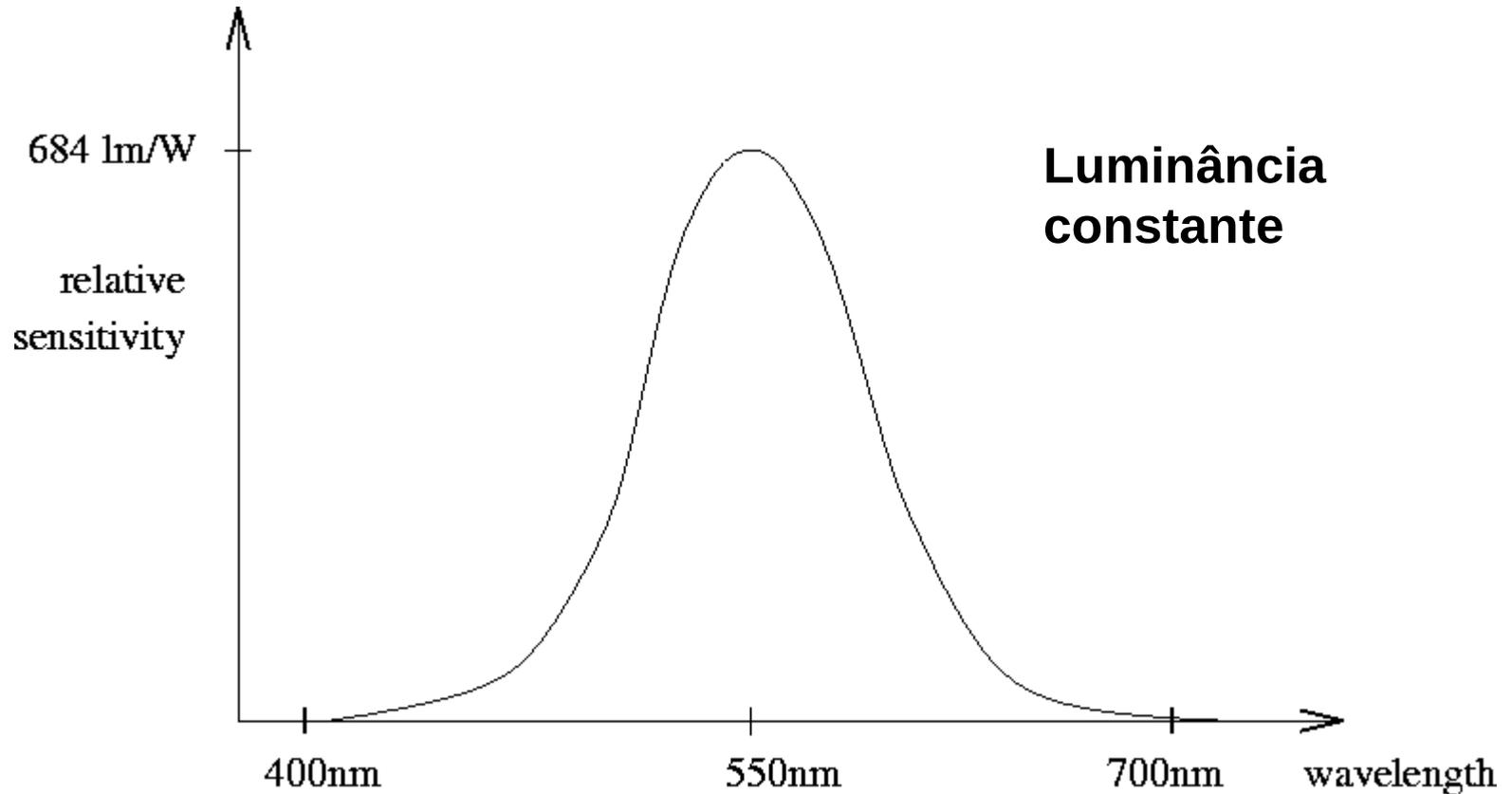
# Espaço de Cores RGB



# Espaço de Cores XYZ



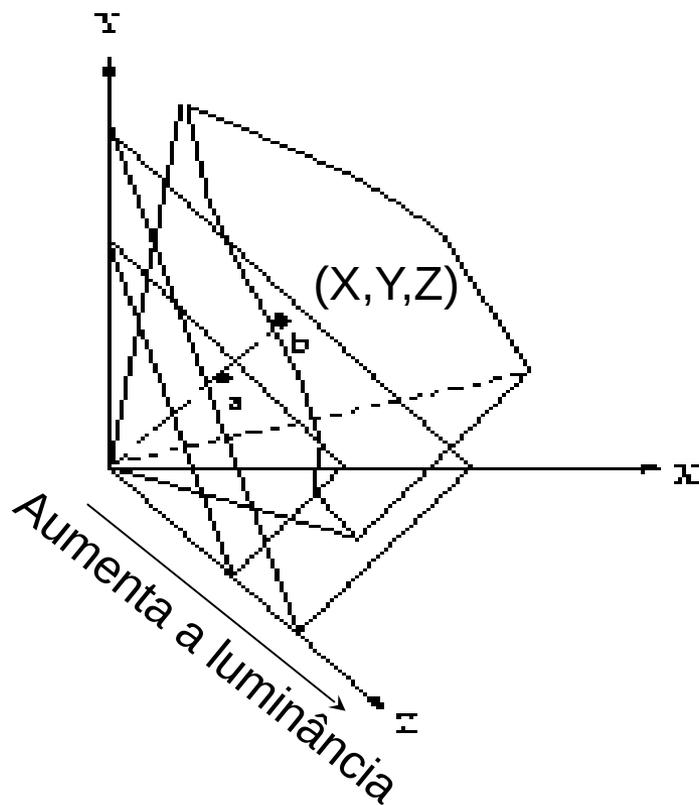
# Função de Eficiência Luminosa



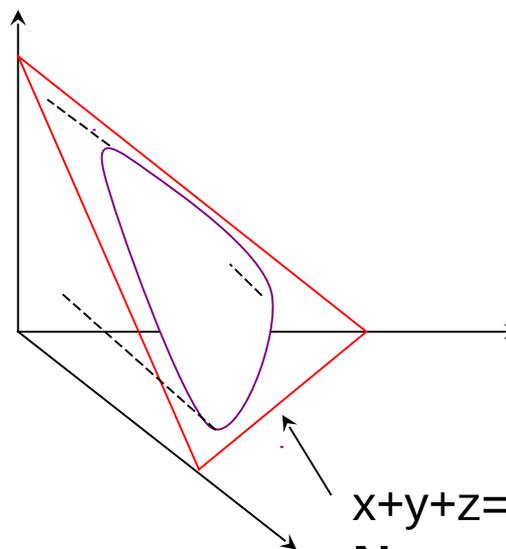
**(R,G,B) → (X,Y,Z)**

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \frac{1}{b_{21}} \begin{bmatrix} b_{11} & b_{12} & b_{13} \\ b_{21} & b_{22} & b_{23} \\ b_{31} & b_{32} & b_{33} \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} = \frac{1}{0.17697} \begin{bmatrix} 0.49 & 0.31 & 0.20 \\ 0.17697 & 0.81240 & 0.01063 \\ 0.00 & 0.01 & 0.99 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

