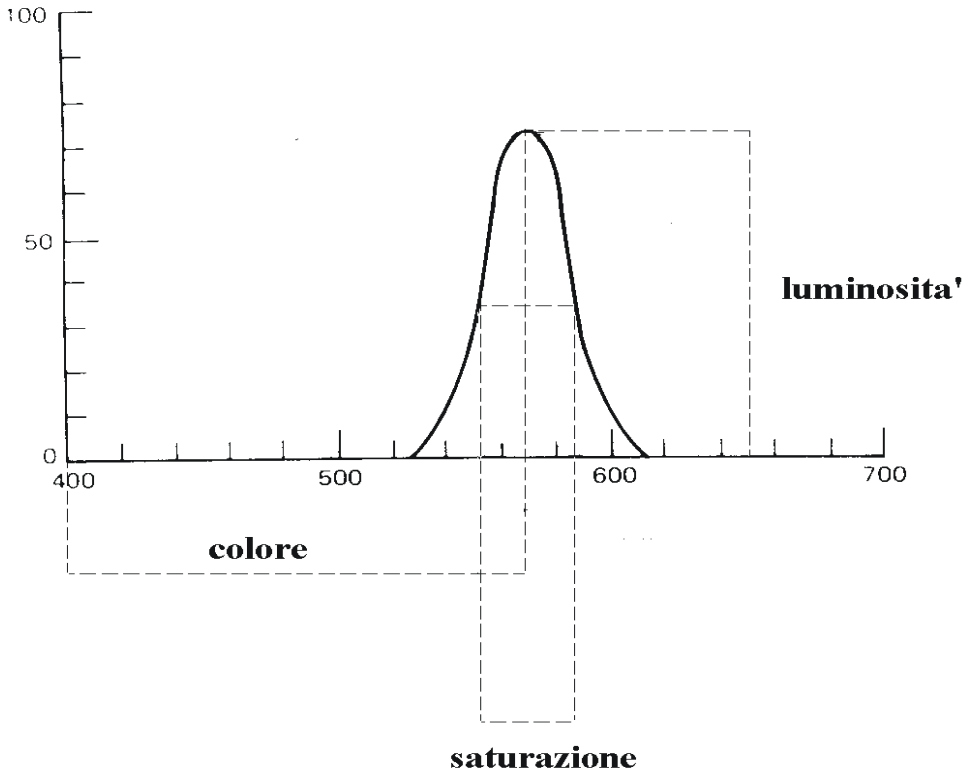
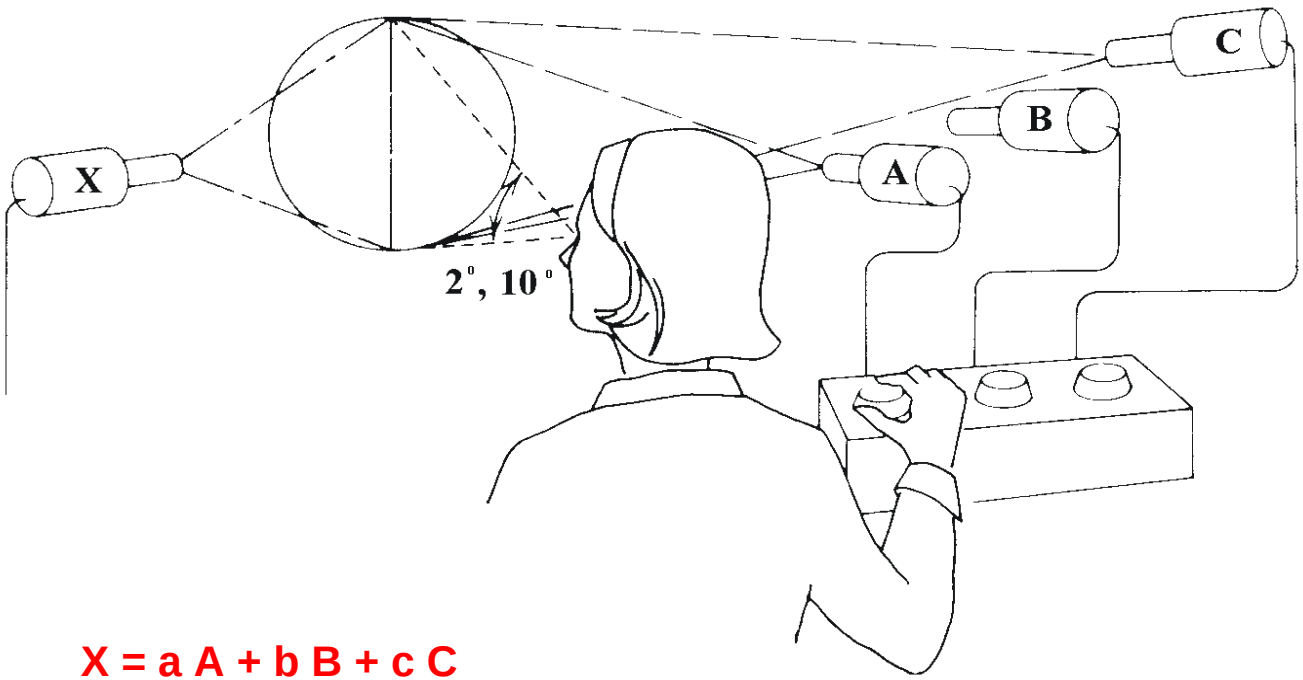
Colorimetria



- **Luminosità**
- **Colore (Hue)**
- **Saturazione**

In qualsiasi sistema colorimetrico un colore è definito da una terna di numeri

Principio di sovrapposizione



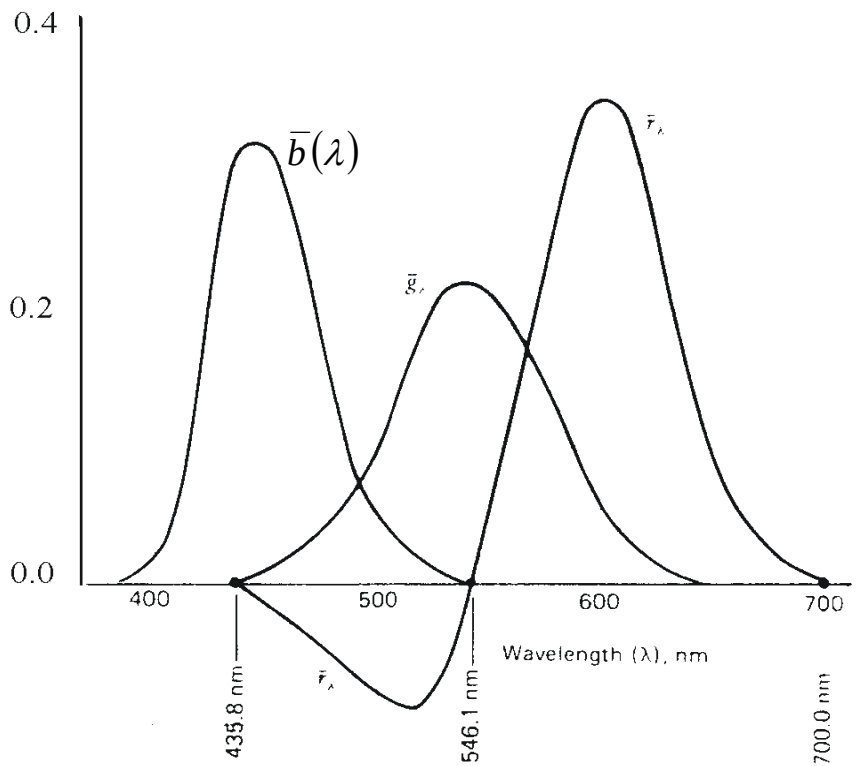
$$X = a\,A + b\,B + c\,C$$

Significato dei coefficienti negativi

$$X + a\,A = b\,B + c\,C \quad \Rightarrow \quad X = -a\,A + b\,B + c\,C$$

CIE 1931 Sistema (R,G,B)

R	**700.0 nm**	**(72.1 μW/sr m²)**
G	**546.1 nm**	**(1.4 μW/sr m²)**
B	**435.8 nm**	**(1.0 μW/sr m²)**



Sorgenti monocromatiche 0.33 μW/(sr m²)

CIE 1931 Sistema (R,G,B)

$P(\lambda)$ **(Spectral Power Distribution)**

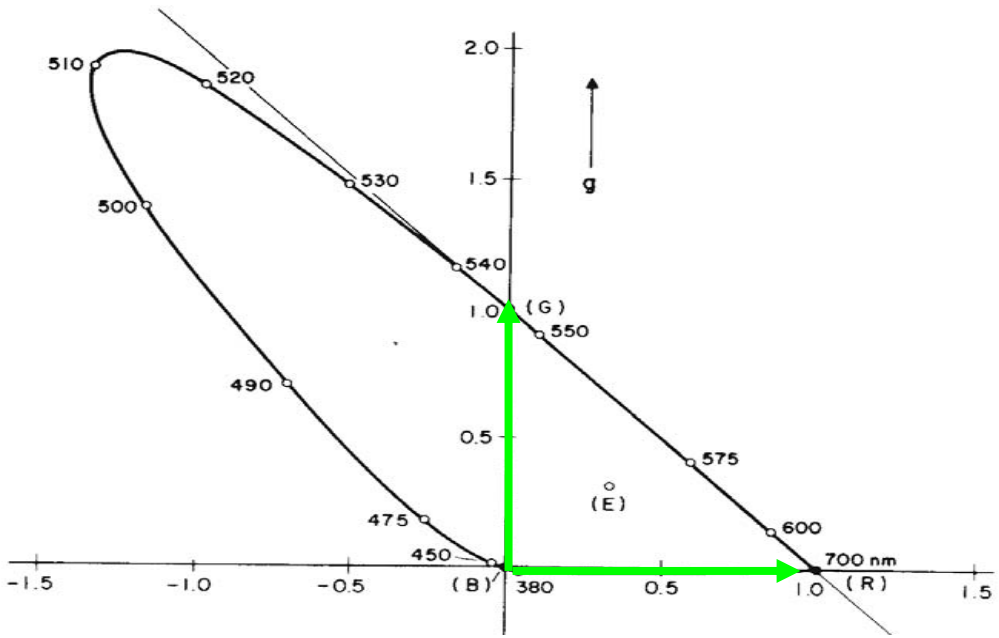
$$R = \int_{\lambda=380}^{\lambda=700} P(\lambda)\bar{r}(\lambda)d\lambda = \sum_i P_{\lambda_i}\bar{r}_{\lambda_i}$$

$$G = \int_{\lambda=380}^{\lambda=700} P(\lambda)\bar{g}(\lambda)d\lambda = \sum_i P_{\lambda_i}\bar{g}_{\lambda_i}$$

$$B = \int_{\lambda=380}^{\lambda=700} P(\lambda)\bar{b}(\lambda)d\lambda = \sum_i P_{\lambda_i}\bar{b}_{\lambda_i}$$

