COLORIMETRIA

&

ESPAÇOS DE COR

Colorimetria

Medida – Quantificação da COR

PROPRIEDADES FÍSICAS

+

EFEITOS FISIOLÓGICOS

percepção + concepção

Colorimetria

Medidores

ESPECTRORADIÔMETRO: Espectrômetro + detector

ESPECTROFOTÔMETRO: Espectrômetro + detector + luz

COLORÍMETROS

+ CALIBRAÇÕES

ESPECIFICAÇÃO DA COR

SISTEMAS QUANTITATIVOS

Variáveis associadas a trí-estímulos

Misturas aditivas de fontes primárias

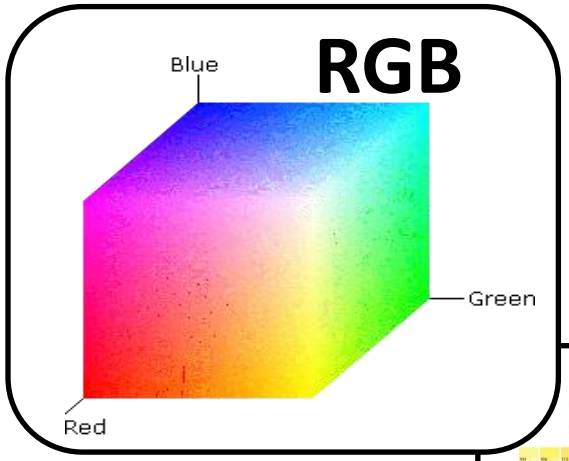
SISTEMAS SEMI-QUANTITATIVOS

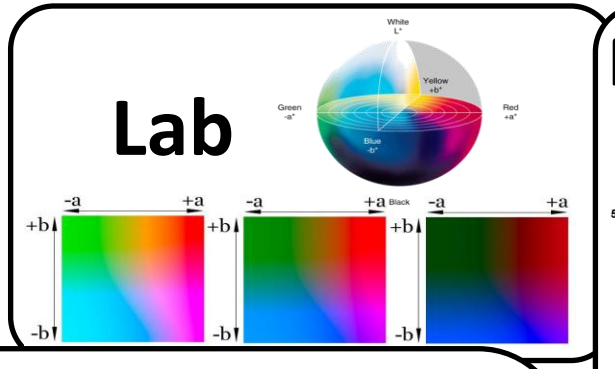
Base RGB + eixos de percepção

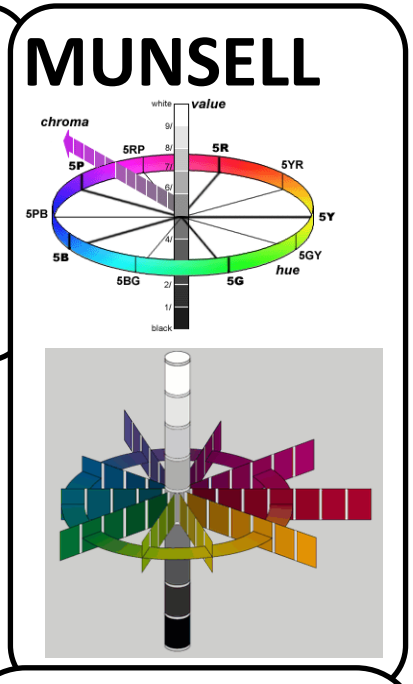
SISTEMAS QUALITATIVOS

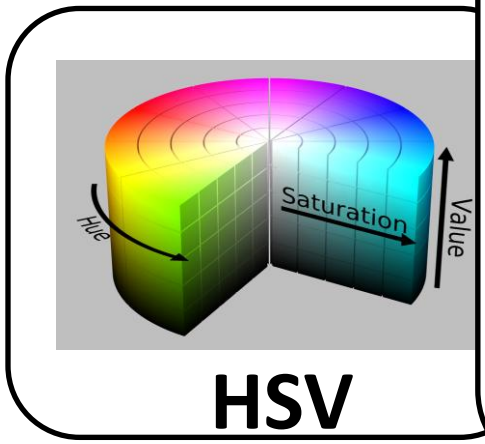
Ordenamento por percepção

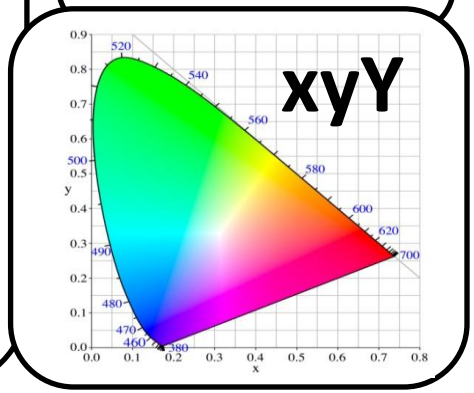
ESPAÇOS DE COR





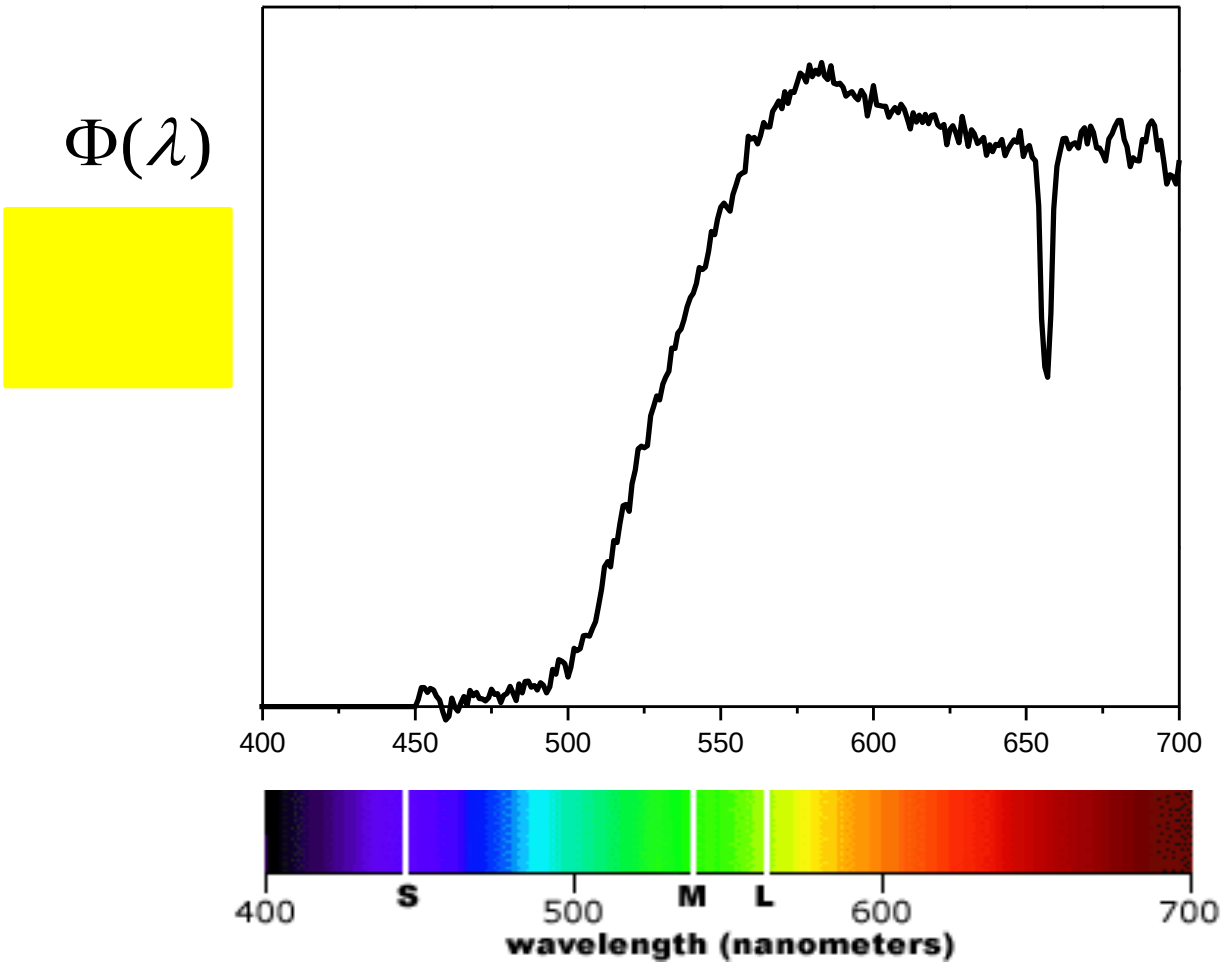






ESPECTRO DETECTADO

$\Phi(\lambda)$

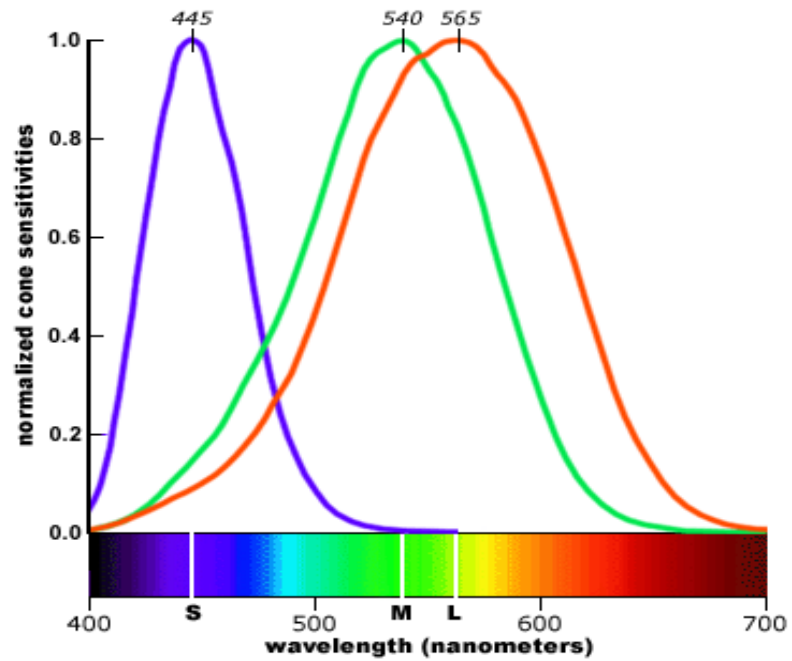


TRÍ-ESTÍMULOS

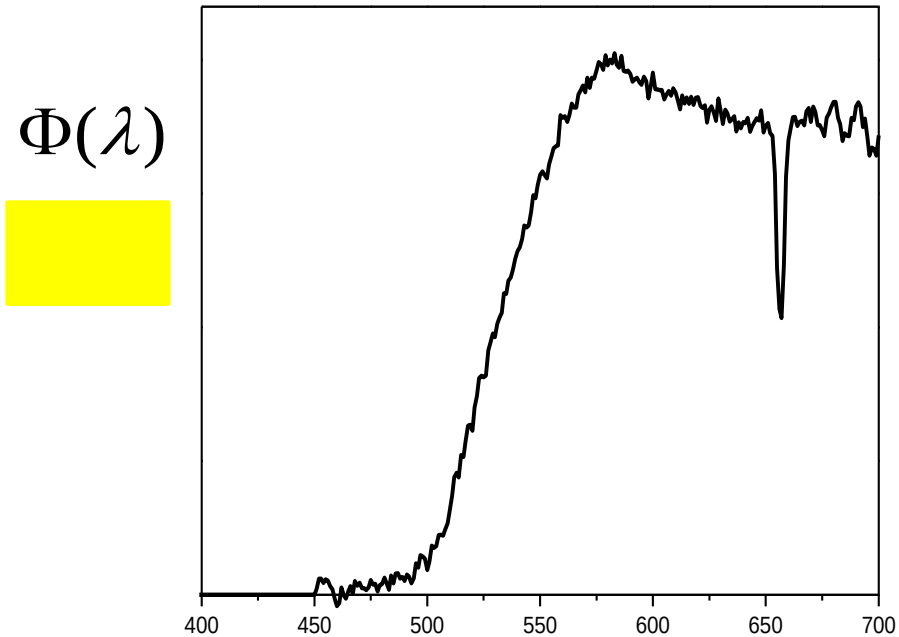
$$L_1 = \int \Phi(\lambda)\, L(\lambda)\, d\lambda$$

$$M_1 = \int \Phi(\lambda)\, M(\lambda)\, d\lambda$$

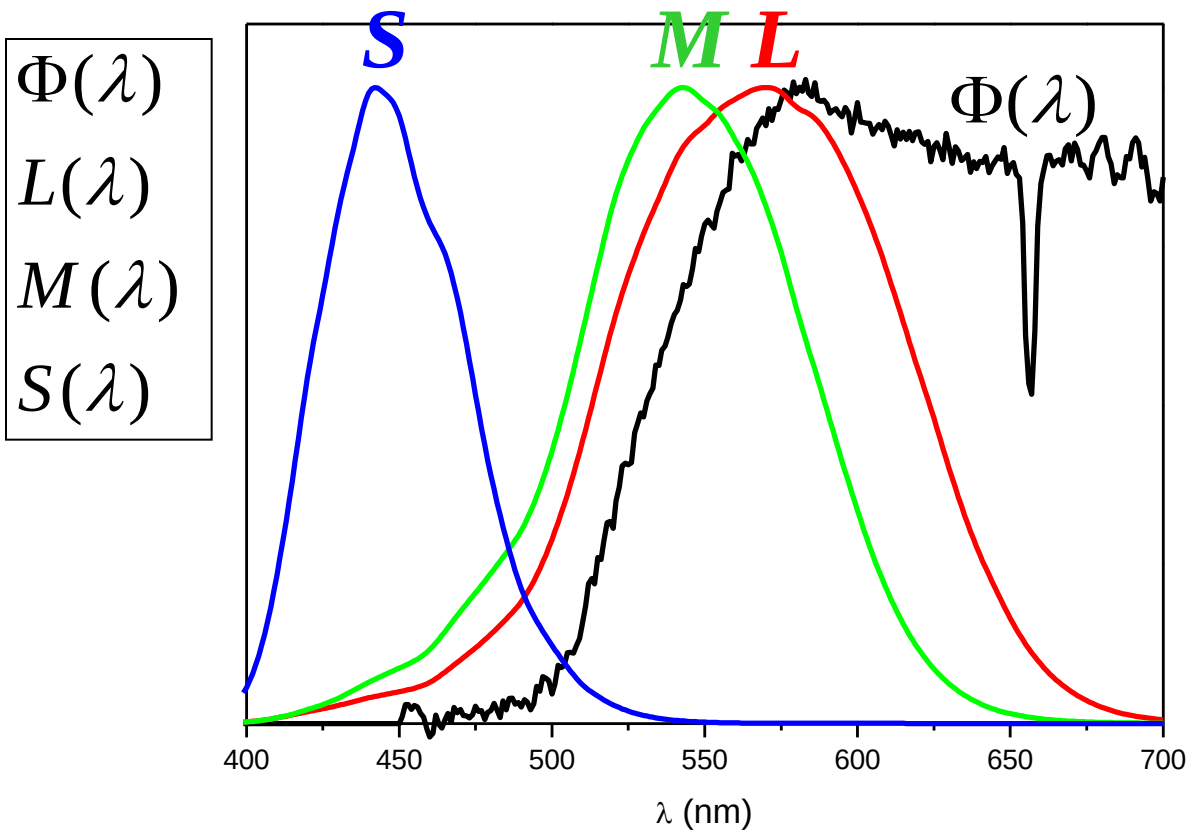
$$S_1 = \int \Phi(\lambda)\, S(\lambda)\, d\lambda$$



