Il colore: dall'apparenza colorata alla misura colorimetrica

XXIX Giornata della Misurazione

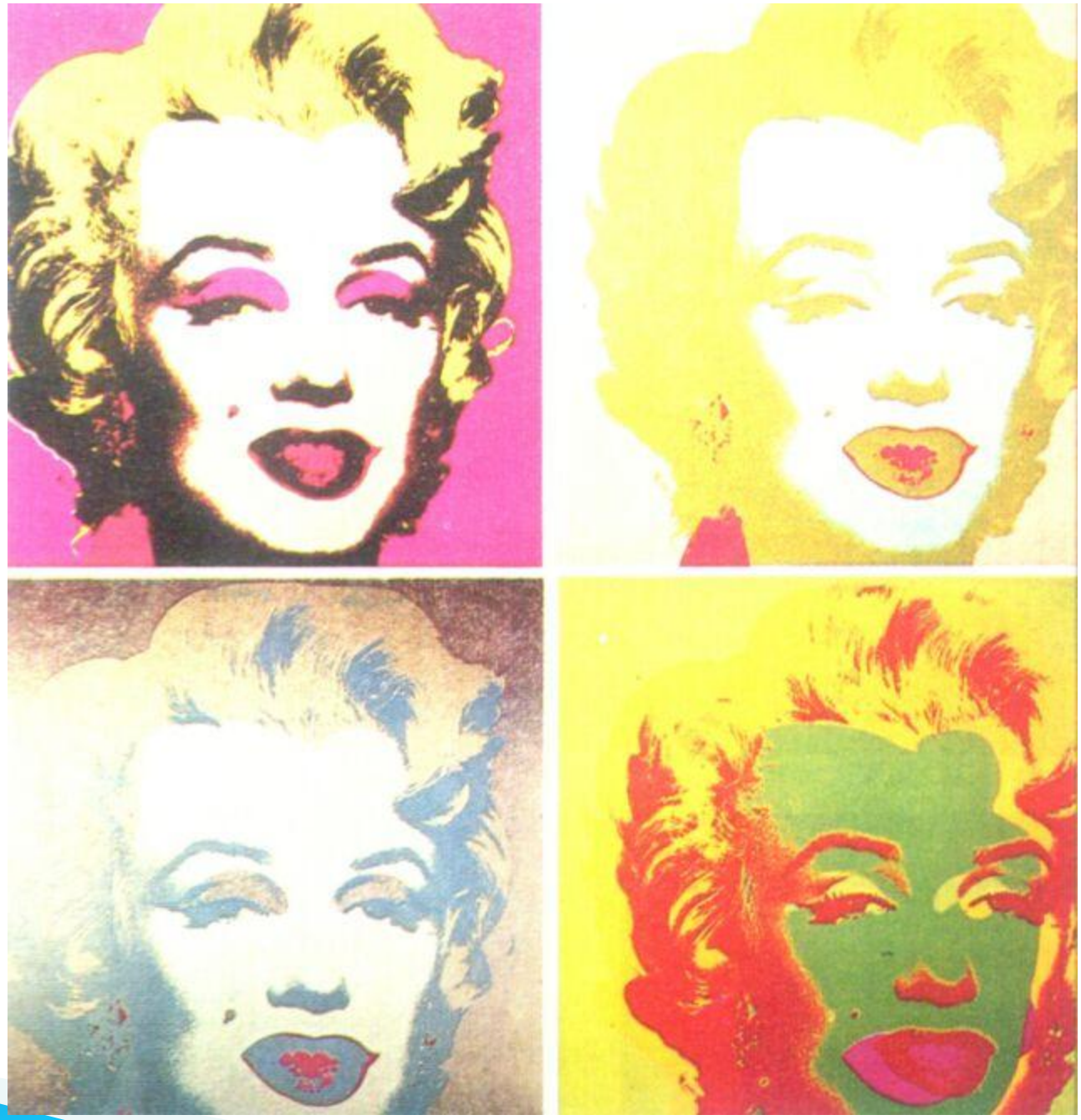
10 giugno 2010, Roma

ISTITUTO
NAZIONALE
DI RICERCA
METROLOGICA

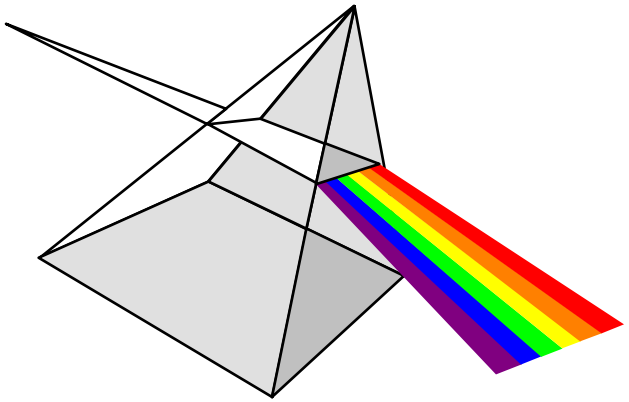
Warhol,

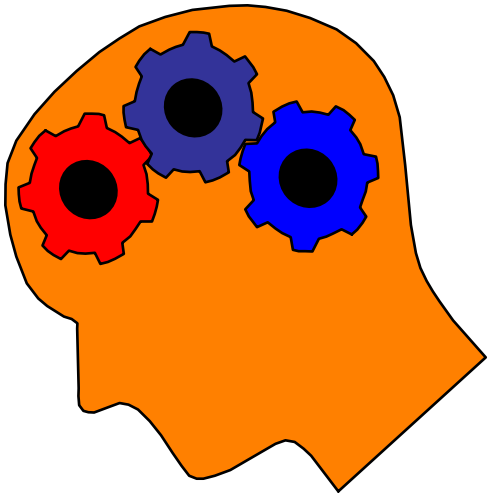
Marilyn

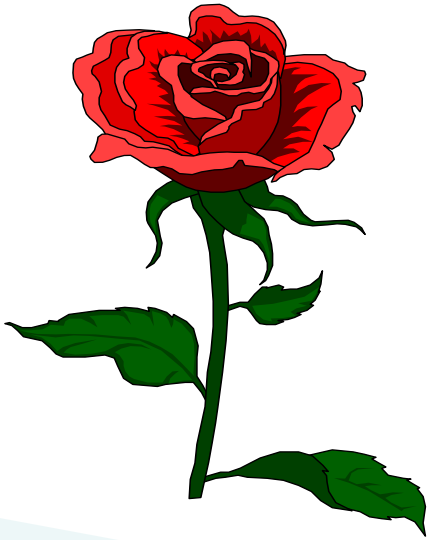
Monroe
(1967)



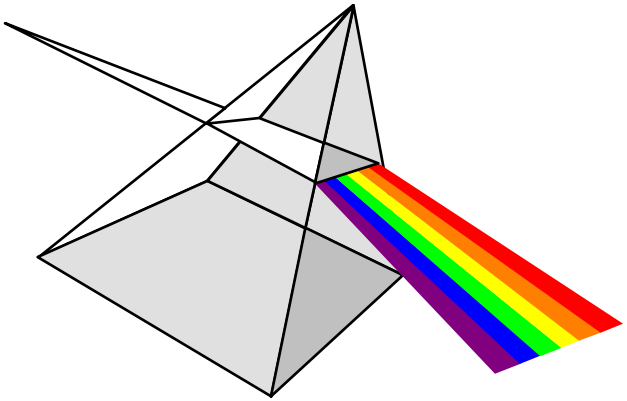
La percezione

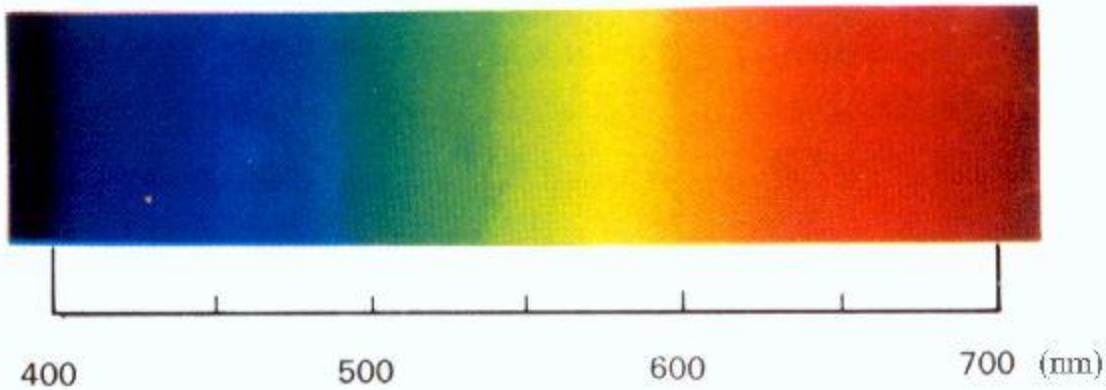


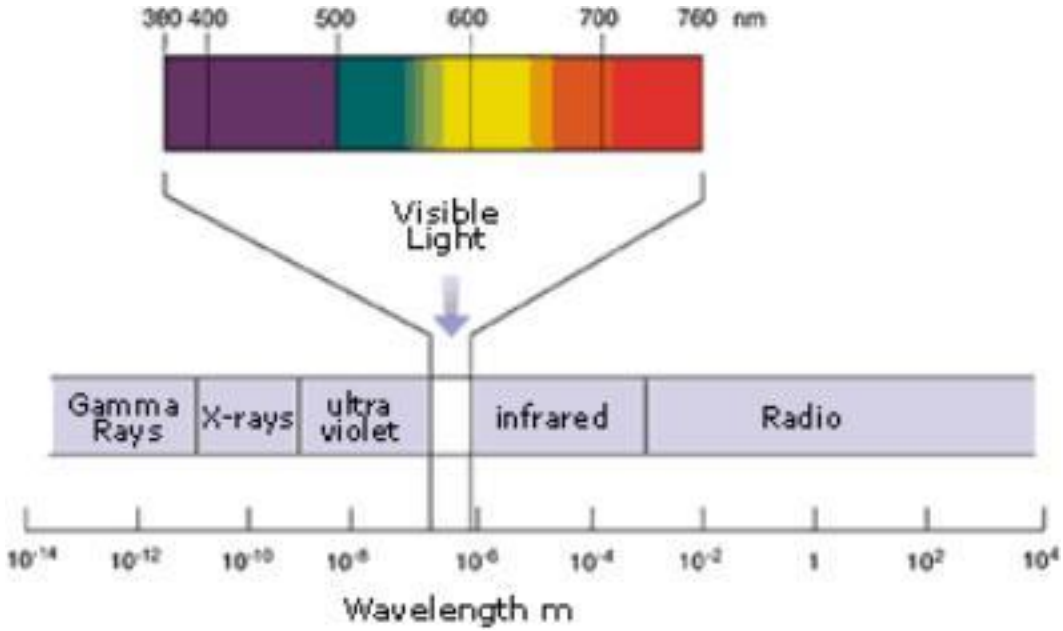


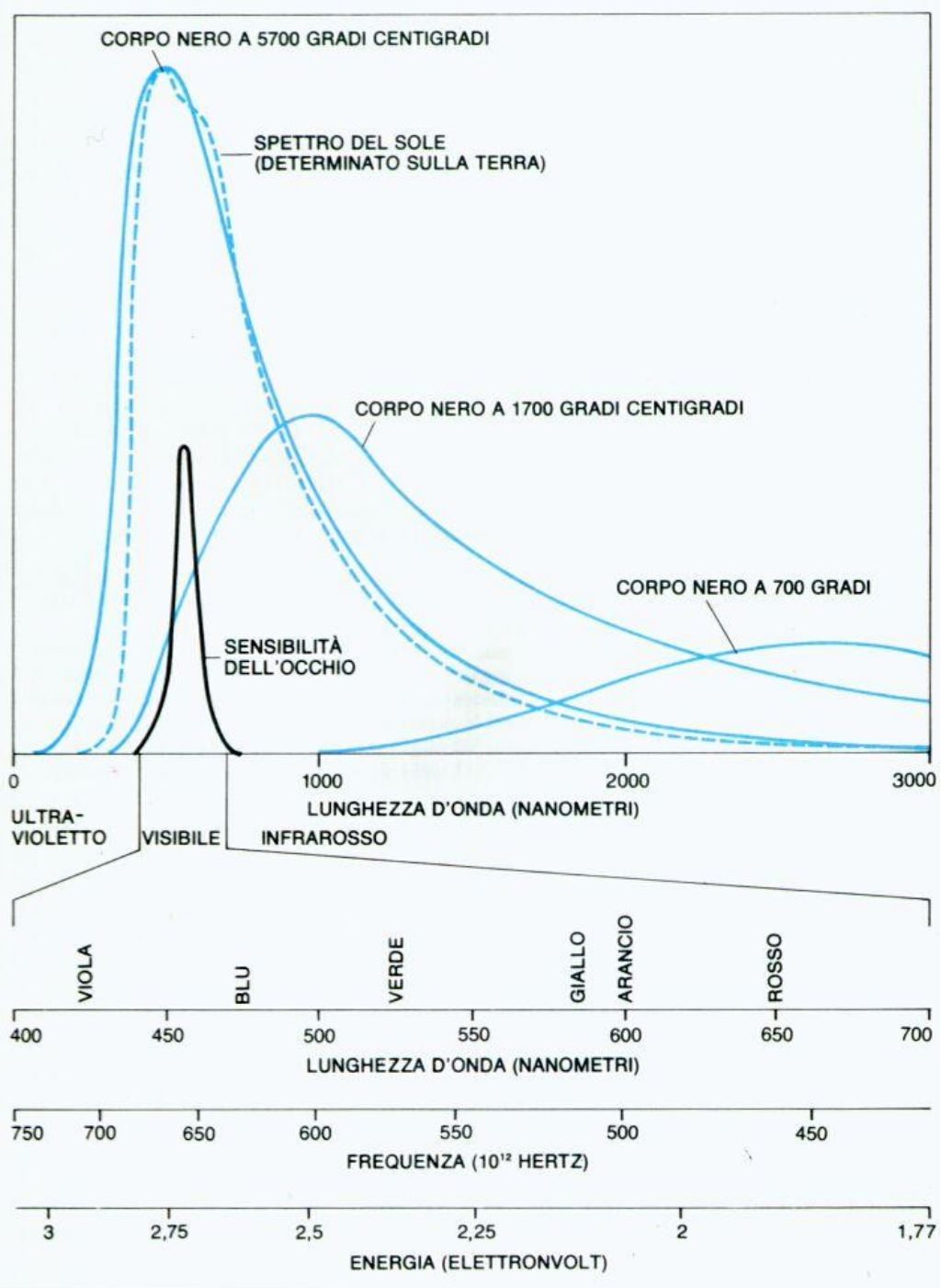


I colori spettrali



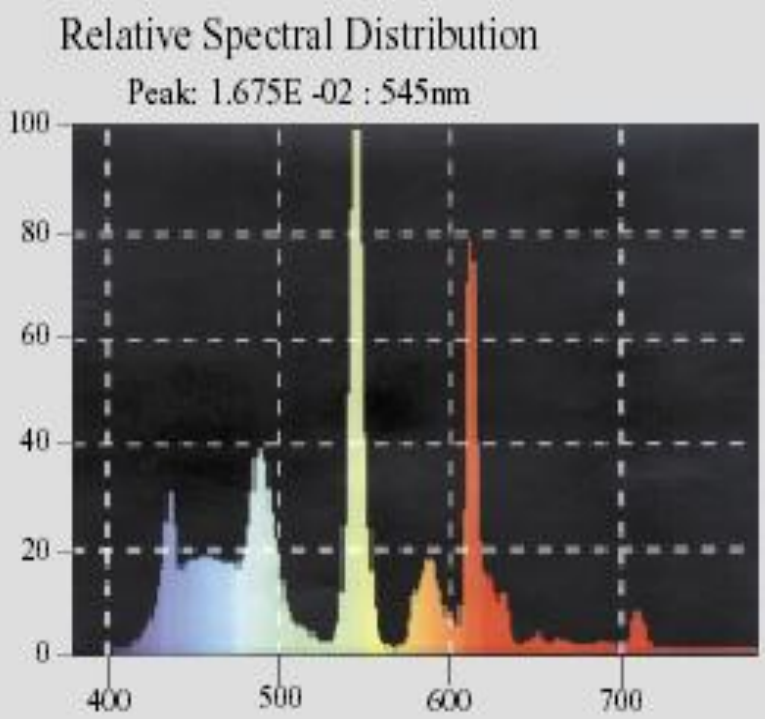

400
500
600
700 (nm)

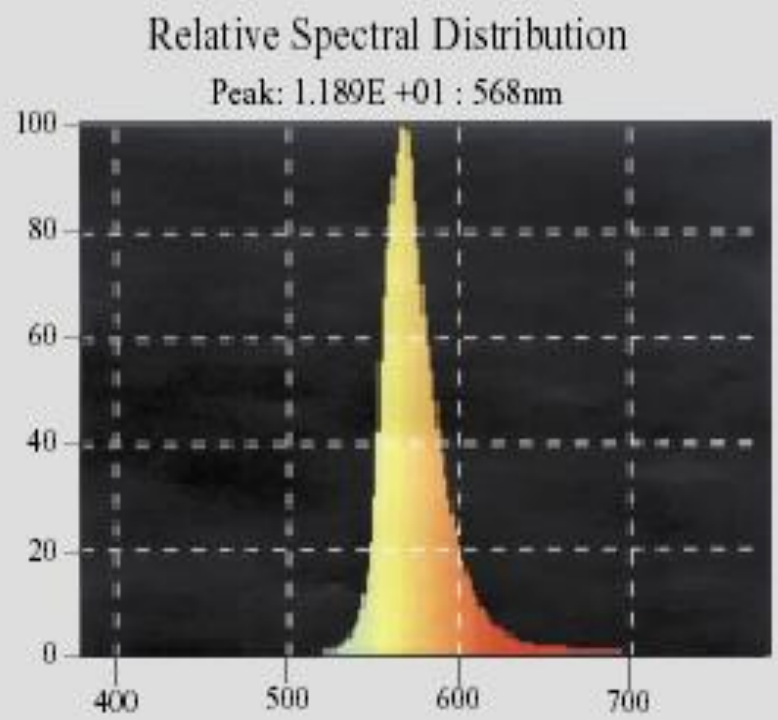

380 400
500
600
700
760 nm
Visible Light
Gamma Rays
X-rays
ultra violet
infrared
Radio
10^{-14}
10^{-12}
10^{-10}
10^{-8}
10^{-6}
10^{-4}
10^{-2}
1
10^{2}
10^{4}
Wavelength m