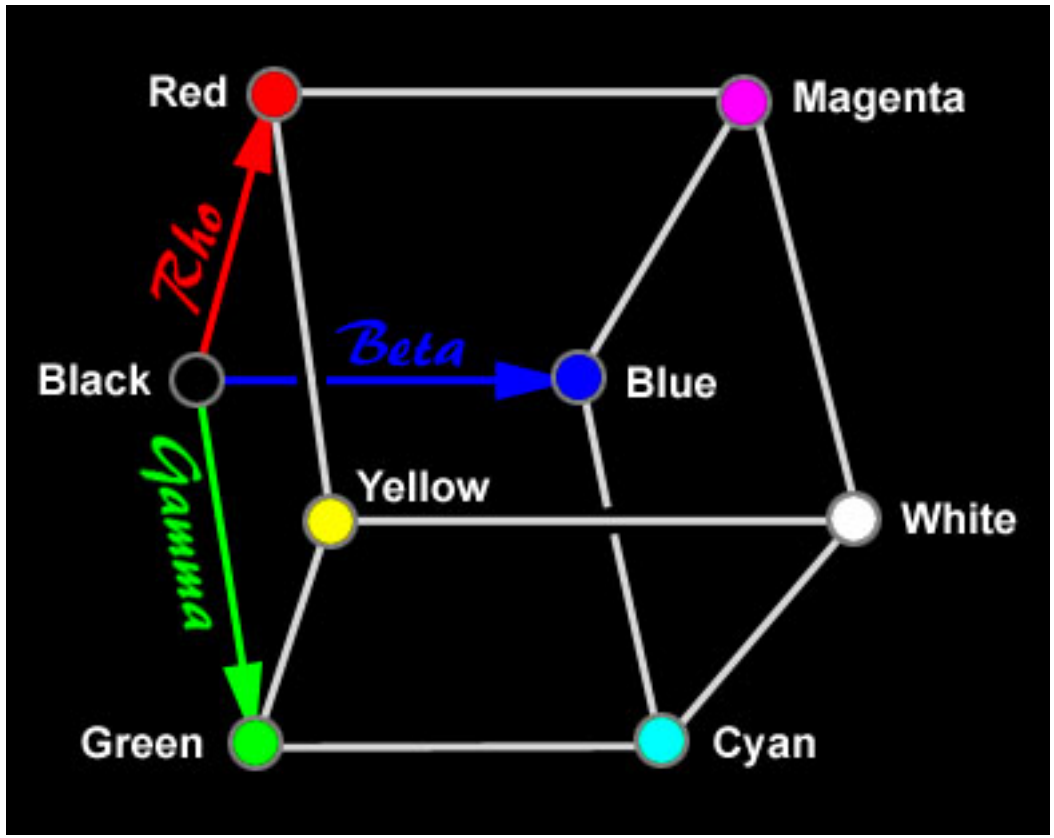
CIE 1931 Sistema (R,G,B)

$$r = \frac{R}{R+G+B} \qquad g = \frac{G}{R+G+B} \qquad b = \frac{B}{R+G+B} \qquad r + g + b = 1$$