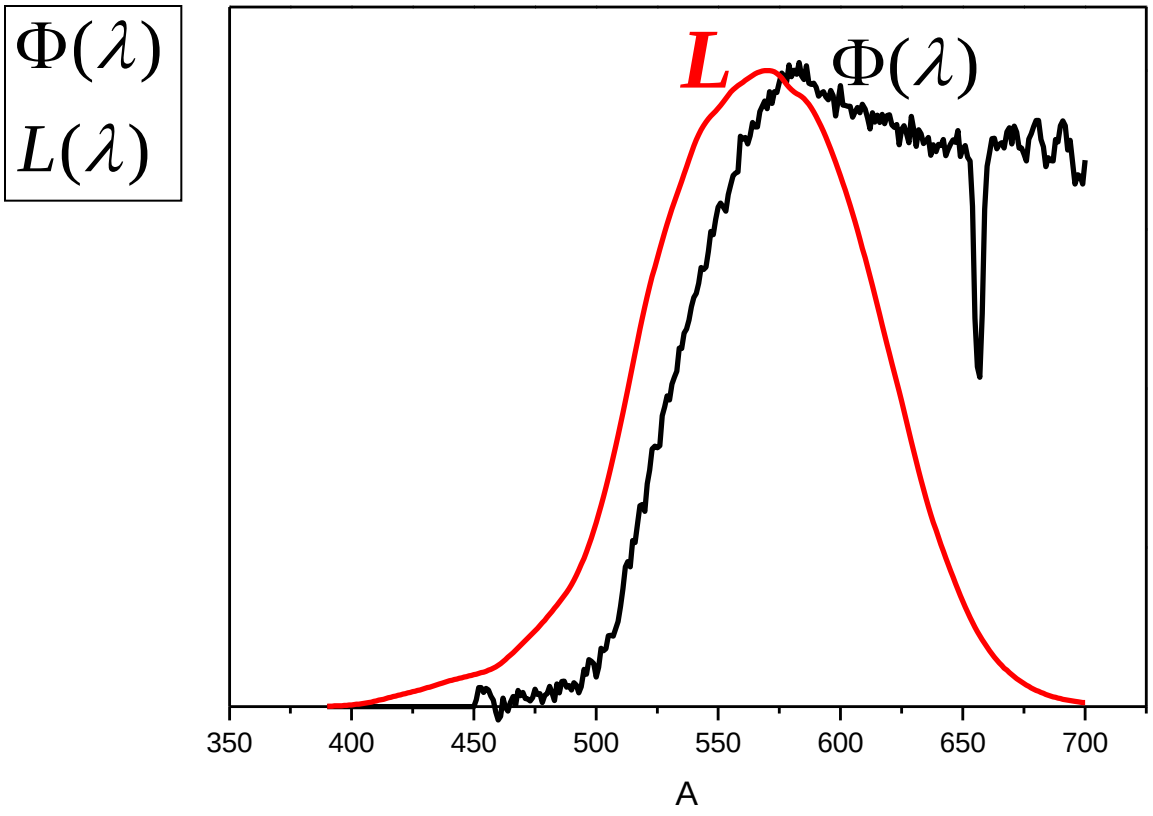
$\Phi(\lambda)$



ESPECTRO & EFICIÊNCIAS

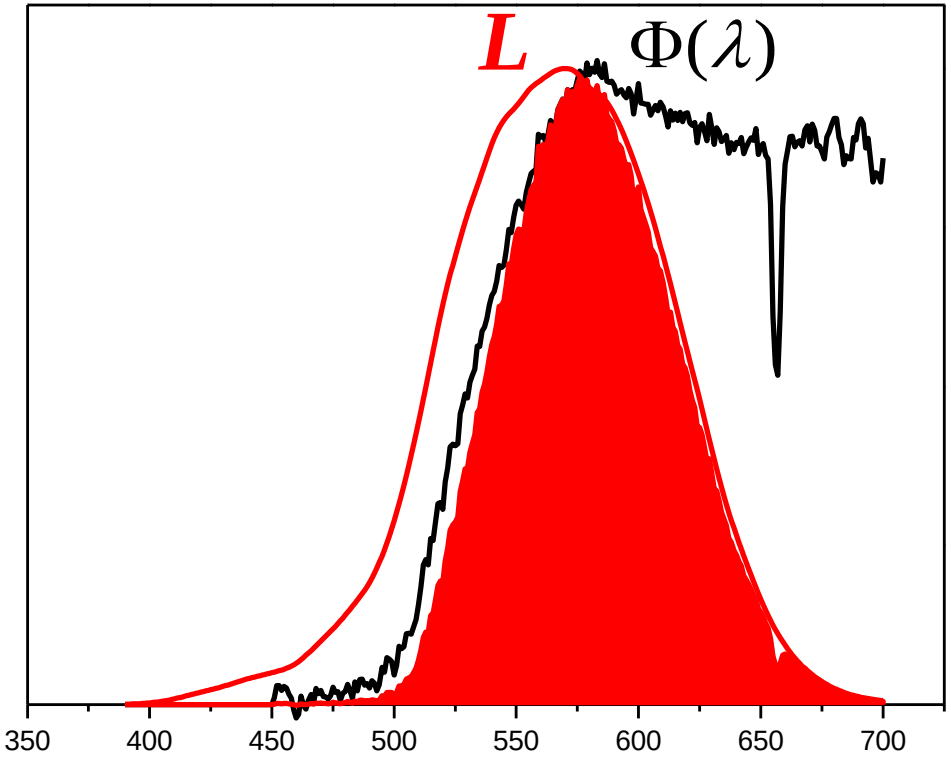


TRÍ-ESTÍMULO L



TRÍ-ESTÍMULO L

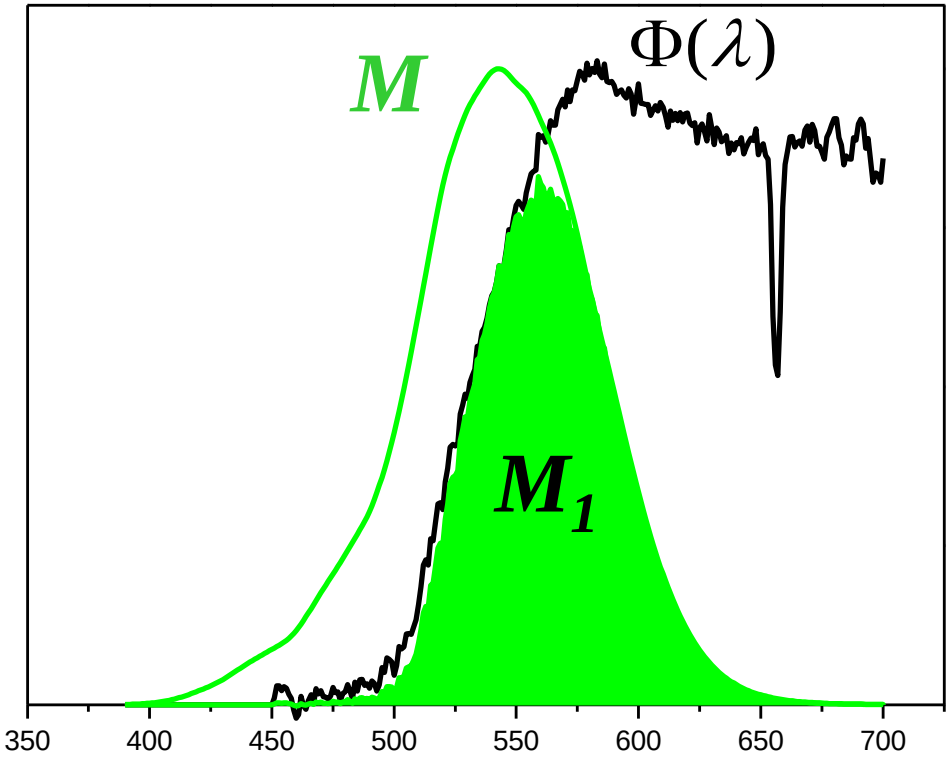
$$\Phi(\lambda)L(\lambda)$$



$$L_1 = \int \Phi(\lambda)\, L(\lambda)\, d\lambda$$

TRÍ-ESTÍMULO M

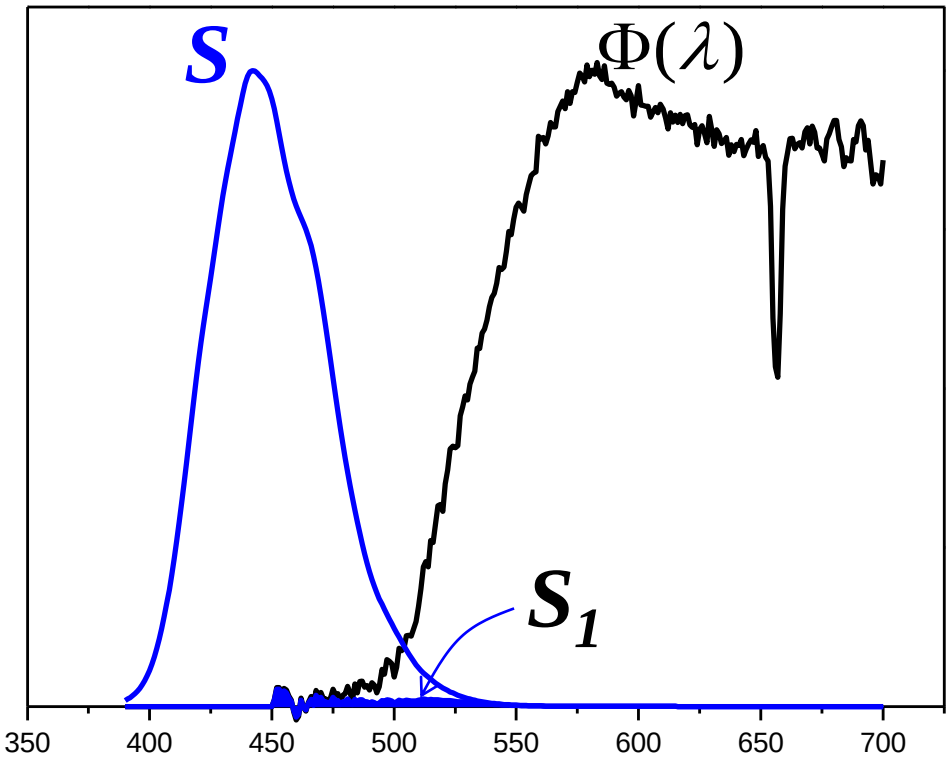
$$\Phi(\lambda)M(\lambda)$$



$$M_1 = \int \Phi(\lambda)\, M(\lambda)\, d\lambda$$

TRÍ-ESTÍMULO S

$$\Phi(\lambda)S(\lambda)$$



$$S_1 = \int \Phi(\lambda)\, S(\lambda)\, d\lambda$$

METAMERISMO

Trí-estimulos **IGUAIS**

Cores **IGUAIS**

$$L_1 = L_2$$

$$M_1 = M_2$$

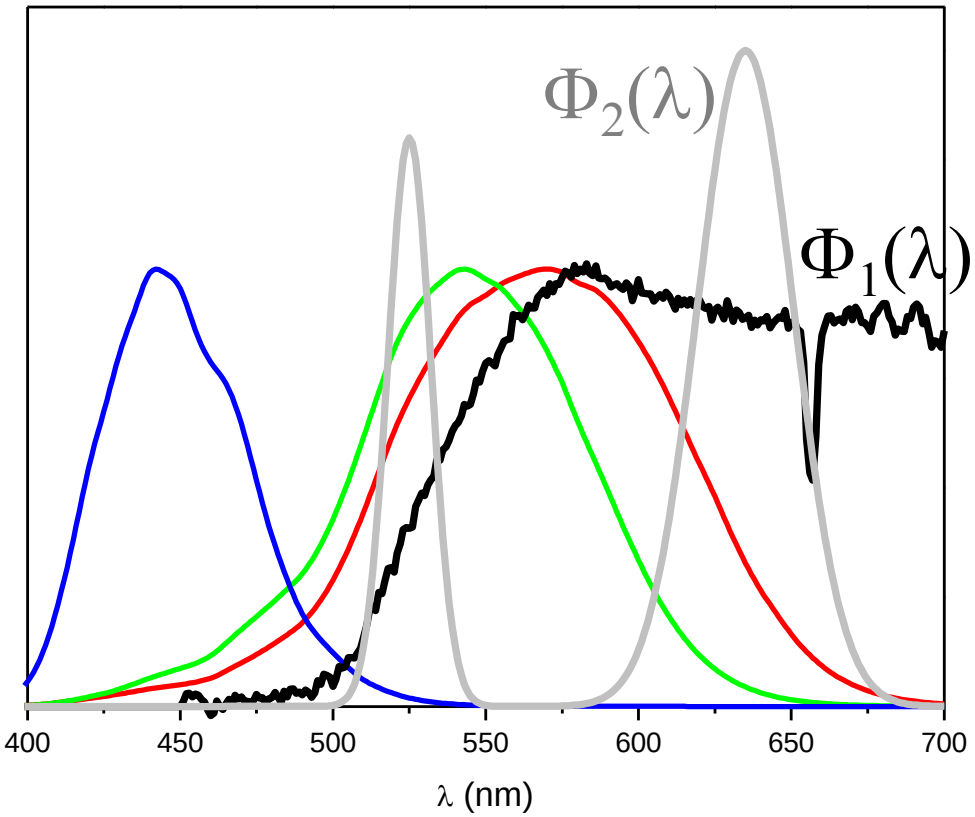
$$S_1 = S_2$$

METAMERISMO

$$L_1 = L_2$$

$$M_1 = M_2$$

$$S_1 = S_2$$

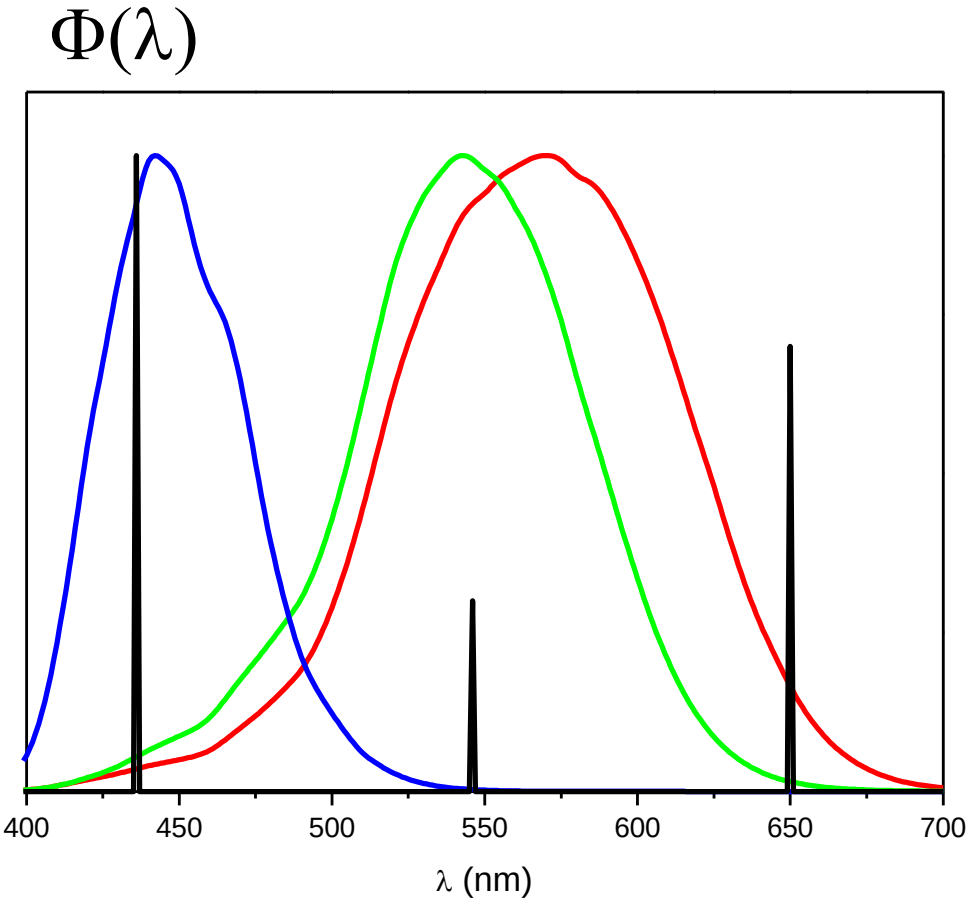


FONTE RGB IDEAL

$$L_1 = \int \Phi(\lambda)\, L(\lambda)\, d\lambda$$

$$M_1 = \int \Phi(\lambda)\, M(\lambda)\, d\lambda$$

$$S_1 = \int \Phi(\lambda)\, S(\lambda)\, d\lambda$$



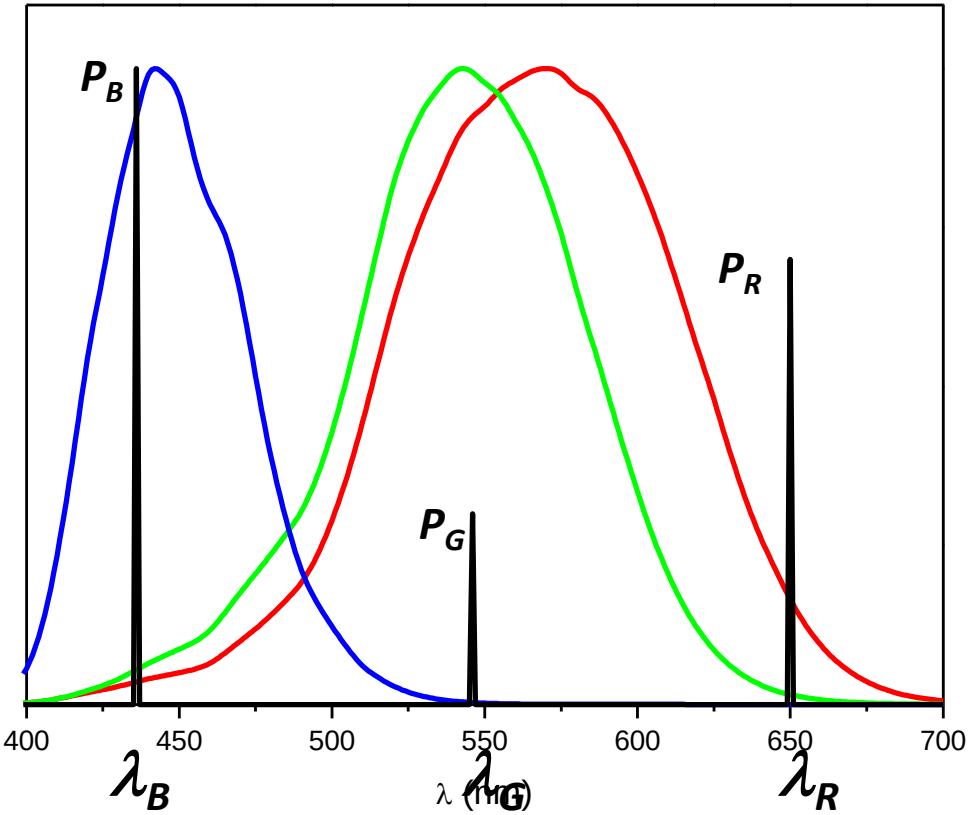
FONTE RGB IDEAL