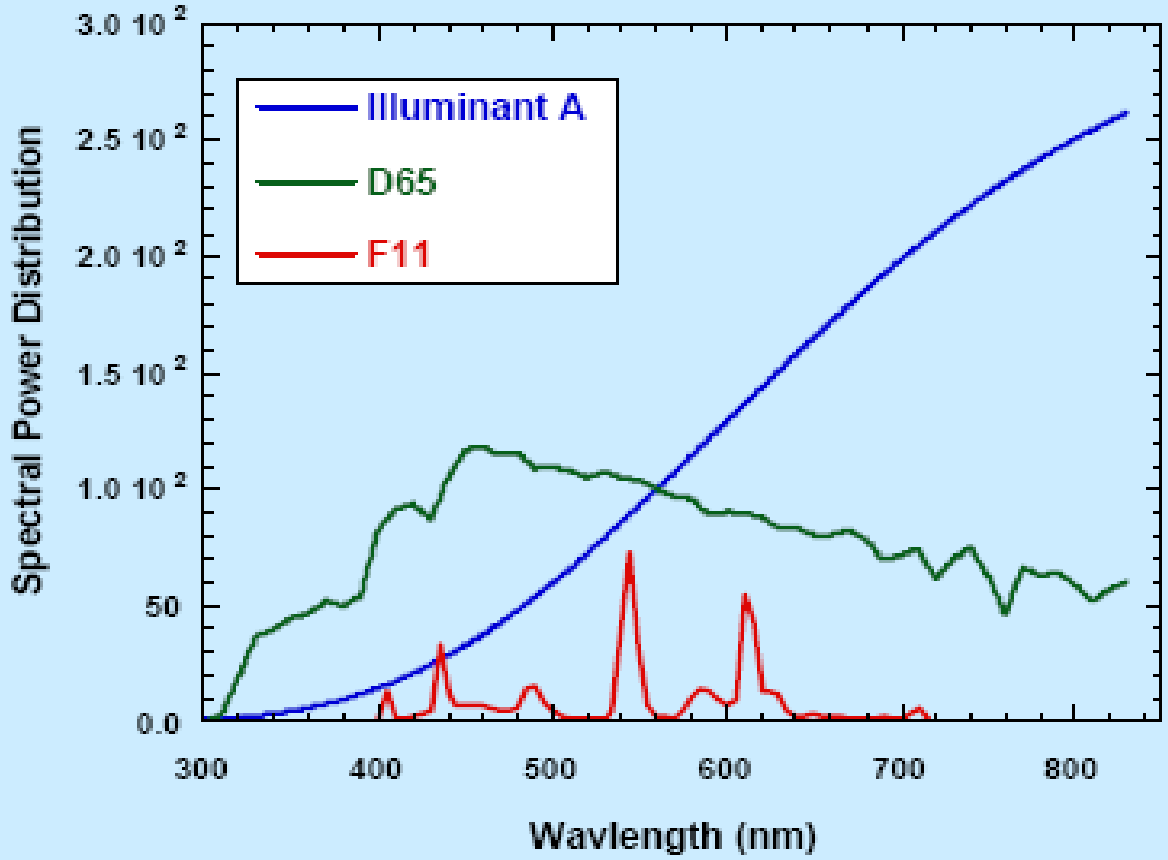

CORPO NERO A 5700 GRADI CENTIGRADI
SPETTRO DEL SOLE
(DETERMINATO SULLA TERRA)
CORPO NERO A 1700 GRADI CENTIGRADI
CORPO NERO A 700 GRADI
SENSIBILITÀ
DELL'OCCHIO
0
1000
2000
3000
LUNGHEZZA D'ONDA (NANOMETRI)
ULTRA-
VIOLETTO
VISIBILE
INFRAROSSO
VIOLA
BLU
VERDE
GIALLO
ARANCIO
ROSSO
400
450
500
550
600
650
700
LUNGHEZZA D'ONDA (NANOMETRI)
750
700
650
600
550
500
450
FREQUENZA (10^{12} HERTZ)
3
2,75
2,5
2,25
2
1,77
ENERGIA (ELETTRONVOLT)

TRANSIZIONI ELETTRONICHE IN ATOMI E IONI LIBERI; TRANSIZIONI VIBRAZIONALI NELLE MOLECOLE	ECCITAZIONI ELETTRONICHE	INCANDESCENZA, FIAMME, ARCHI, SCINTILLE, FULMINI, SCARICHE NEI GAS, ALCUNI LASER
	VIBRAZIONI	COLORE VERDE-AZZURRO DELL'ACQUA PURA E DEL GHIACCIO
COLORI DEL CAMPO CRISTALLINO	COMPOSTI DI METALLI DI TRANSIZIONE	TURCHESI, MOLTISSIMI PIGMENTI, ALCUNI LASER, ALCUNI FOSFORI, ALCUNI MATERIALI FLUORESCENTI
	IMPUREZZE DI METALLI DI TRANSIZIONE	RUBINO, SMERALDO, QUARZITE ROSSA, ALCUNI LASER, ALCUNE FLUORESCENZE
	CENTRI DI COLORE	AMETISTA, QUARZO AFFUMICATO, VETRO AMETISTA DEL DESERTO, ALCUNE FLUORESCENZE
TRANSIZIONI FRA ORBITALI MOLECOLARI	TRASFERIMENTO DI CARICA	ZAFFIRO BLU, MAGNETITE
	LEGAMI CONIUGATI	COLORANTI ORGANICI, MOLTISSIMI COLORI VEGETALI E ANIMALI, LAPISLAZZULI, LUCCIOLE, LASER A COLORANTE, ALCUNE FLUORESCENZE.
TRANSIZIONI IN MATERIALI CON STRUTTURA A BANDE	CONDUTTORI METALLICI	RAME, ARGENTO, ORO, FERRO, OTTONE
	SEMICONDUTTORI PURI	SILICIO, GALENA, CINABRO, DIAMANTE
	SEMICONDUTTORI DROGATI	DIAMANTE BLU, DIAMANTE GIALLO, DIODI LUMINESCENTI, LASER A SEMICONDUTTORE, ALCUNI FOSFORI
OTTICA GEOMETRICA E FISICA	RIFRAZIONE DISPERSIVA	ARCOBALENO, «FIAMMA» NELLE GEMME, ABERRAZIONE CROMATICA
	DIFFUSIONE	BLU DEL CIELO, ROSSO DEL TRAMONTO, PIETRA DI LUNA, RUBINO ASTERIA
	INTERFERENZA	FILM DI BENZINA SULL'ACQUA, TRATTAMENTI ANTIRIFLESSI, ALCUNI COLORI DI INSETTI
	RETICOLO DI DIFFRAZIONE	OPALE, CRISTALLI LIQUIDI, ALCUNI COLORI DI INSETTI

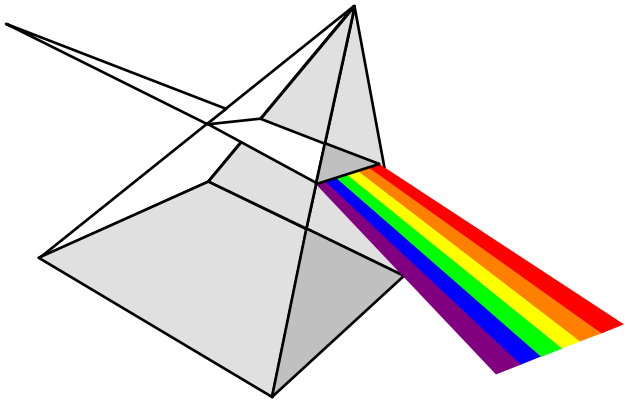
I meccanismi di formazione del colore possono venire suddivisi in 14 [illegible] cambiamenti nello stato degli elettroni nella materia. [illegible]

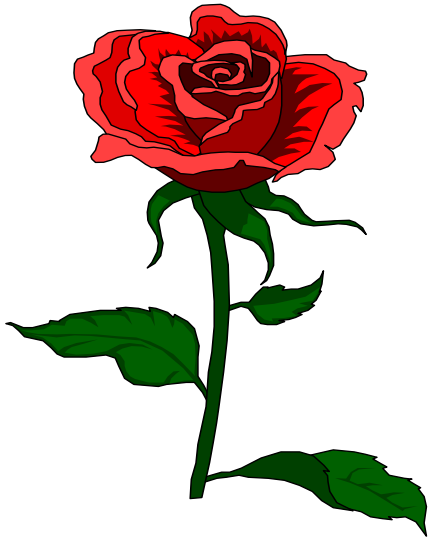

Relative Spectral Distribution
Peak: 1.675E -02 : 545nm
100
80
60
40
20
0
400
500
600
700

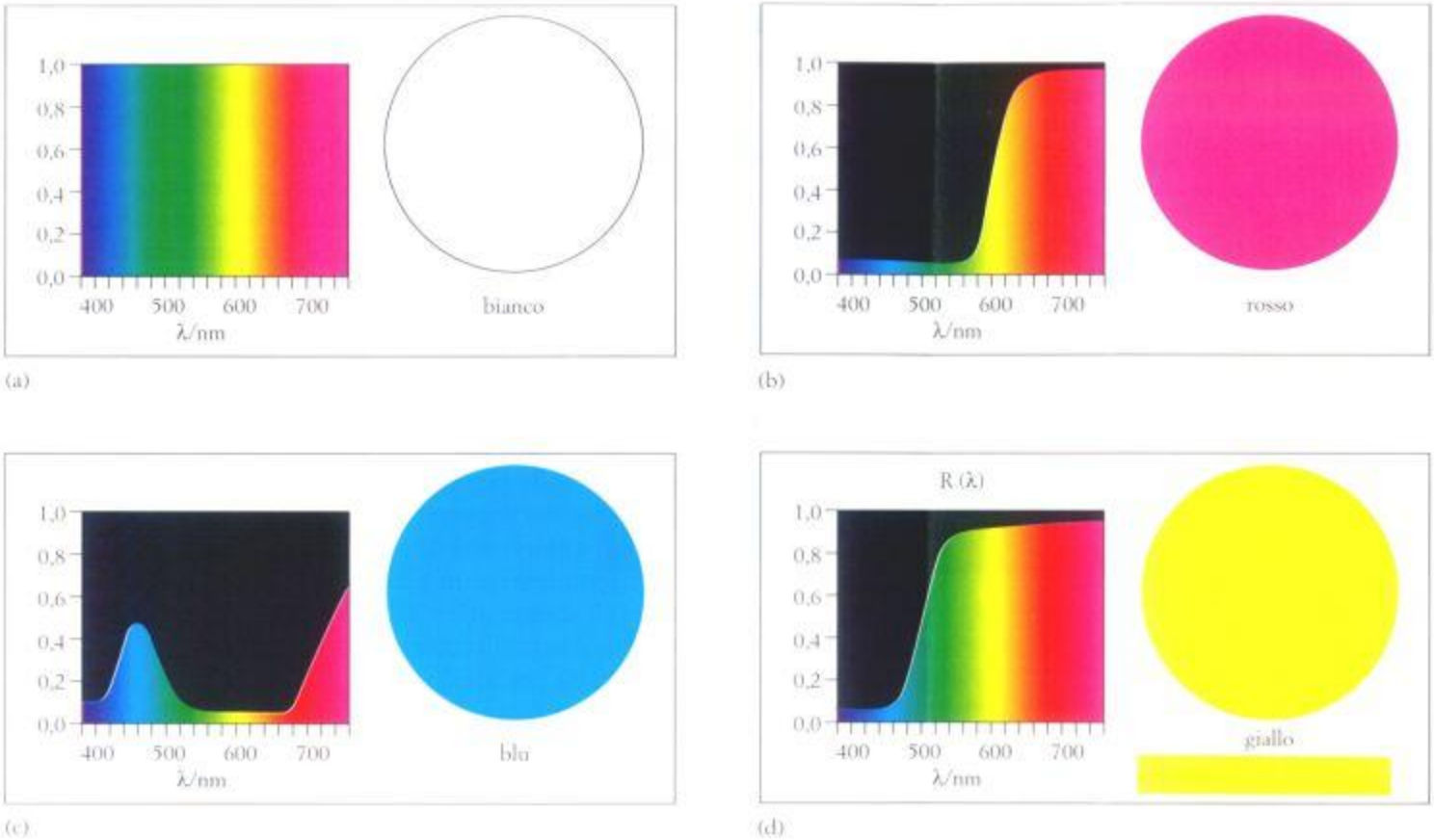

Relative Spectral Distribution
Peak: 1.189E +01 : 568nm
100
80
60
40
20
0
400
500
600
700


Illuminant A
D65
F11
Spectral Power Distribution
3.0 10 2
2.5 10 2
2.0 10 2
1.5 10 2
1.0 10 2
50
0.0
300
400
500
600
700
800
Wavlength (nm)

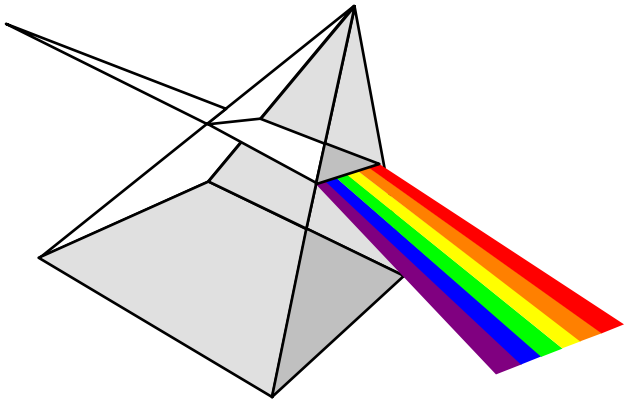
La percezione

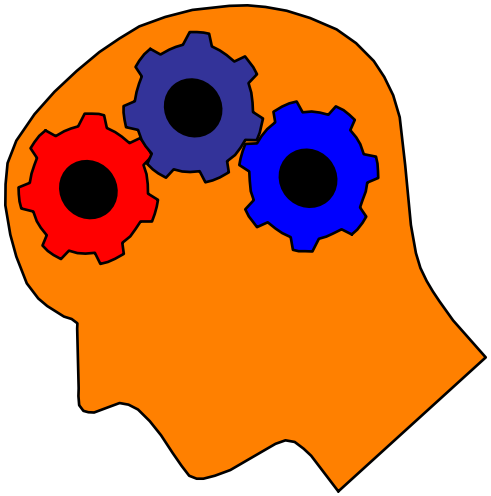


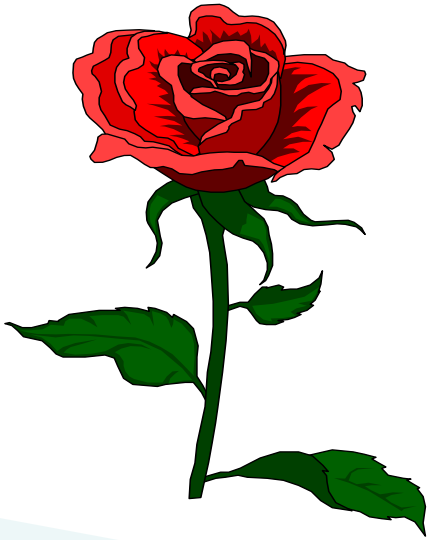


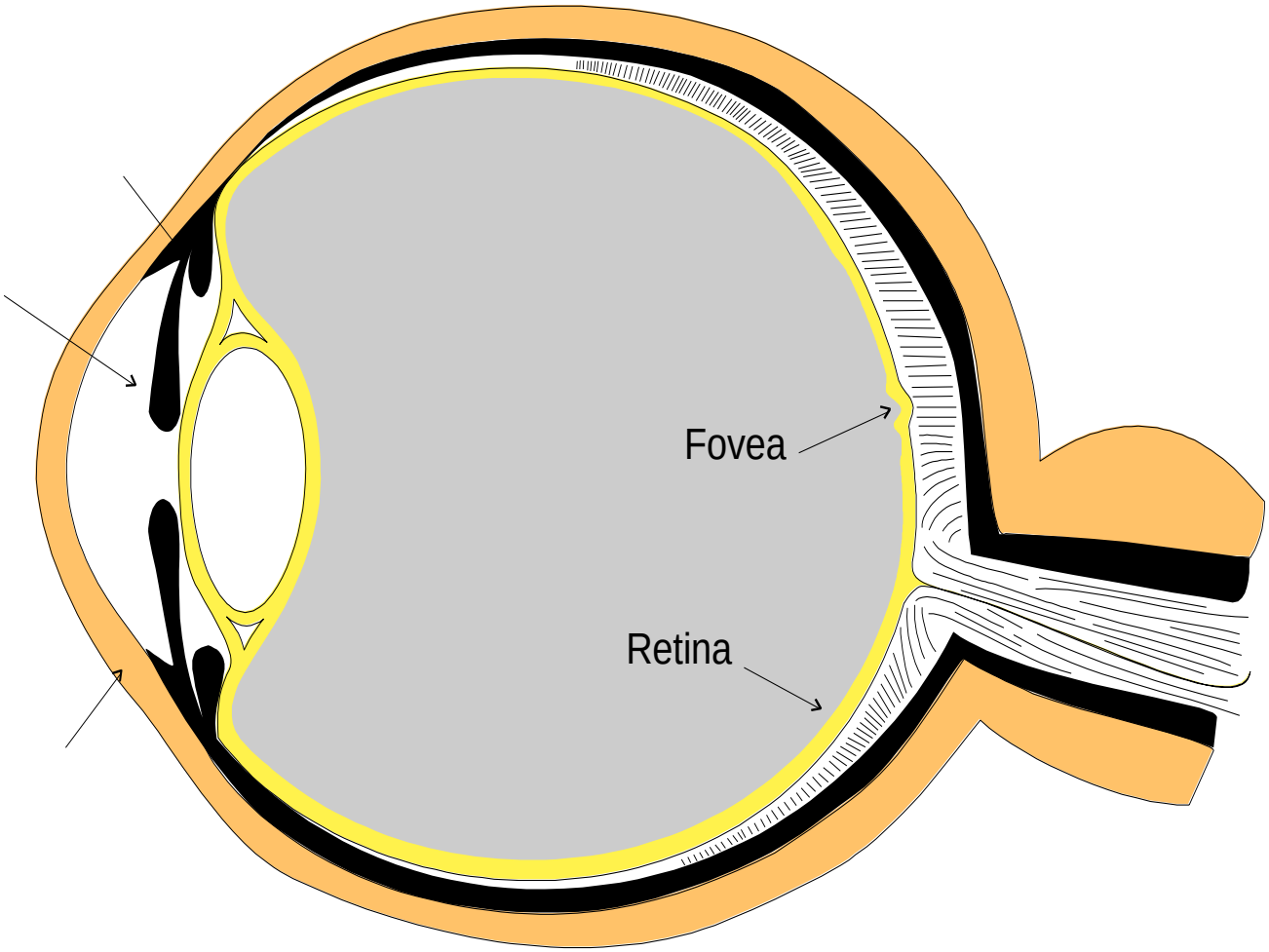

1,0
0,8
0,6
0,4
0,2
0,0
400
500
600
700
λ/nm
bianco
(a)
rosso
(b)
blu
(c)
R (λ)
giallo
(d)