# Espaço de Cores XYZ



$$X+Y+Z = C$$



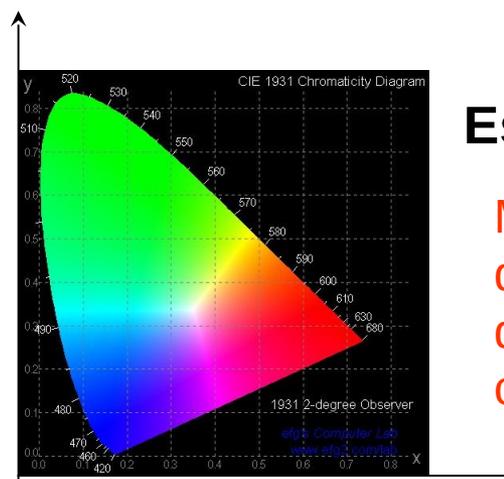
$$x = \frac{X}{C}$$

$$y = \frac{Y}{C}$$

$$z = \frac{Z}{C}$$

$$C = X + Y + Z$$

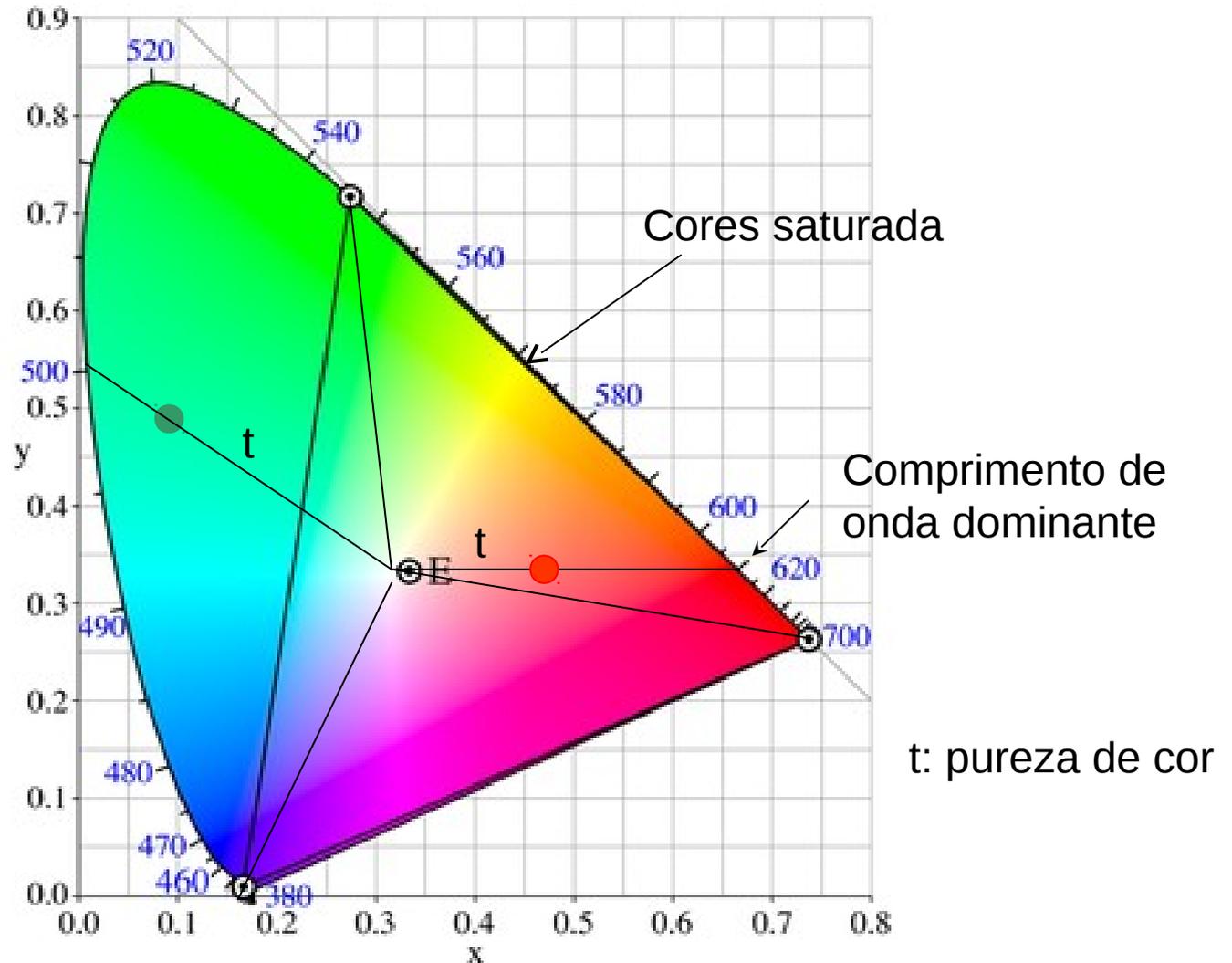
**Normalização**



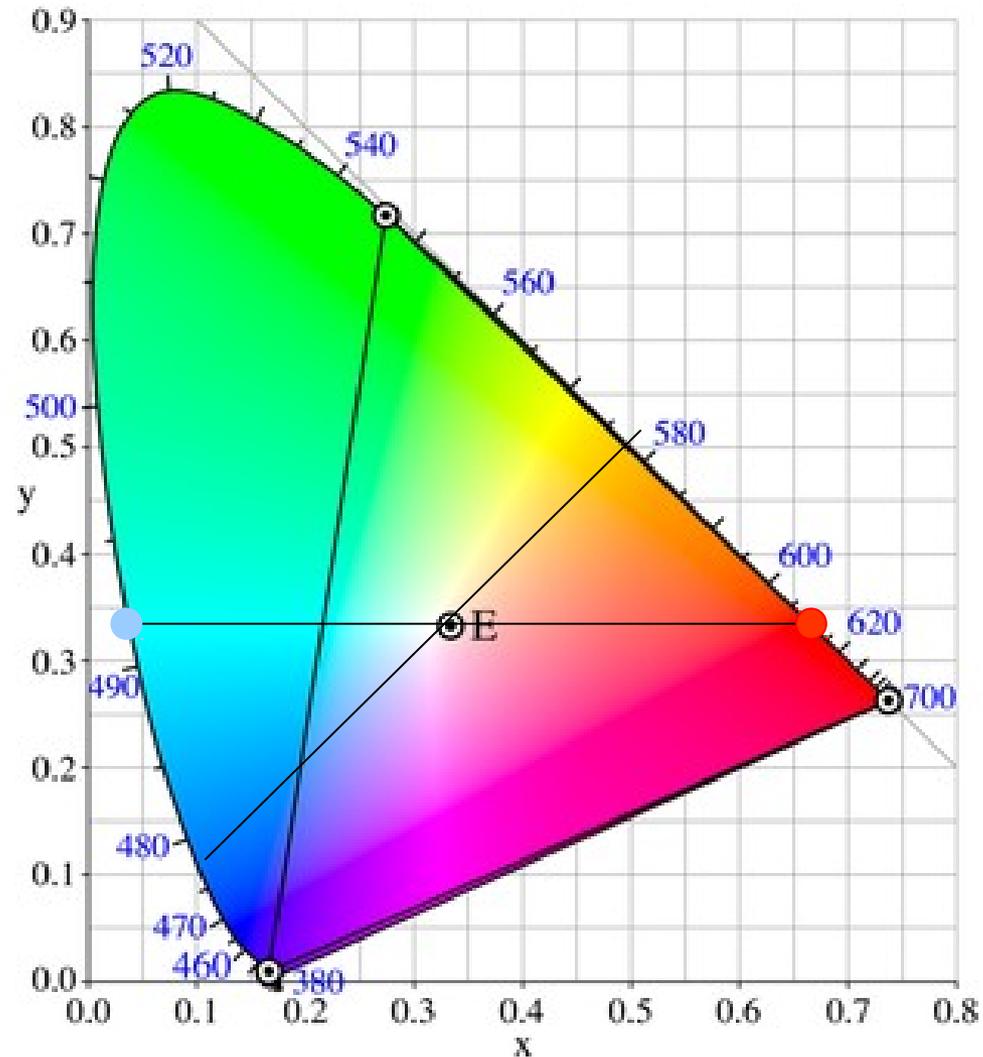
**Espaço Homogêneo**

Mostra a porcentagem das cores primárias que compõem o croma

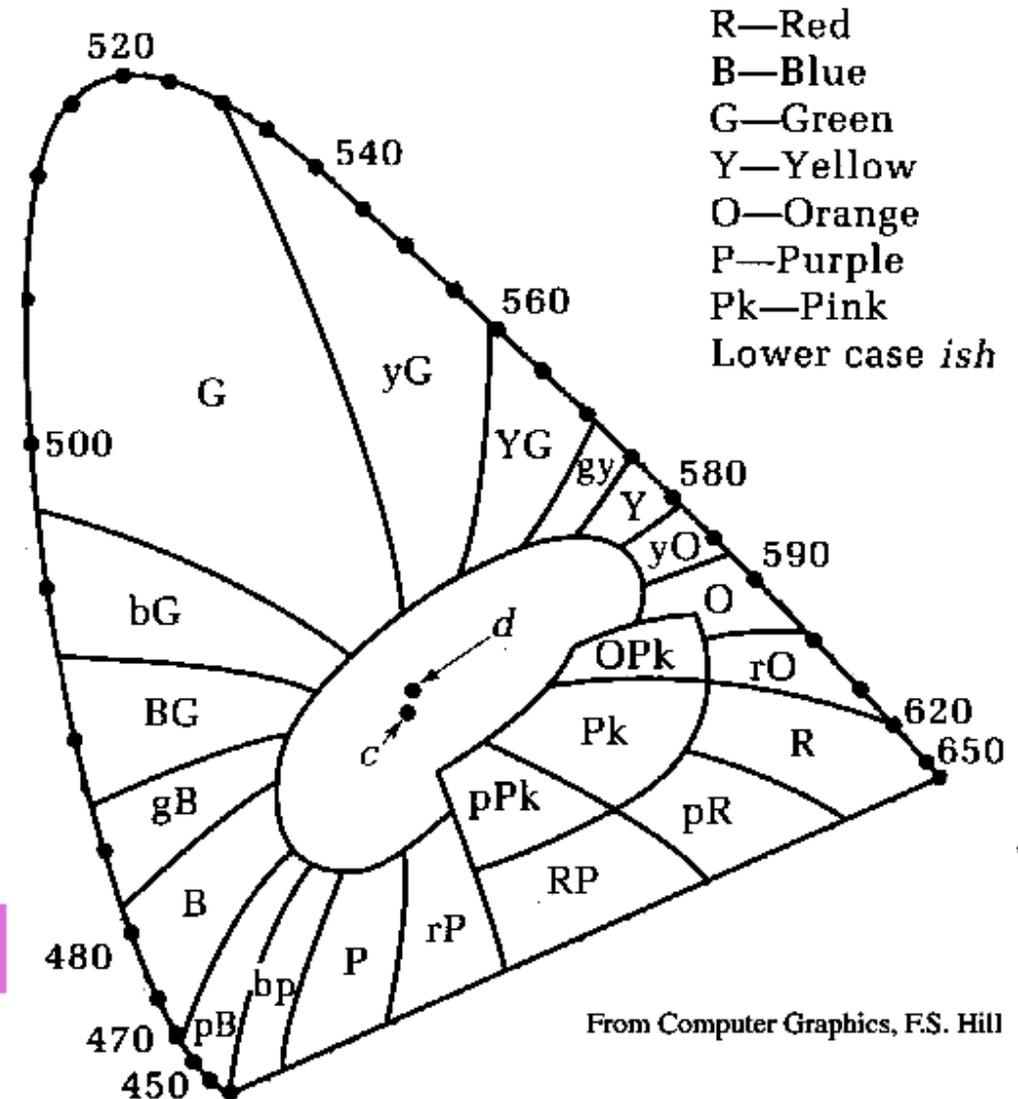
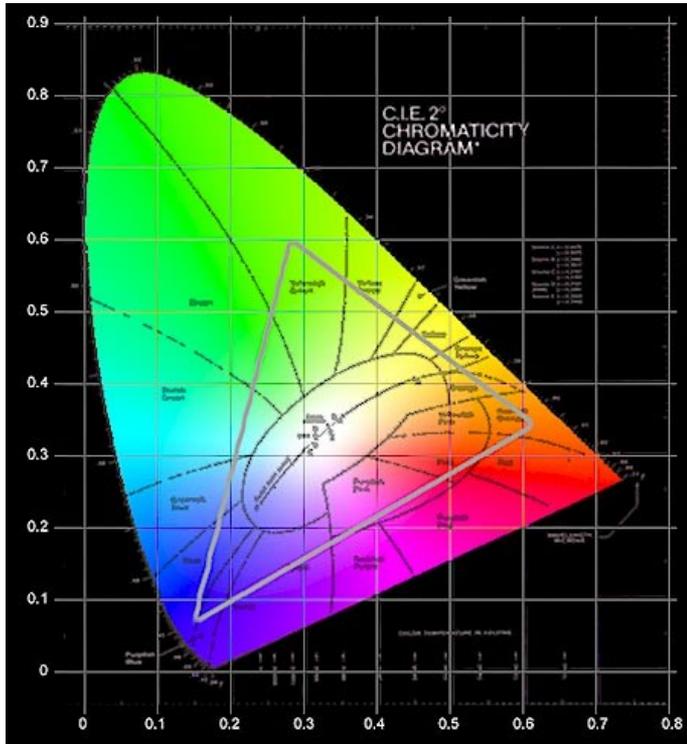
# Aplicação 1: Saturação/Pureza de Cor



# Aplicação 2: Cor Complementar



# Aplicação 3: Metâmeras

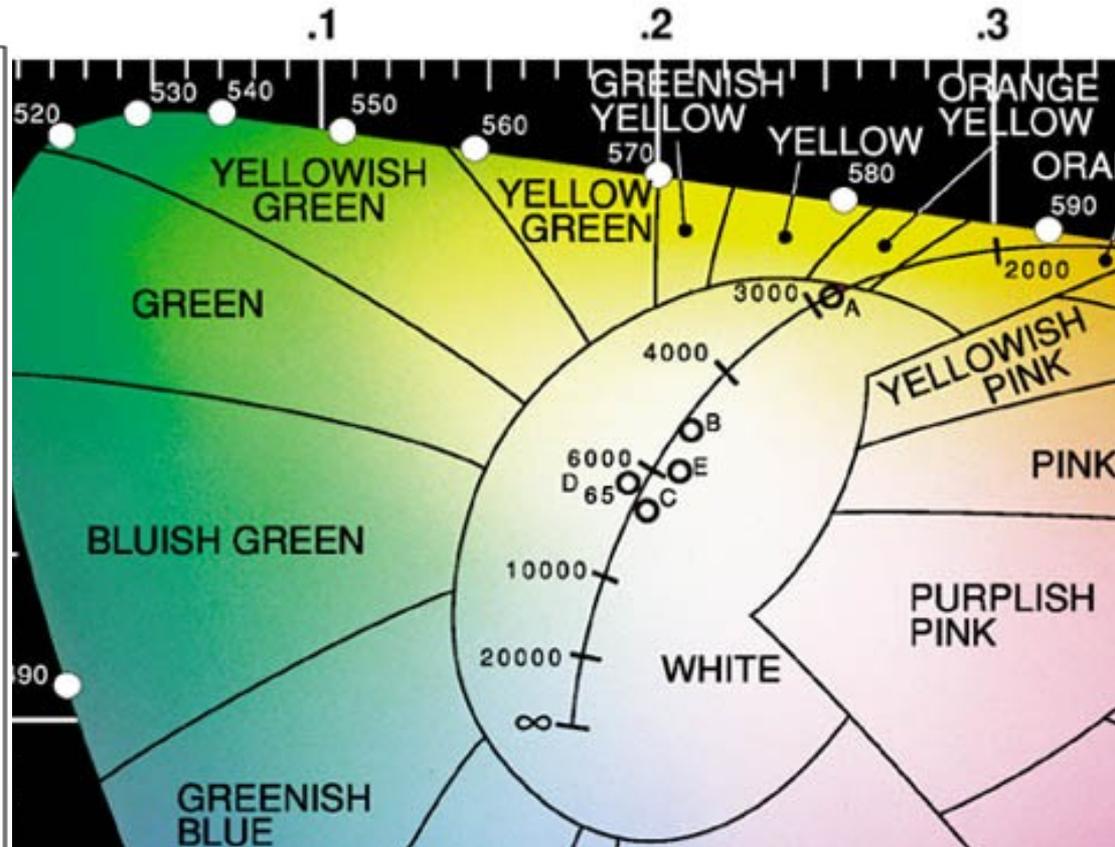
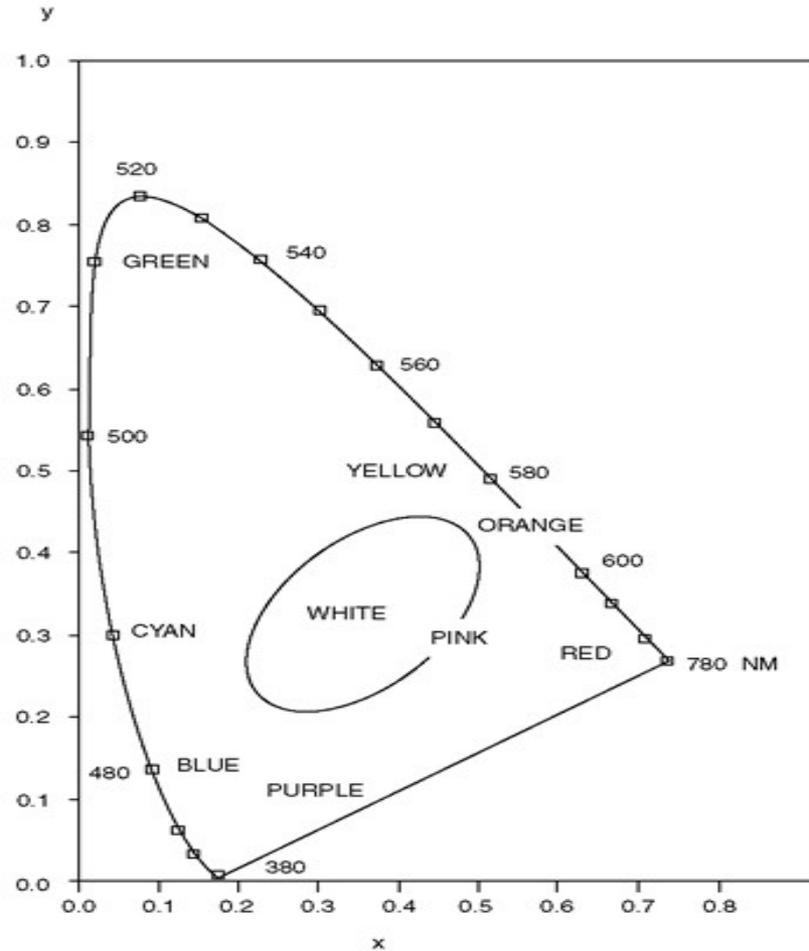