$$\Phi(\lambda) = \mathbf{P_B} \,.\, \delta(\lambda-\lambda_B) + \mathbf{P_G} \,.\, \delta(\lambda-\lambda_G) + \mathbf{P_R} \,.\, \delta(\lambda-\lambda_R)$$

$$S_1 = P_B.\, S(\lambda_B) + P_G.\, S(\lambda_G) + P_R.\, S(\lambda_R)$$

$$M_1 = P_B.\, M(\lambda_B) + P_G.\, M(\lambda_G) + P_R.\, M(\lambda_R)$$

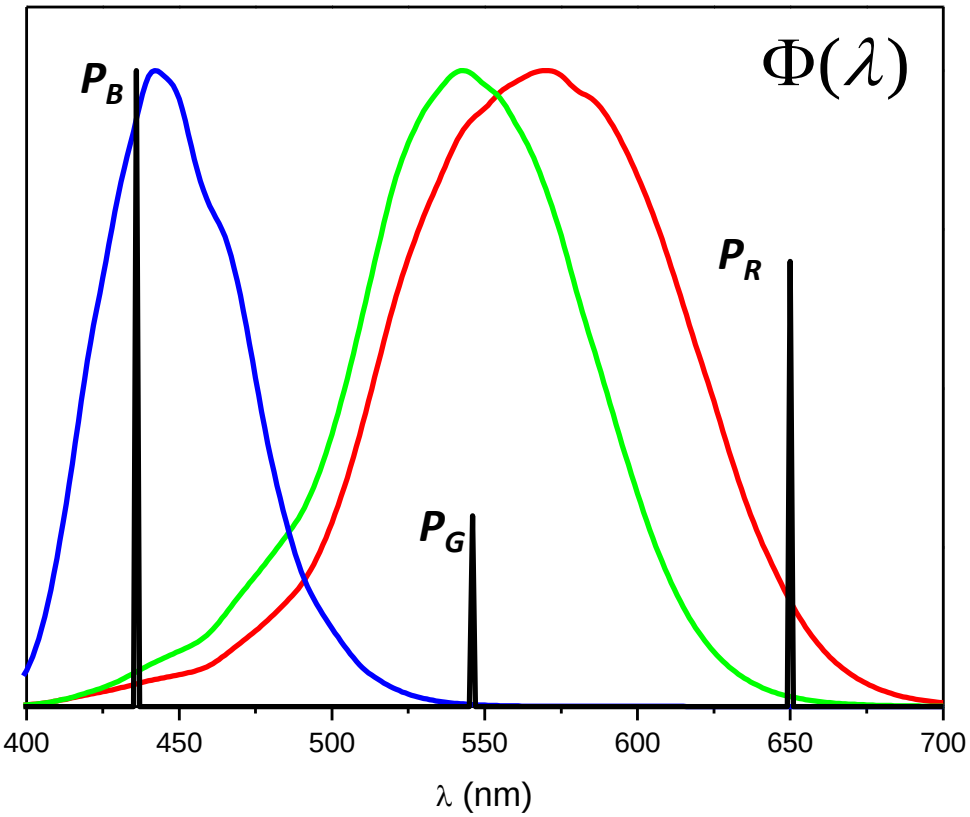
$$L_1 = P_B.\, L(\lambda_B) + P_G.\, L(\lambda_G) + P_R.\, L(\lambda_R)$$



FONTE RGB IDEAL

Caracterização do RGB

$$\begin{bmatrix} S_1 \\ M_1 \\ L_1 \end{bmatrix} = \begin{bmatrix} S(\lambda_B) & S(\lambda_G) & S(\lambda_R) \\ M(\lambda_B) & M(\lambda_G) & M(\lambda_R) \\ L(\lambda_B) & L(\lambda_G) & L(\lambda_R) \end{bmatrix} . \begin{bmatrix} P_B \\ P_G \\ P_R \end{bmatrix}$$

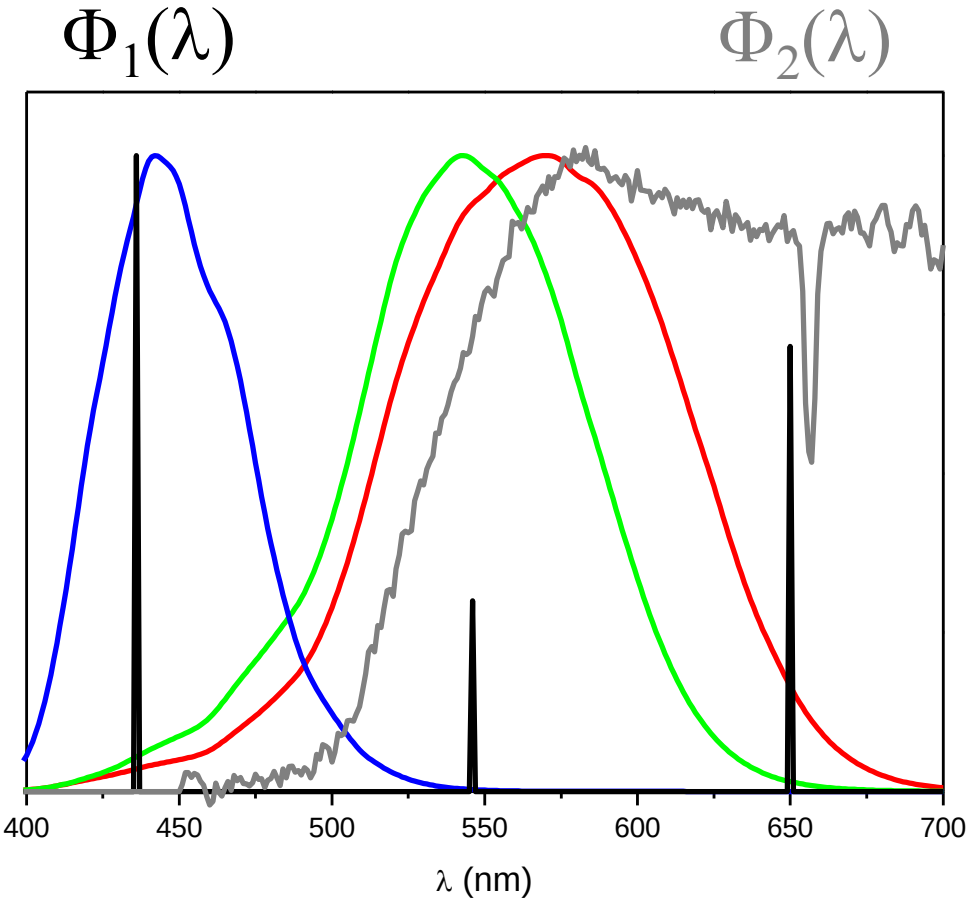


FONTE RGB IDEAL

$$L_1 = L_2$$

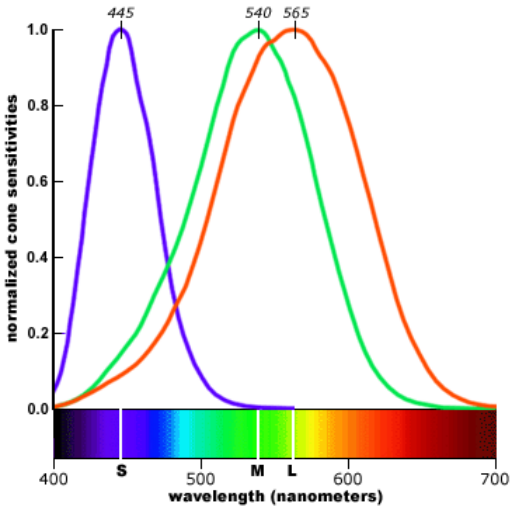
$$M_1 = M_2$$

$$S_1 = S_2$$

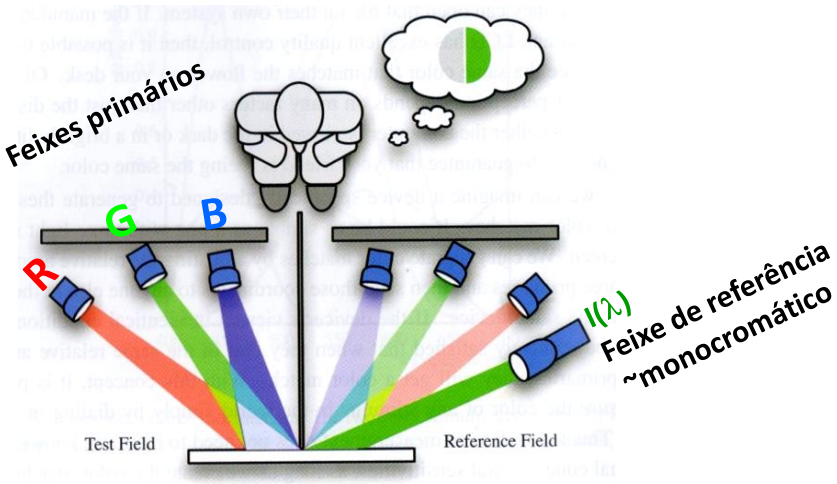


COLOR MATCHING FUNCTIONS

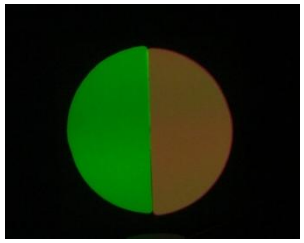
Respostas dos cones só foram bem estabelecidas nas últimas décadas