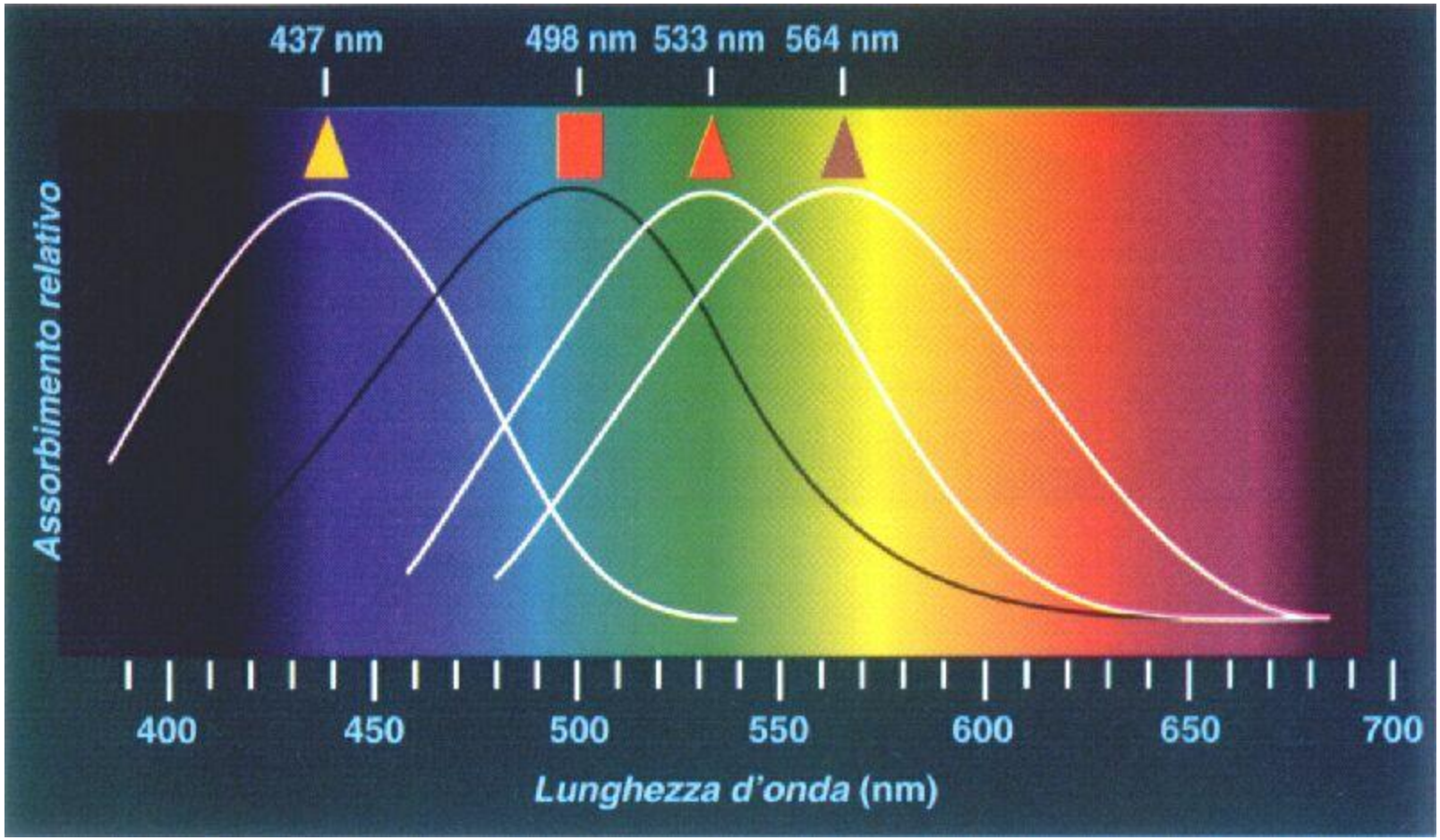
La percezione

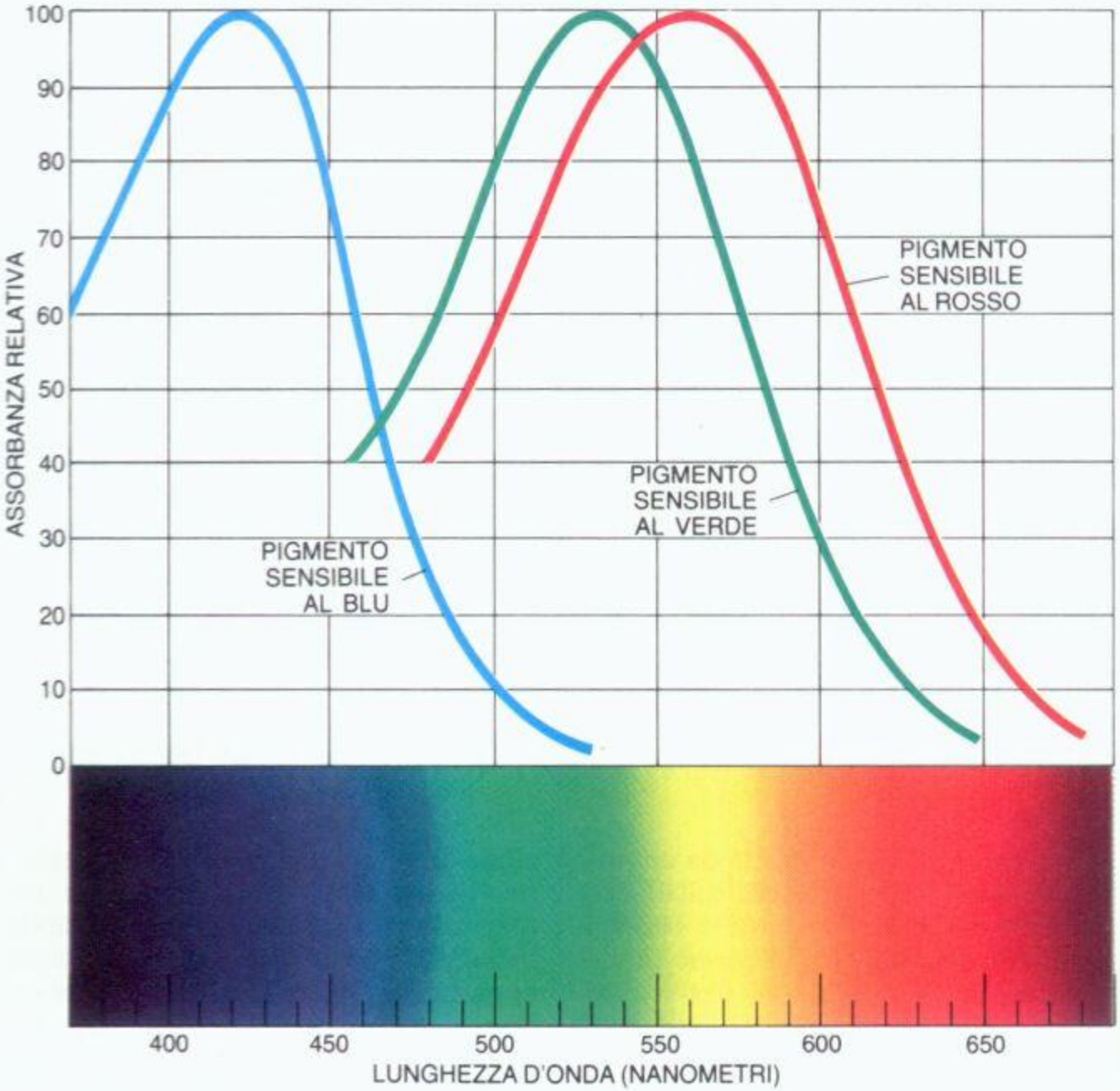


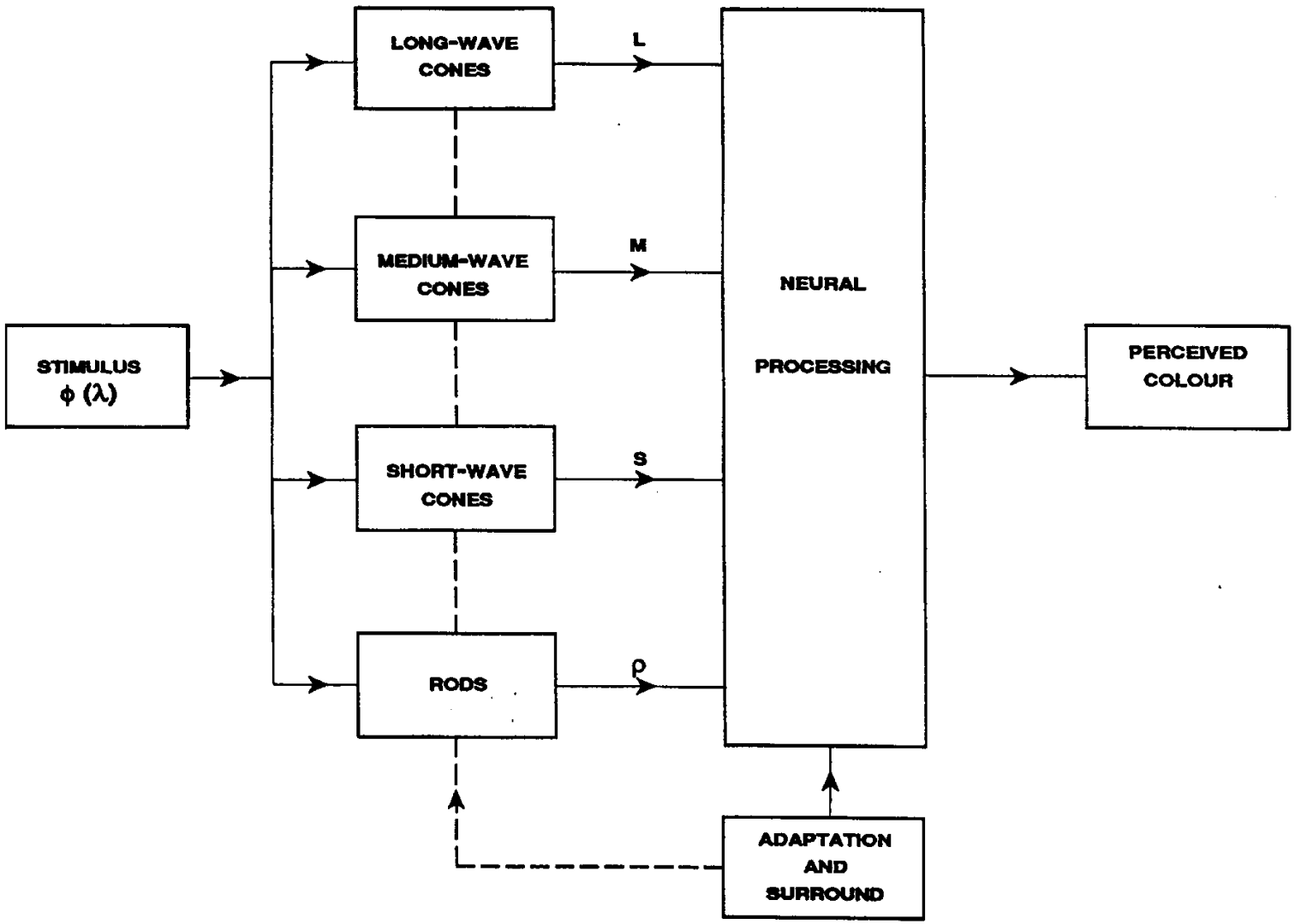


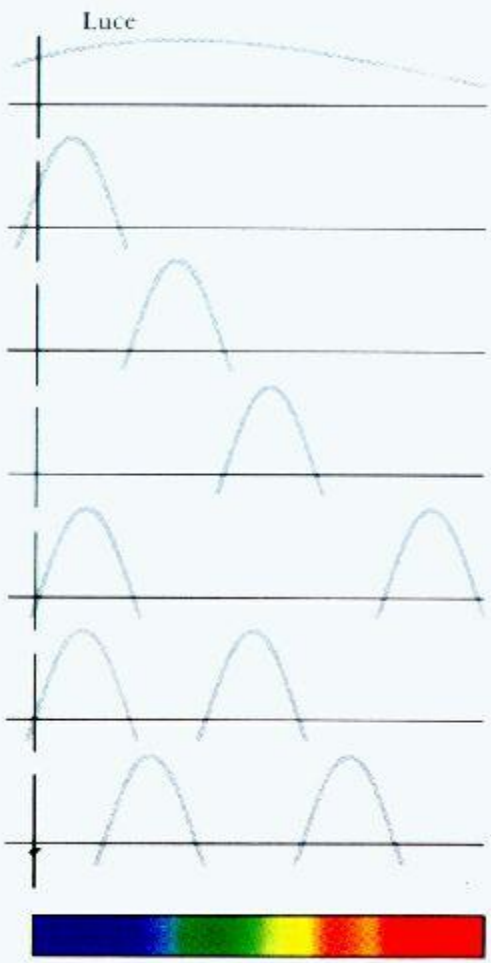



Fovea
Retina


437 nm
498 nm
533 nm
564 nm
Assorbimento relativo
400
450
500
550
600
650
700
Lunghezza d'onda (nm)