red yellow green blue purple

IA725-1S2U16 - 11ng

From Computer Graphics, F.S. Hill

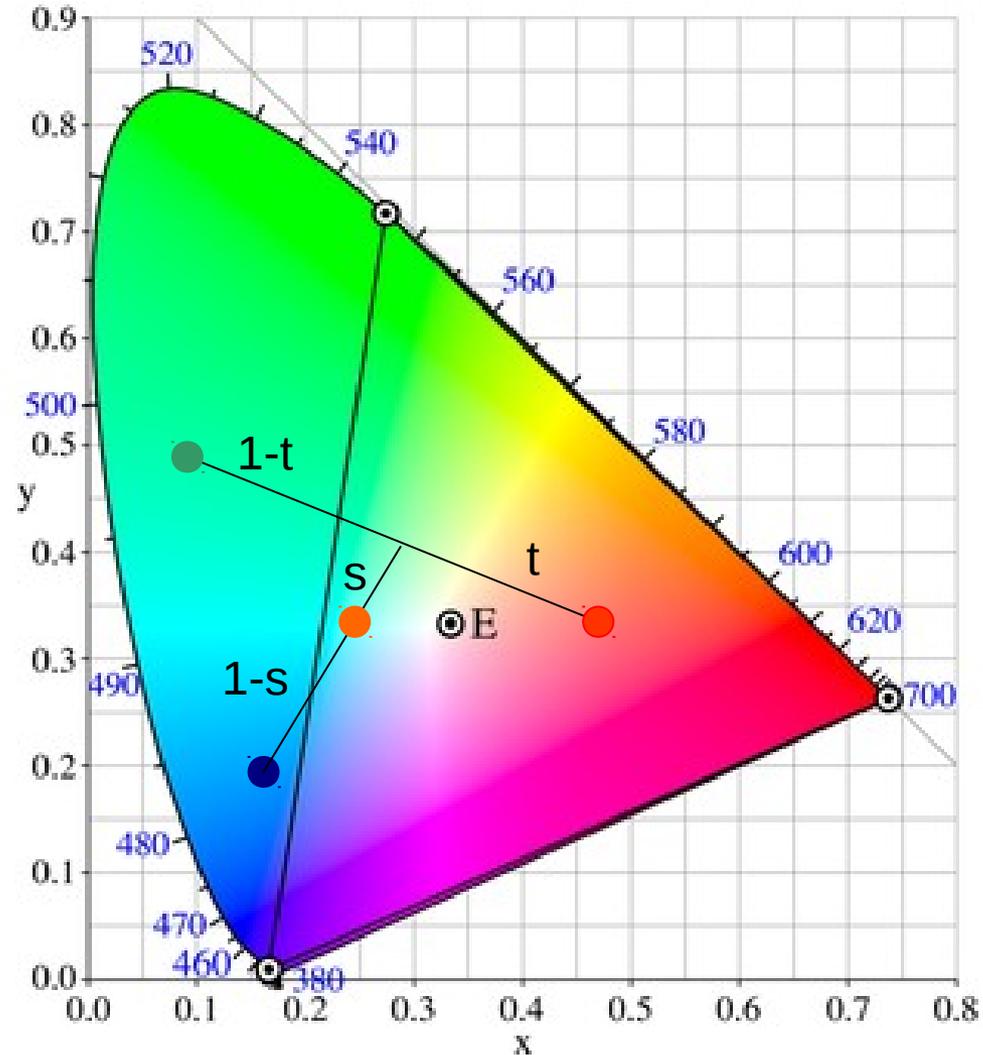
# Aplicação 4: Identificação de “Brancos”



# Alguns “brancos-padrão”

Nome	Temperatura	Coordenadas	Fonte
Illuminant A	2856	(0.44757,0.40745)	[Wyszecki82, p 139] [Agoston87, p. 103]
Illuminant B	4874	(0.34842,0.35161)	[Wyszecki82, p 139] [Agoston87, p. 103]
Illuminant C	6774	(0.31006,0.31616)	[Wyszecki82, p 139] [Agoston87, p. 103]
Illuminant D65	6504	(0.3127,0.3291)	[Walker98] [Agoston87, p. 103]
Direct Sunlight	5335	(0.3362,0.3502)	[Agoston87, p. 103]
Light from overcast sky	6500	(0.3134,0.3275)	[Agoston87, p. 103]
Light from north sky on a 45-degree plane	10,000	(0.2773,0.2934)	[Agoston87, p. 103]
Illuminant E	5400	(1/3,1/3)	[Wyszecki82, p 139] [Agoston87, p. 103]

# Aplicação 5: Mistura de Cores



# Exemplo

Determine as coordenadas de cromaticidade CIE do resultado da mistura das 3 cores  $C_1=(0.1,0.3,10)$ ,  $C_2 = (0.35,0.2,10)$  e  $C_3 = (0.2, 0.05,10)$ .

$$C_1 = Y_1/y_1; X_1 = x_1 C_1; Z_1 = (1-x_1-y_1)C_1$$

$$C_2 = Y_2/y_2; X_2 = x_2 C_2; Z_2 = (1-x_2-y_2)C_2$$

$$C_3 = Y_3/y_3; X_3 = x_3 C_3; Z_3 = (1-x_3-y_3)C_3$$

$$X_{123} = (x_1 C_1 + x_2 C_2 + x_3 C_3)/(C_1 + C_2 + C_3)$$

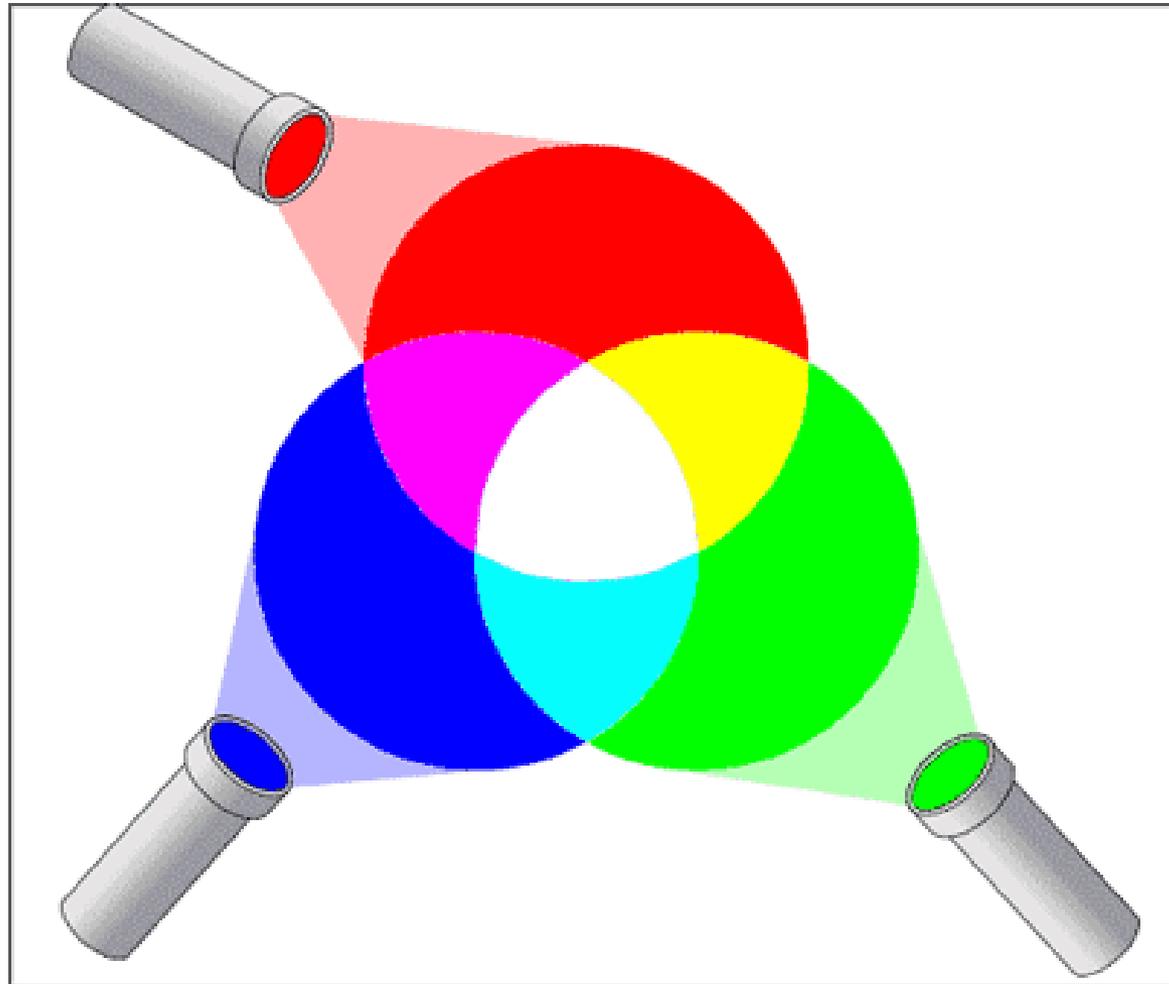
$$y_{123} = (y_1 C_1 + y_2 C_2 + y_3 C_3)/(C_1 + C_2 + C_3)$$

$$Y_{123} = Y_1 + Y_2 + Y_3$$

Resposta: (0.215,0.106,30)