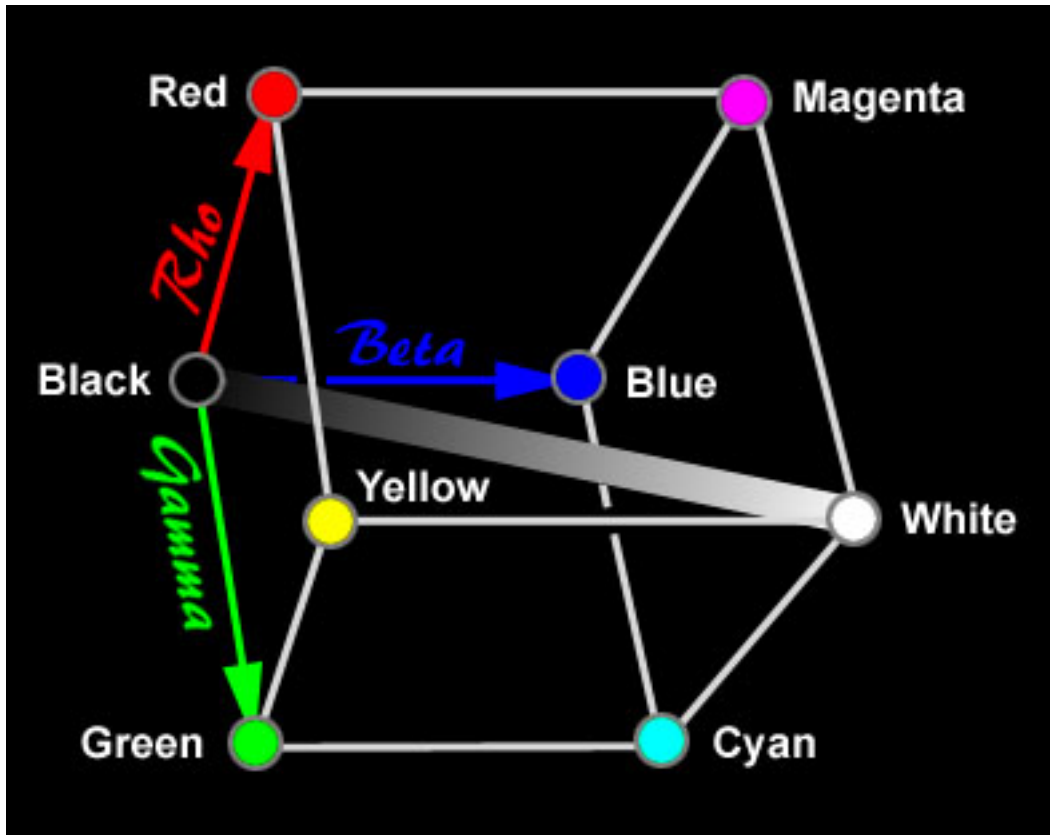


Colore ⟶ r, g, R

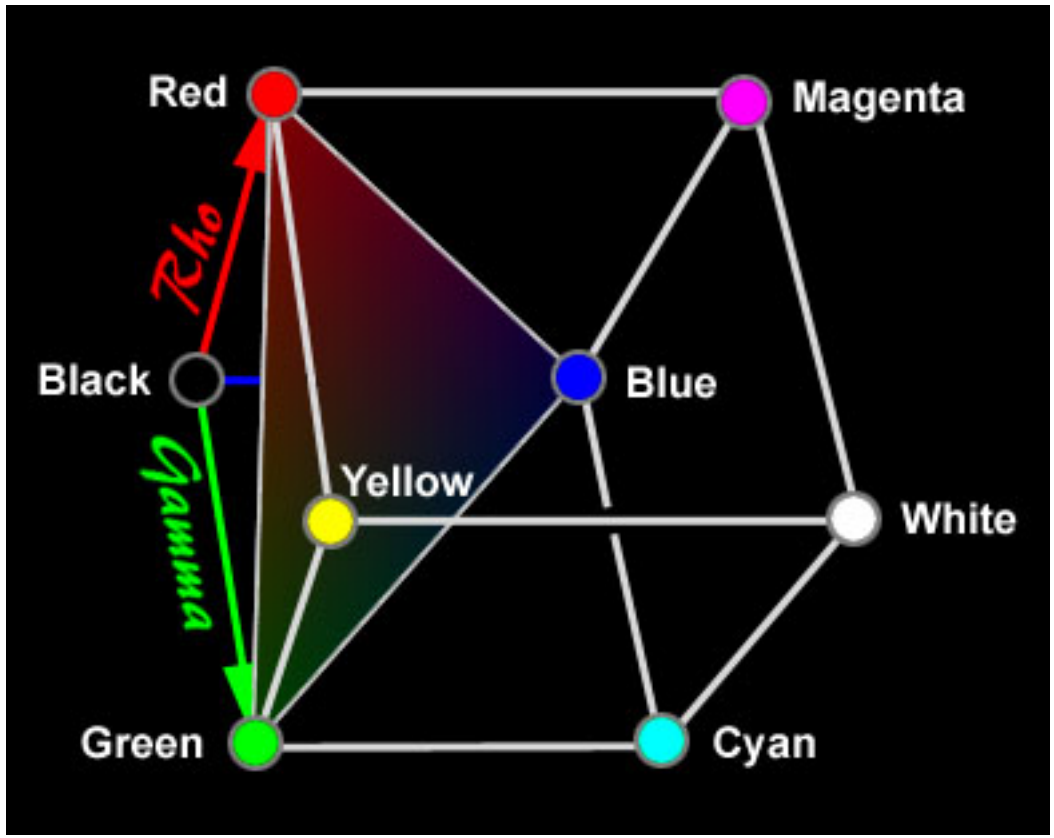
Cubo dei colori



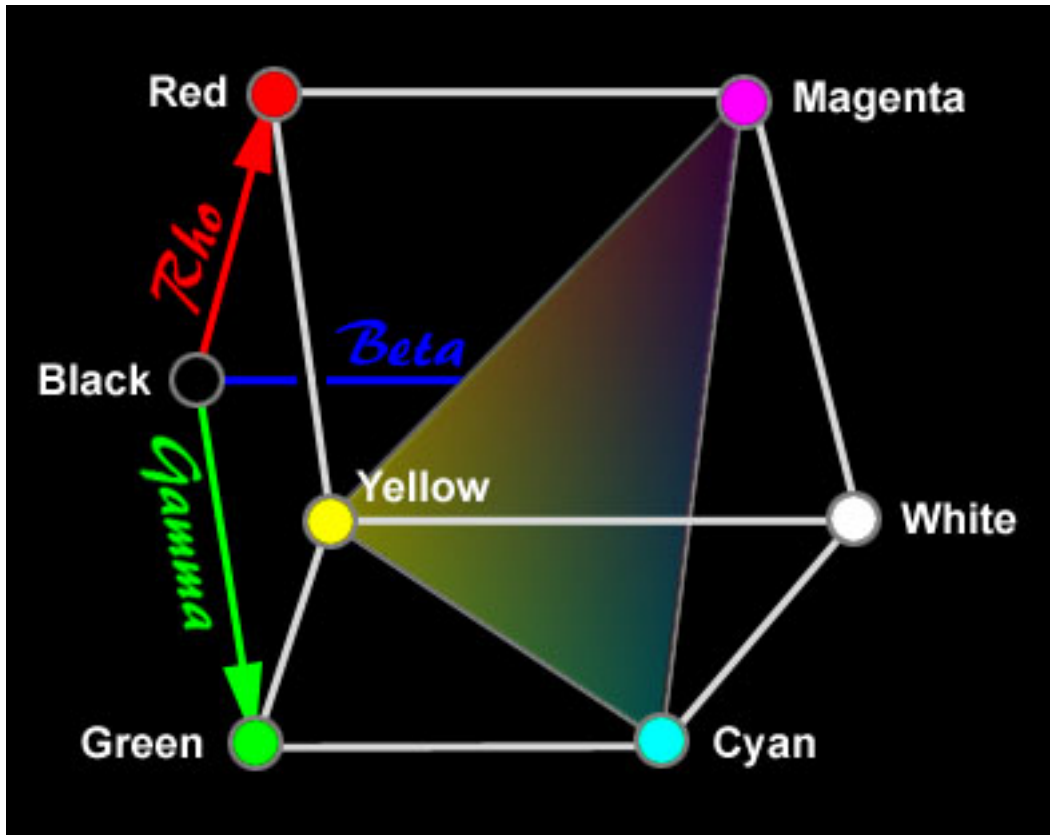
Cubo dei colori



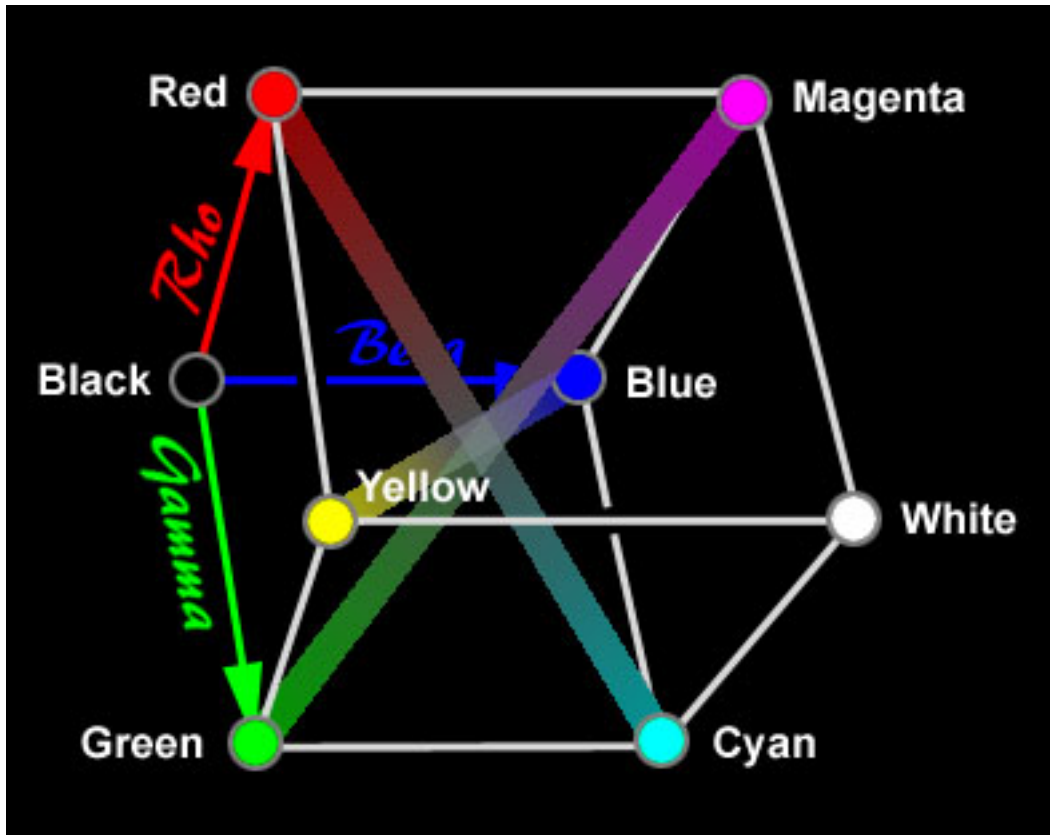
Cubo dei colori



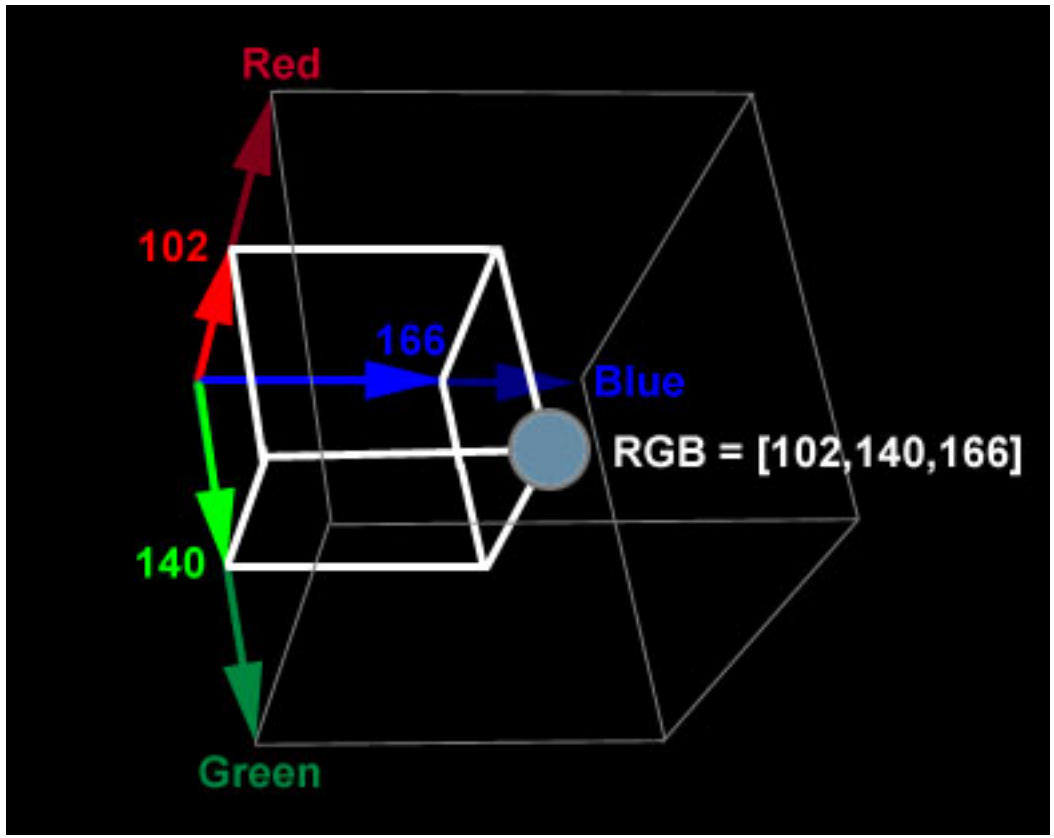
Cubo dei colori



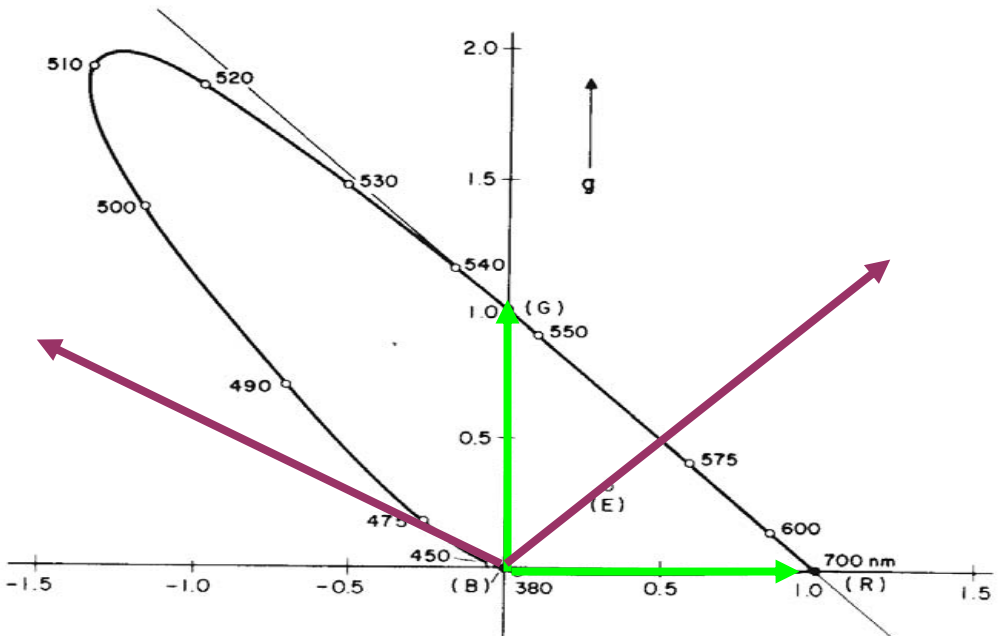
Cubo dei colori



Cubo dei colori



CIE 1931 Sistema (R,G,B) → CIE 1931 Sistema (X,Y,Z)



CIE 1931 Sistema (X,Y,Z)

Colore: vettore nello spazio lineare tridimensionale di base (**R**, **G**, **B**)

(**R**, **G**, **B**) ⇒ (**X, Y, Z**)

$$X = a_{11} R + a_{12} G + a_{13} B$$

$$Y = a_{21} R + a_{22} G + a_{23} B$$

$$Z = a_{31} R + a_{32} G + a_{33} B$$

$$X = 0.49000\, R + 0.31000\, G + 0.20000\, B$$

$$Y = 0.17697\, R + 0.81240\, G + 0.01063\, B$$

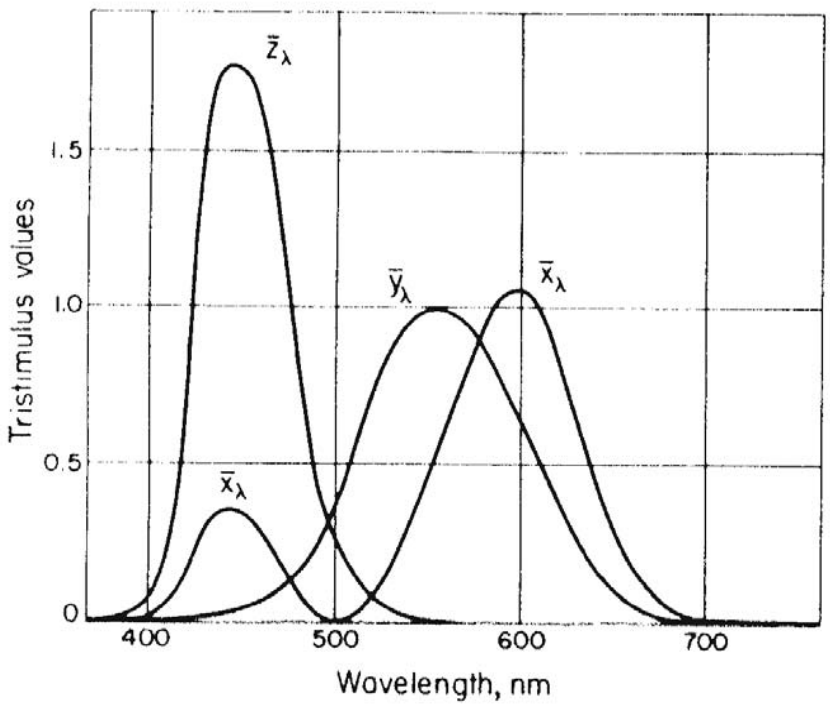
$$Z = 0.00000\, R + 0.01000\, G + 0.99000\, B$$

1) In questa base qualsiasi colore, ovvero qualsiasi punto del *locus* dei colori è identificato da tre coordinate positive.