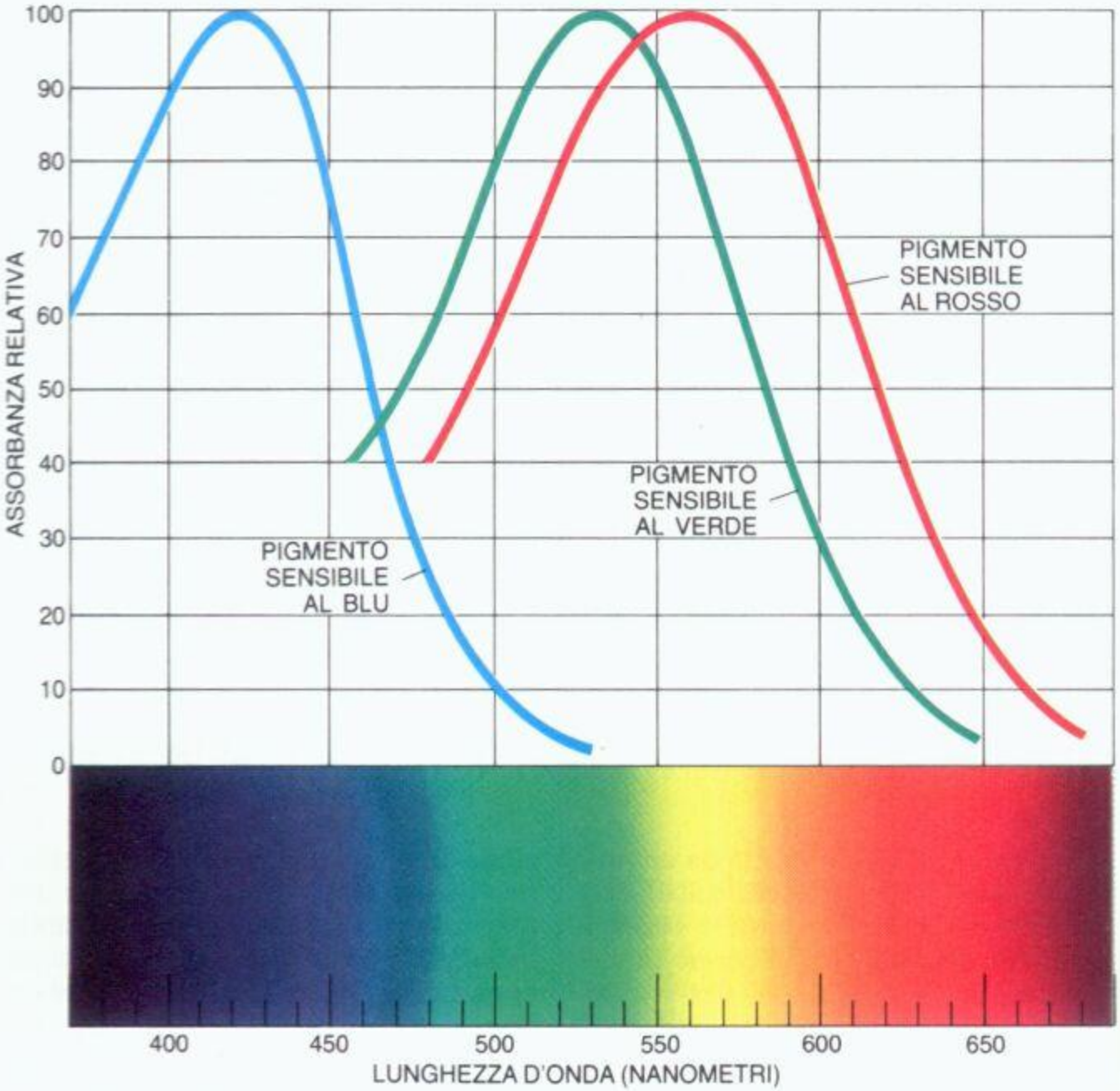

ASSORBANZA RELATIVA
100
90
80
70
60
50
40
30
20
10
0
PIGMENTO SENSIBILE AL ROSSO
PIGMENTO SENSIBILE AL VERDE
PIGMENTO SENSIBILE AL BLU
400
450
500
550
600
650
LUNGHEZZA D'ONDA (NANOMETRI)


STIMULUS
ϕ (λ)
LONG-WAVE CONES
MEDIUM-WAVE CONES
SHORT-WAVE CONES
RODS
L
M
S
ρ
NEURAL PROCESSING
PERCEIVED COLOUR
ADAPTATION AND SURROUND



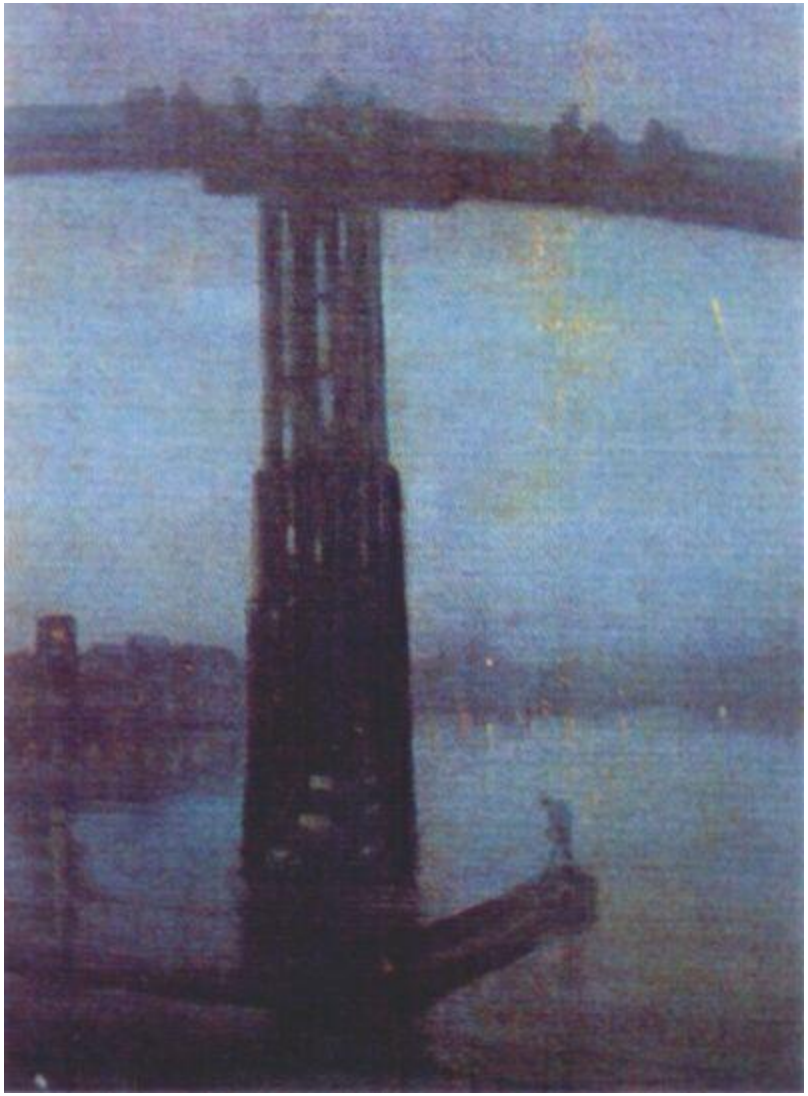
Tipo di coni attivati	Sensazione cromatica
Blu, verde, rosso	Bianco
Blu	Violetto
Blu, verde	Blu, ciano
Verde, rosso	Giallo
Blu, rosso	Porpora
Blu, verde, rosso	Bianco
Blu, verde, rosso	Bianco

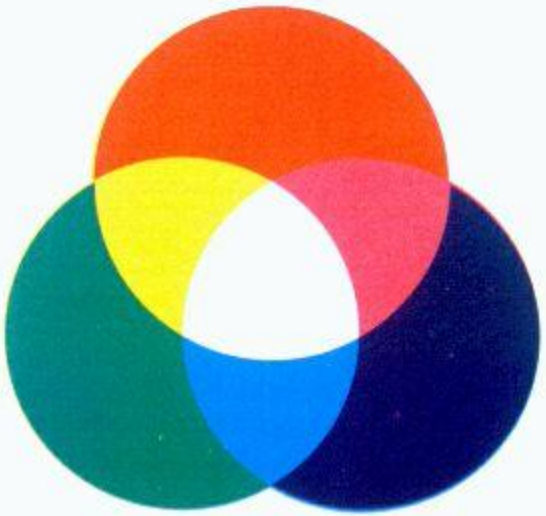
ISTITUTO NAZIONALE DI RICERCA METROLOGICA


ASSORBANZA RELATIVA
100
90
80
70
60
50
40
30
20
10
0
PIGMENTO SENSIBILE AL ROSSO
PIGMENTO SENSIBILE AL VERDE
PIGMENTO SENSIBILE AL BLU
400
450
500
550
600
650
LUNGHEZZA D'ONDA (NANOMETRI)

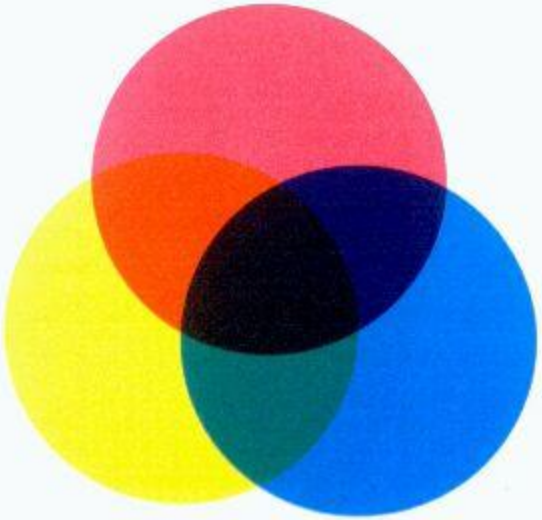
J. Whistler,

Il vecchio ponte di Battersea. Notturno in blu e oro.