Medidas de casamento de cores com fontes RGB



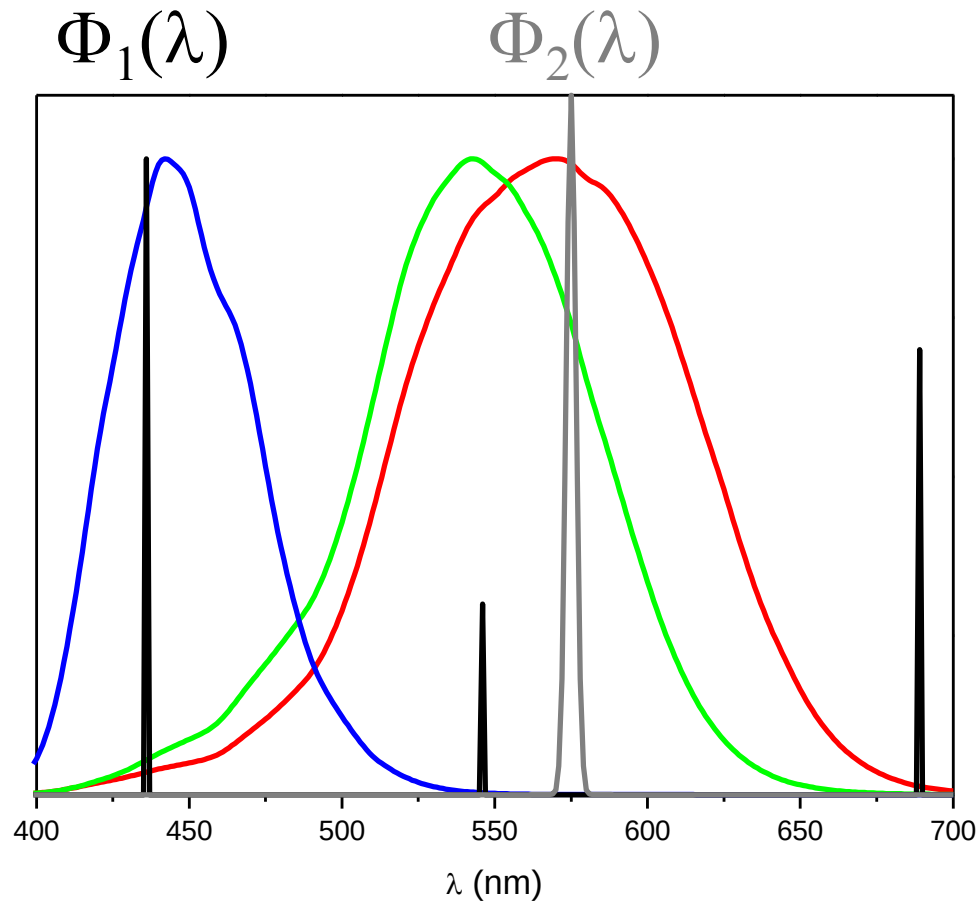
COLOR MATCHING FUNCTIONS



$$L_1 = L_2$$

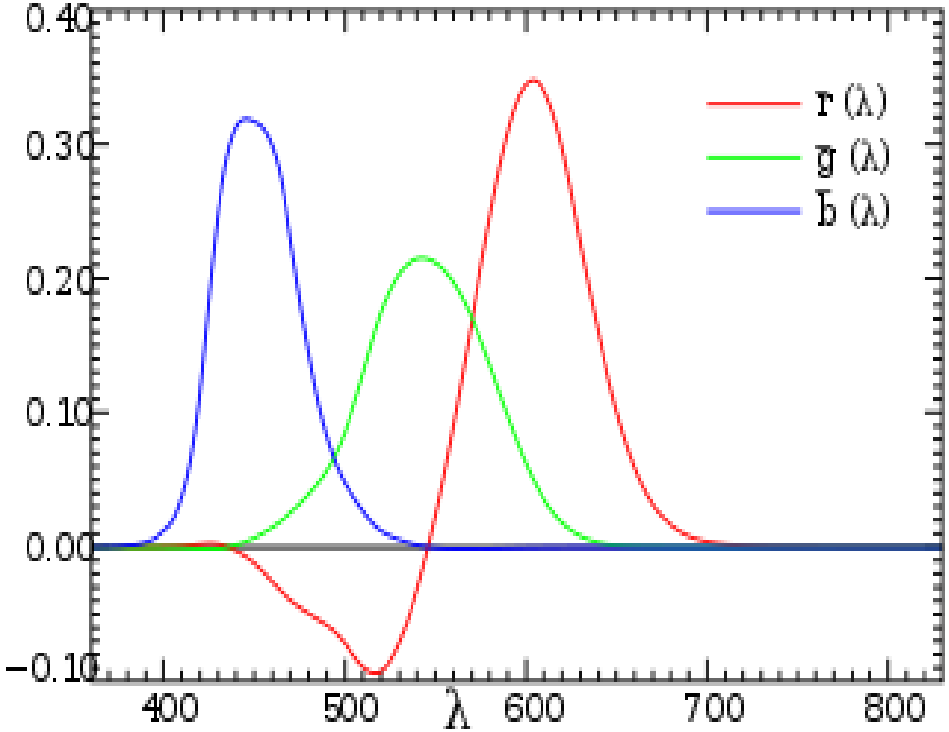
$$M_1 = M_2$$

$$S_1 = S_2$$

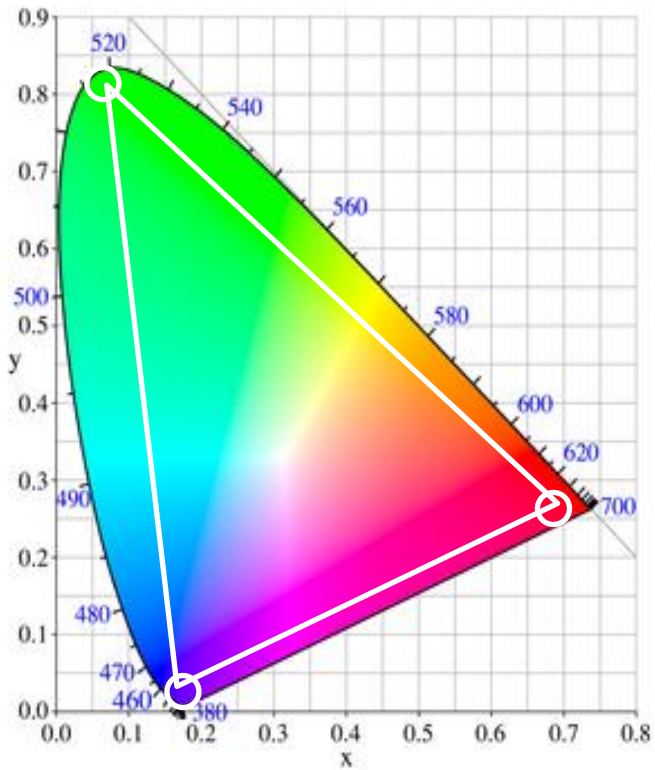


COLOR MATCHING FUNCTIONS

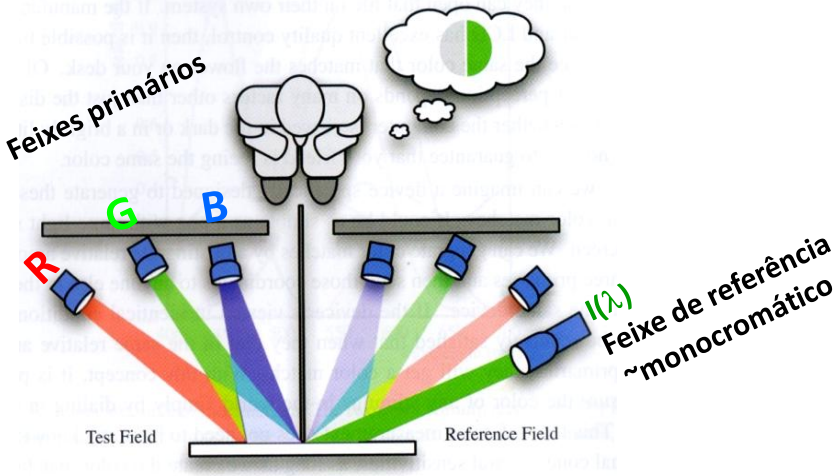
$$I(\lambda) = r(\lambda) \,.\, R + g(\lambda) \,.\, G + b(\lambda) \,.\, B$$



CORES "IMPOSSÍVEIS"



Feixes "negativos"



LEIS DE GRASSMANN

ADITIVIDADE

Se uma **cor A** casa com uma **cor B**

e uma **cor C** casa com uma **cor D**,

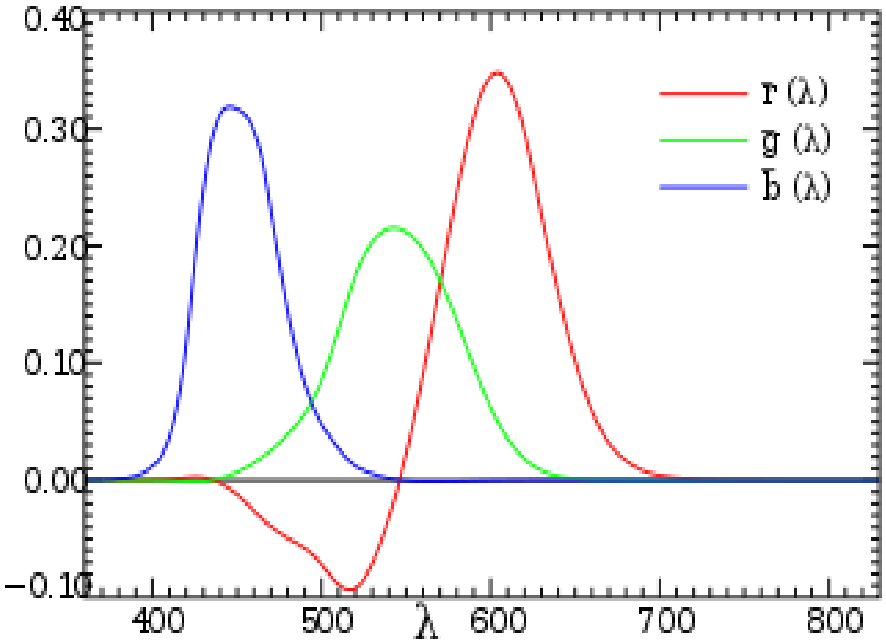
então a **cor A+C** casa com a **cor B+D**.