2) La scelta dei coefficienti della coordinate *Y* è tale che $Y(\lambda)$ si identifica esattamente con la curva di sensibilità diurna (***fotopica***)

CIE 1931 Sistema (X,Y,Z)

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



CIE 1931 Sistema (X,Y,Z)

$P(\lambda)$ **(Spectral Power Distribution)**

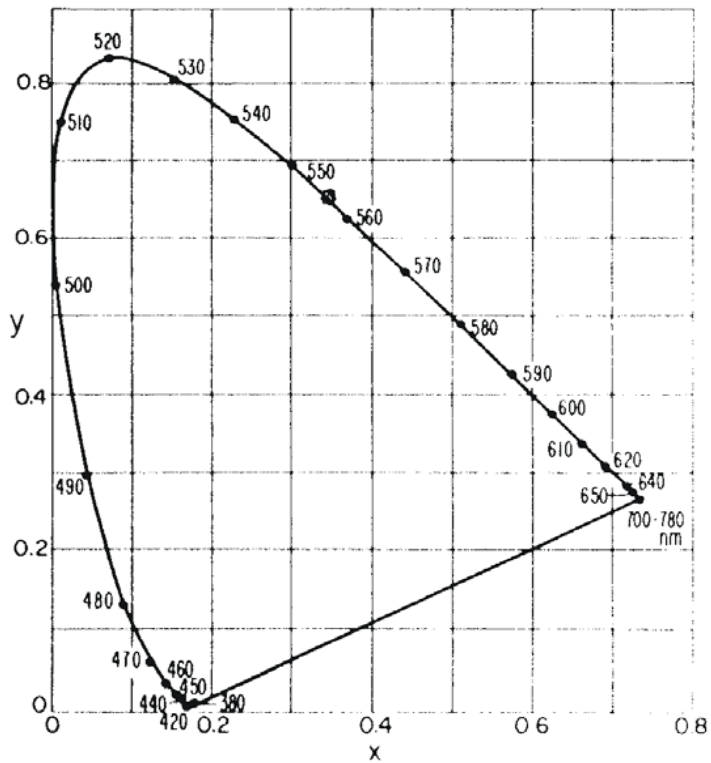
$$X = \int_{\lambda=380}^{\lambda=700} P(\lambda)\bar{x}(\lambda)d\lambda = \sum_i P_{\lambda_i}\bar{x}_{\lambda_i}$$

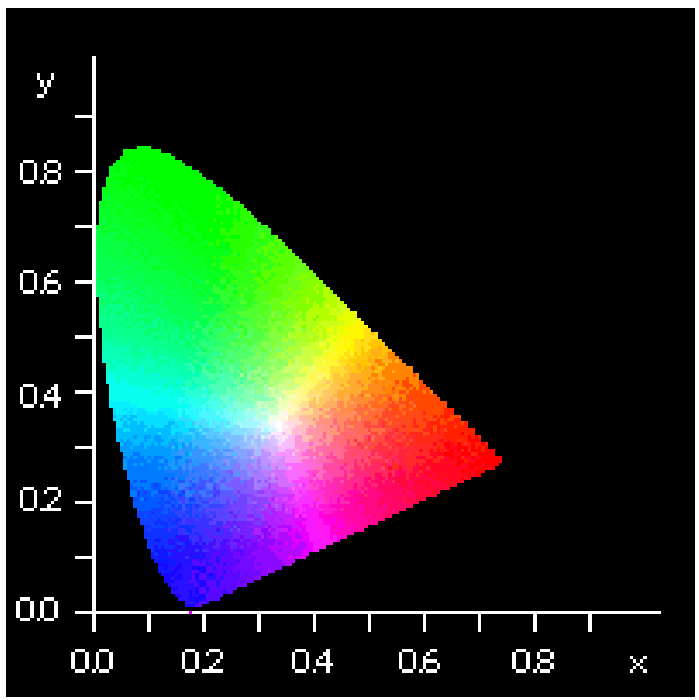
$$Y = \int_{\lambda=380}^{\lambda=700} P(\lambda)\bar{y}(\lambda)d\lambda = \sum_i P_{\lambda_i}\bar{y}_{\lambda_i}$$

$$Z = \int_{\lambda=380}^{\lambda=700} P(\lambda)\bar{z}(\lambda)d\lambda = \sum_i P_{\lambda_i}\bar{z}_{\lambda_i}$$

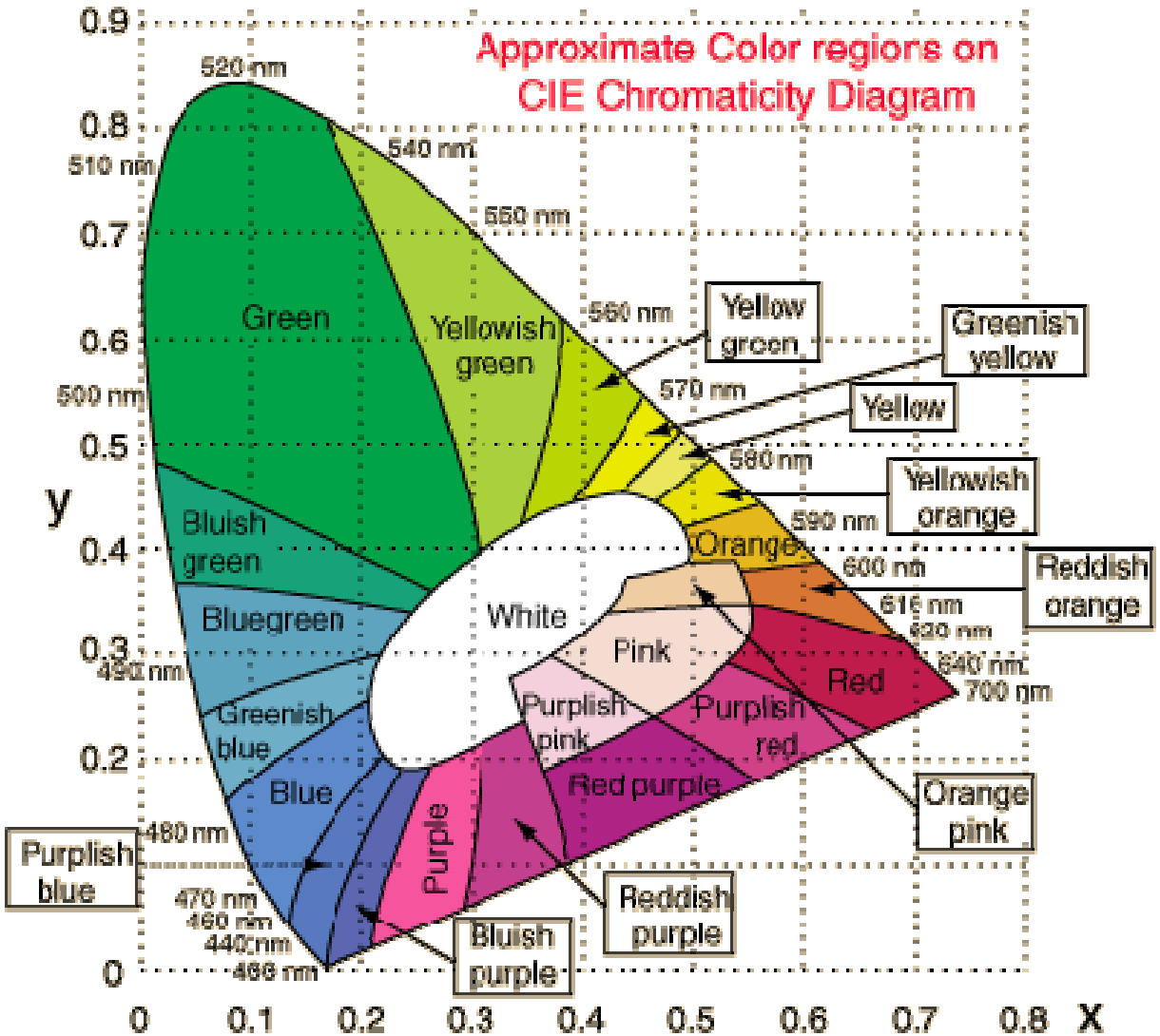
CIE 1931 Sistema (X,Y,Z)

$$x = \frac{X}{X+Y+Z} \quad y = \frac{Y}{X+Y+Z} \quad z = \frac{Z}{X+Y+Z} \qquad x + y + z = 1$$