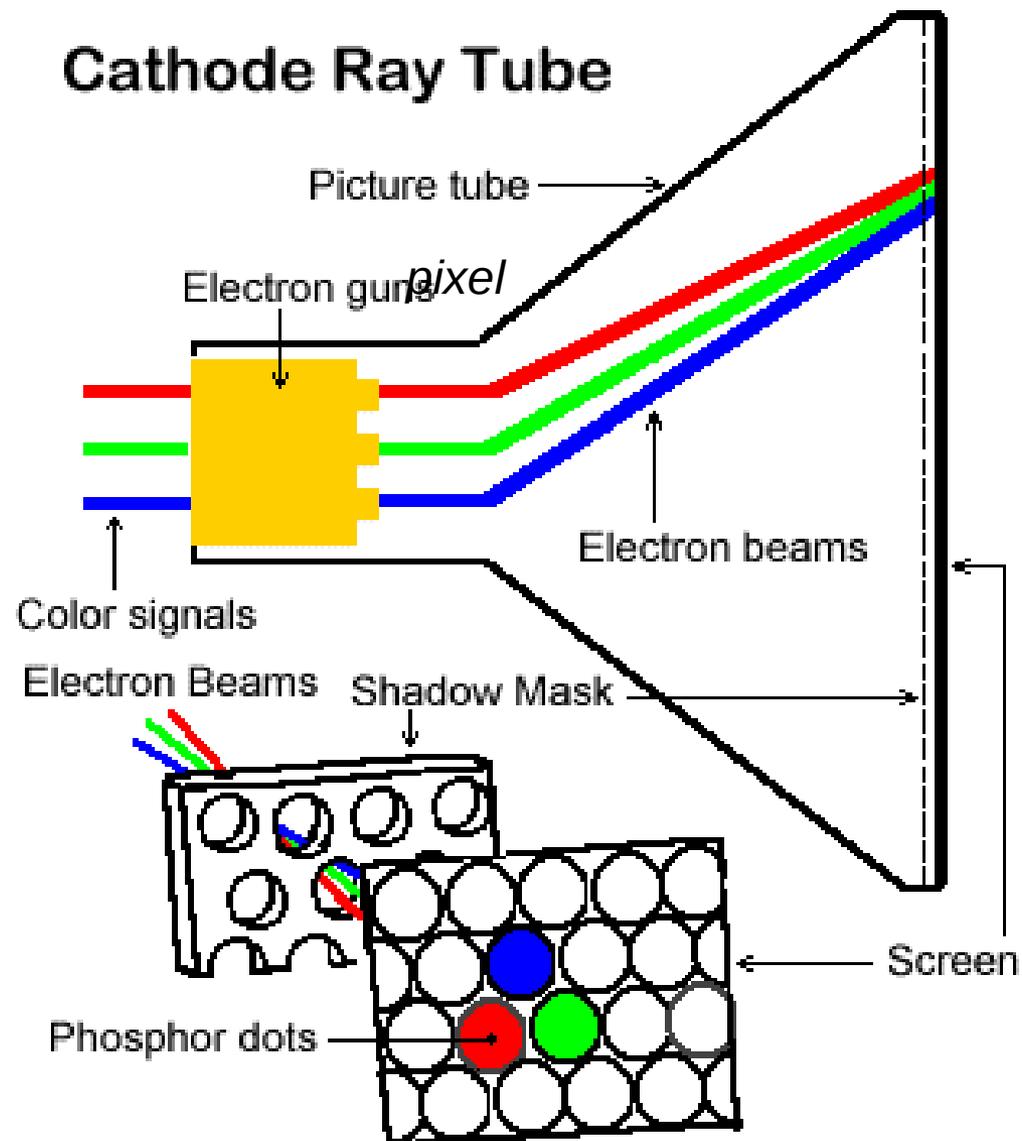
# Formação Aditiva de Cores

Vermelho  
Verde  
Azul

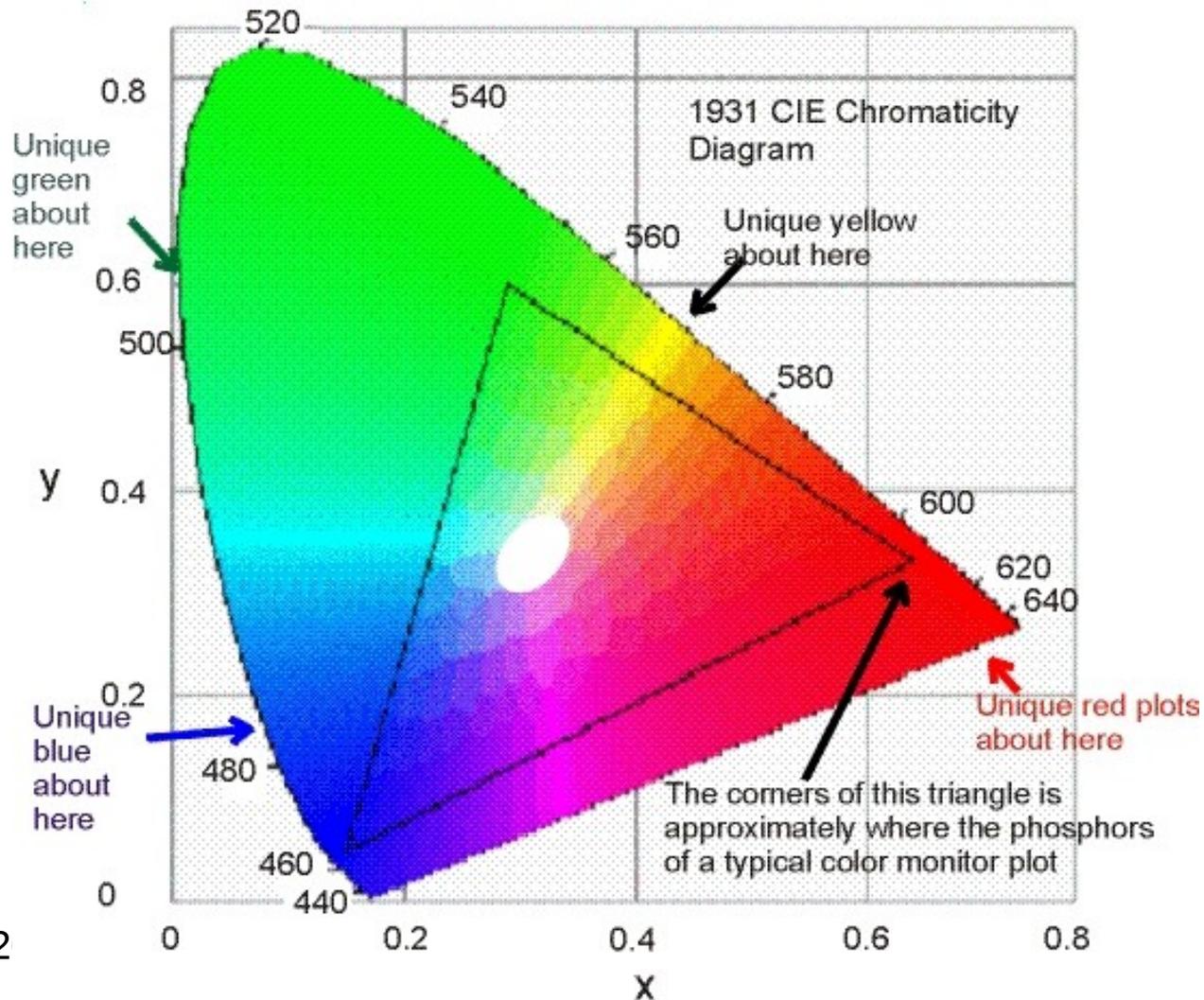


# Monitores

## Cathode Ray Tube



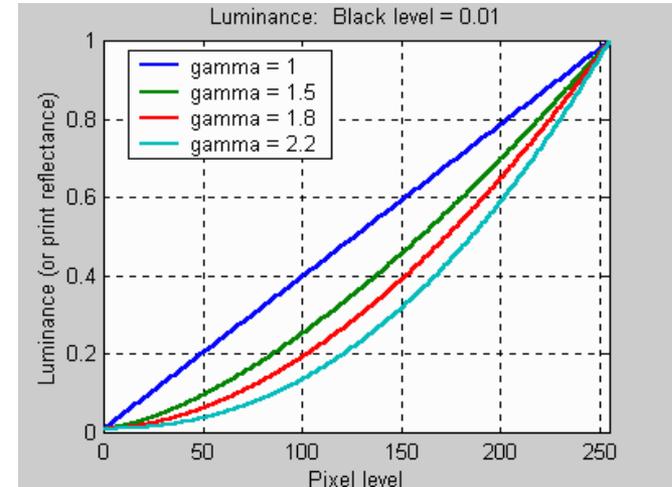
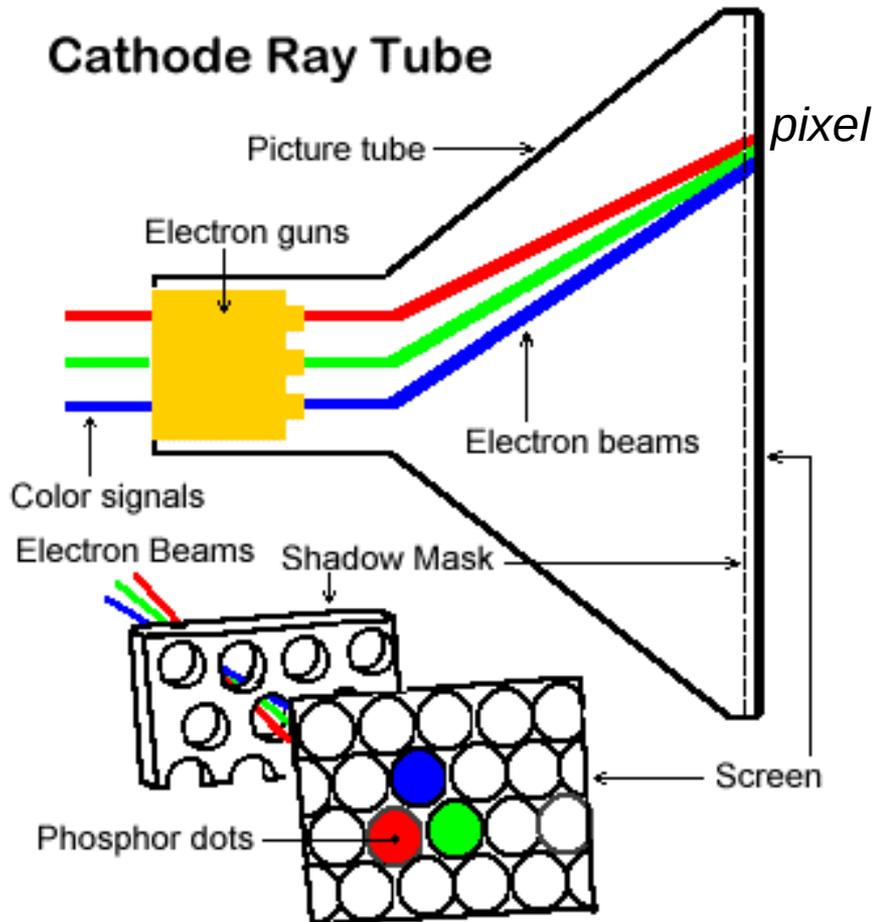
# Aplicação 6: Gamute de Dispositivos



# Cromaticidade dos Fósforos de Monitores

Nome	R	G	B	Branco
Short-Persistence	(0.61,0.35)	(0.29,0.59)	(0.15,0.063)	
Long-Persistence	(0.62,0.33)	(0.21,0.685)	(0.15,0.063)	
NTSC	(0.67,0.33)	(0.21,0.71)	(0.14,0.08)	Iluminante C
EBU	(0.64,0.33)	(0.30,0.60)	(0.15,0.06)	Iluminante D65
Dell (all monitors except 21" Mitsubishi p/n 65532)	(0.625,0.340)	(0.275,0.605)	(0.150,0.065)	9300K
SMPTE	(0.630,0.340)	(0.310,0.595)	(0.155,0.070)	Iluminante D65
P22 phosphor in NEC Multisync C400	(0.610,0.350)	(0.307,0.595)	(0.150,0.065)	(0.280,0.315)
P22 phosphor in KDS VS19	(0.625,0.340)	(0.285,0.605)	(0.150,0.065)	(0.281,0.311)
High Brightness LEDs	(0.700,0.300)	(0.170,0.700)	(0.130,0.075)	(0.310,0.320)

# Monitores



$$L = KV^\gamma$$

- L: luminância em cada *pixel*
- K: constante, ajustado pelo controle de contraste
- V: tensão de excitação dos feixes de elétrons
- $\gamma$ : gamma, tipicamente entre [1.4, 2.5]
- $V = V_s^{(1/\gamma)}$ : correção gamma