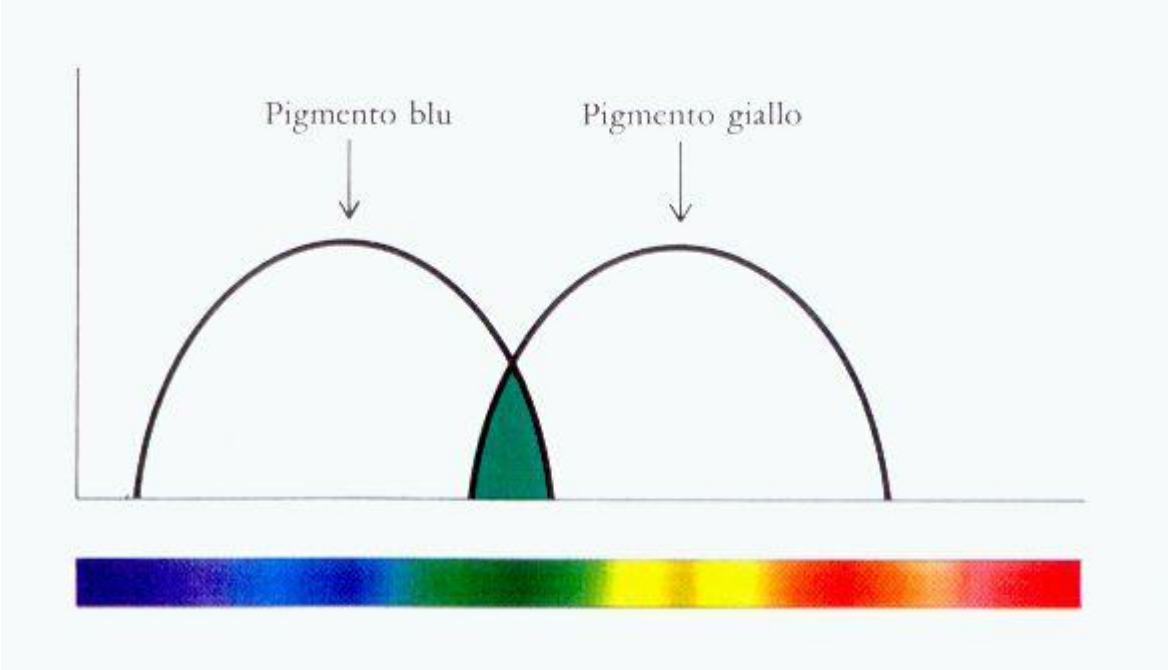


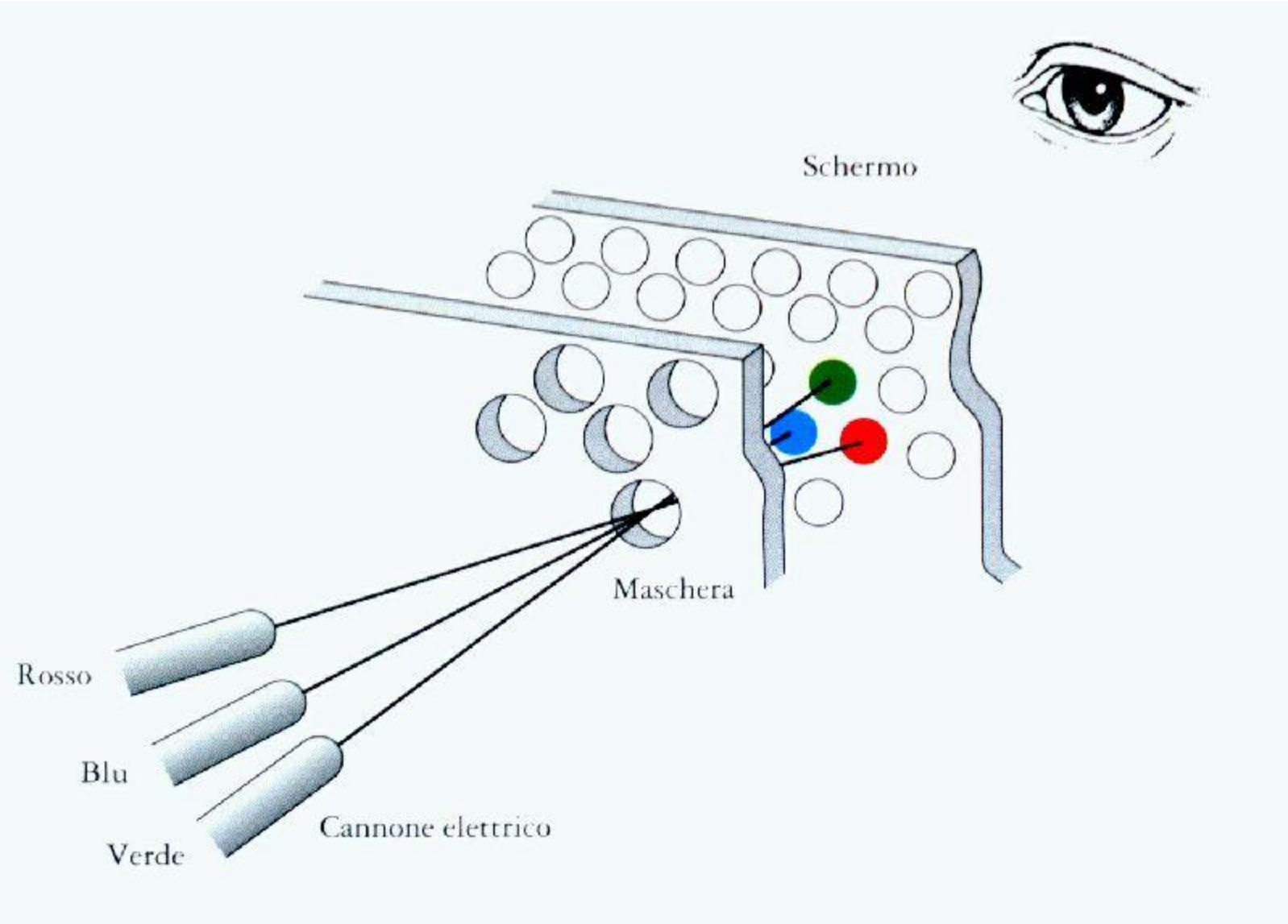


somma di luci



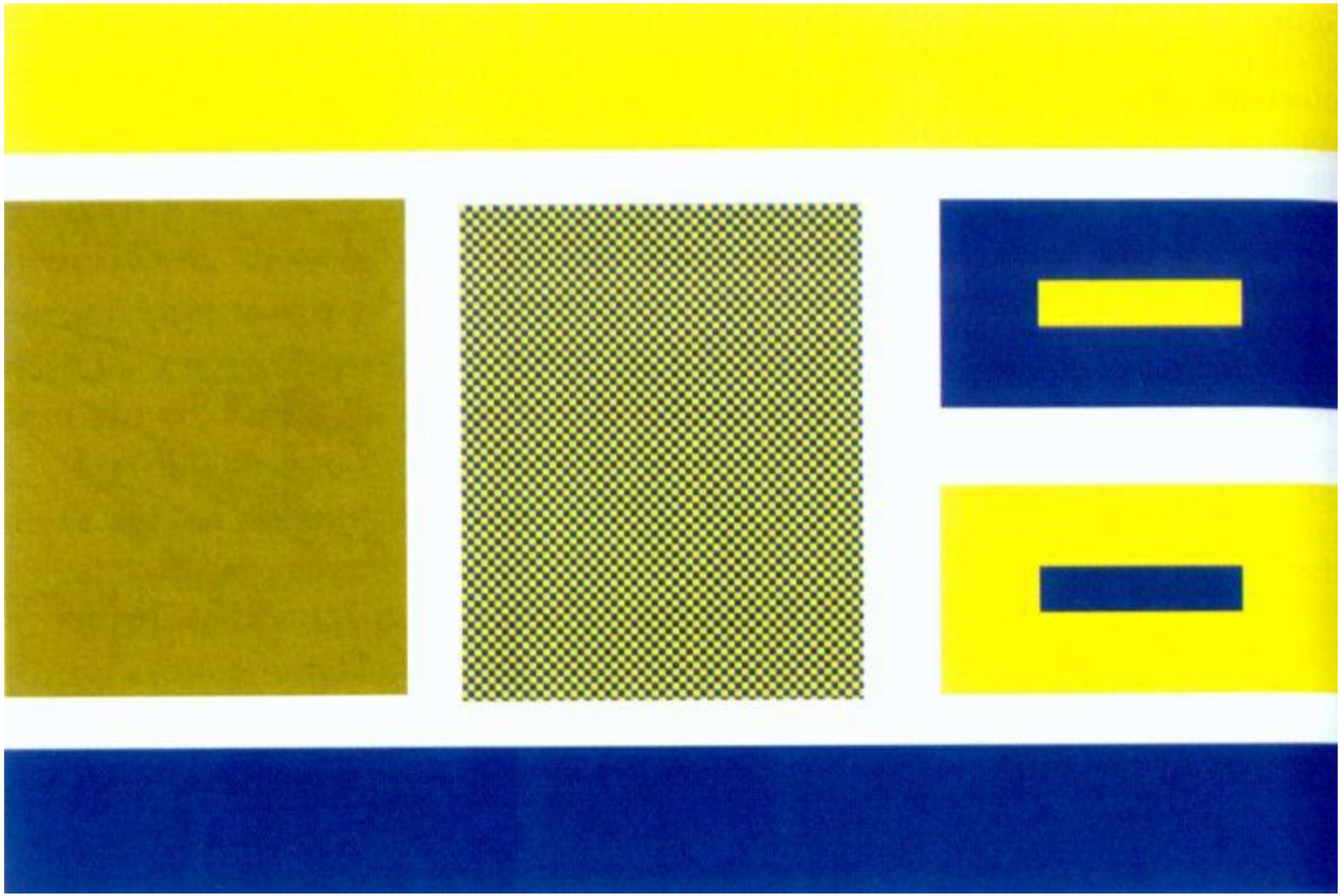
sottrazione di luci

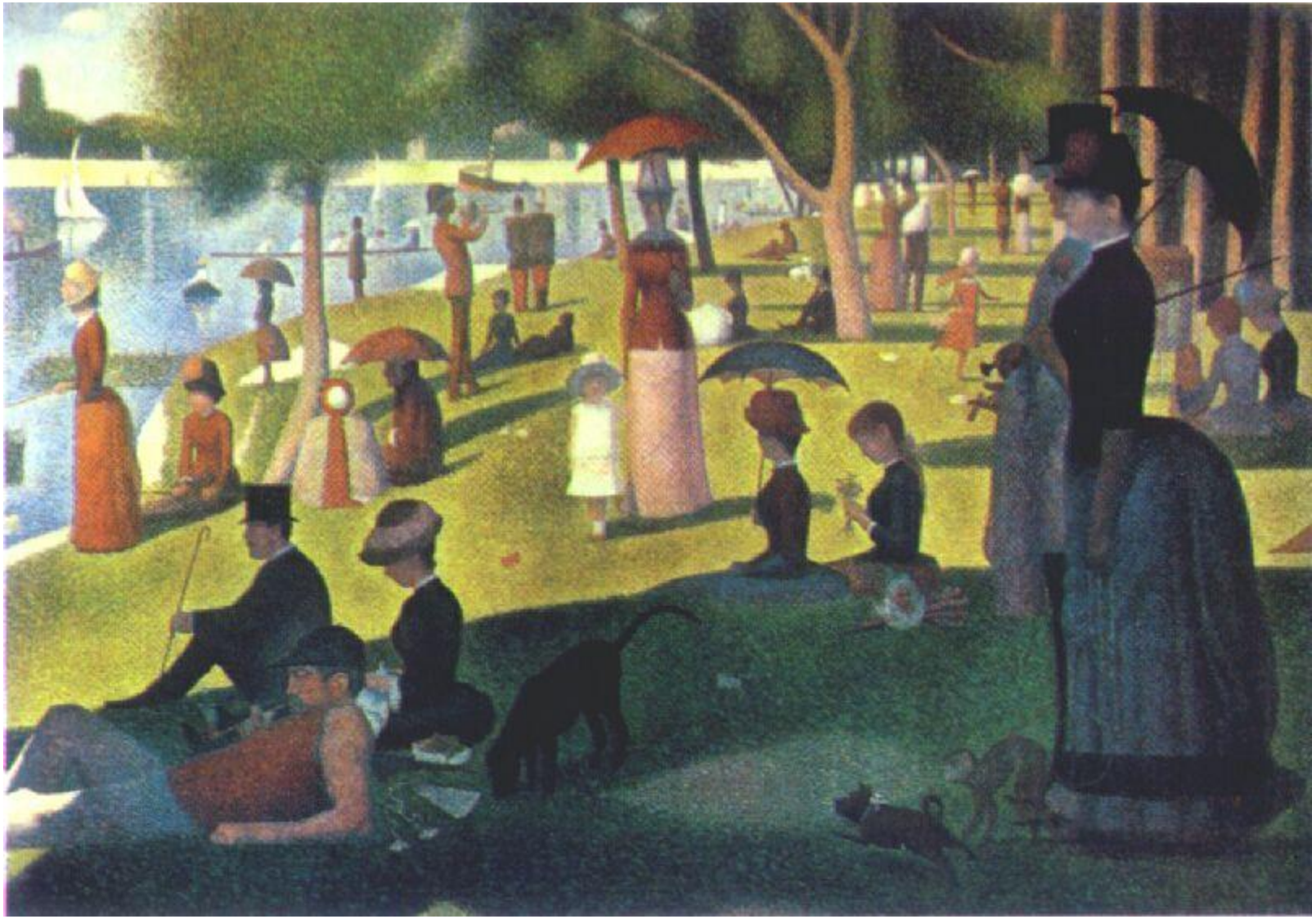

Pigmento blu
Pigmento giallo


Schermo
Maschera
Rosso
Blu
Verde
Cannone elettrico

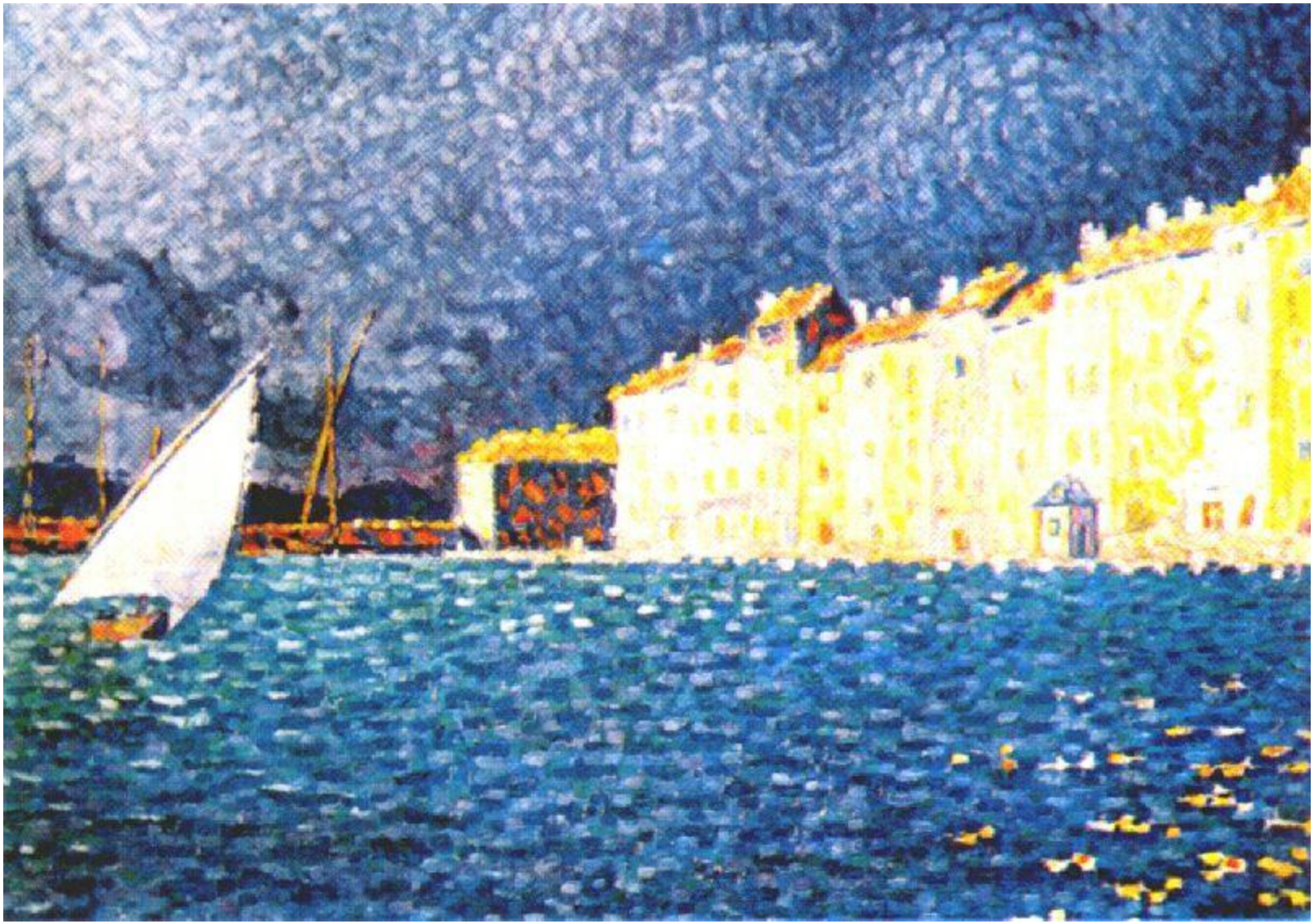
Gesù di Nazareth come Christus Imperator. Ravenna

ISTITUTO
NAZIONALE
DI RICERCA
METROLOGICA





Geoges Seurat, *Un dimanche d'eté à la Grande Jatte* (1886)



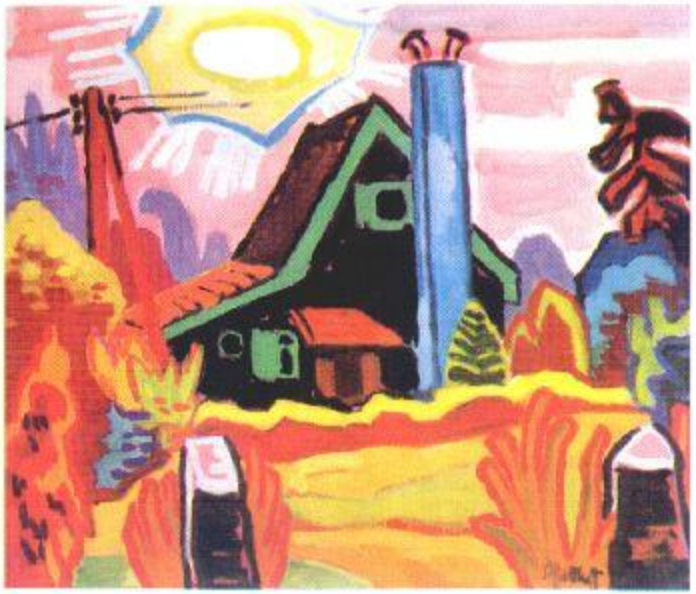
Paul Signac, *Il temporale* (1895)

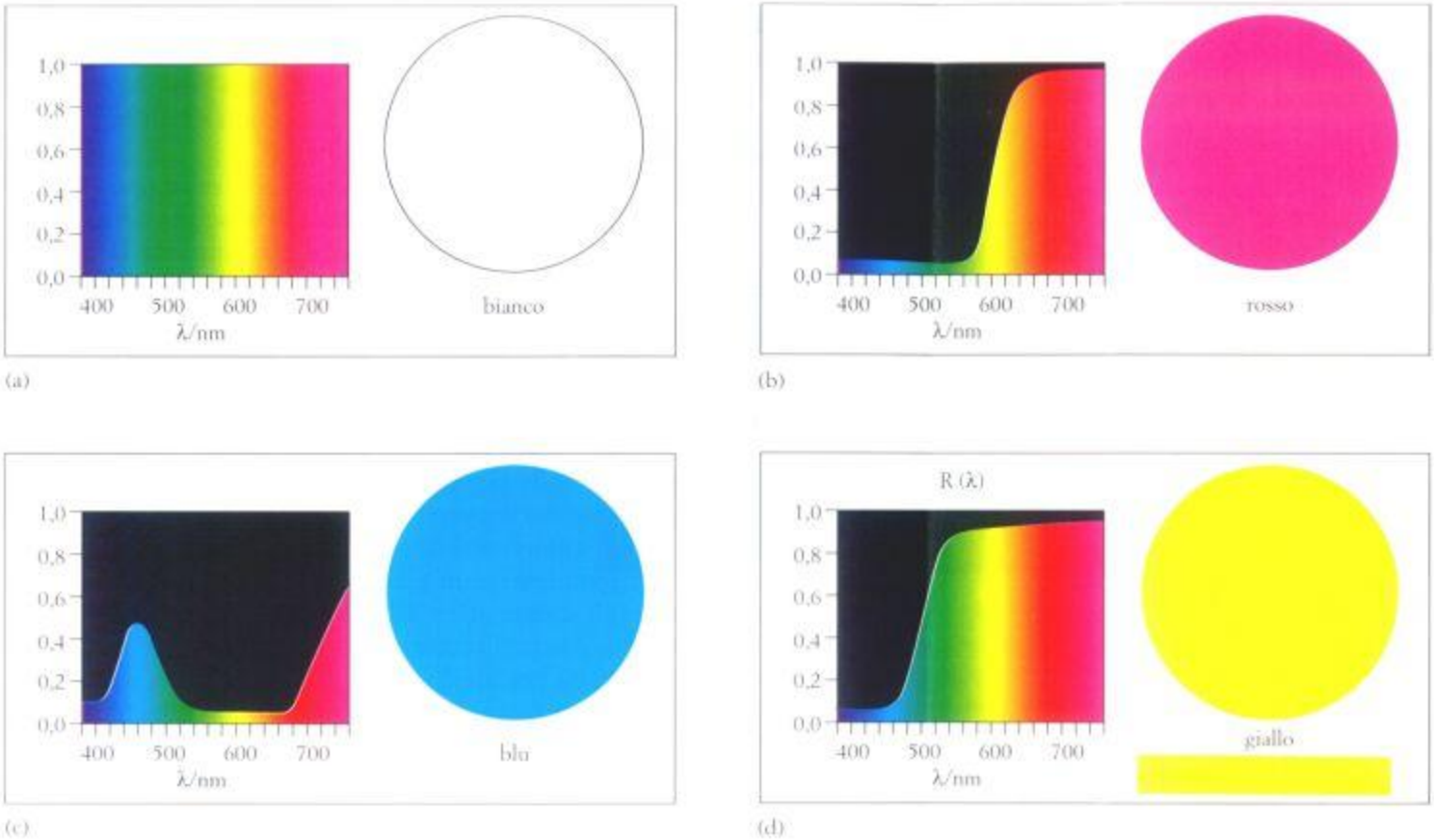
A. Mantegna
(1497-1550)

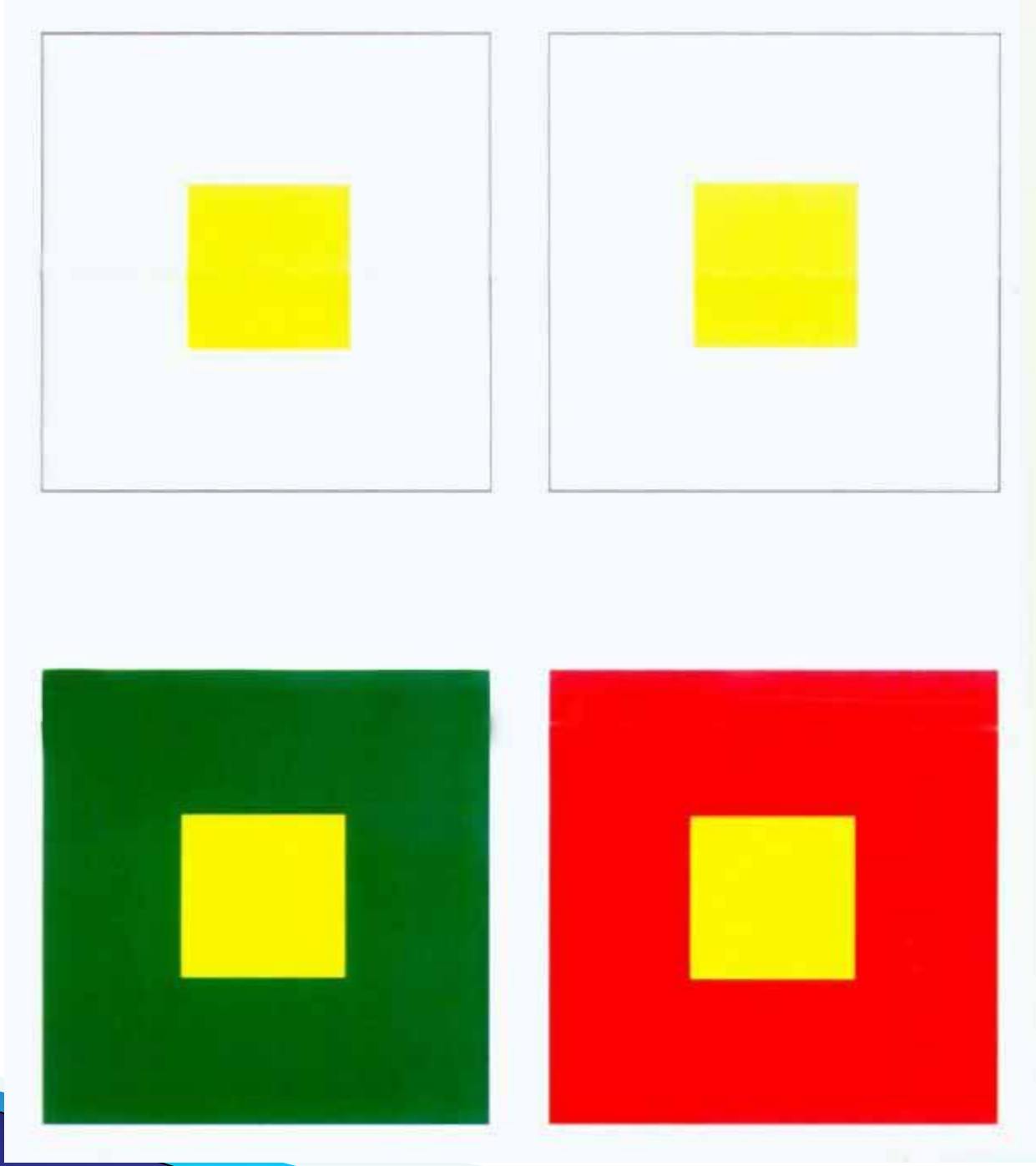
L'adorazione dei Magi

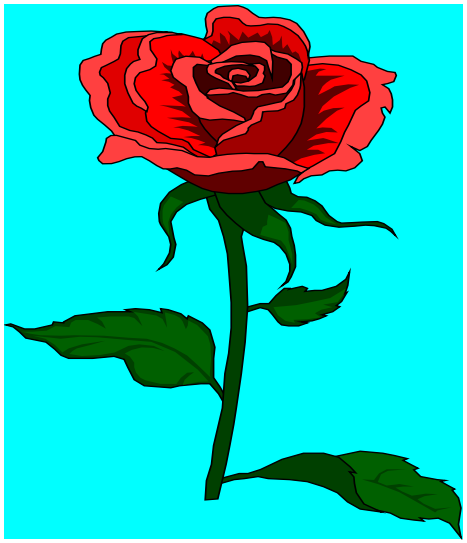
ISTITUTO NAZIONALE DI RICERCA METROLOGICA