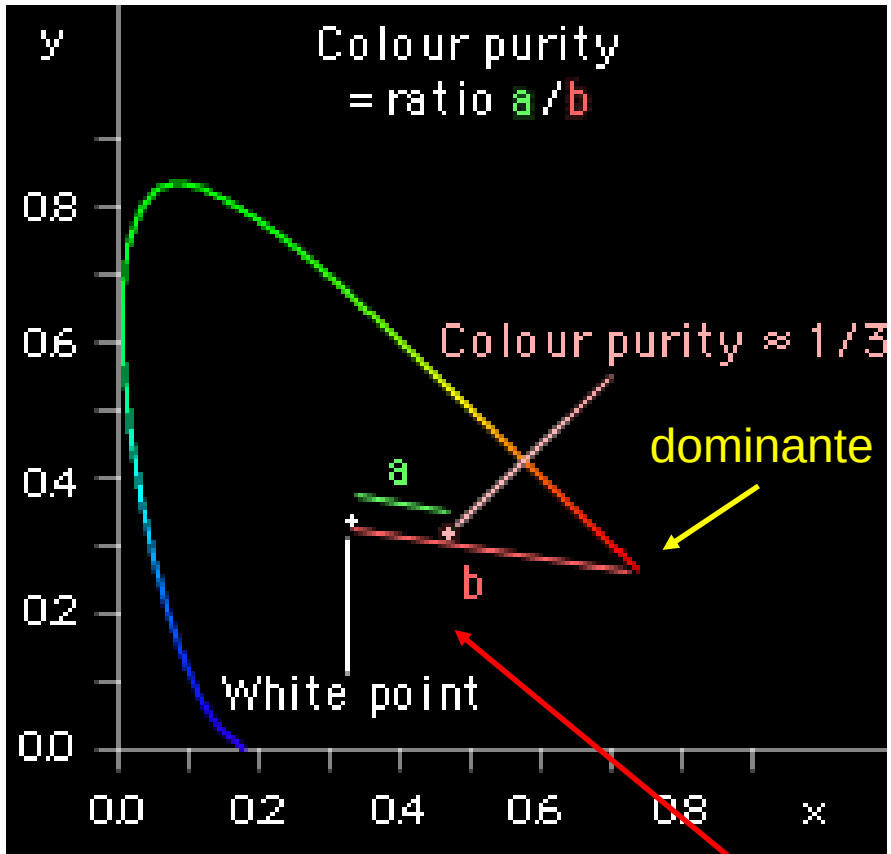


CIE 1931 Sistema (X,Y,Z)



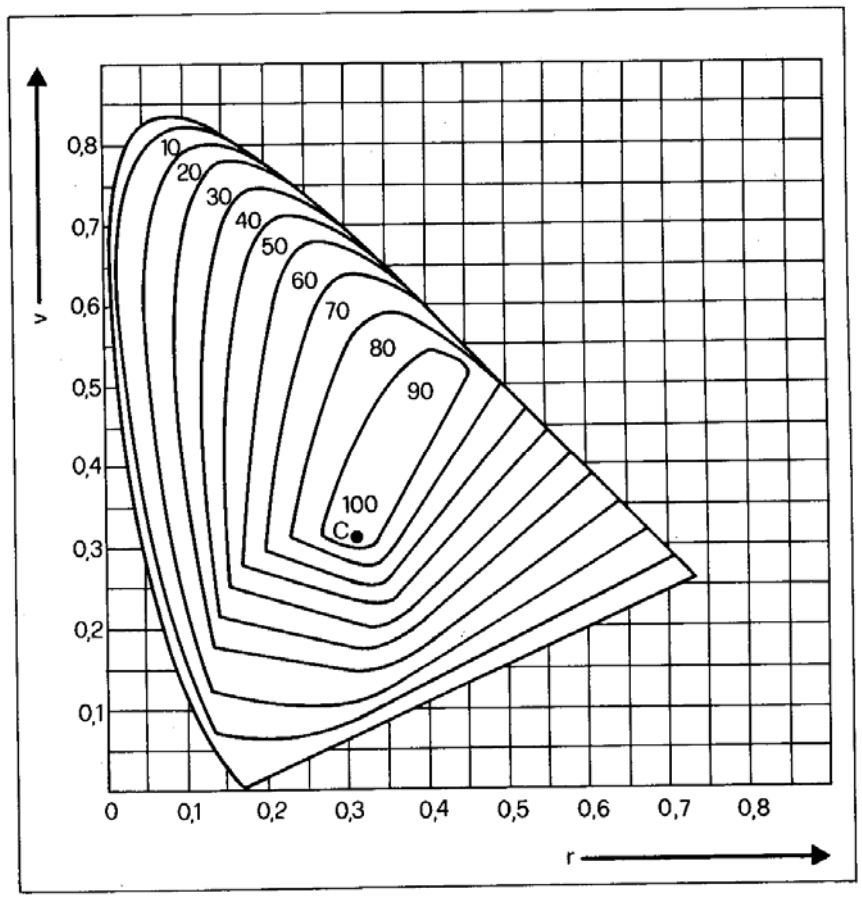
CIE 1931 Sistema (X,Y,Z)

Saturazione (colour purity)

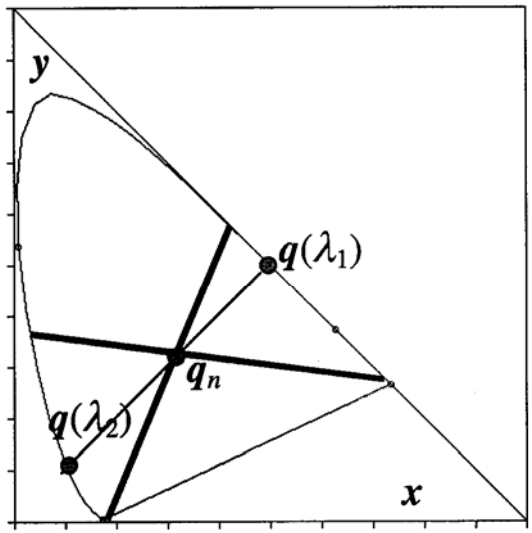


Per questi colori si considera la lunghezza d'onda complementare

Curve di livello del locus tridimensionale

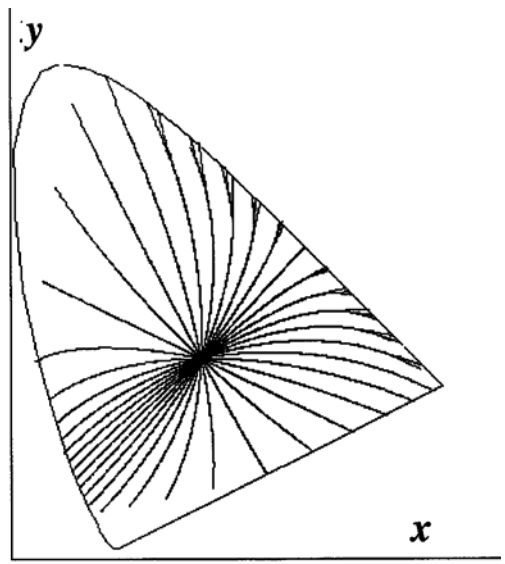


CIE 1931 Sistema (X,Y,Z)

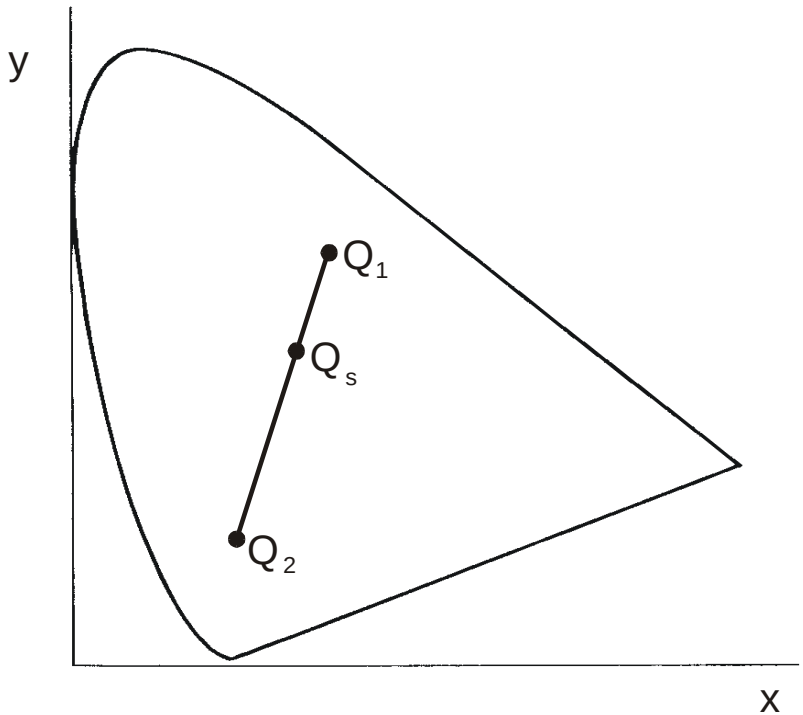


Colori complementari

Curve isocolore (hue)