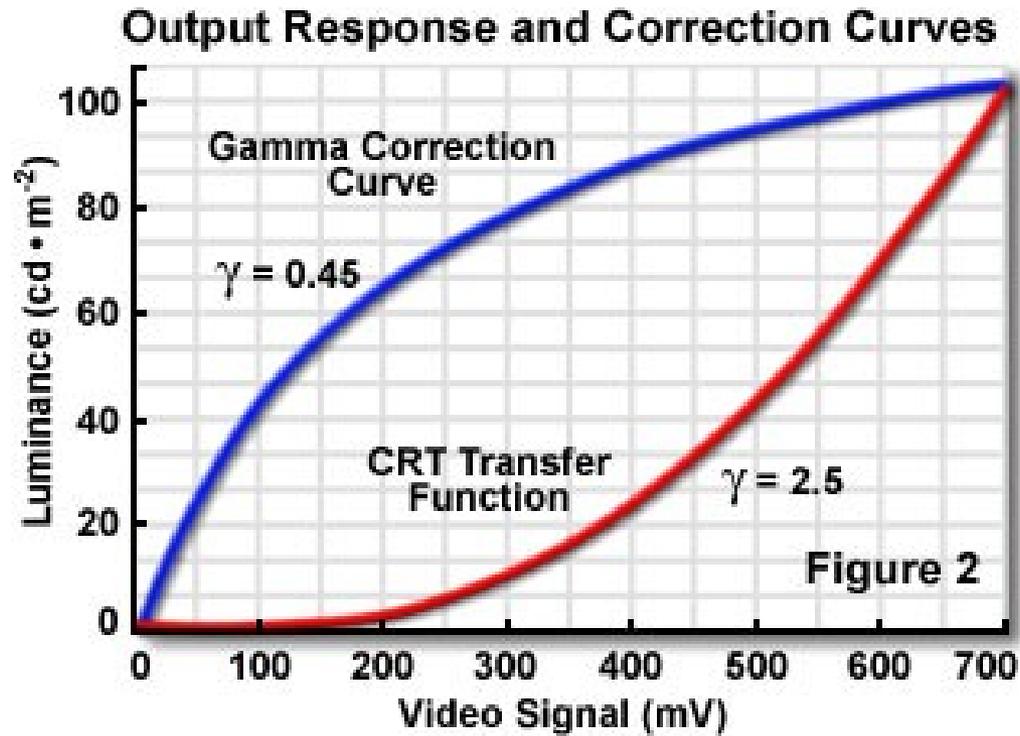
# Influência de $\gamma$



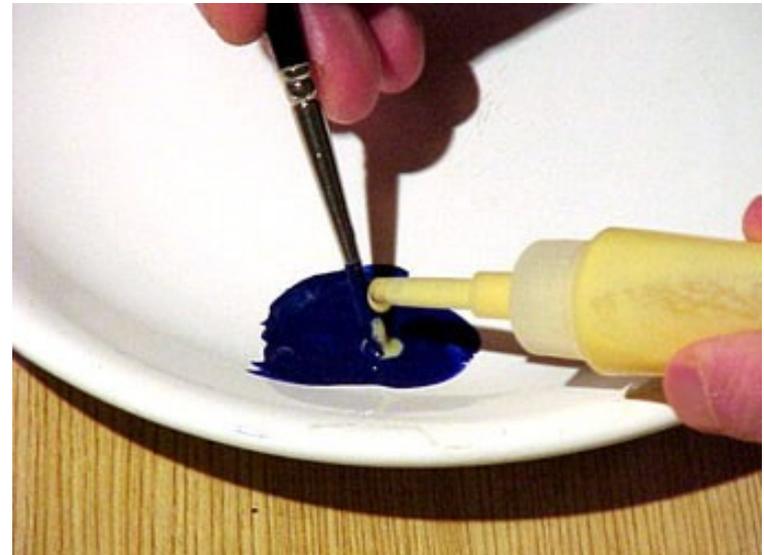
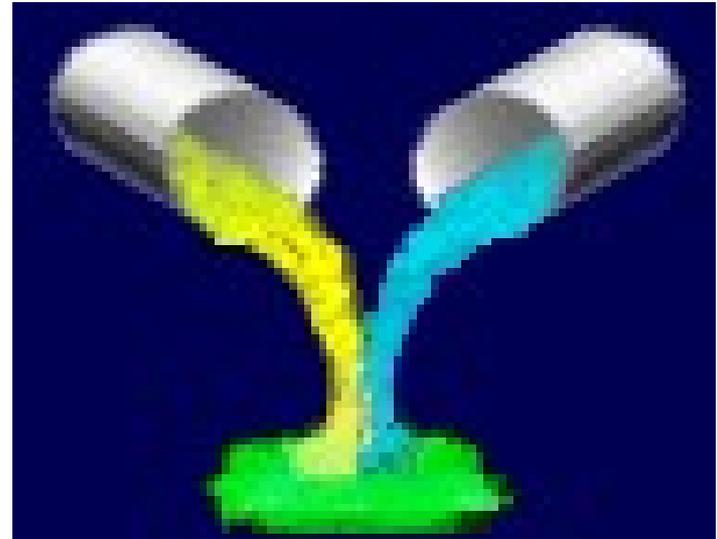
$$\gamma = 1.8$$