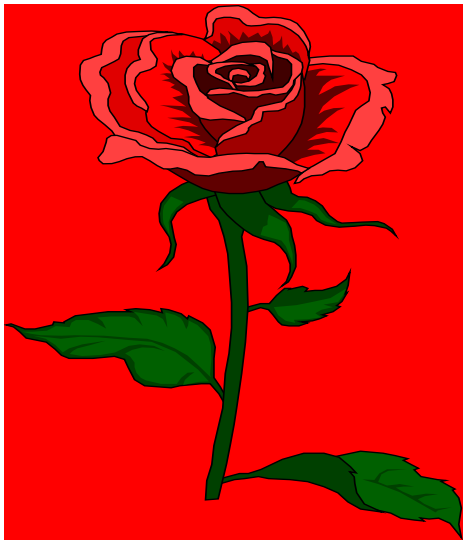
Schmidt-Rottluf, *La casa nera* (1958)

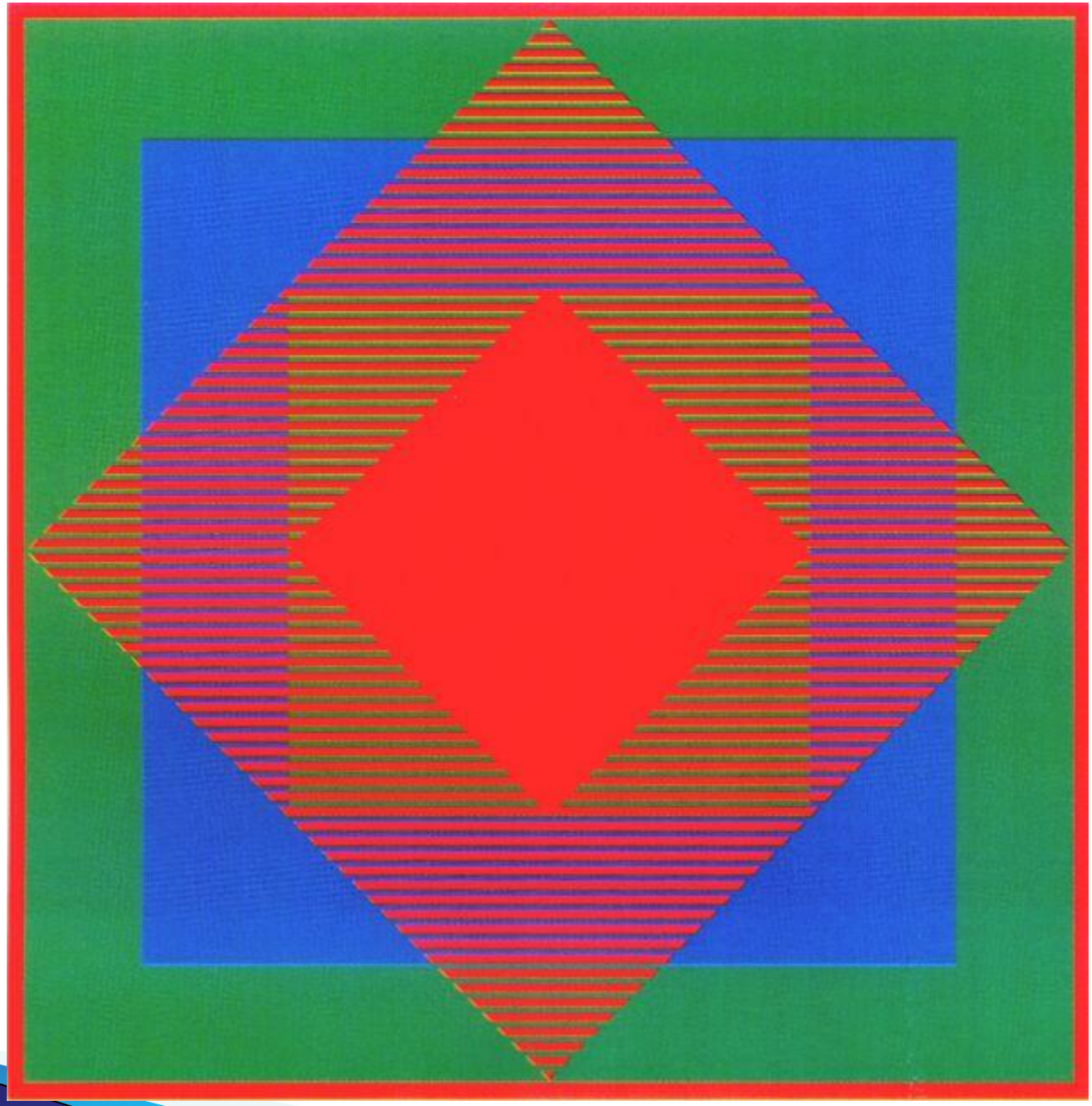


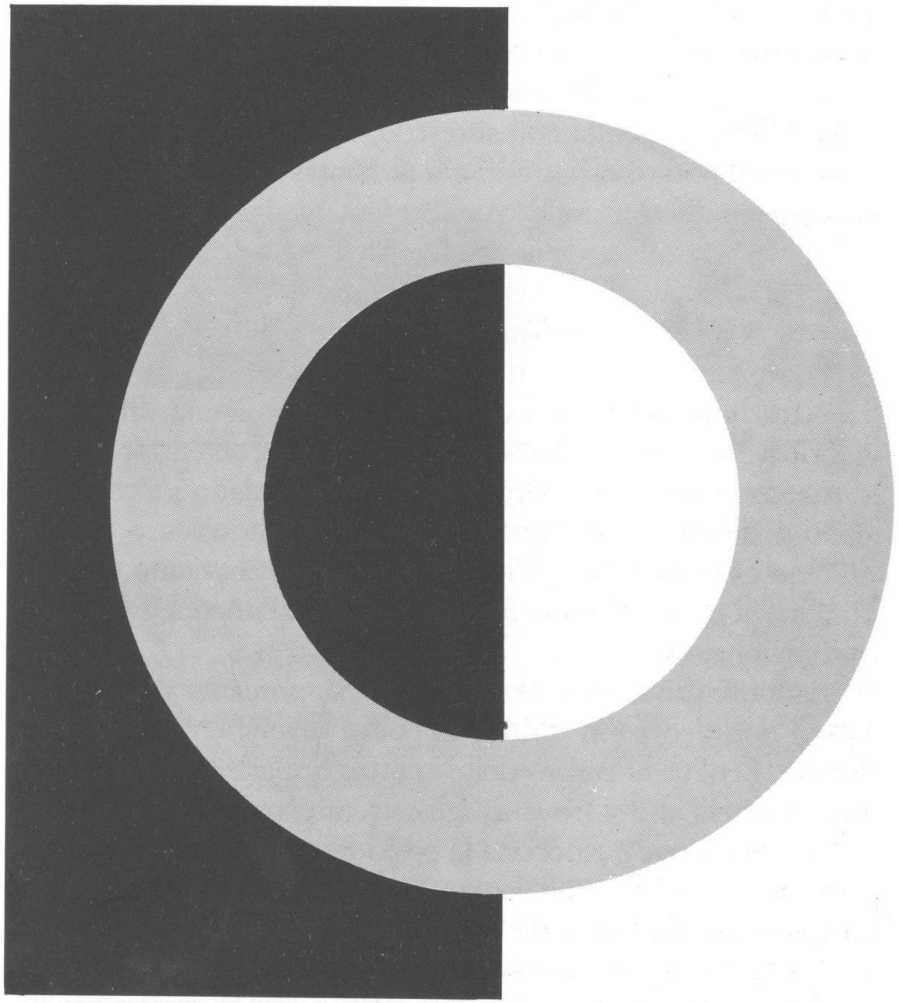

1,0
0,8
0,6
0,4
0,2
0,0
400
500
600
700
λ/nm
bianco
(a)
rosso
(b)
blu
(c)
R (λ)
giallo
(d)