SOMMA DI COLORI

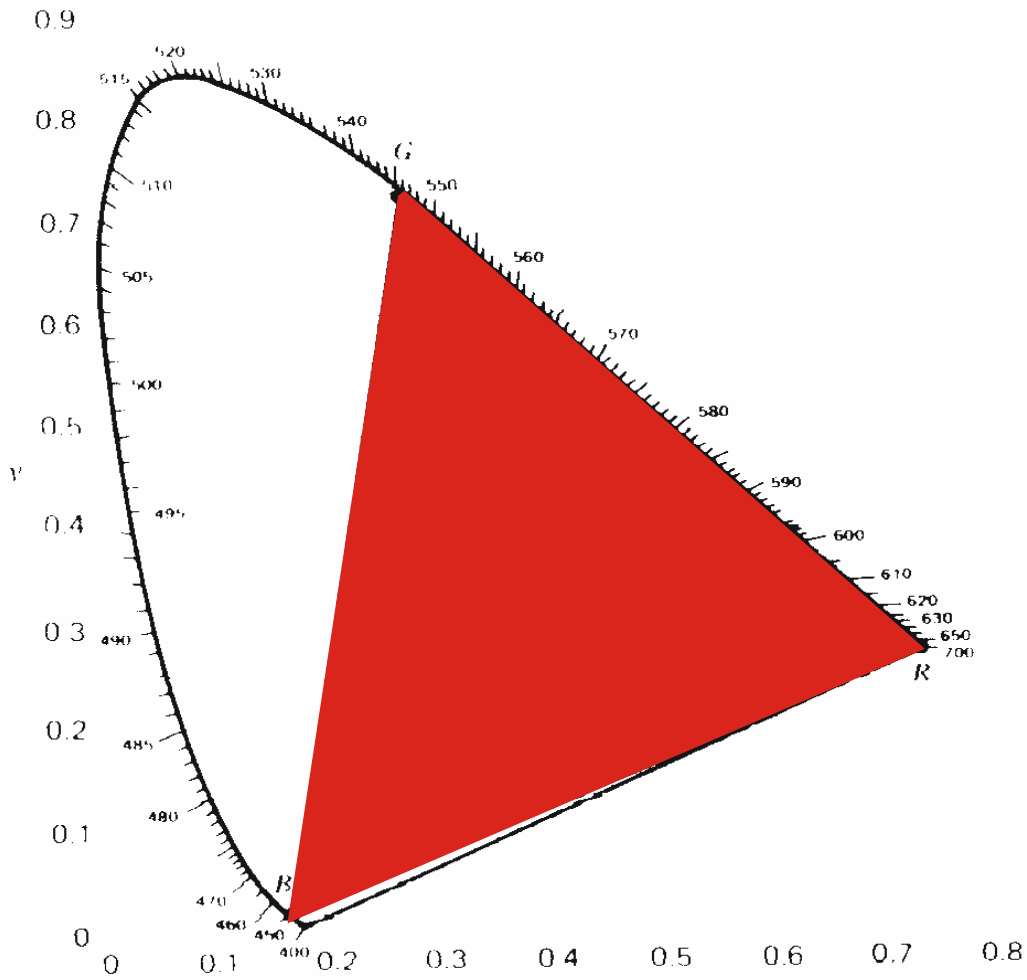


$$x_s = \frac{w_1 x_1 + w_2 x_2}{w_1 + w_2}$$

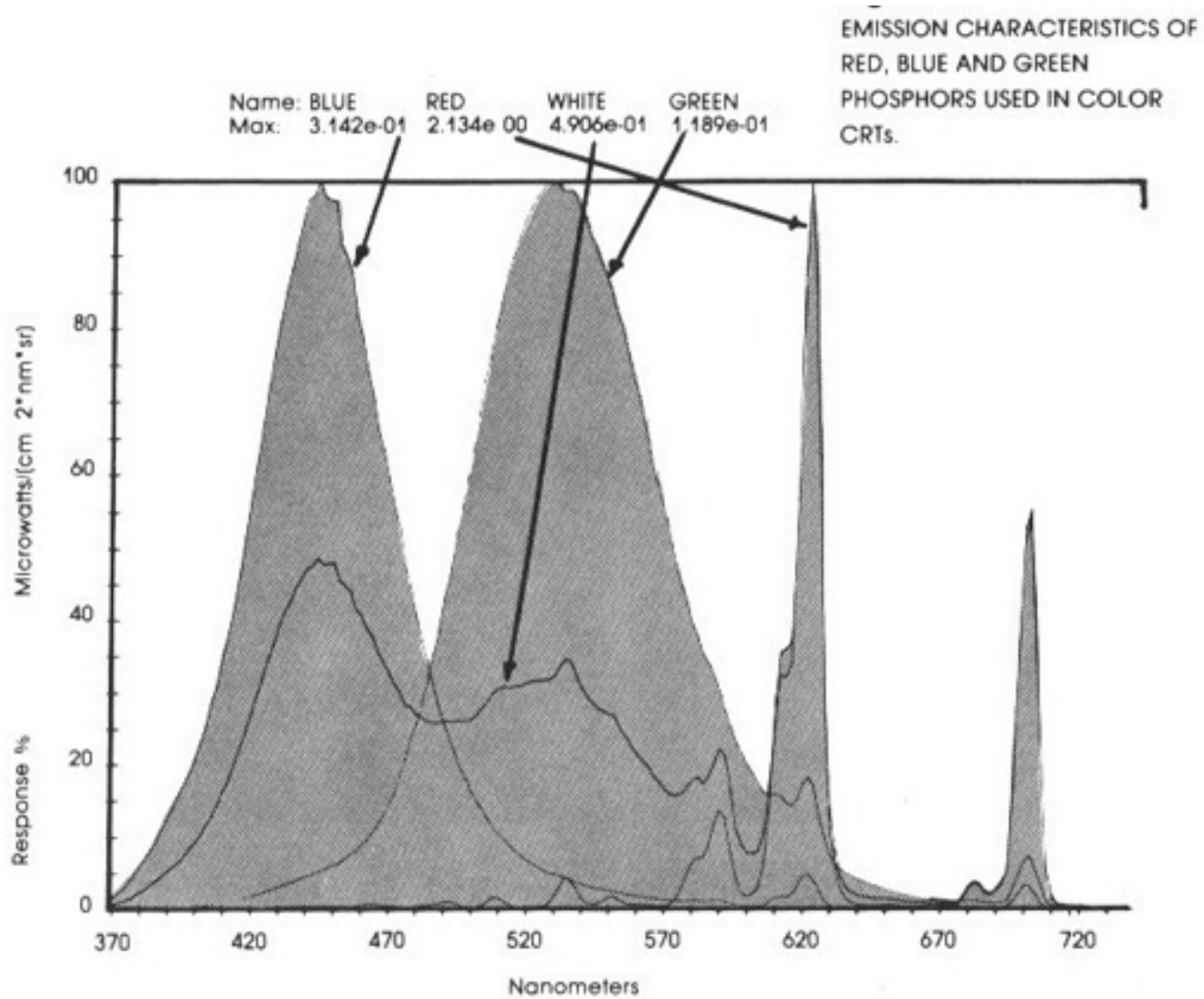
$$y_s = \frac{w_1 y_1 + w_2 y_2}{w_1 + w_2}$$

$$w_i = \frac{1}{X_i + Y_i + Z_i}$$

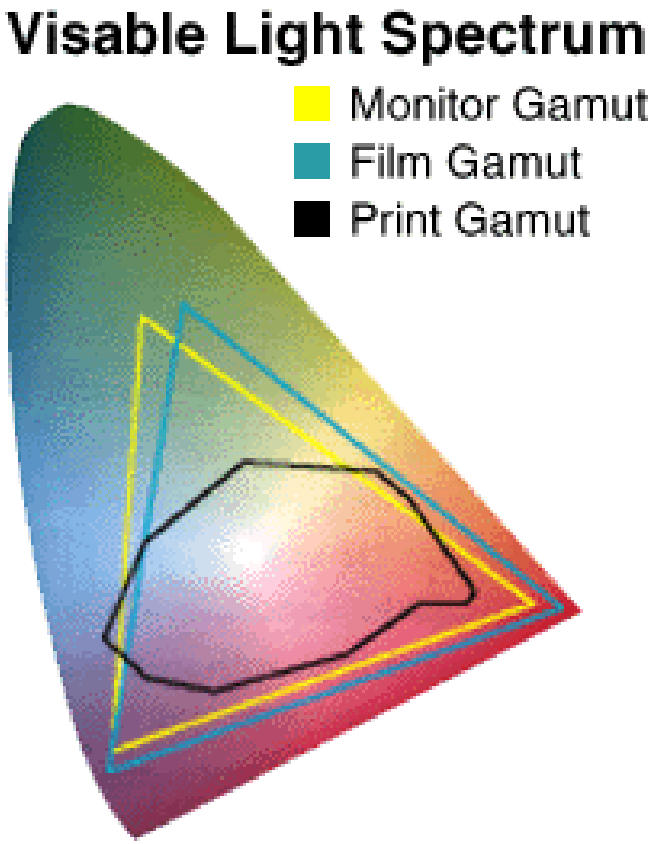
IL GAMUT


0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
y
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
520
515
510
505
500
495
490
485
480
475
470
460
450
400
540
550
560
570
580
590
600
610
620
630
650
700
G
R
B