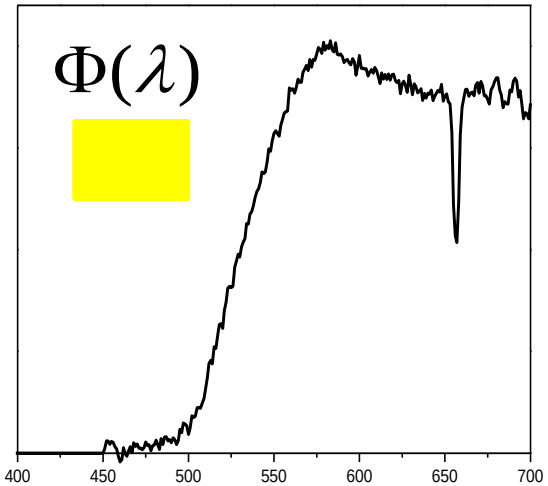
TRÍ-ESTÍMULO RGB

$$R = \int \Phi(\lambda)\, \bar{r}(\lambda)\, d\lambda$$

$$G = \int \Phi(\lambda)\, \bar{g}(\lambda)\, d\lambda$$

$$B = \int \Phi(\lambda)\, \bar{b}(\lambda)\, d\lambda$$



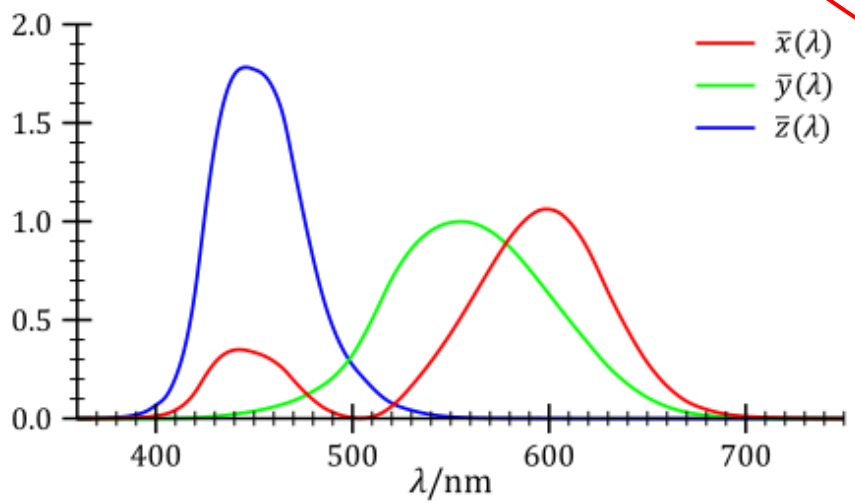


CIE 1931 2°

COLOR MATCHING FUNCTIONS POSITIVAS:

$\bar{r}(\lambda)\ \bar{g}(\lambda)\ \bar{b}(\lambda) \rightarrow \bar{x}(\lambda)\ \bar{y}(\lambda)\ \bar{z}(\lambda)$

Fontes imaginárias

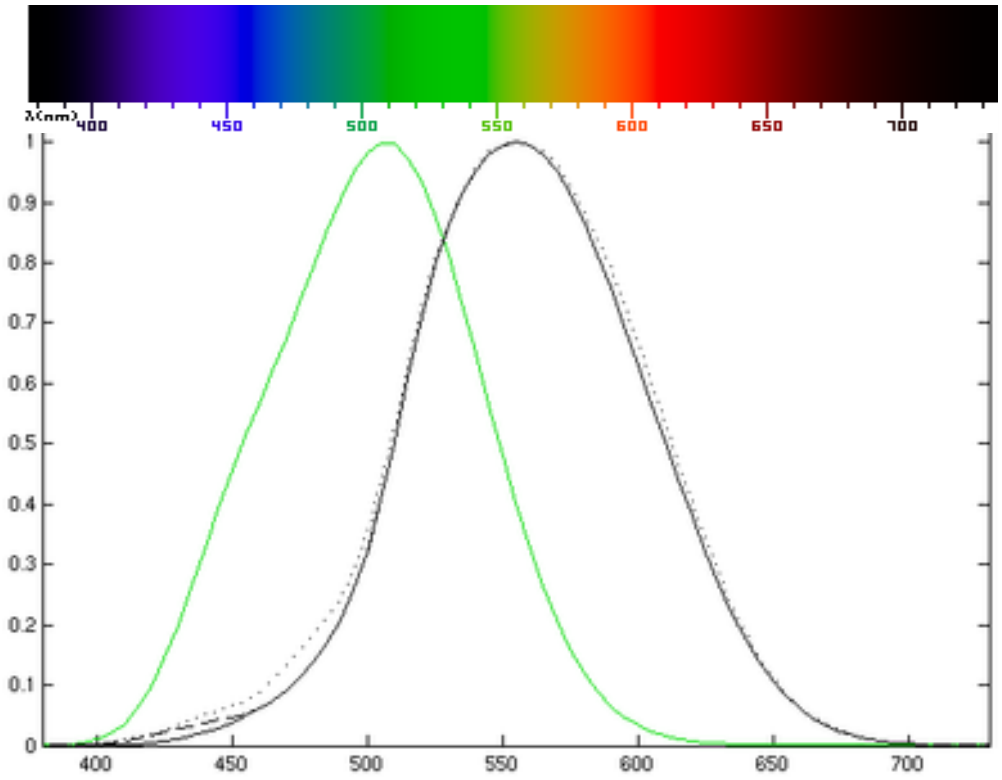


$V(\lambda)$
Função resposta da luminância Fotópica - Cones

TRI-ESTÍMULO *XYZ*

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \frac{1}{0.17697} \begin{bmatrix} 0.49000 & 0.31000 & 0.20000 \\ 0.17697 & 0.81240 & 0.01063 \\ 0.00000 & 0.01000 & 0.99000 \end{bmatrix} . \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

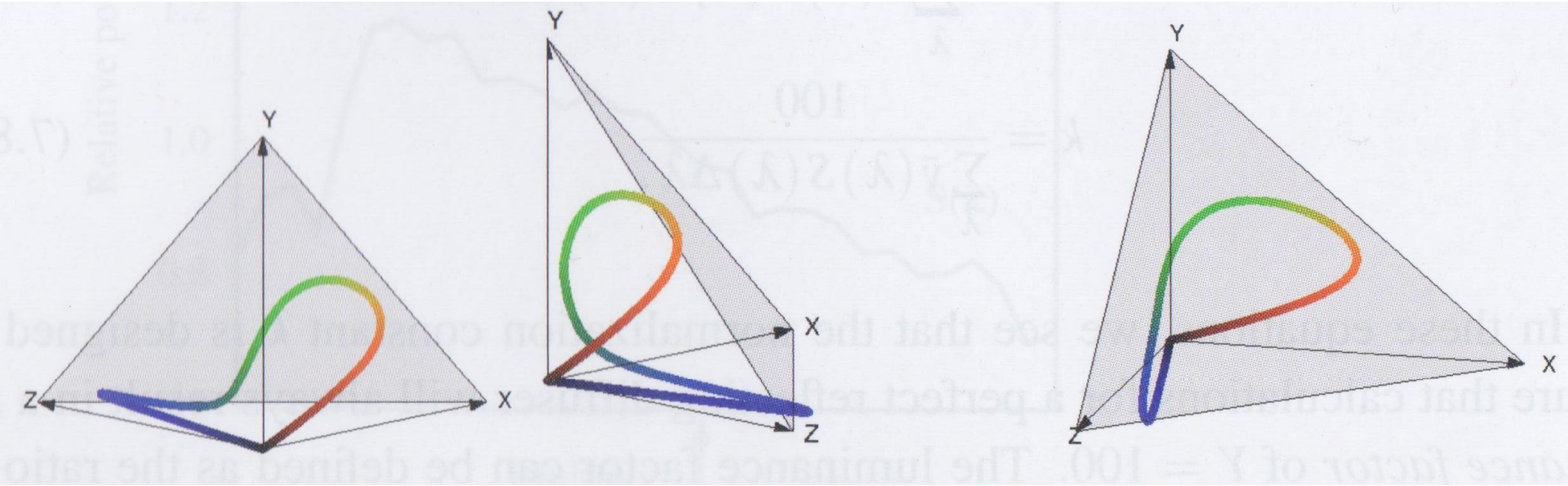
FUNÇÃO RESPOSTA DA LUMINÂNCIA



Photopic : cones : DIA

Scotopic : rods : NOITE

ESPAÇO XYZ



Spectrum Locus

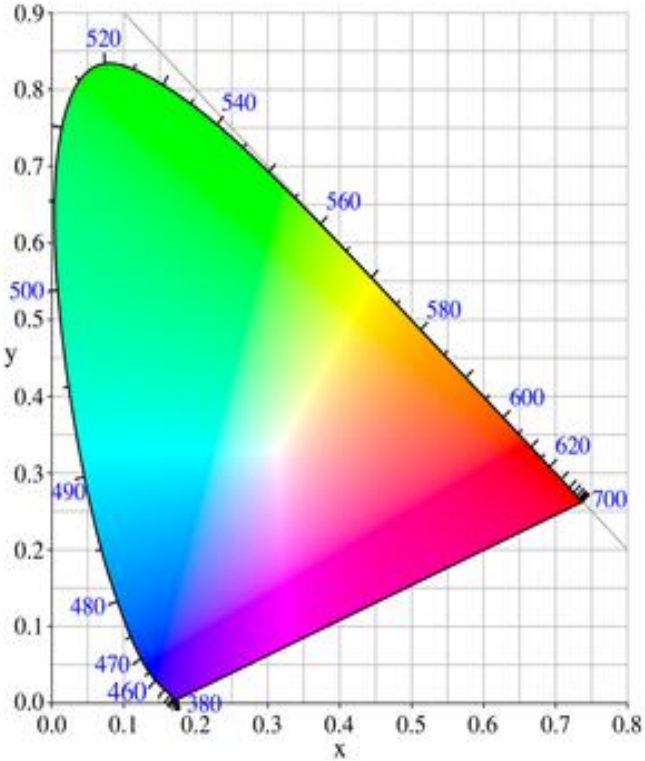
CIE *xyY*

3D → 2D + **LUMINÂNCIA** Y

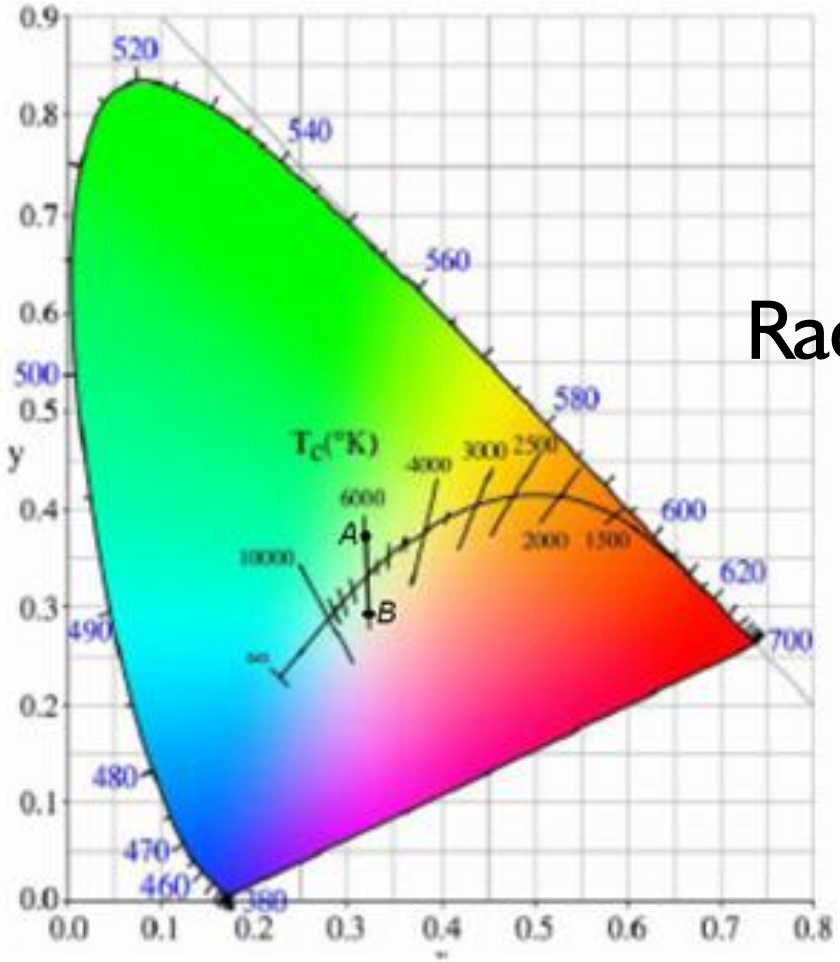
Informação cromática

$$\begin{cases} x = X / (X+Y+Z) \\ y = Y / (X+Y+Z) \\ z = Z / (X+Y+Z) \end{cases}$$