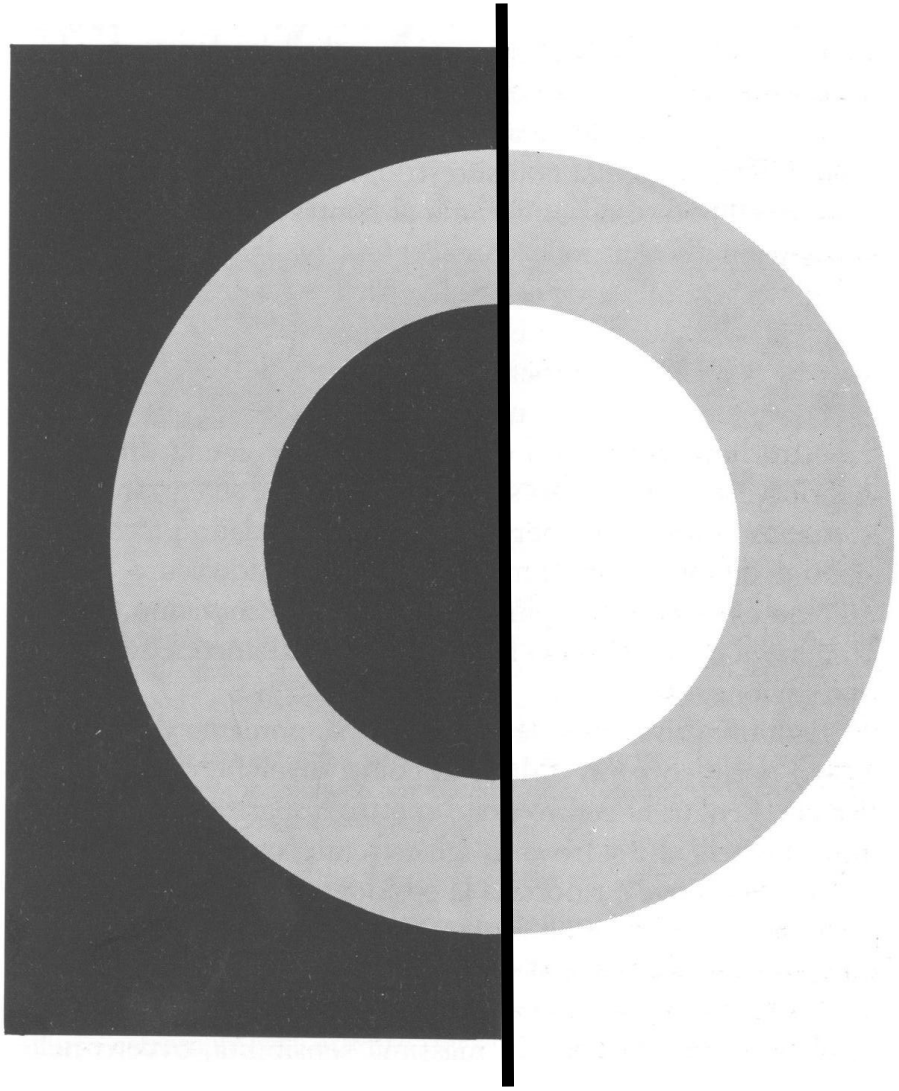




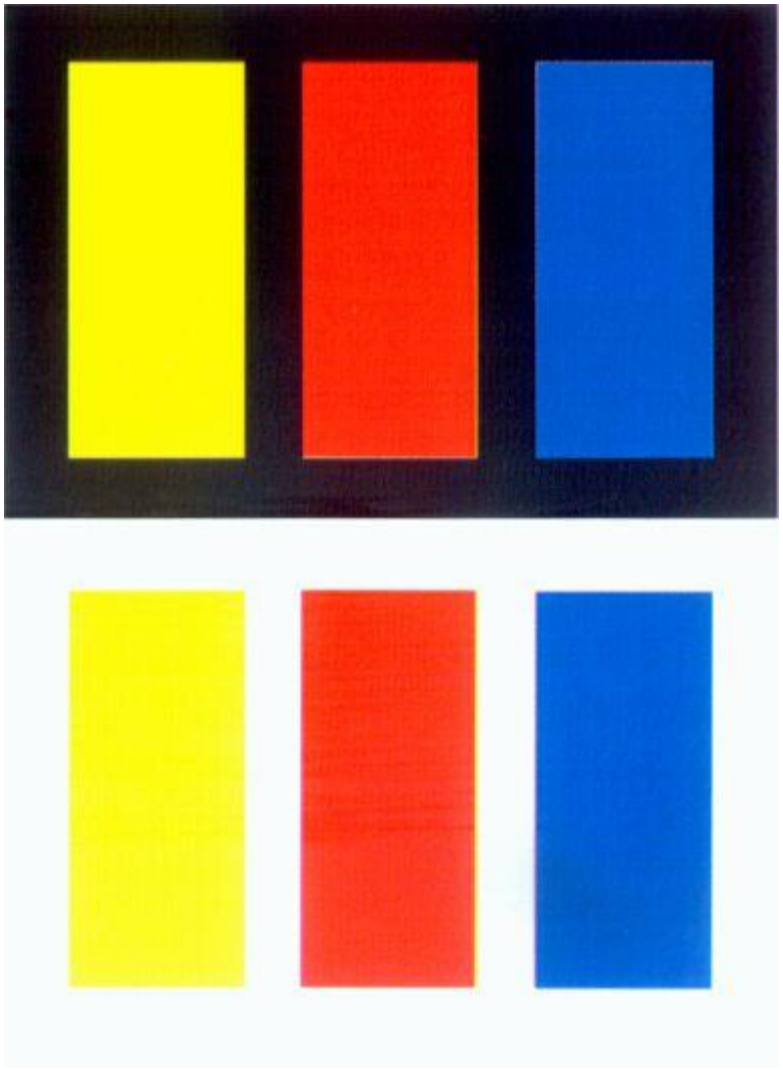


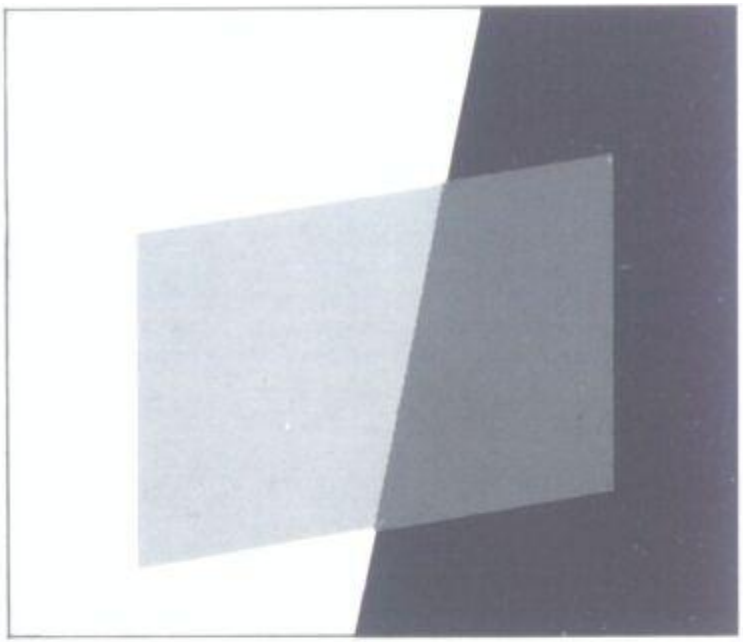


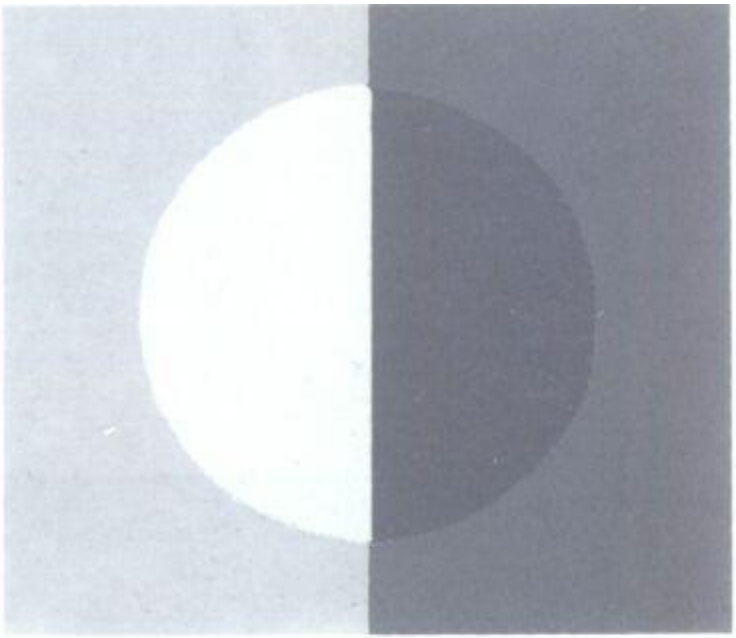


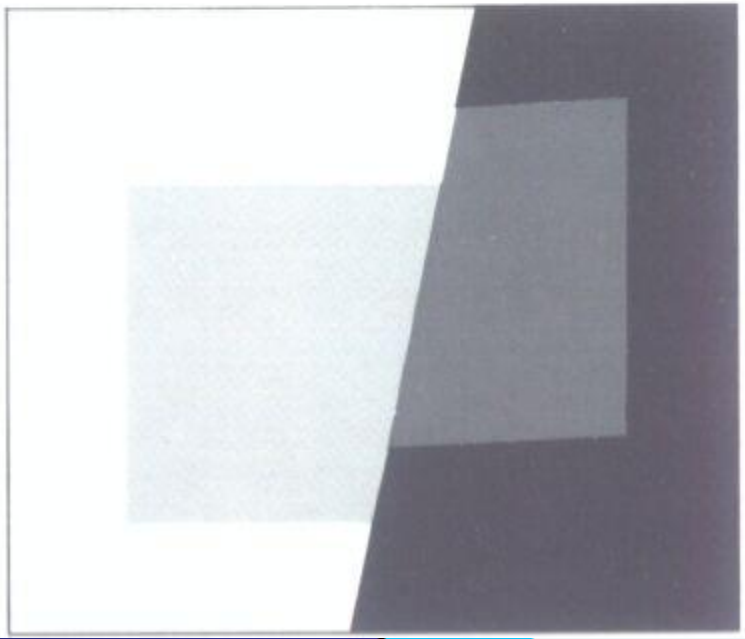


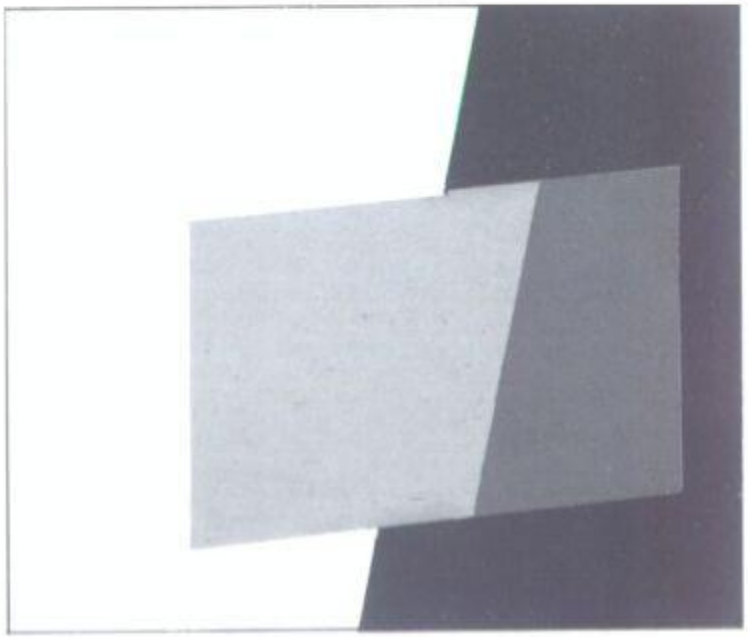
ISTITUTO
NAZIONALE
DI RICERCA
METROLOGICA

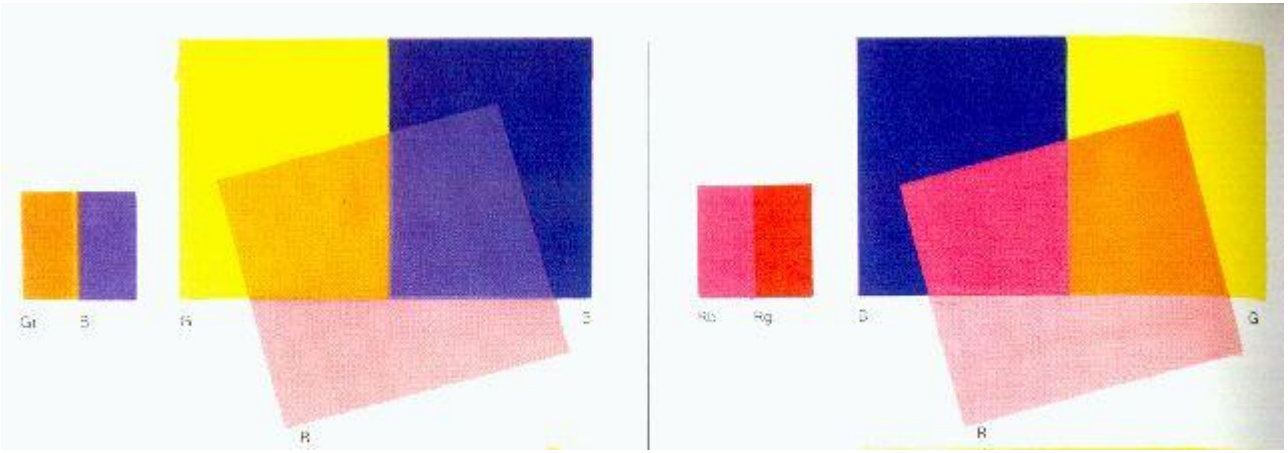











Gr
S
R
S
R
Rb
Rg
B
G
R

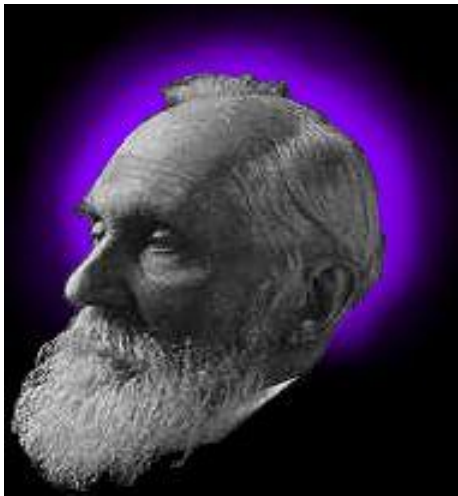
Wassily Kandinskij, *Alcuni cerchi* (1926)

La couleur contribue à exprimer la lumière, non pas le phénomene physique, mais la seule lumière qui existe en fait, celle du cerveau de l’artiste.

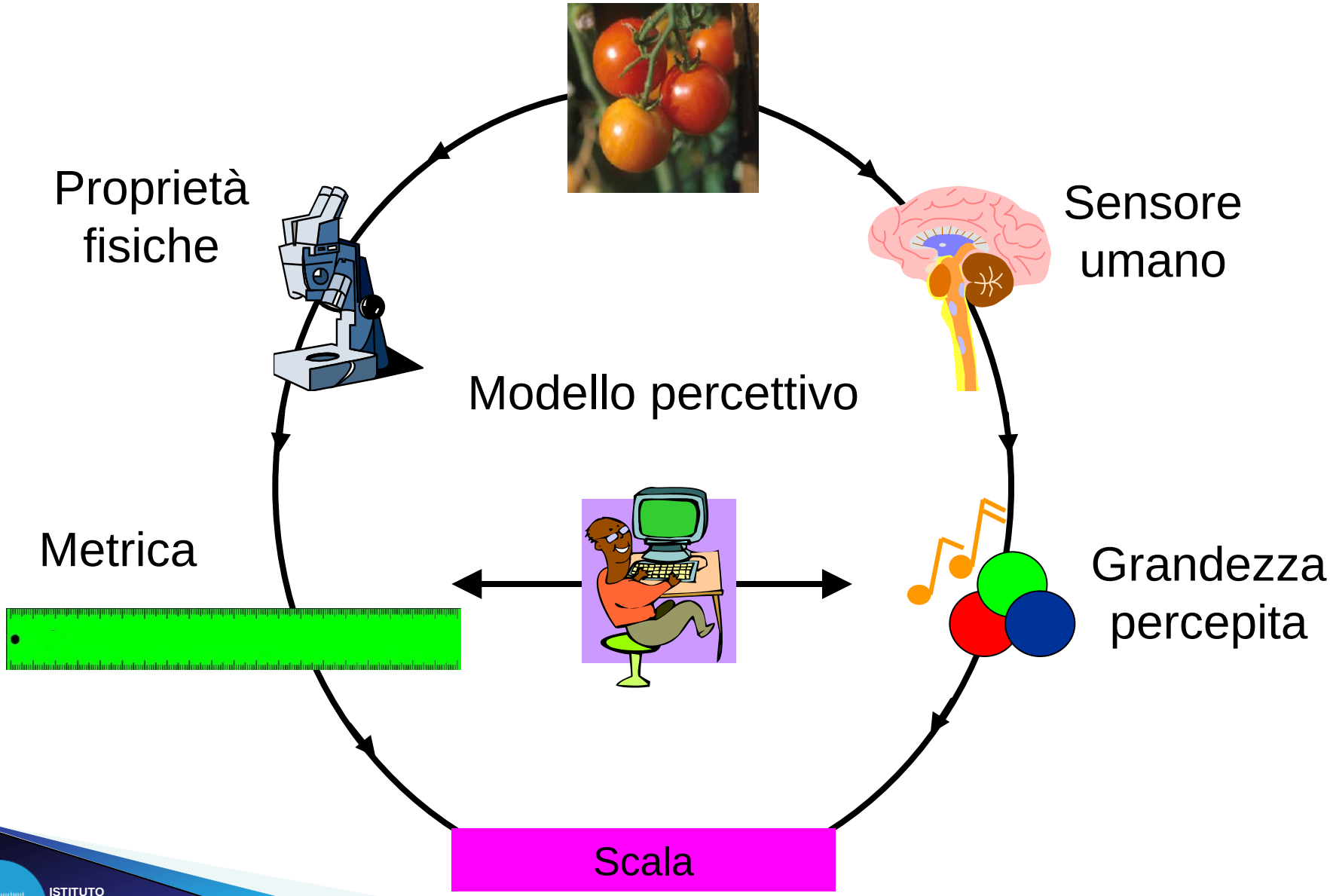
Henri Matisse, *Scritti sull’arte*

“When you can measure what you are speaking about and express it in numbers, you know something about it; but when you cannot measure it , … your knowledge is meagre and unsatisfactory.”

Lord Kelvin



Come misurare la percezione?



Il caso della fotometria: il sensore umano

Anni ‘20

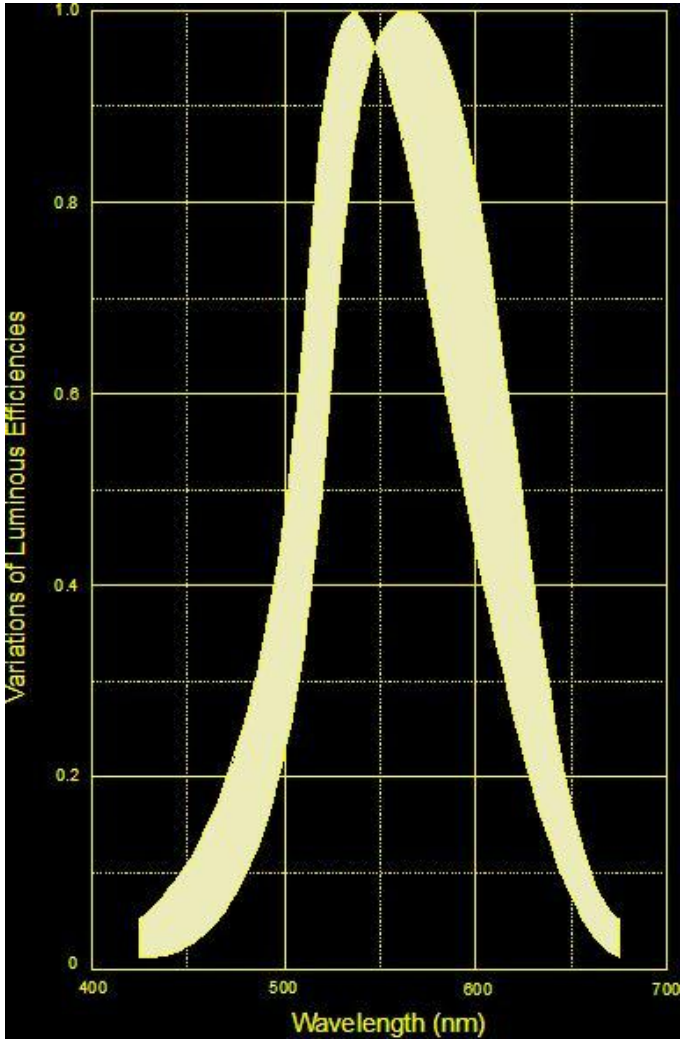
-~ 200 individui di età 18-60 anni

- confronto di brillanza dei colori

- media: osservatore di riferimento adottato dalla CIE

- Variazioni significative con età e sesso

- osservatore definito: donna ~ 27 anni



Il caso della fotometria: il modello

$$\Phi_{\mathrm{v}} = K_{\mathrm{m}} \cdot \int_{380\mathrm{nm}}^{780\mathrm{nm}} \Phi_{\mathrm{e},\lambda}(\lambda) \cdot V(\lambda) \cdot \mathrm{d}\lambda$$

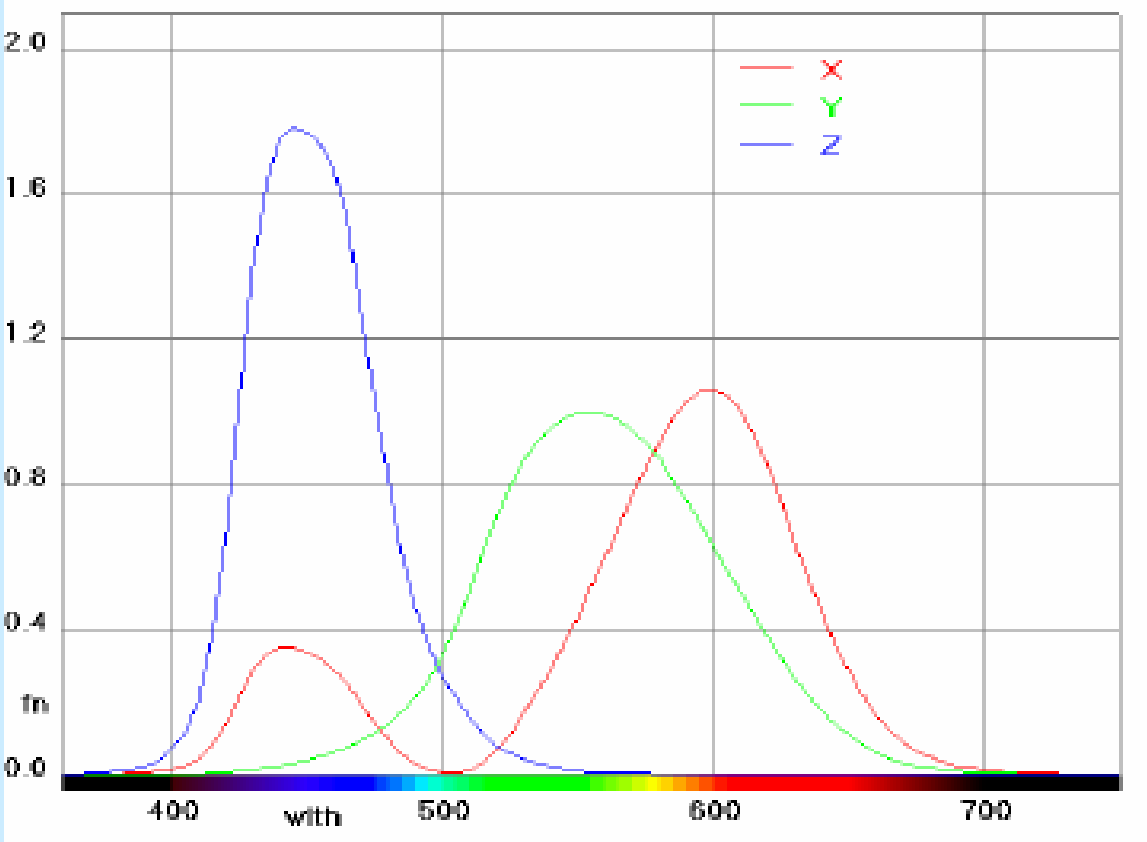
Tre ipotesi:

- linearità
- osservatore di riferimento
- unità di misura: il valore di K_{m} è dato dalla definizione SI della candela

Il caso del colore: i sensori umani

1931 CIE Colour Matching Functions (2º Observer)

$$\bar{x}(\lambda), \bar{y}(\lambda), \bar{z}(\lambda)$$



Il caso del colore: il modello

Tristimulus Values

$$X = k\int E(\lambda)\bar{x}(\lambda)d\lambda$$

$$Y = k\int E(\lambda)\bar{y}(\lambda)d\lambda$$

$$Z = k\int E(\lambda)\bar{z}(\lambda)d\lambda$$

$E(\lambda)$ = spectral irradiance

Conversion to Photometric Units:

$\bar{y}(\lambda) = V(\lambda)$ normalised to 1 at 555 nm.

k=683 lumen / watt → Y= illuminance [lx]

Il caso del colore: lo spazio

Chromaticity Coordinates

Tristimulus Values

X

Y

Z

Chromaticity Coords.