$$\gamma = 1.0$$

# Correção de $\gamma$

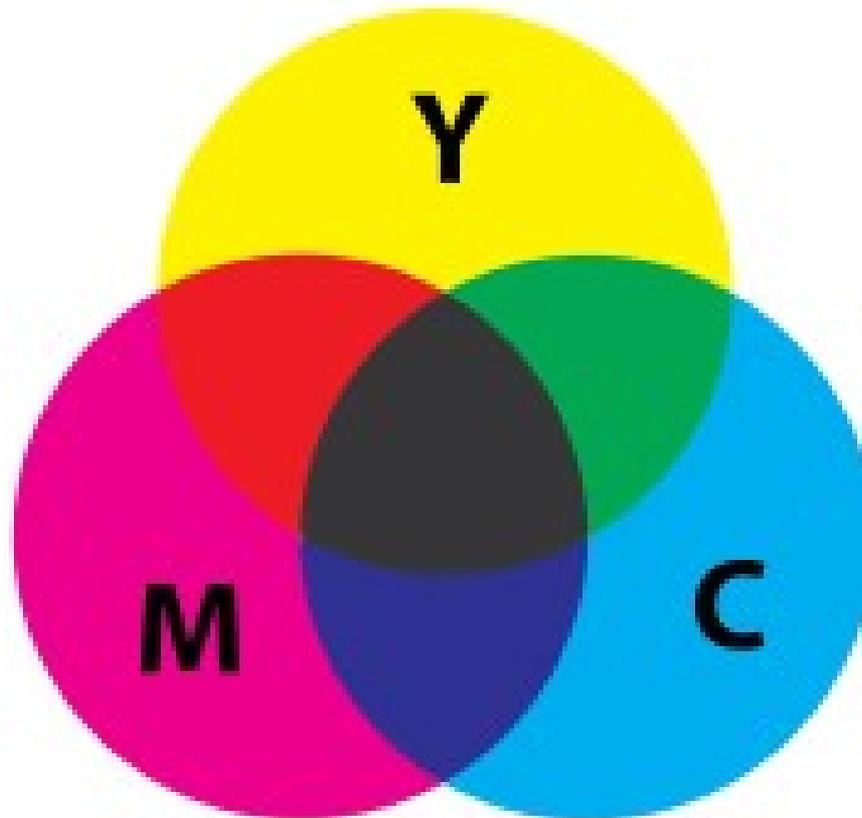


# Pigmentação

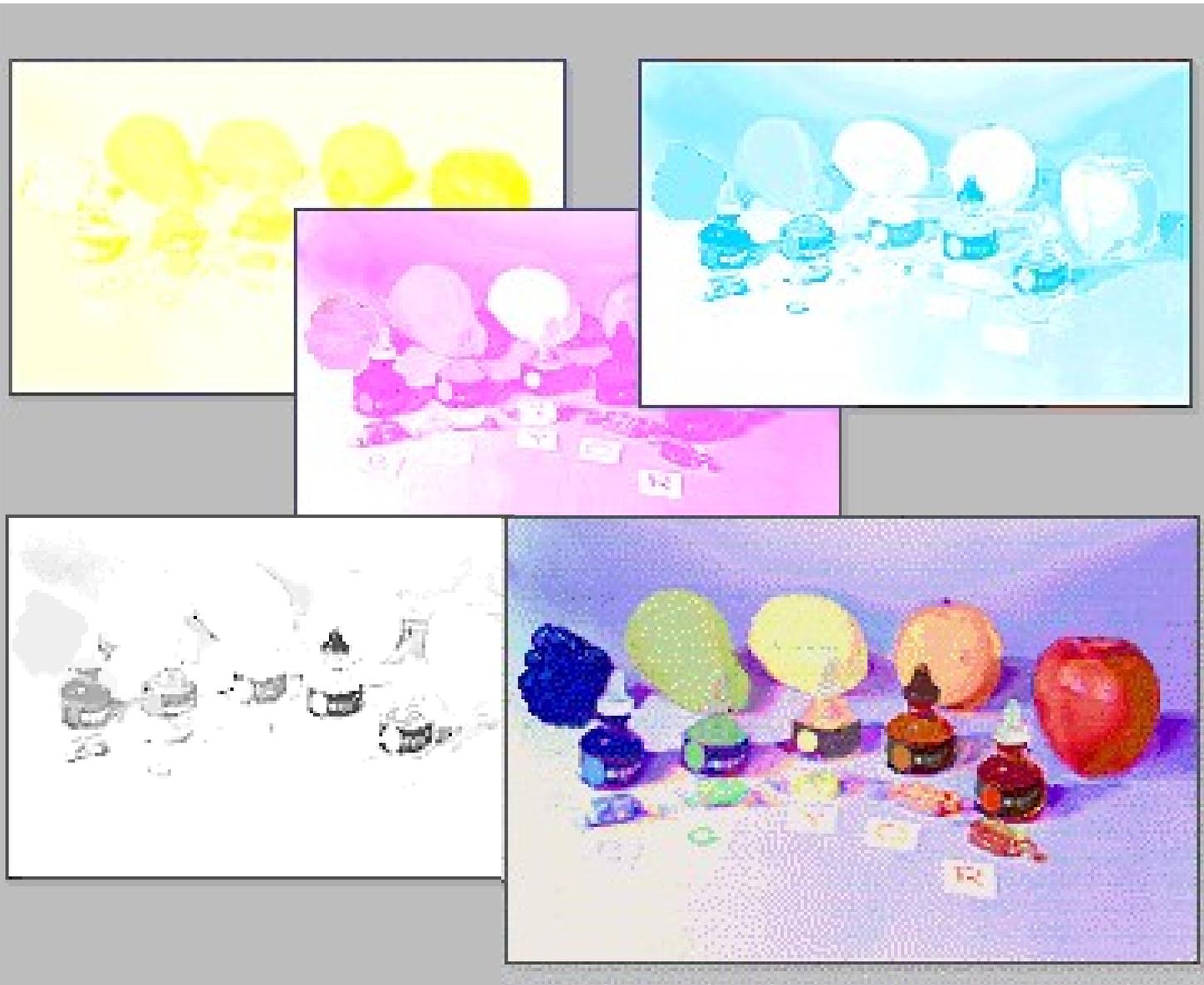


# Formação Subtrativa de Cores

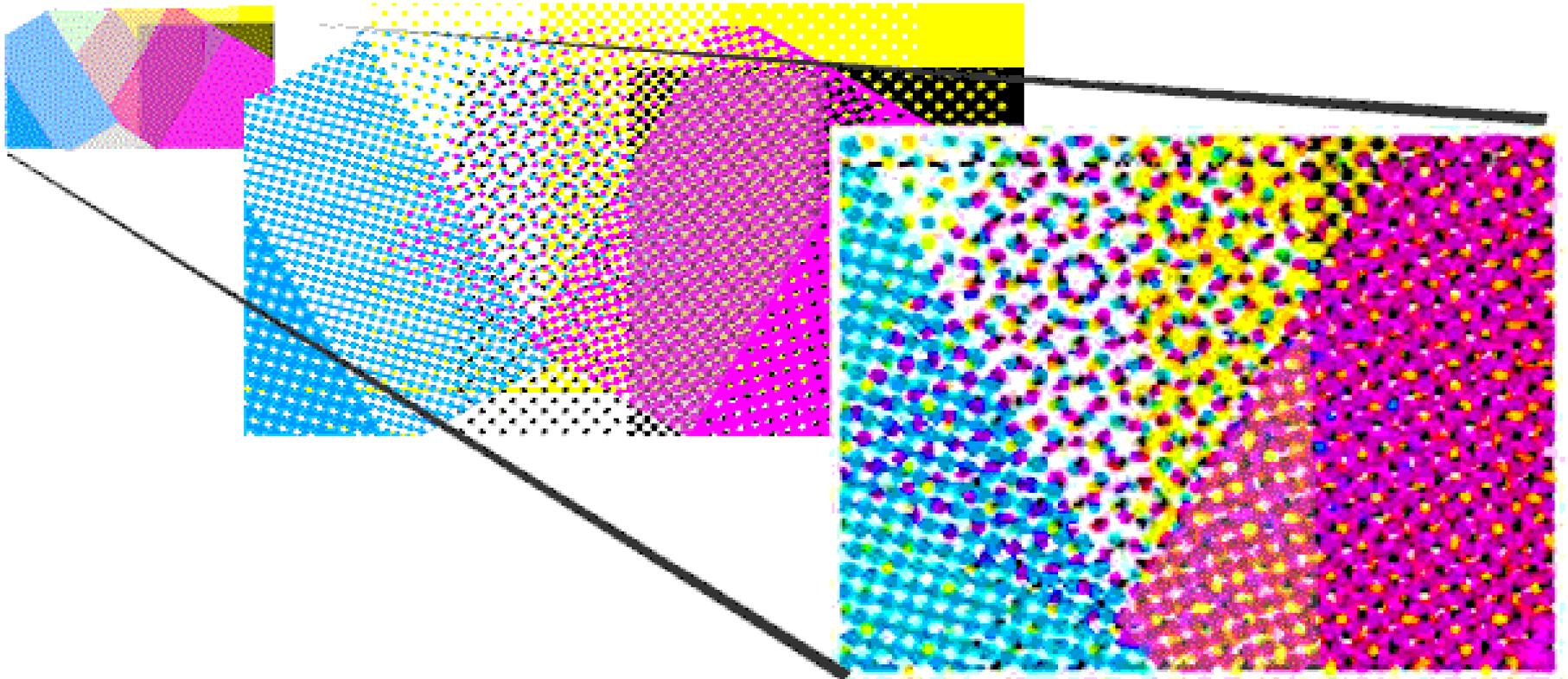
Magenta  
Amarelo  
Ciano



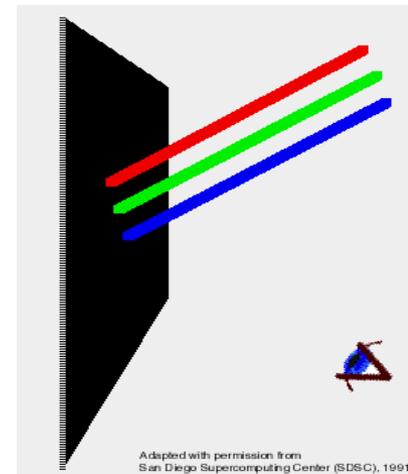
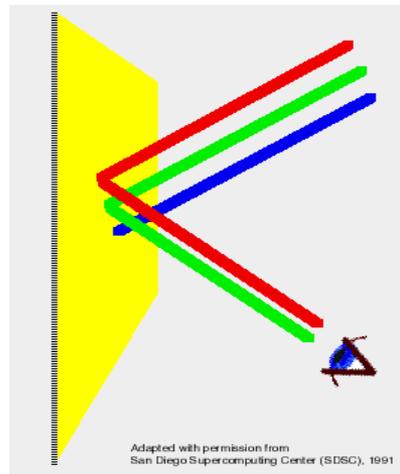
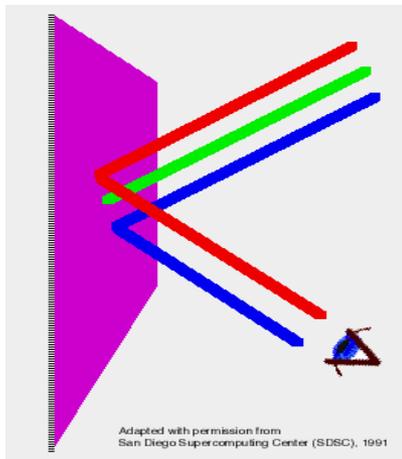
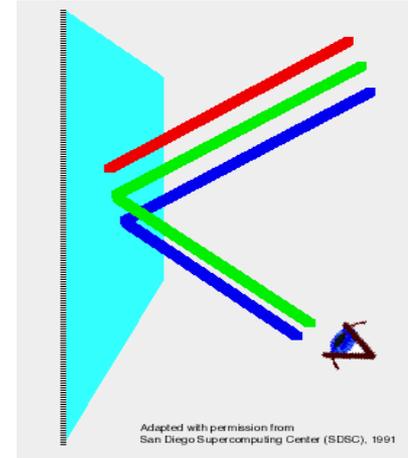
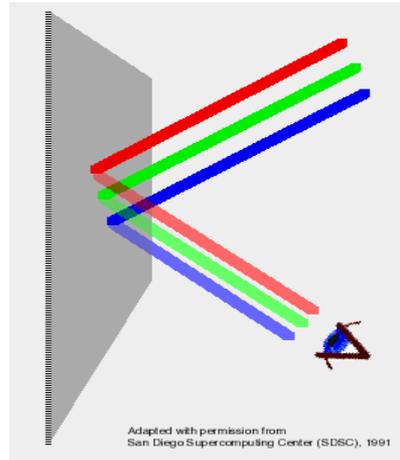
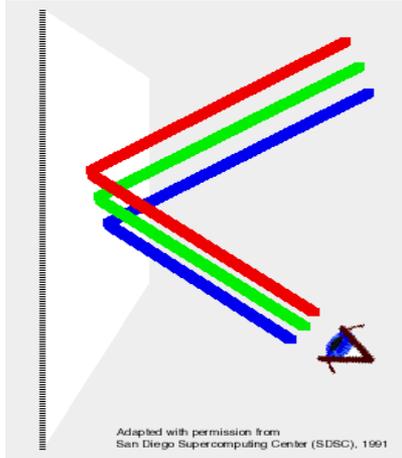
# Impressoras



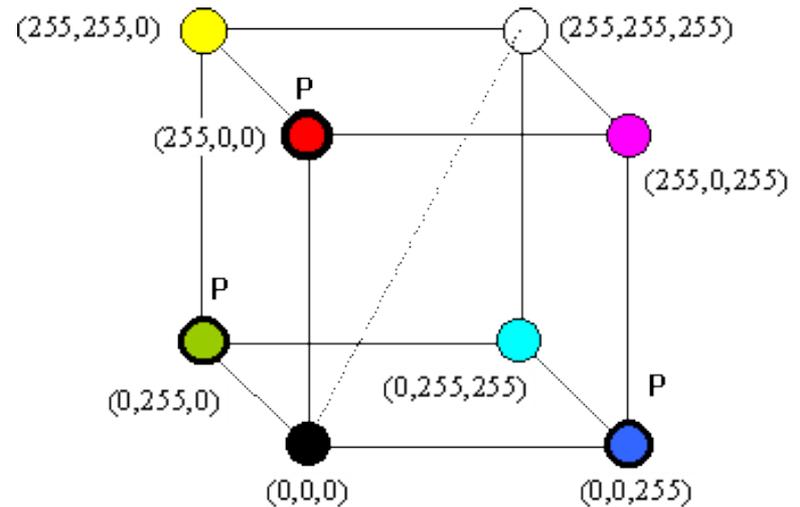
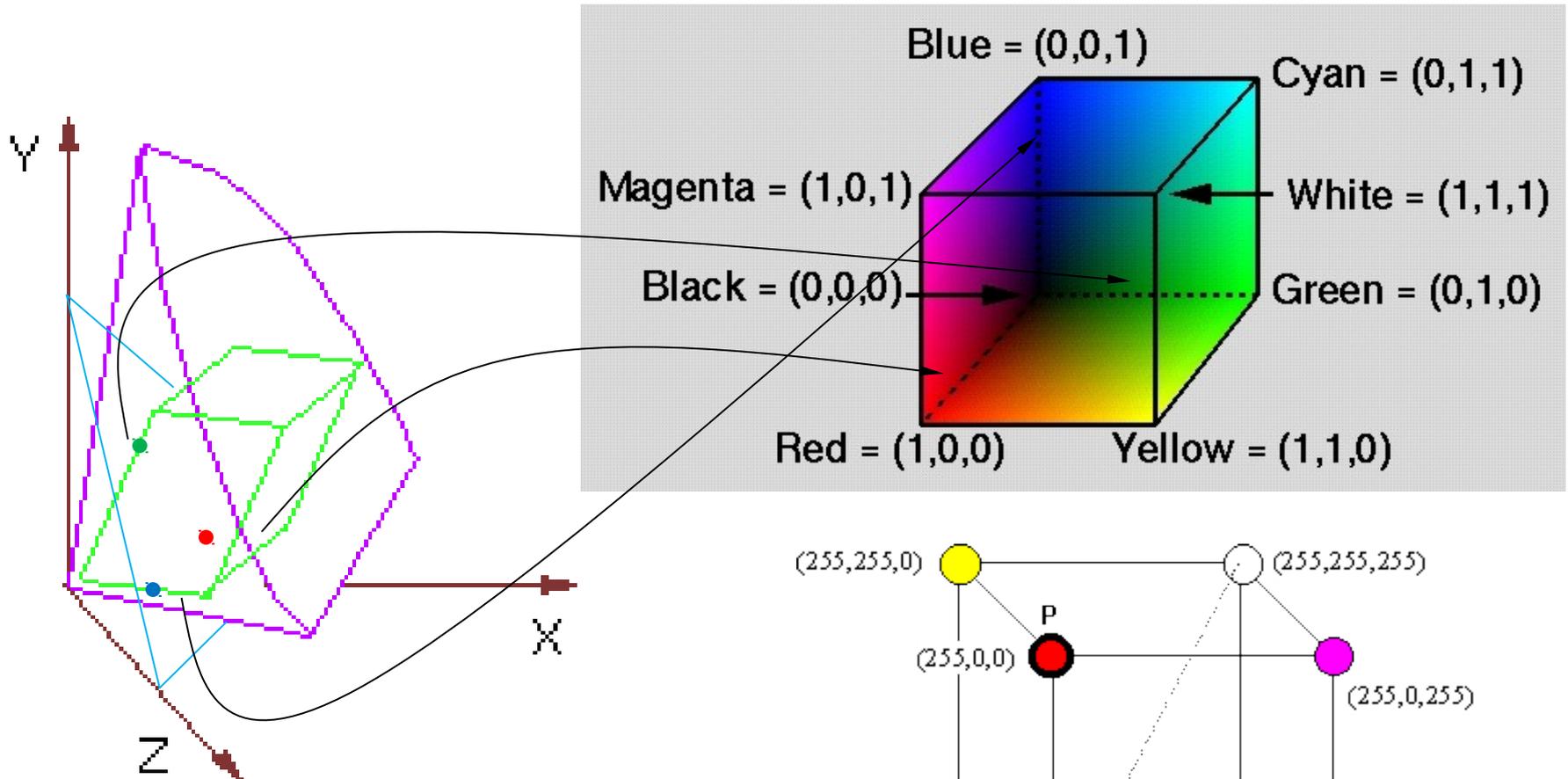
# Impressoras