Spettri tipici di emissione dei fosfori per CRT

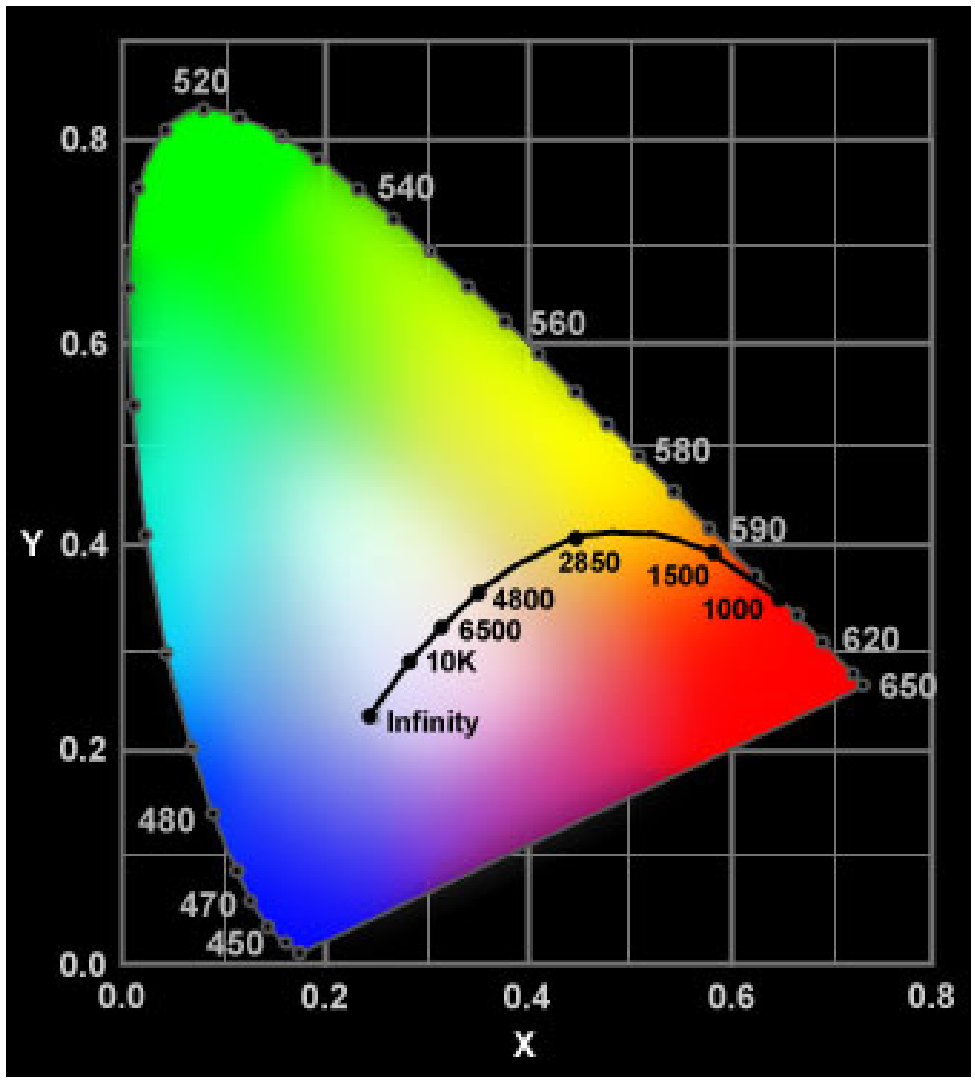


IL GAMUT

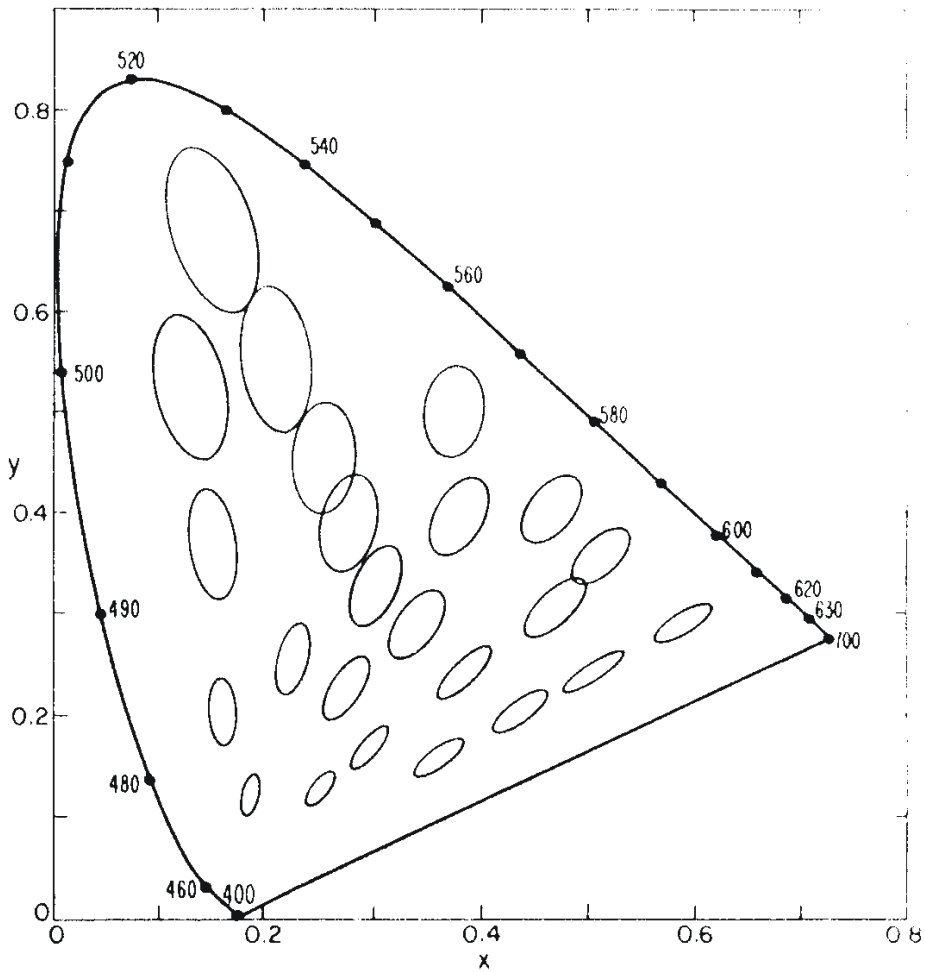


Color gamuts of color monitor,
film and print shown transposed
on the 1931 CIE x*y*z* color space.

Curva del corpo nero



IL PROBLEMA DELLE DIFFERENZE DI COLORE



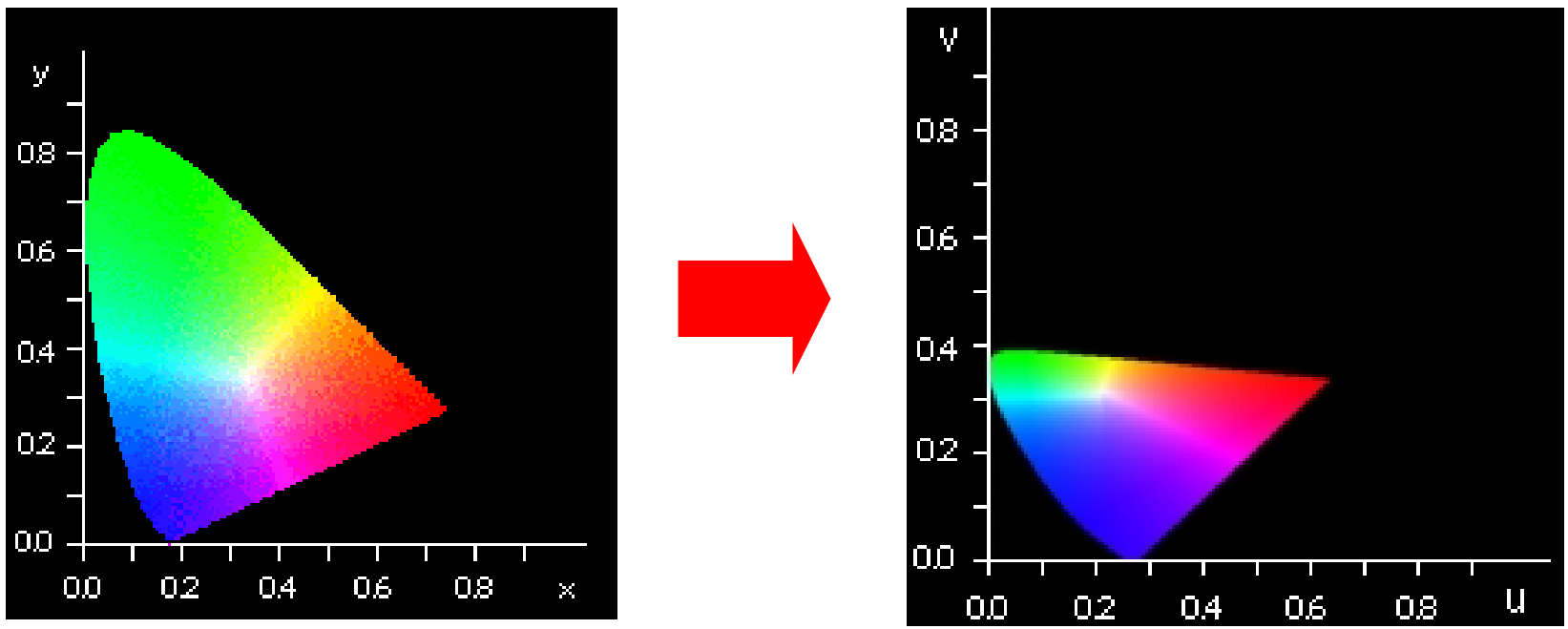
Ellissi JND ingrandite di un fattore 10

CIE 1960 Sistema (u,v,w)

$$u = 4x / (3 - 2x + 12y)$$

$$v = 6y/ (3 - 2x + 12y)$$

$$w = (6y - 6x + 3) / (3 - 2x + 12y)$$

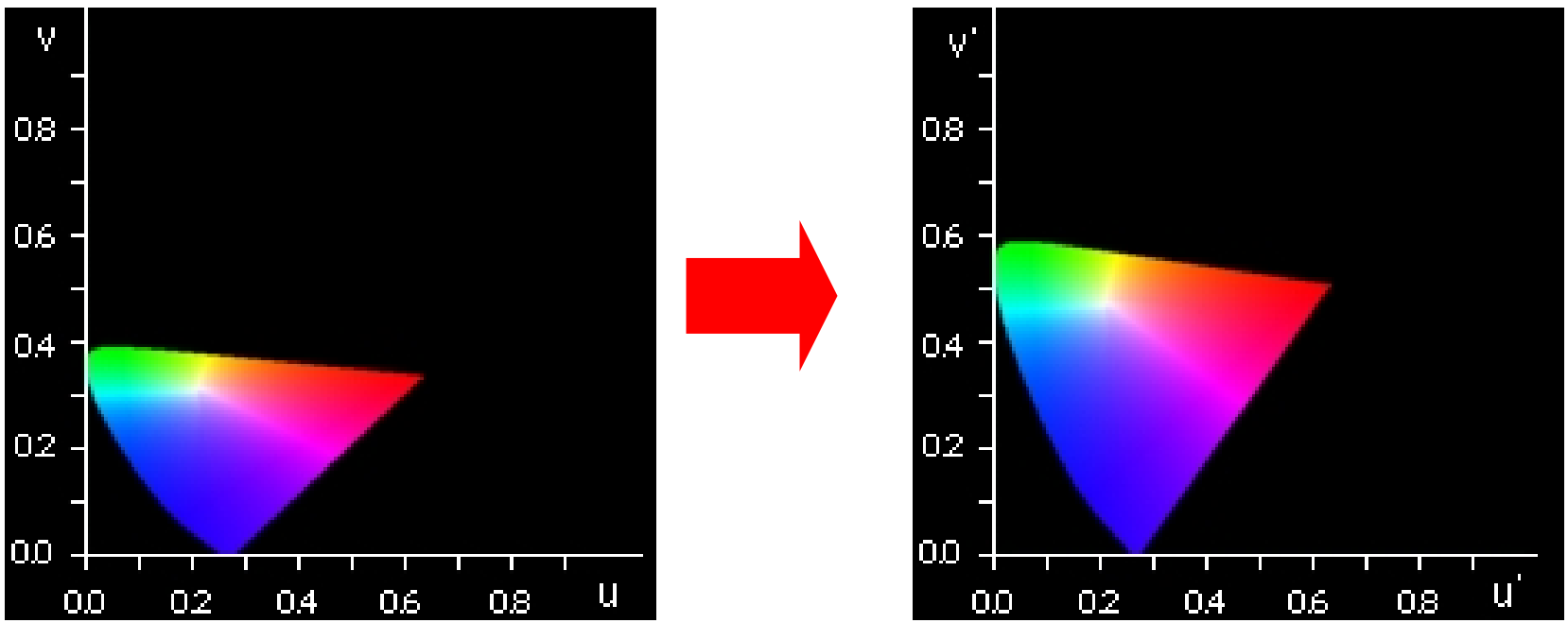


CIE 1976 Sistema (u’,v’,w’)