$$x + y + z = 1$$



CIE *xyY*

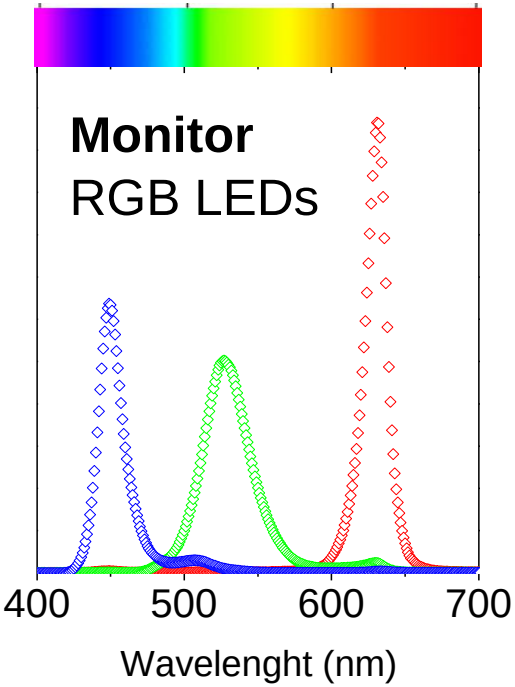


Radiação de corpo-negro

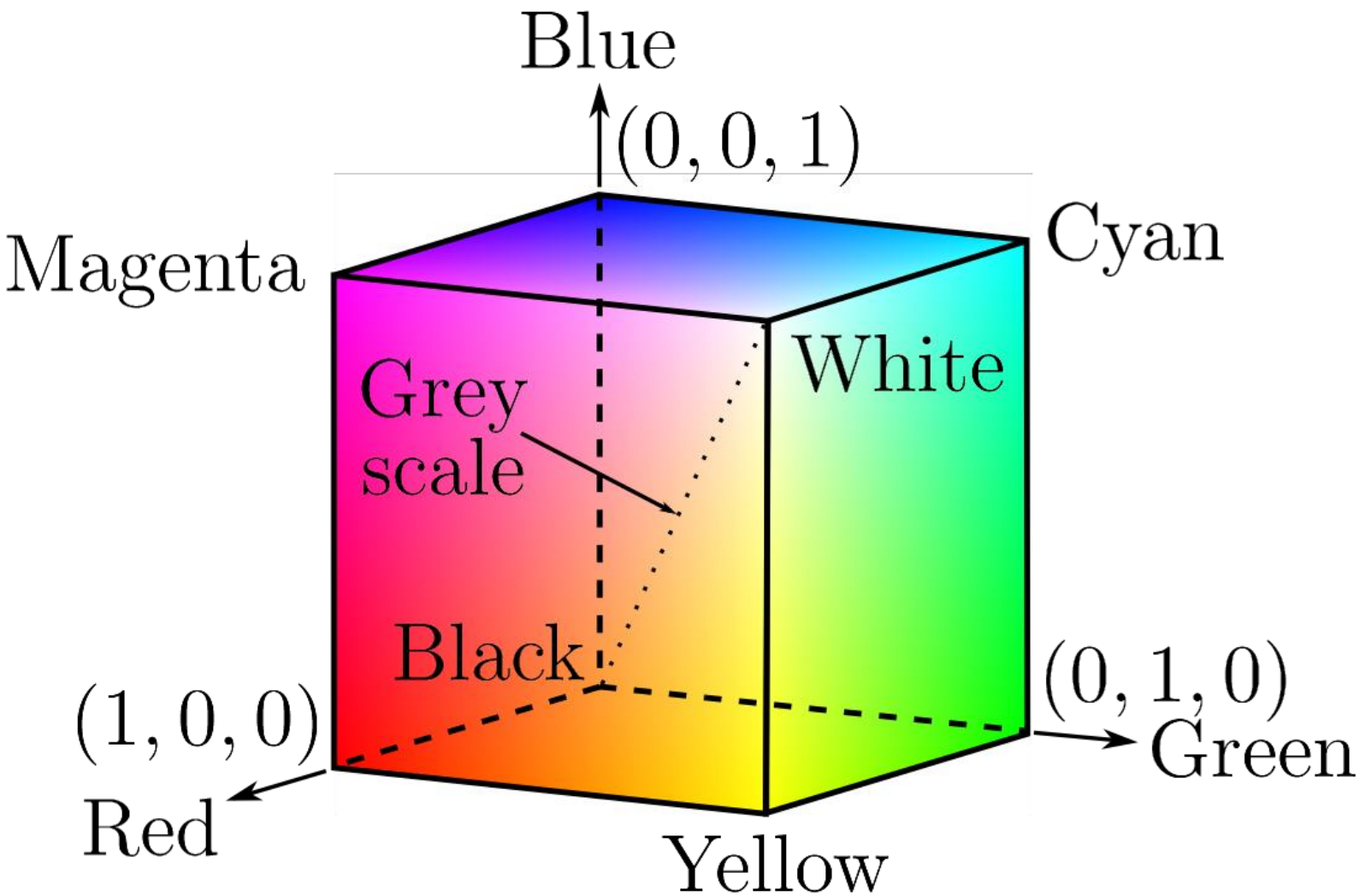
RGB MONITORES

Transformando primárias

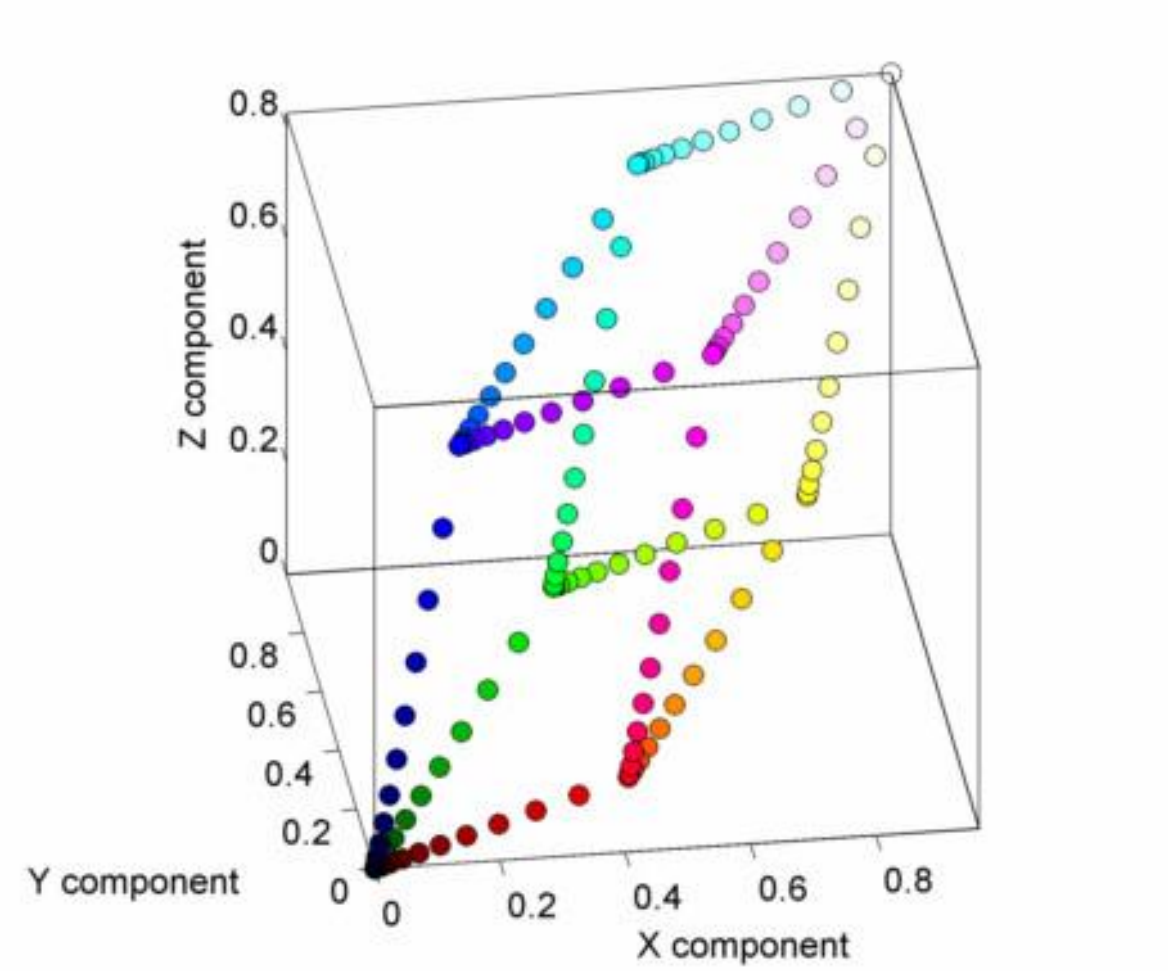
$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} X_{red} & X_{green} & X_{blue} \\ Y_{red} & Y_{green} & Y_{blue} \\ Z_{red} & Z_{green} & Z_{blue} \end{bmatrix} \cdot \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$



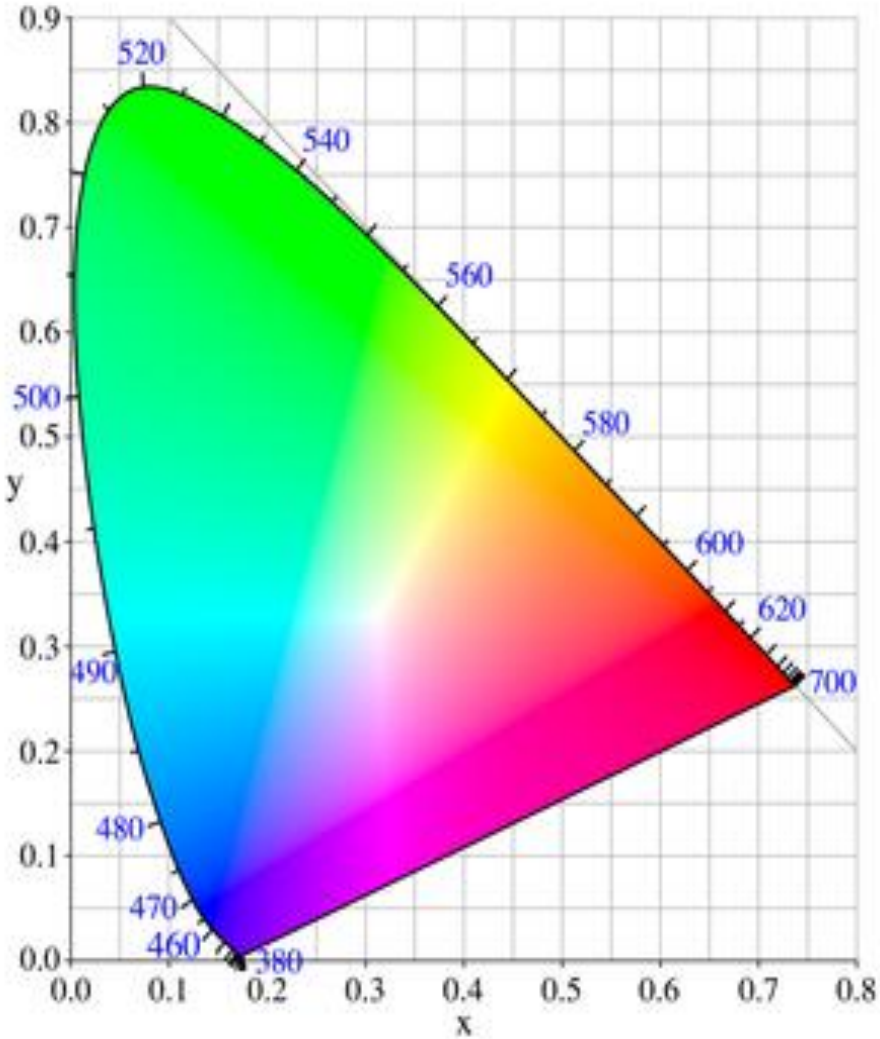
ESPAÇO RGB


Blue
(0, 0, 1)
Magenta
Cyan
Grey
scale
White
Black
(1, 0, 0)
(0, 1, 0)
Red
Green
Yellow

RGB no espaço XYZ

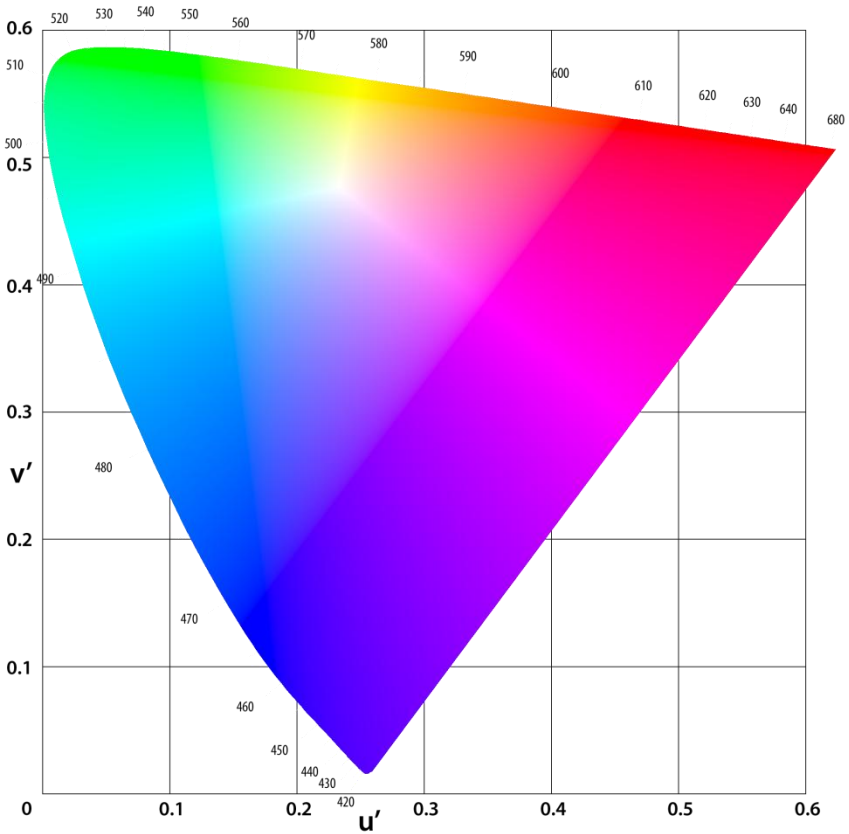


ESPAÇO *xyY*



Não é um espaço "uniformemente espaçado" na percepção de cor

ESPAÇO $Y\,u'v'$



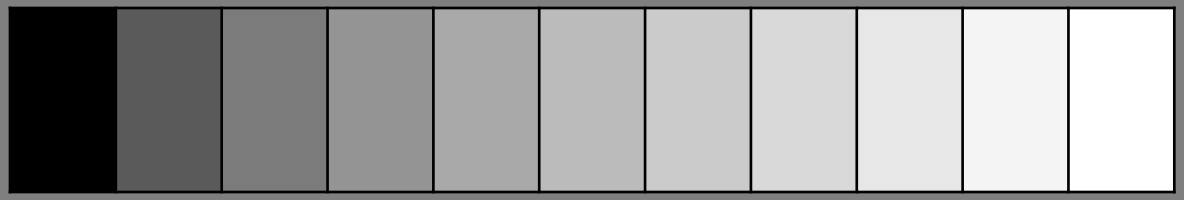
Uniform
Chromaticity Scale
UCS

$$\begin{cases} u' = 4x / (-2x + 12y + 3) \\ v' = 9y / (-2x + 12y + 3) \end{cases}$$