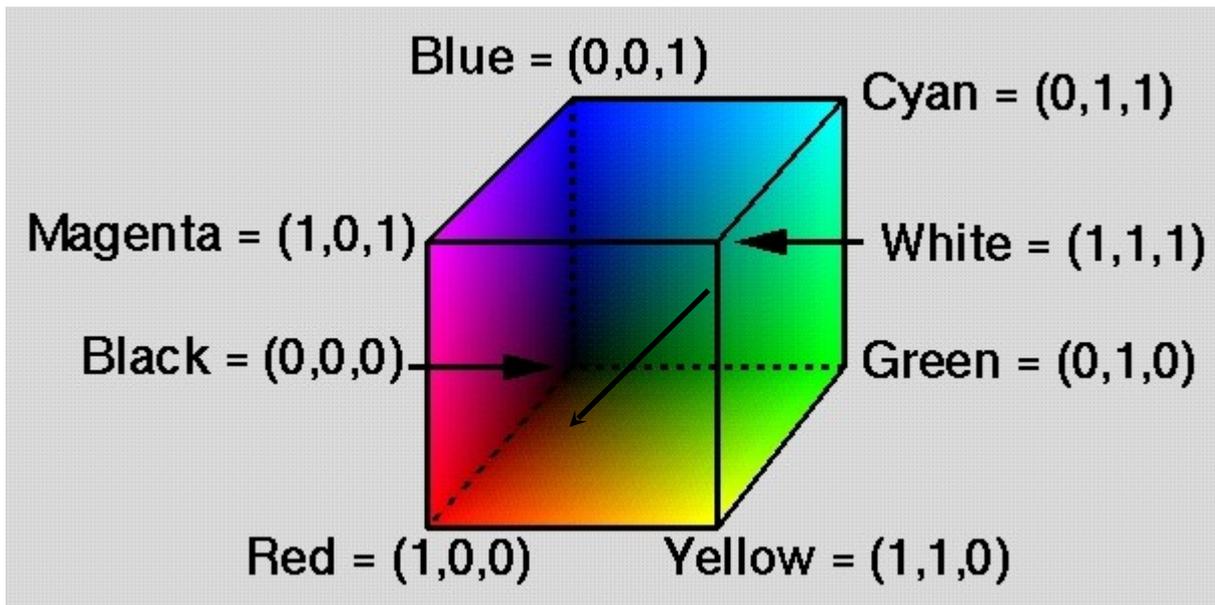
# Mistura Subtrativa



# Modelo RGB



# Modelo HSV



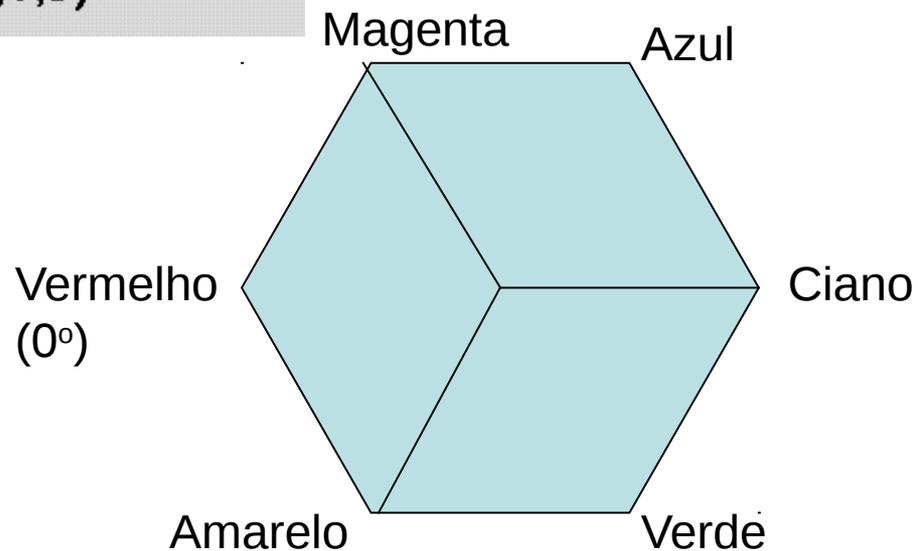
$$V = \max(R, G, B)$$

$$S = (V - \min(R, G, B)) / V$$

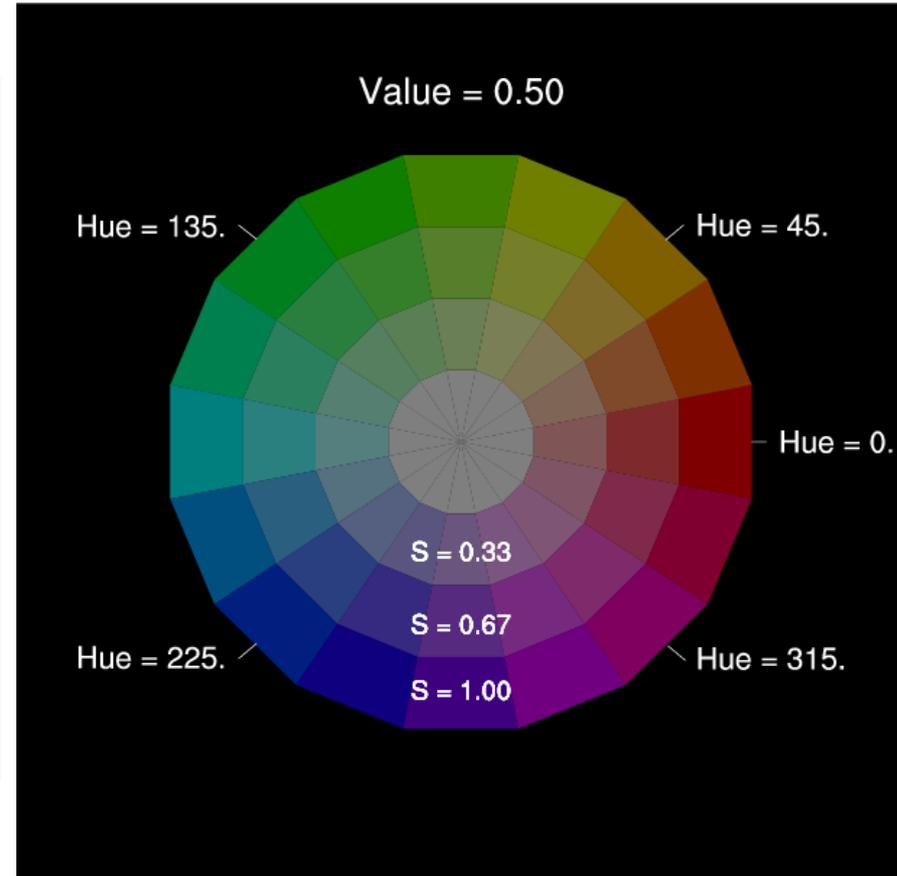
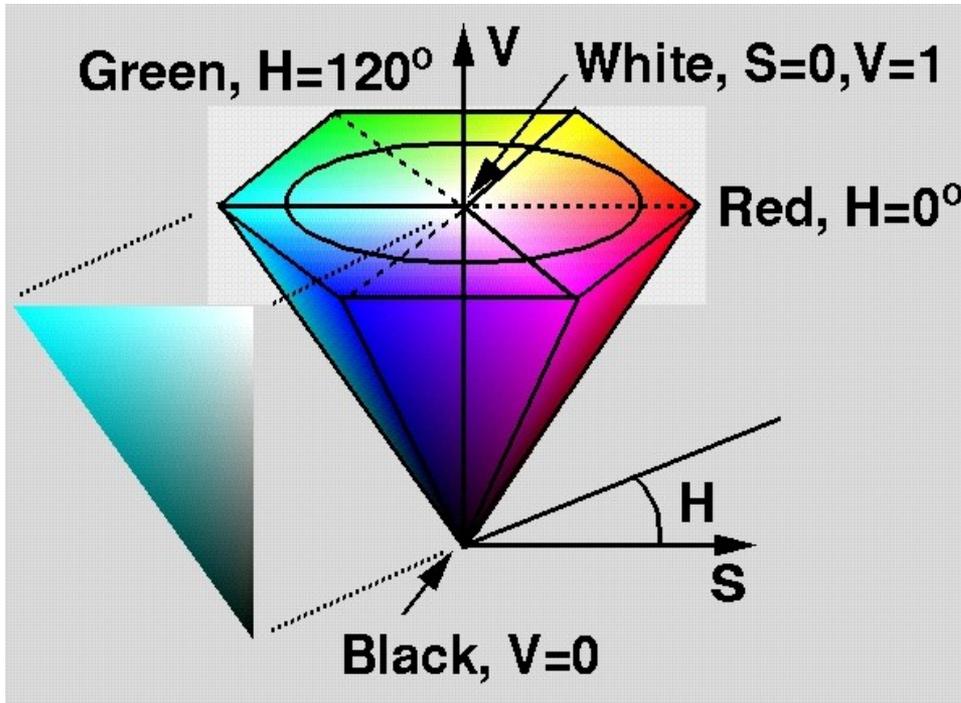
$$Cr = (V - R) / (V - \min(R, G, B))$$

$$Cg = (V - G) / (V - \min(R, G, B))$$

$$Cb = (V - B) / (V - \min(R, G, B))$$



# Modelo HSV



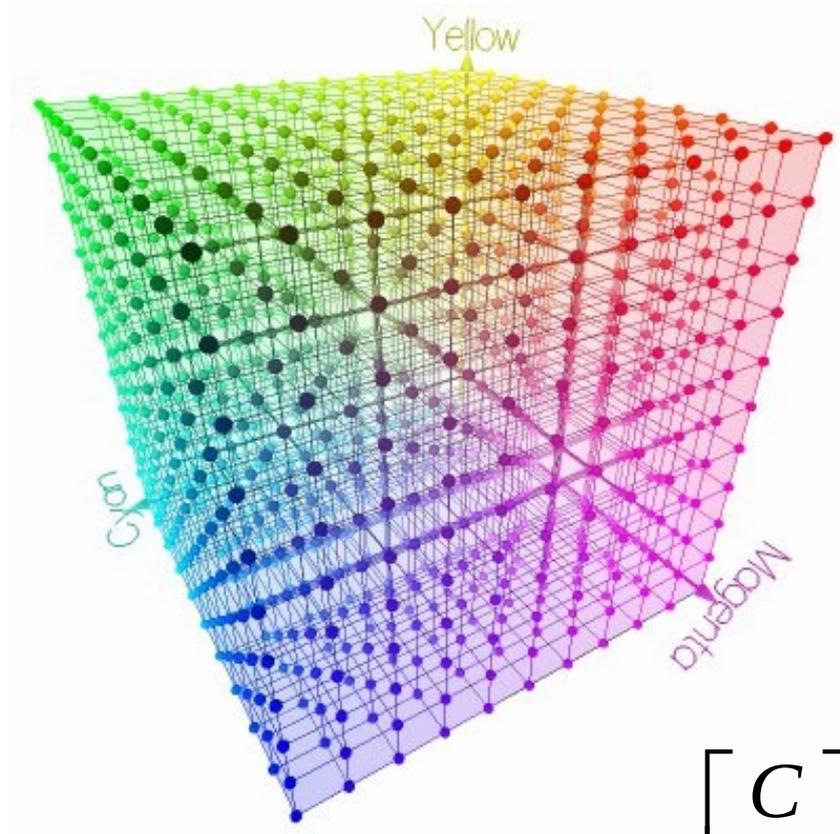
# RGB → HSV

```
HSVType RGB_to_HSV( RGBType RGB ) {  
    // RGB are each on [0, 1]. S and V are returned on [0, 1] and H is  
    // returned on [0, 6]. Exception: H is returned UNDEFINED if S==0.  
    float R = RGB.R, G = RGB.G, B = RGB.B, v, x, f;  
    int i;  
    HSVType HSV;  
  
    x = min(R, G, B);  
    v = max(R, G, B);  
    if(v == x) RETURN_HSV(UNDEFINED, 0, v);  
    f = (R == x) ? G - B : ((G == x) ? B - R : R - G);  
    i = (R == x) ? 3 : ((G == x) ? 5 : 1);  
    RETURN_HSV(i - f / (v - x), (v - x) / v, v);  
}
```

# HSV → RGB

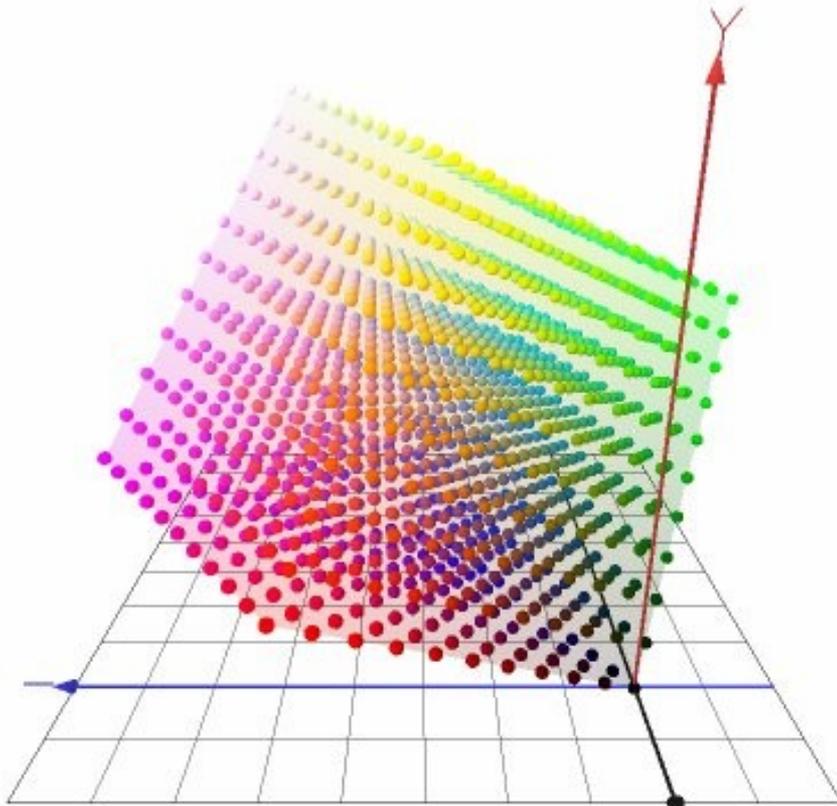
```
RGBType HSV_to_RGB( RGBType RGB ) {  
    // H is given on [0, 6] or UNDEFINED. S and V are given on [0, 1].  
    // RGB are each returned on [0, 1].  
    float h = HSV.H, s = HSV.S, v = HSV.V, m, n, f;  
    int i; RGBType RGB; if (h == UNDEFINED) RETURN_RGB(v, v, v);  
    i = floor(h); f = h - i;  
    if ( !(i&1) ) f = 1 - f; // if i is even  
    m = v * (1 - s); n = v * (1 - s * f);  
    switch (i) {  
        case 6:  
        case 0:  
            RETURN_RGB(v, n, m);  
        case 1: RETURN_RGB(n, v, m);  
        case 2: RETURN_RGB(m, v, n);  
        case 3: RETURN_RGB(m, n, v);  
        case 4: RETURN_RGB(n, m, v);  
        case 5: RETURN_RGB(v, m, n);  
    }  
}
```