u’ = u

v’ = (3/2) v

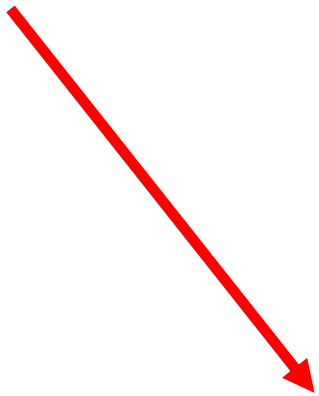
w’ = w



CIE 1960-1976-1994

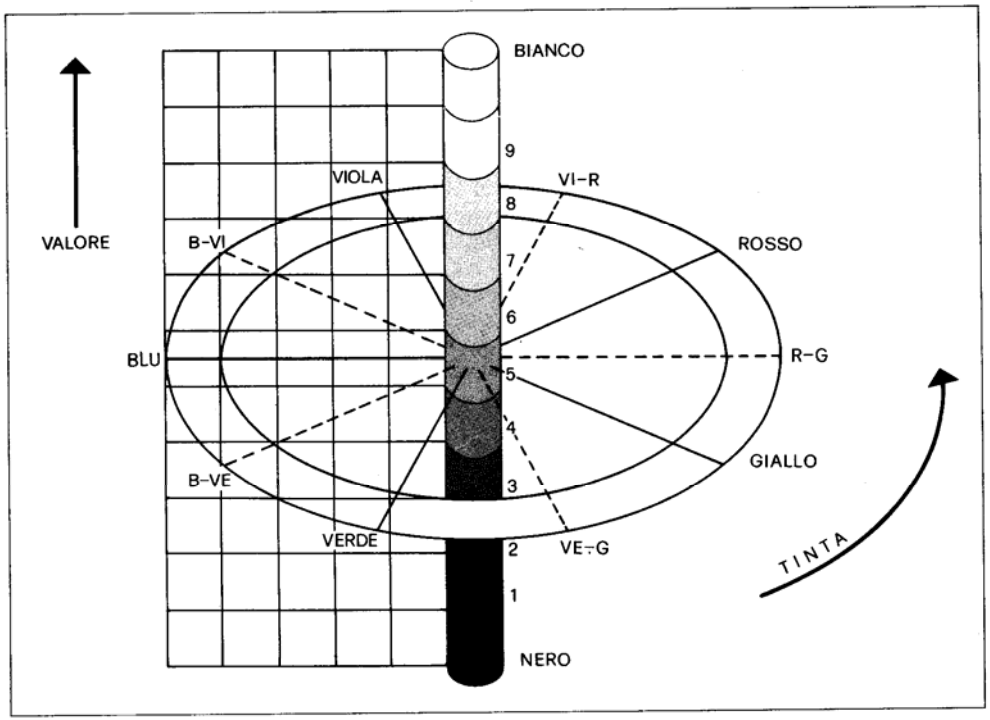
1) **Illuminante**

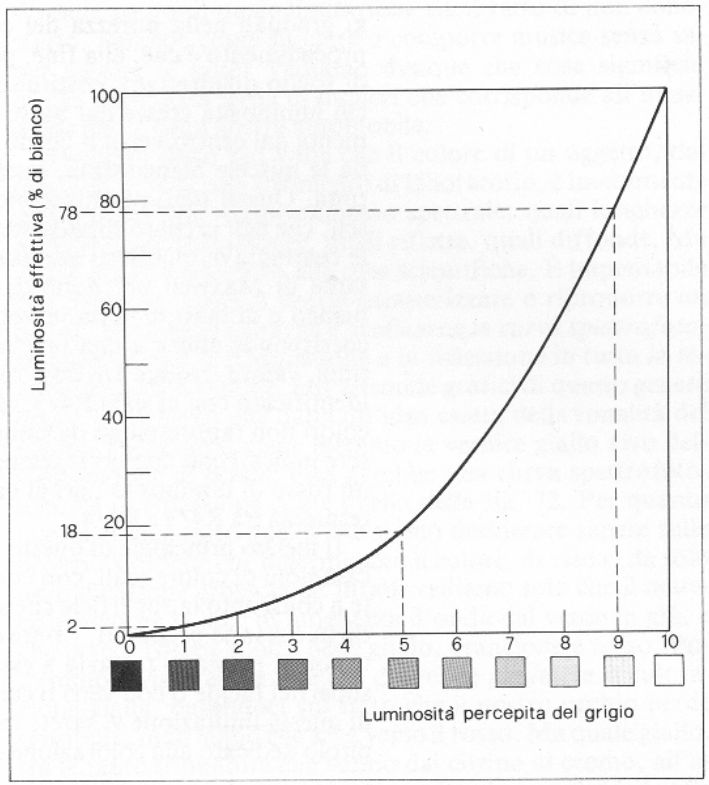
2) **Differenze di colore**



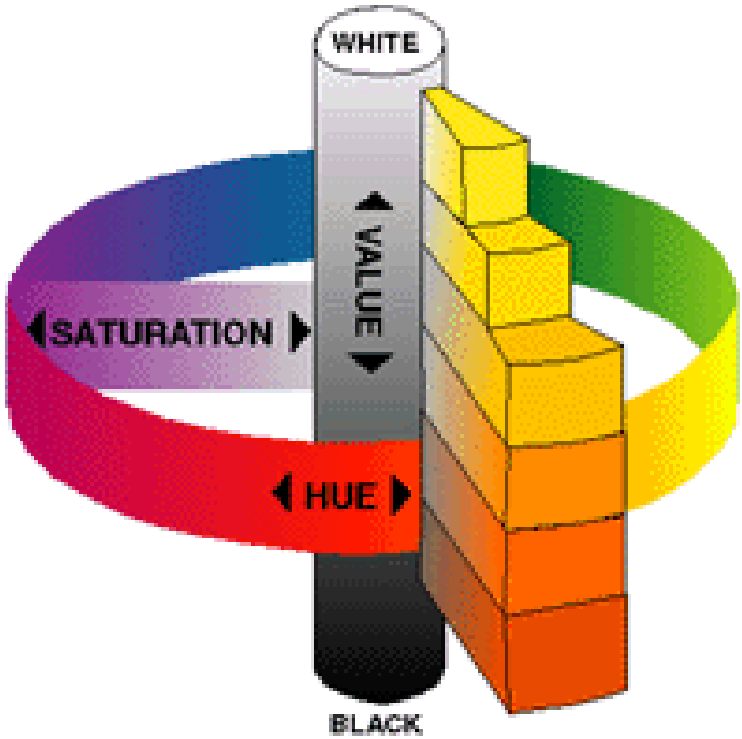
Lo spazio dei colori ora è uno **spazio metrico**,
ma **non** uno **spazio vettoriale**

Atlante dei colori di Munsel 1915-1929

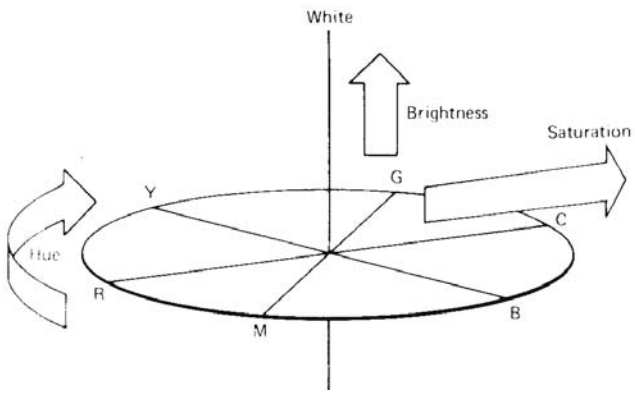




CIE 1976 Sistema Lab



Hue, Saturation and Value Diagram



CIE 1976 Sistema Lab

$$X^* = \sqrt[3]{\frac{X}{X_n}} \qquad Y^* = \sqrt[3]{\frac{Y}{Y_n}} \qquad Z^* = \sqrt[3]{\frac{Z}{Z_n}}$$

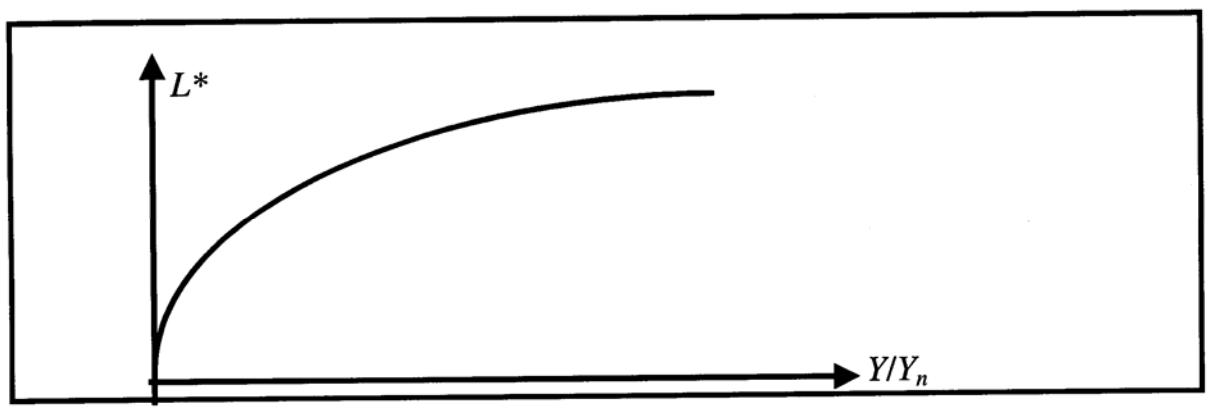
$$a = 500\,(X^* - Y^*)$$

$$b = 500\,(Y^* - Z^*)$$

$$C = \sqrt{a^2 + b^2} \qquad h = arctg\,\frac{b}{a}$$

$$L = 116\,Y^* - 16 \qquad for\ Y^* > 0.008856$$

$$L = 903.3\,Y^* \qquad for\ Y^* < 0.008856$$



CIE 1976 Sistema Lab

$$\Delta E^2 = (a_T - a_R)^2 + (b_T - b_R)^2 + (L_T - L_R)^2$$

$$\Delta E^2 = (\Delta L)^2 + (\Delta C)^2 + (\Delta H)^2$$

$$\Delta L = L_T - L_R$$

$$\Delta C = C_T - C_R$$

$$\Delta H = \sqrt{\Delta E^2 - \Delta L^2 - \Delta C^2}$$

CIE 1976 Sistema Lab

$$\Delta E^2 = (\Delta L)^2 + (\Delta C)^2 + (\Delta H)^2$$

$$\Delta E^2 = \left(\frac{\Delta L}{S_L}\right)^2 + \left(\frac{\Delta C}{S_C}\right)^2 + \left(\frac{\Delta H}{S_H}\right)^2$$

$$S_L = \frac{0.040975L}{1 + 0.01765L}$$

$$S_C = \frac{0.0638C}{1 + 0.0131C} + 0.638$$

$$S_H = \frac{S_C}{Tf + 1 - f}$$

$$T = 0.36 + \left|0.4\cos\left(H + 35\right)\right|$$

$$T = 0.36 + \left|0.2\cos\left(H + 168°\right)\right|$$

$$164° < H < 345°$$

$$f = \frac{4C}{4C + 1900}$$

CIE 1994 Sistema Lab

$$\Delta E^2 = \left(\frac{\Delta L}{S_L}\right)^2 + \left(\frac{\Delta C}{S_C}\right)^2 + \left(\frac{\Delta H}{S_H}\right)^2$$

$$S_L = 1$$

$$S_C = 1 + 0.045C$$

$$S_H = 1 + 0.015C$$

CIE Sistema Lab