Transformação NÃO - LINEAR

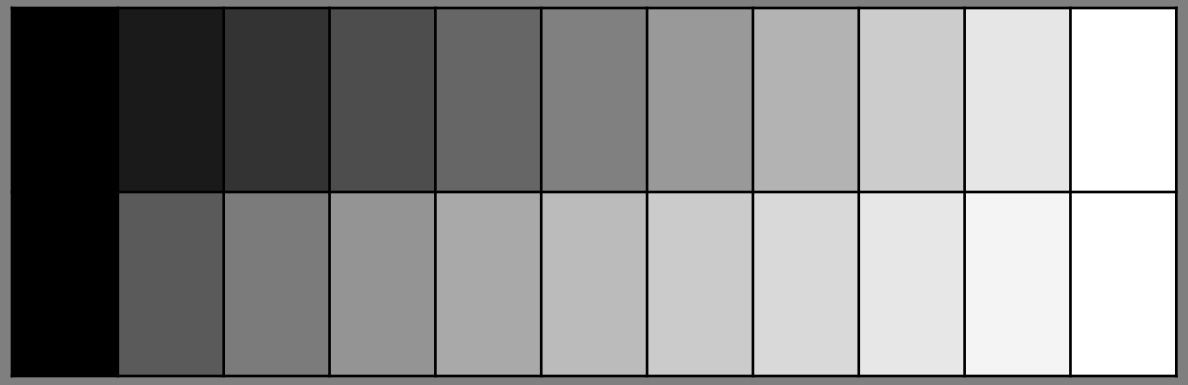
PERCEPÇÃO DA LUMINÂNCIA

Passos iguais de



Luminância

PERCEPÇÃO DA LUMINÂNCIA

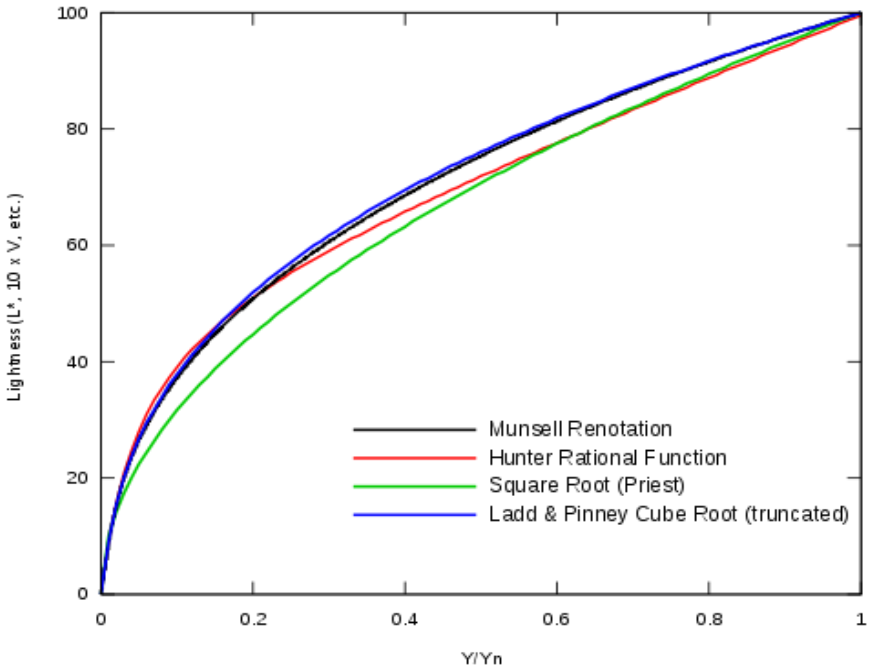


Passos iguais de

Percepção

Luminância

PERCEPÇÃO DA LUMINÂNCIA

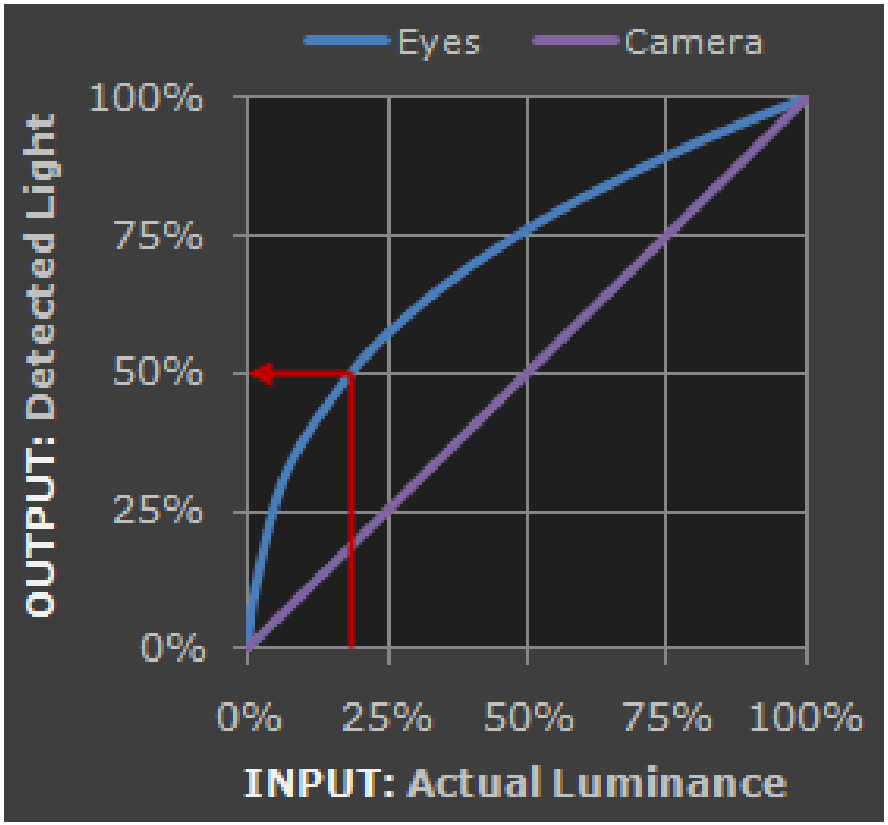


$$L^* = L_o\, Y^{\gamma}$$

$$L^* \sim L_o\, Y^{1/3}$$

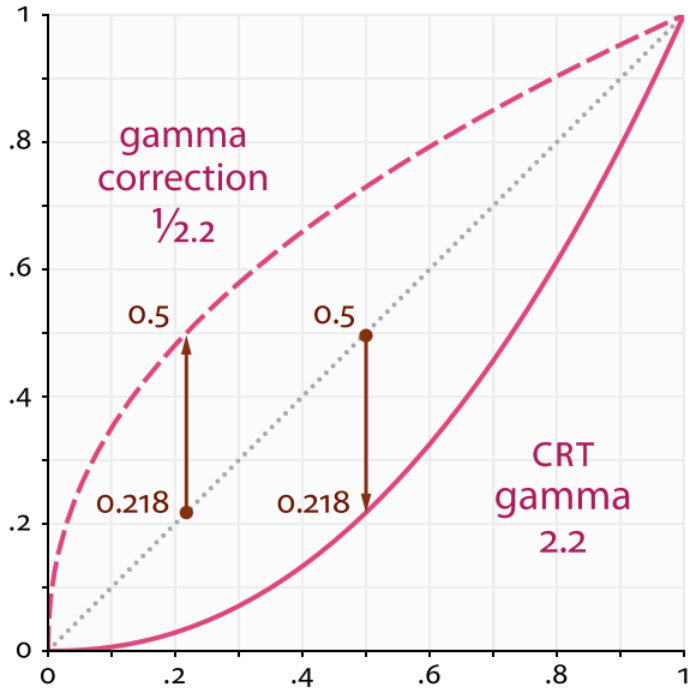
$$L^* \sim L_o\, Y^{1/2.43}$$

GAMMA ENCODING

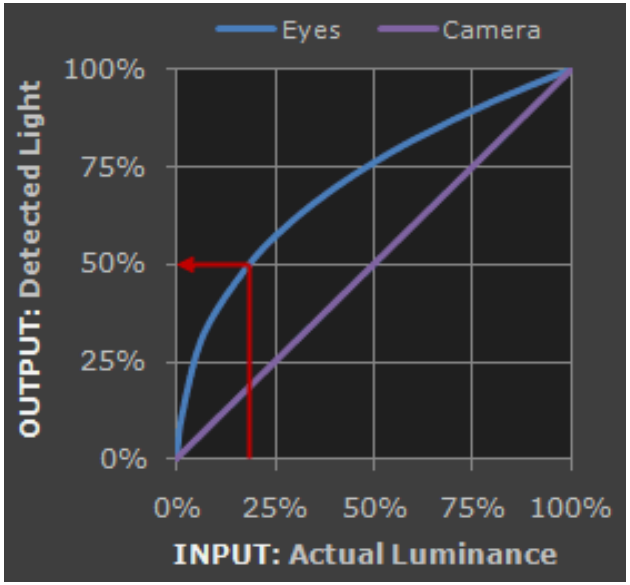


GAMMA ENCODING

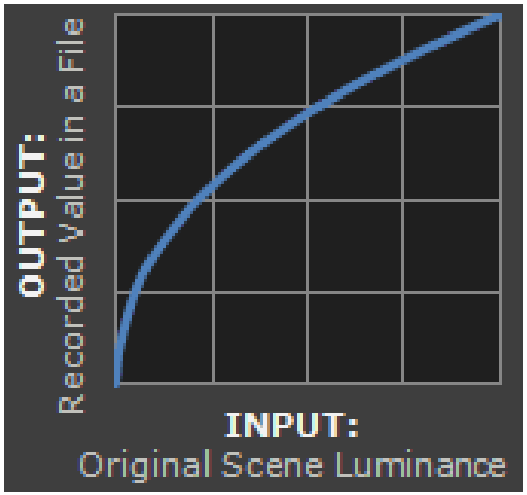
Usando mais bits para guardar a informação sobre as cores mais escuras.



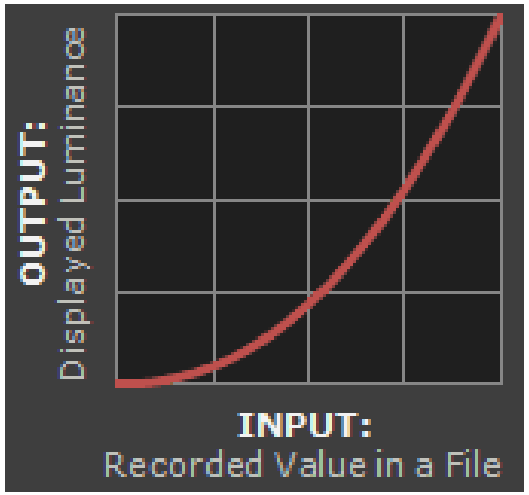
GAMMA ENCODING



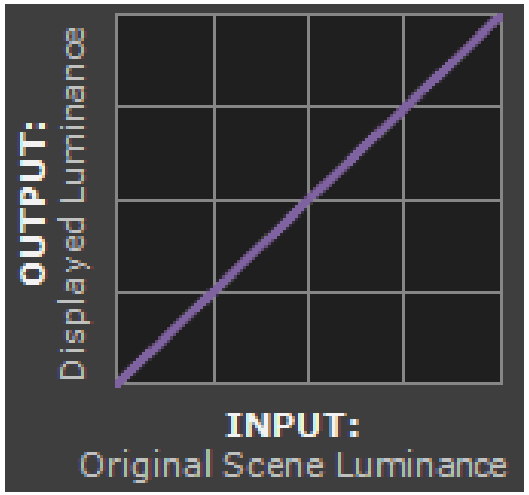
Origem do termo:
Monitores não-lineares
CRT (cathode ray tube)
$I = V^{\gamma}$ $\gamma=2.2$