# Modelo CMY



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

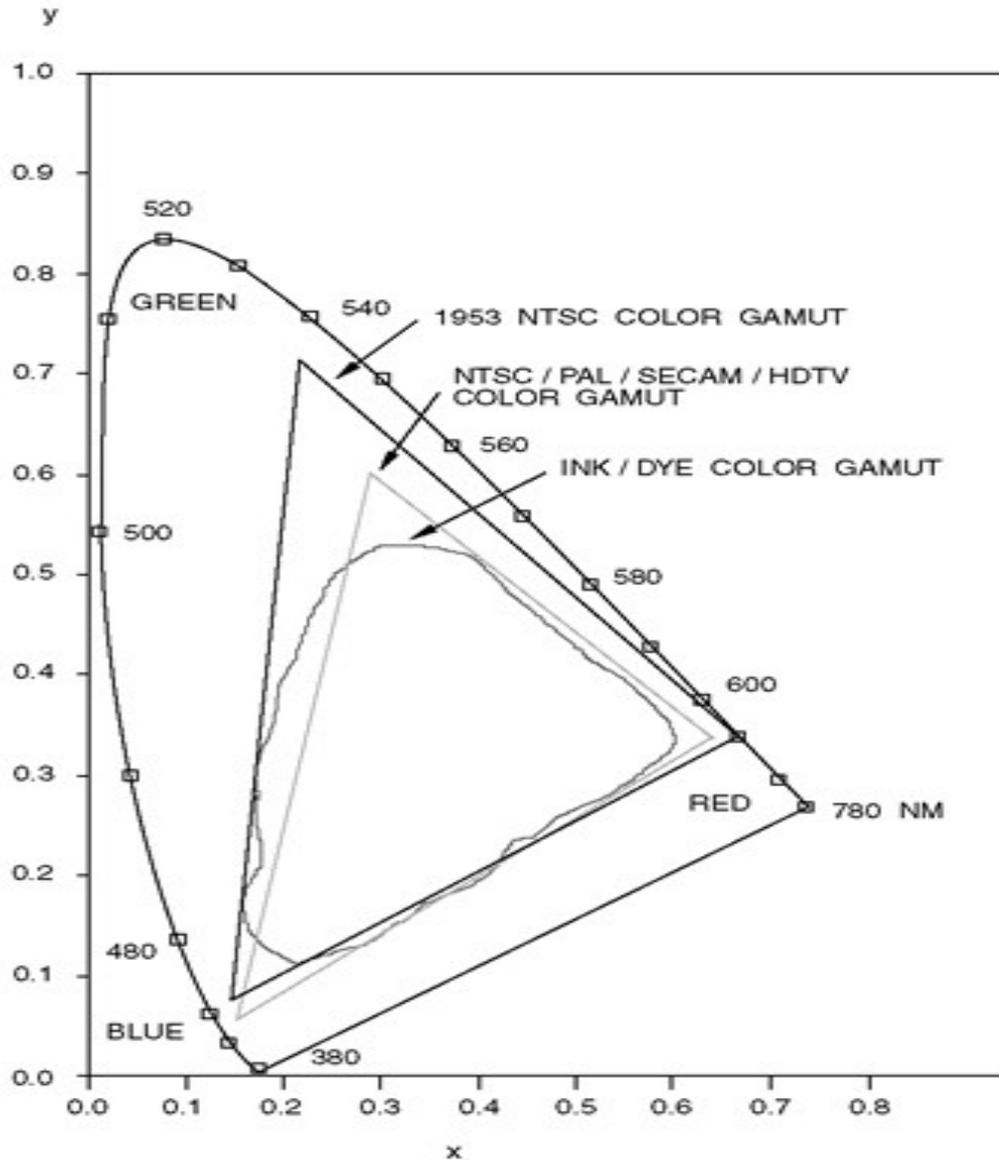
# YIQ: Sistema de televisão NTSC



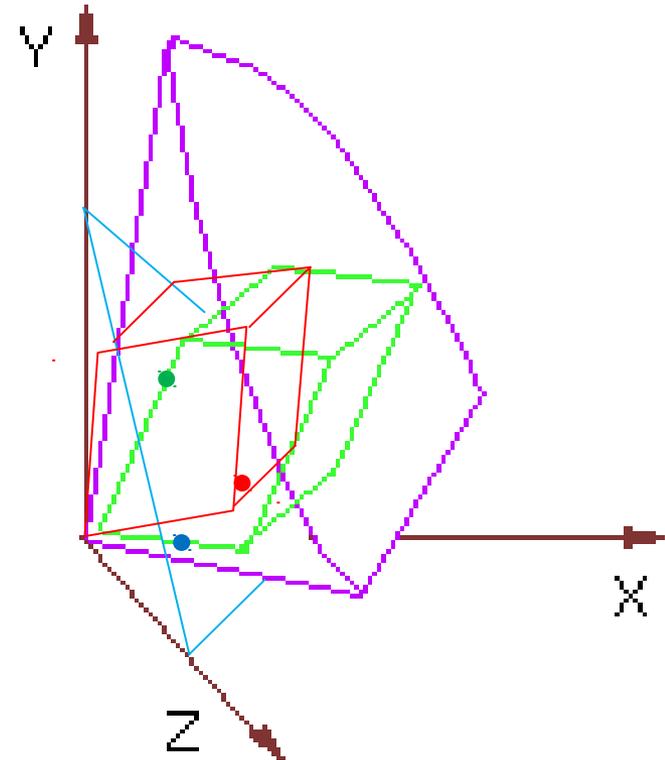
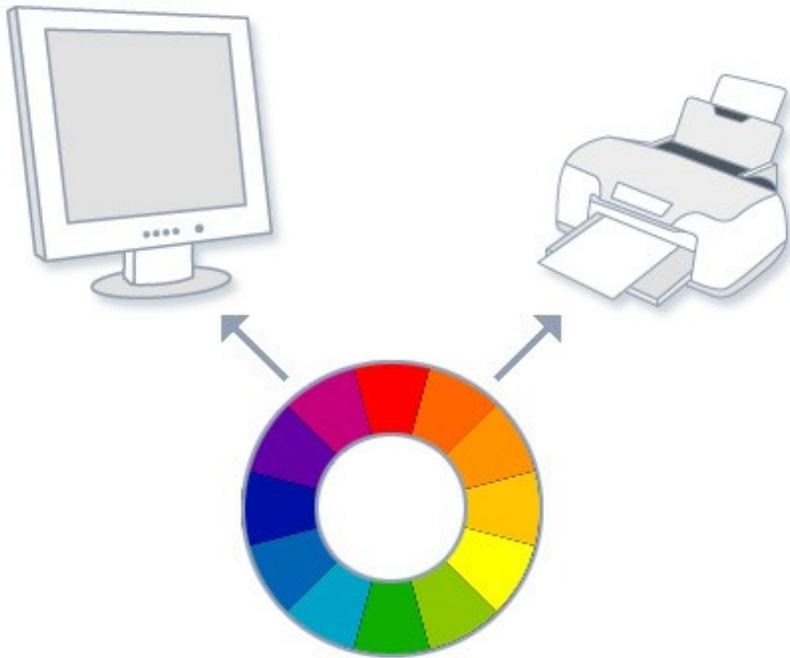
I : faixa laranja - azul  
Q: faixa verde violeta  
Y: luminância

$$\begin{bmatrix} Y \\ I \\ Q \end{bmatrix} = \begin{bmatrix} 0.299 & 0.578 & 0.114 \\ 0.596 & -0.275 & -0.321 \\ 0.212 & -0.523 & 0.311 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

# Aplicação 7: Comparação entre subespaços de cores



# Conversão entre Dispositivos



# Conversão entre Dispositivos

## Mudança de base

$$(R_1, G_1, B_1) \xrightarrow{M_1} (X, Y, Z)$$

$$r = (x_{r,1} C_{r,1}, y_{r,1} C_{r,1}, z_{r,1} C_{r,1})$$

$$g = (x_{g,1} C_{g,1}, y_{g,1} C_{g,1}, z_{g,1} C_{g,1})$$

$$b = (x_{b,1} C_{b,1}, y_{b,1} C_{b,1}, z_{b,1} C_{b,1})$$

$$\begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} \xleftrightarrow{M_1} \begin{pmatrix} x_{r,1} C_{r,1} & x_{g,1} C_{g,1} & x_{b,1} C_{b,1} \\ y_{r,1} C_{r,1} & y_{g,1} C_{g,1} & y_{b,1} C_{b,1} \\ z_{r,1} C_{r,1} & z_{g,1} C_{g,1} & z_{b,1} C_{b,1} \end{pmatrix}$$

$$M_1 = \begin{pmatrix} x_{r,1} C_{r,1} & x_{g,1} C_{g,1} & x_{b,1} C_{b,1} \\ y_{r,1} C_{r,1} & y_{g,1} C_{g,1} & y_{b,1} C_{b,1} \\ z_{r,1} C_{r,1} & z_{g,1} C_{g,1} & z_{b,1} C_{b,1} \end{pmatrix}$$

# Conversão entre Dispositivos

## Mudança de base

$$(R_1, G_1, B_1) \xrightarrow{M_1} (X, Y, Z) \xleftarrow{M_2} (R_2, G_2, B_2)$$
$$M_1 = \begin{pmatrix} X_{r,1} C_{r,1} & X_{g,1} C_{g,1} & X_{b,1} C_{b,1} \\ Y_{r,1} C_{r,1} & Y_{g,1} C_{g,1} & Y_{b,1} C_{b,1} \\ Z_{r,1} C_{r,1} & Z_{g,1} C_{g,1} & Z_{b,1} C_{b,1} \end{pmatrix} \begin{pmatrix} X_{r,2} C_{r,2} & X_{g,2} C_{g,2} & X_{b,2} C_{b,2} \\ Y_{r,2} C_{r,2} & Y_{g,2} C_{g,2} & Y_{b,2} C_{b,2} \\ Z_{r,2} C_{r,2} & Z_{g,2} C_{g,2} & Z_{b,2} C_{b,2} \end{pmatrix} = M_2$$

1. As luminâncias máximas das 3 cores são conhecidas:  $Y_{r,1}$ ,  $Y_{g,1}$  e  $Y_{b,1}$

$$C_{r,1} = \frac{Y_{r,1}}{y_{r,1}} \quad C_{g,1} = \frac{Y_{g,1}}{y_{g,1}} \quad C_{b,1} = \frac{Y_{b,1}}{y_{b,1}}$$

2. A cor de referência branca é conhecida ( $X_w, Y_w, Z_w$ )

$$\begin{pmatrix} X_{r,1} & X_{g,1} & X_{b,1} \\ Y_{r,1} & Y_{g,1} & Y_{b,1} \\ Z_{r,1} & Z_{g,1} & Z_{b,1} \end{pmatrix}^{-1} \begin{pmatrix} X_w \\ Y_w \\ Z_w \end{pmatrix} = \begin{pmatrix} C_r \\ C_g \\ C_b \end{pmatrix} \quad \text{Em RGB} = (1,1,1)$$

# Transformação entre Referências

Seja um monitor com as seguintes características:

Branco: D65 (0.313,0.329,1.0)

Vermelho: (0.62,0.34)

Verde: (0.29, 0.59)

Azul: (0.15, 0.06)

Qual é a matriz de transformação das coordenadas RGB para as coordenadas XYZ?

Resposta:

0.437	0.339	0.175
0.240	0.690	0.070
0.028	0.140	0.920