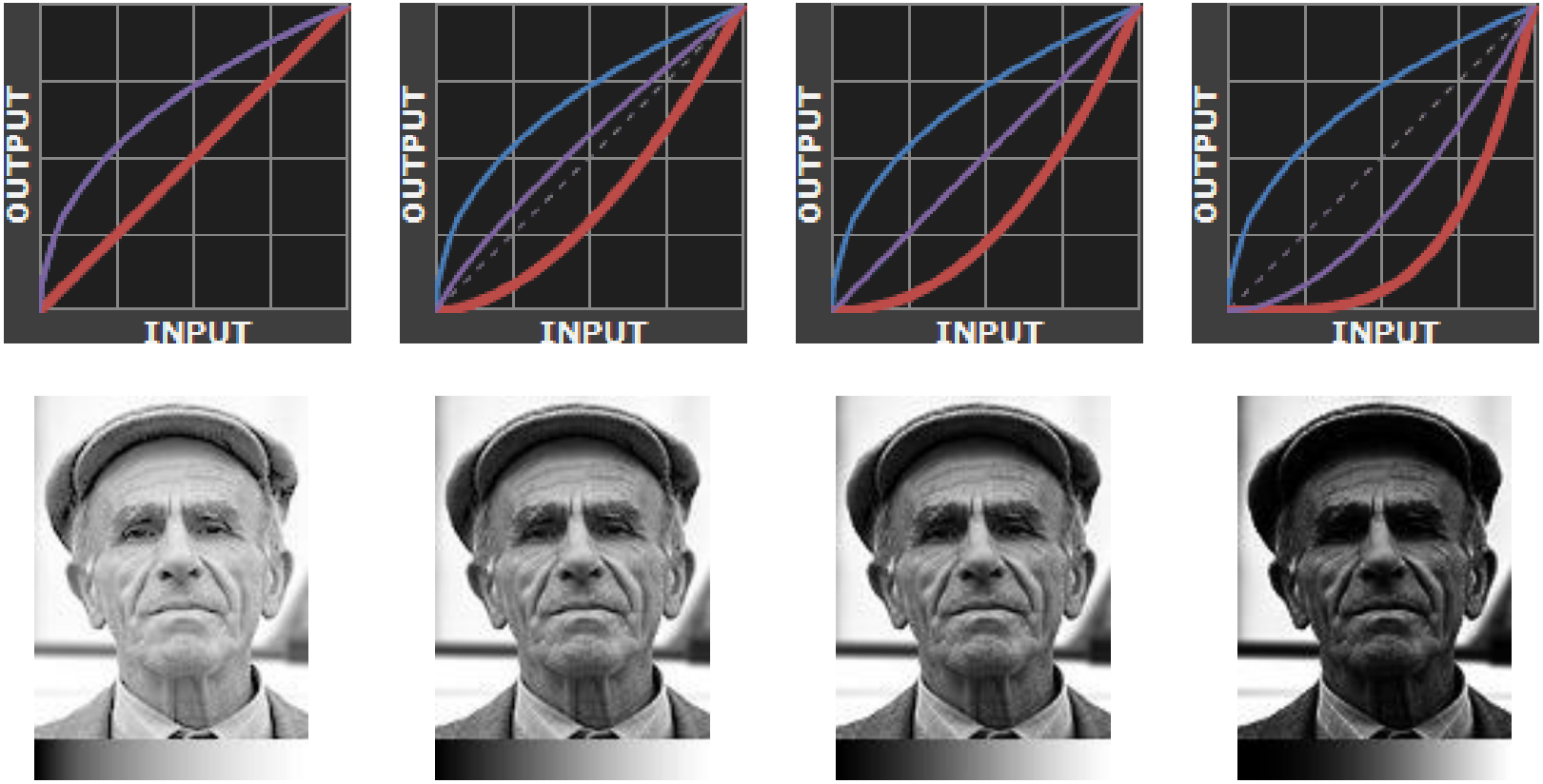
+



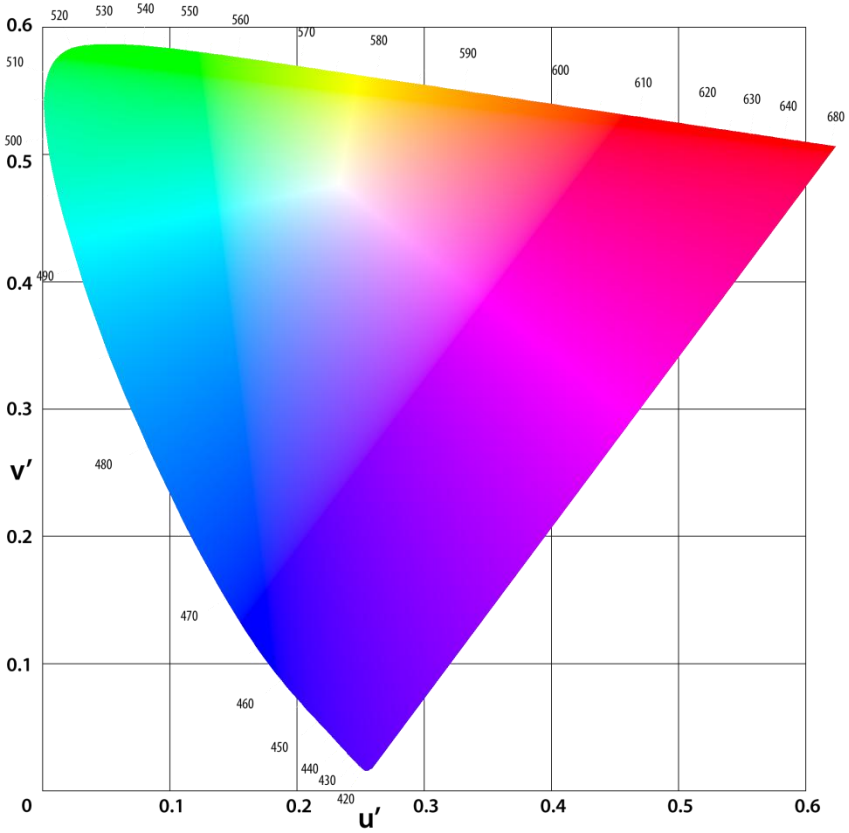
=



PADRÃO $\gamma = 2.2$



ESPAÇO $L^* u' v'$



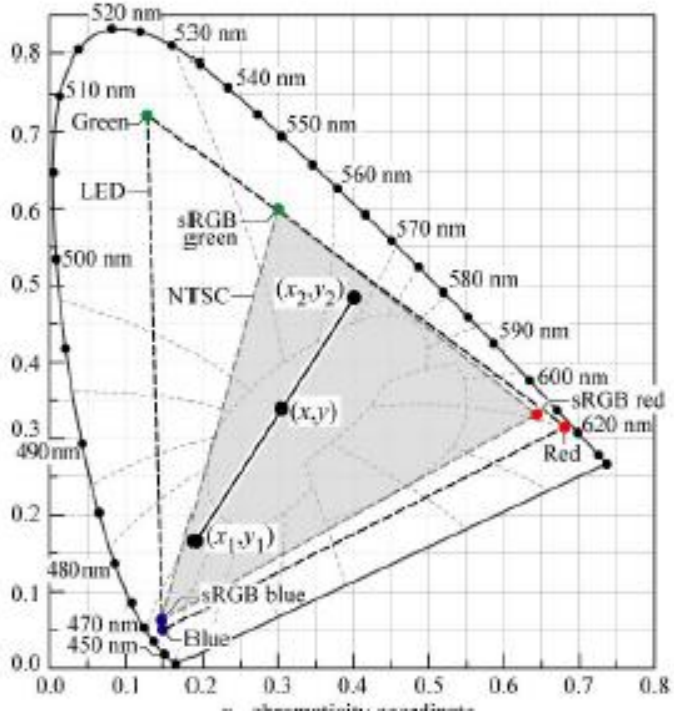
$$\begin{cases} u' = 4x / (-2x + 12\,y + 3) \\ v' = 9y / (-2x + 12\,y + 3) \end{cases}$$

ESPAÇO RGB NÃO-LINEAR

RGB COM CORREÇÃO γ

XYZ (matrix)→ RGB linear (fator g)→
RGB não-linear

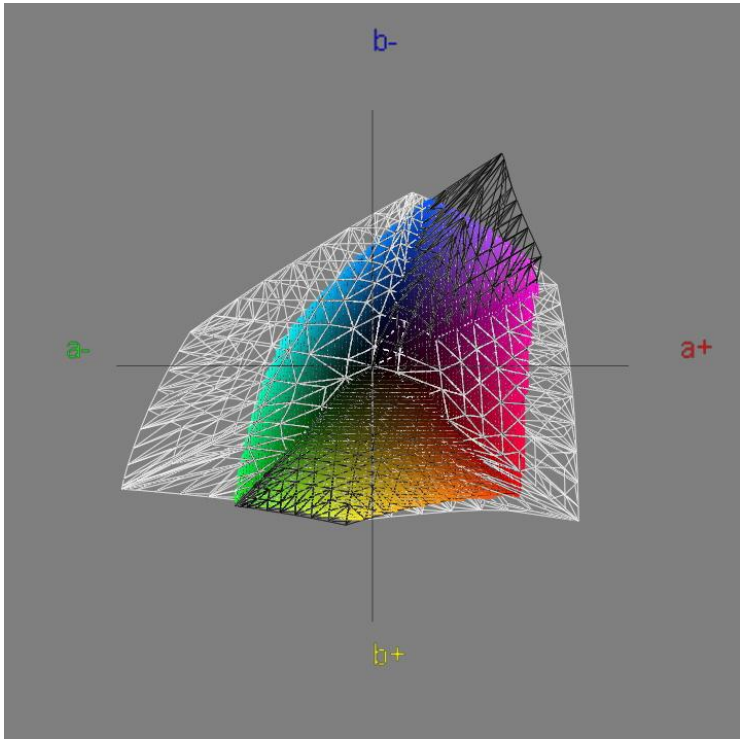
ESPAÇO *sRGB*



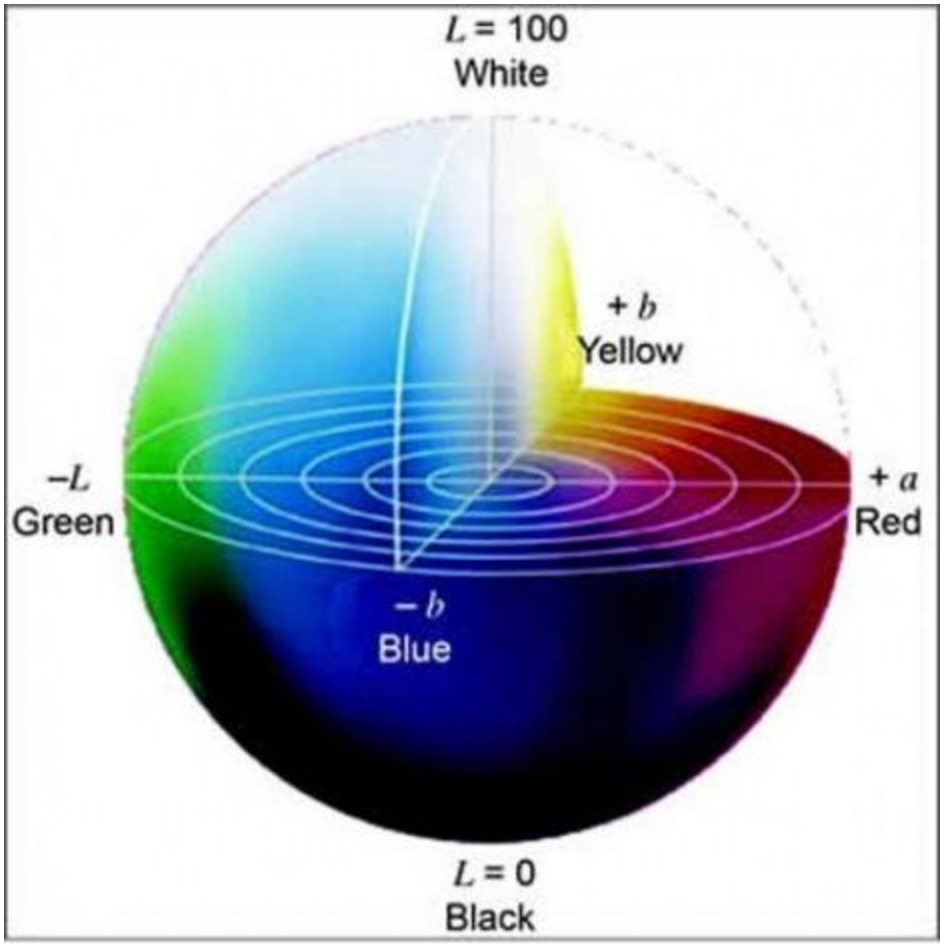
Standard RGB

Proposto por HP e Microsoft

Não-linear* $\gamma_{efetivo}=2.2$



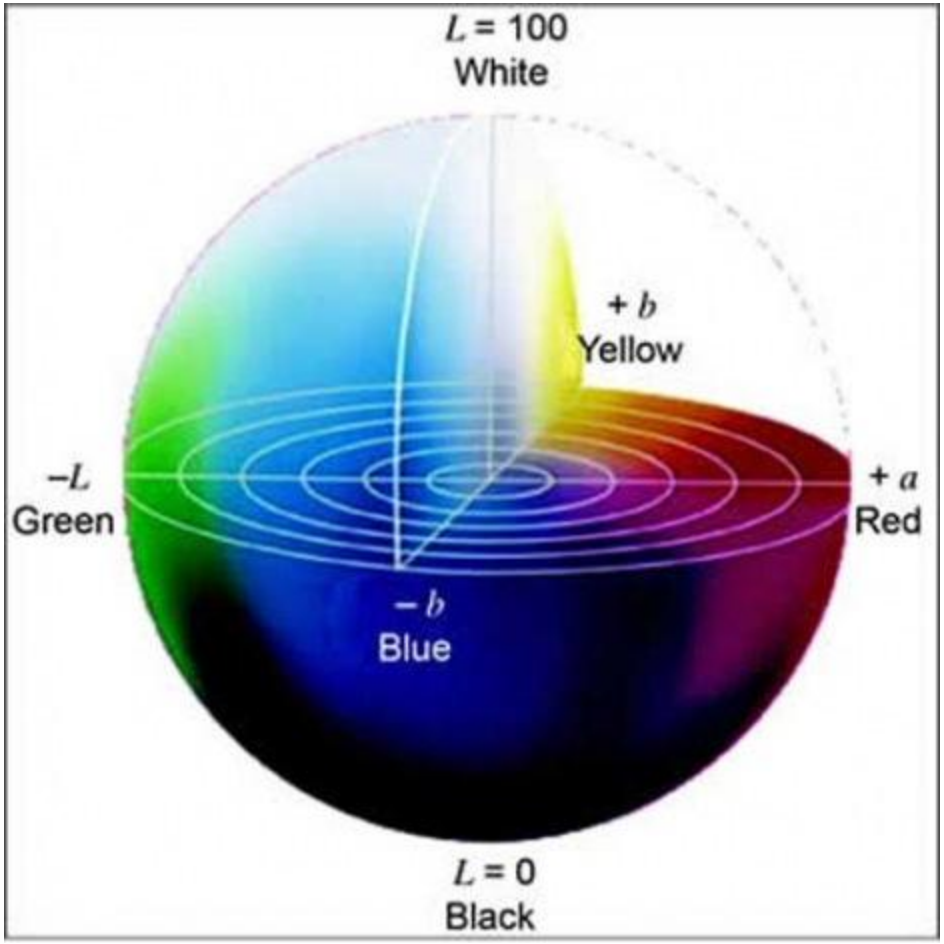
ESPAÇO *L*ab*

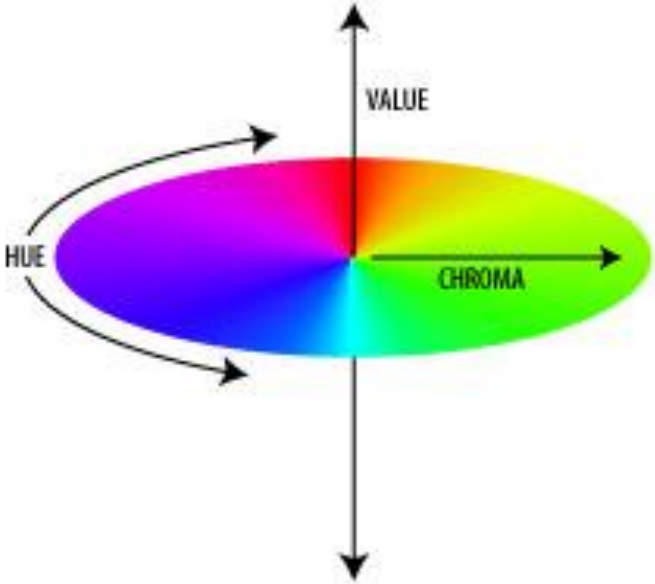


Transformação matemática complexa

Relação com sinais da percepção humana

ESPAÇO *L*ab*


L = 100
White
+ b
Yellow
−L
Green
+ a
Red
− b
Blue
L = 0
Black


VALUE
HUE
CHROMA

ATRIBUTOS DA COR

HUE : **MATIZ** : Nome da cor (azul, verde, ...)

LIGTHNESS : **LUMINOSIDADE** : Intensidade luminosa relativa a uma cor branca em condições similares
BRIGHTNESS : **BRILHO** : Intensidade luminosa absoluta

COLORFULNESS : **?** : Diferença entre a cor e o cinza

CHROMA : **CROMA** : *Colorfulness* relativa ao brilho de uma cor branca em condições similares

SATURATION : **SATURAÇÃO** : *Colorfulness* relativa ao seu próprio brilho (constante do material)