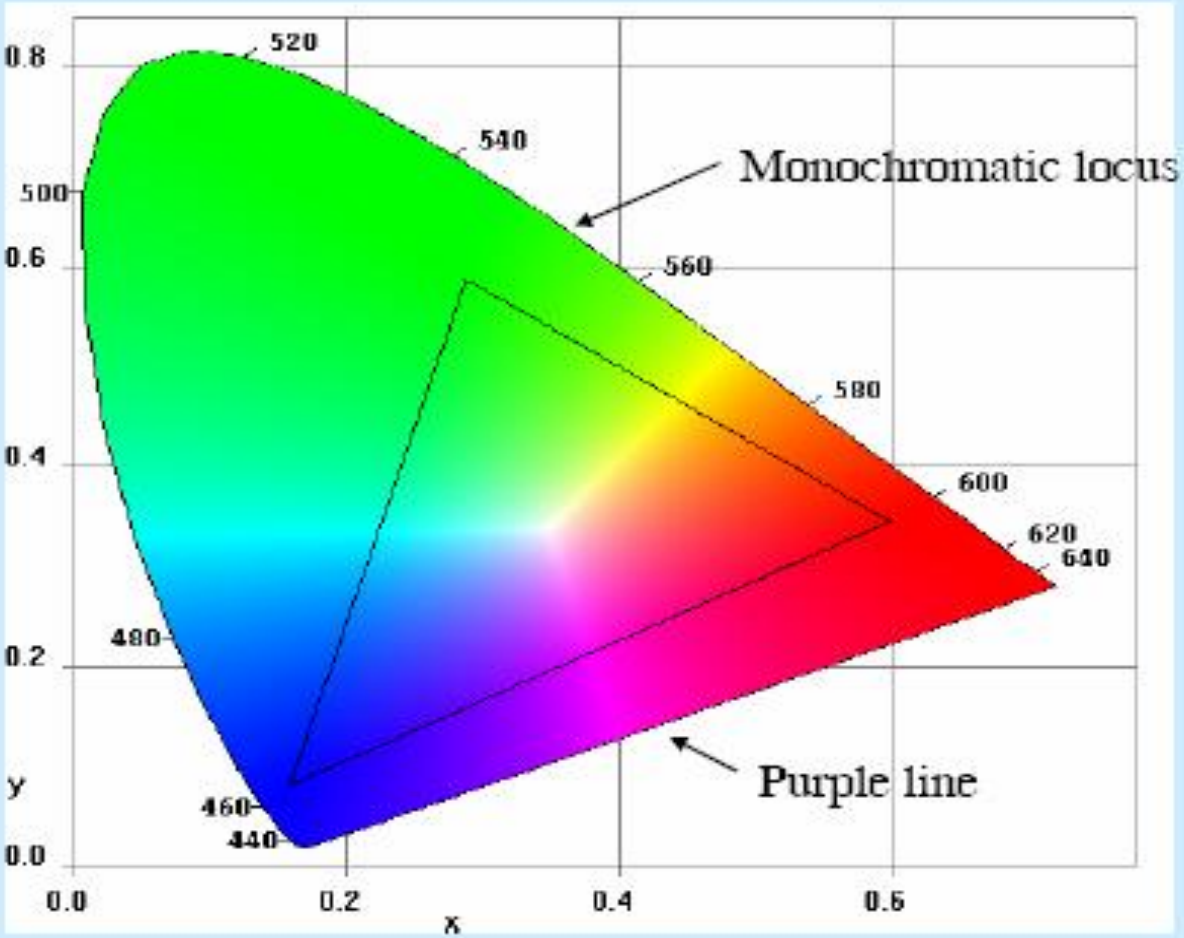
$$x = \frac{X}{X+Y+Z}$$

$$y = \frac{Y}{X+Y+Z}$$

$$z = \frac{Z}{X+Y+Z}$$

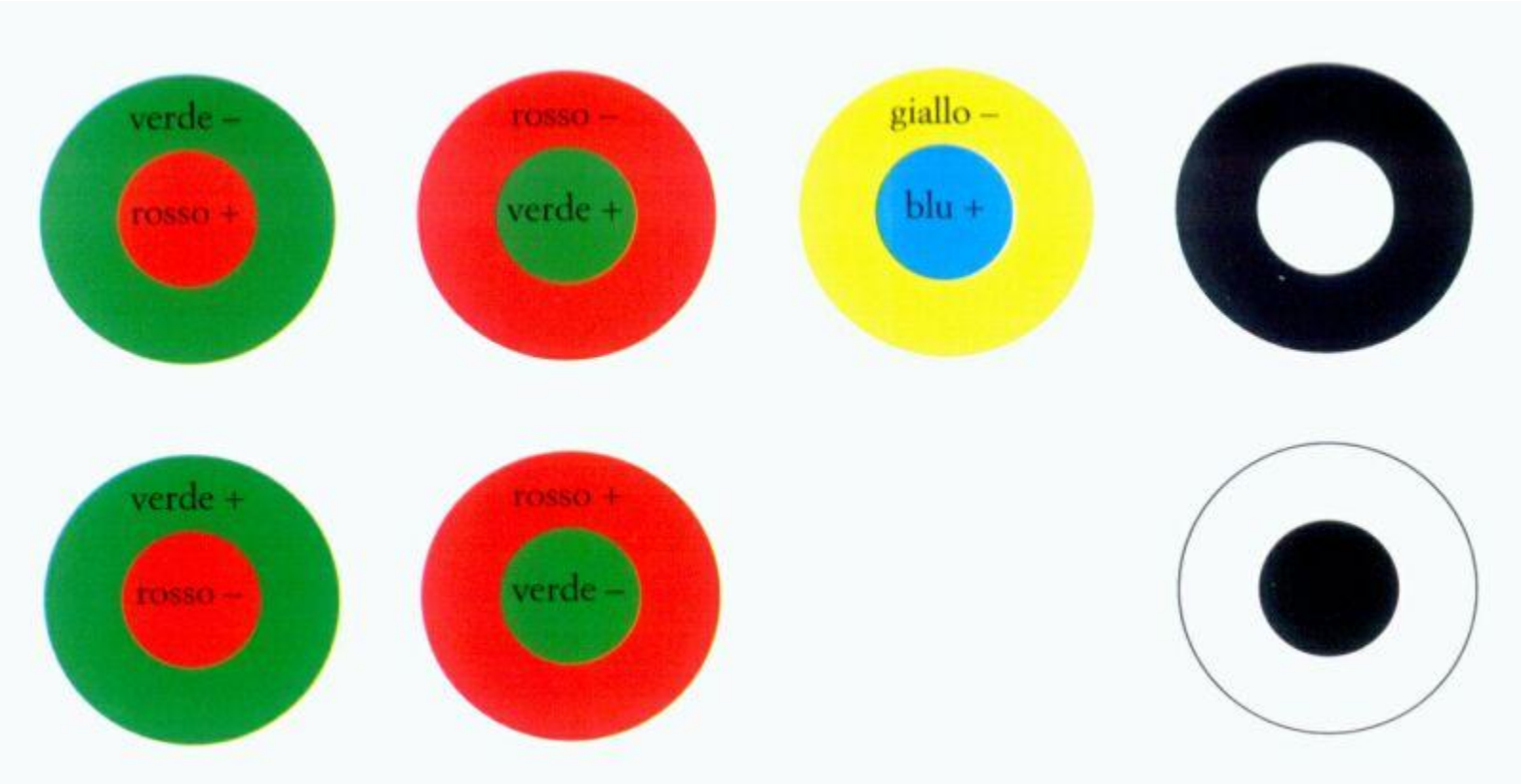
- $x + y + z = 1$
- (x, y) is a 2-dimensional representation of chromaticity.
- Y is a measure of luminance (photometric brightness).
- x, y, Y fully describe colour (3 dimensions).

CIE 1931 Chromaticity Diagram

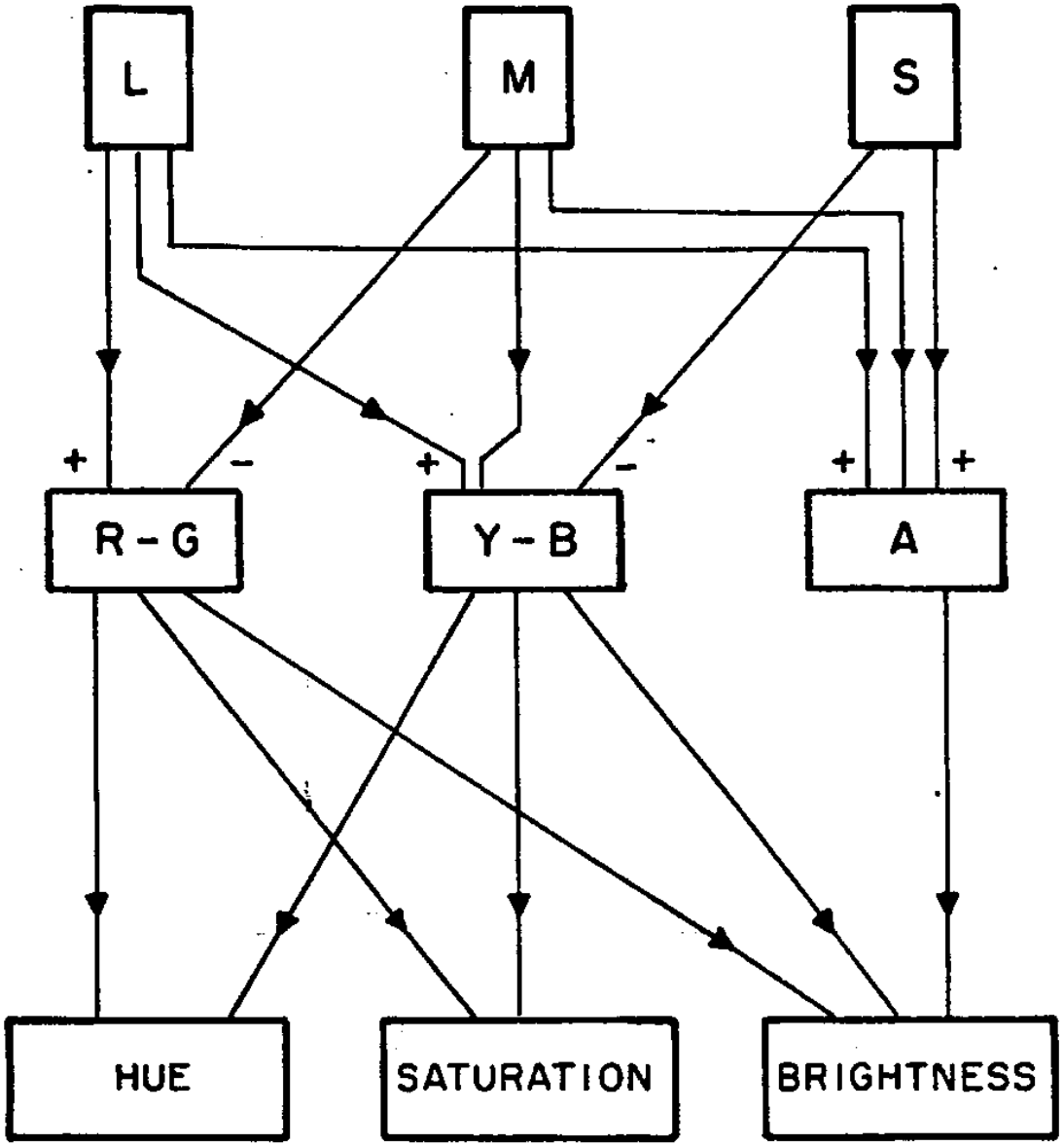


(2° observer)

Il caso del colore



Il caso del colore: il modello



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Il caso del colore: il modello

CIE 1976 CIELAB: L* a* b*

$$L^* = 116\left(\frac{Y}{Y_N}\right)^{1/3} - 16$$

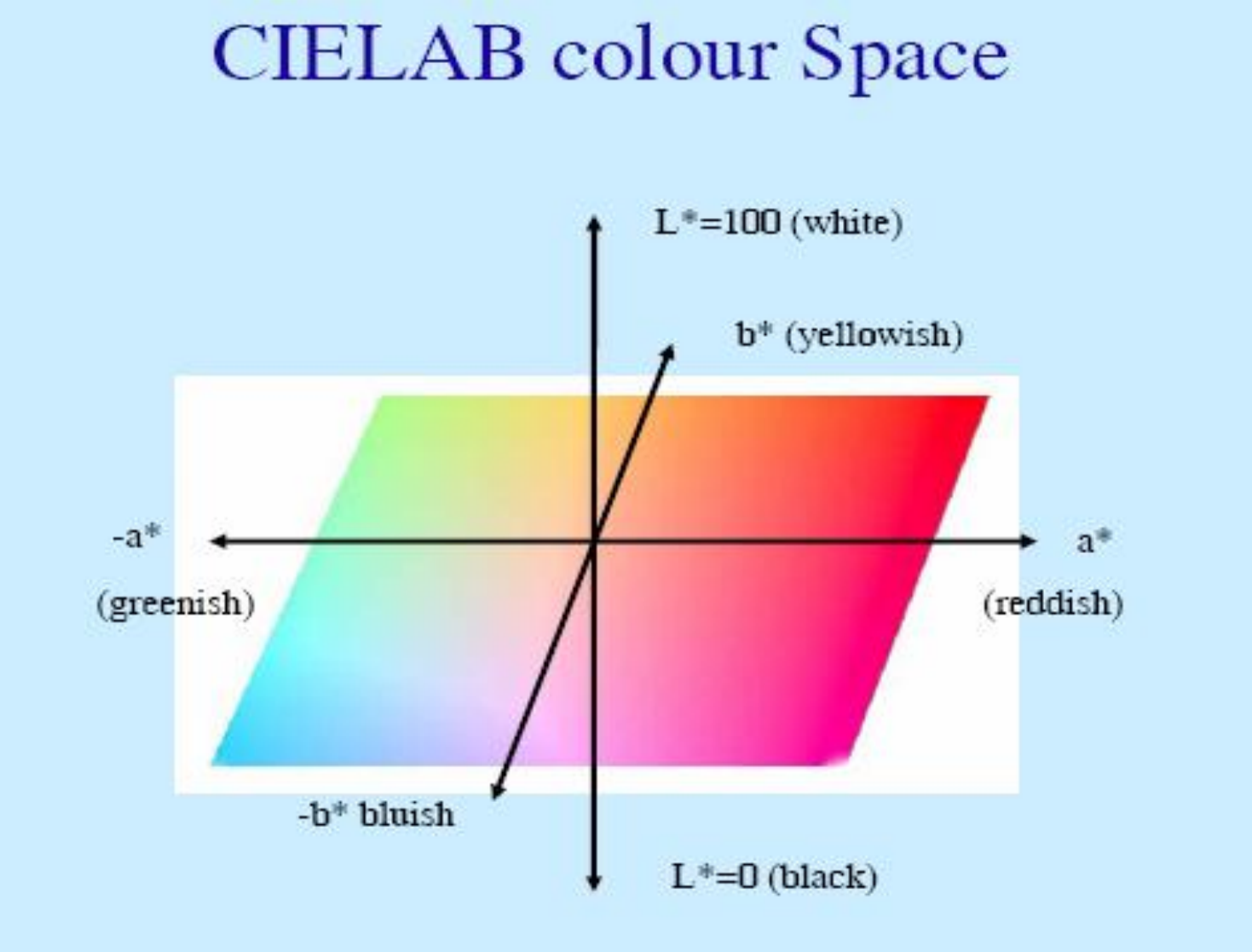
$$a^* = 500\left[\left(\frac{X}{X_N}\right)^{1/3} - \left(\frac{Y}{Y_N}\right)^{1/3}\right]$$

$$b^* = 200\left[\left(\frac{Y}{Y_N}\right)^{1/3} - \left(\frac{Z}{Z_N}\right)^{1/3}\right]$$

for X/X_N ; Y/Y_N ; $Z/Z_N > 0.01$

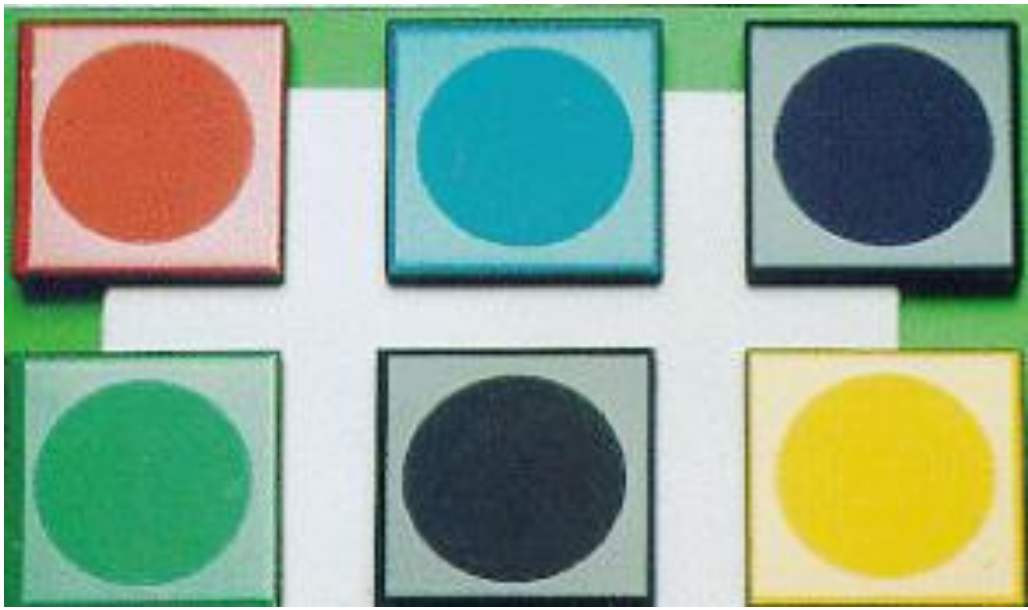
Subscript N refers to a normally white object-colour stimulus, such as one of the CIE Standard Illuminants (A or D65)

Il caso del colore: lo spazio



Metrologia sensoriale

- Attribuire un numero alla percezione
- Scale basate su valutazioni soggettive
- Proprietà fisiche che determinano la percezione



Misurazione oggettiva che metta in relazione le proprietà fisiche con la risposta percettiva

Perché?

- La capacità di predire la risposta sensoriale a partire dalle proprietà fisiche permette :
  - Progettazione di prodotti/interni che inducono una specifica reazione
  - Sviluppo di nuovi materiali per risolvere specifici problemi
  - Product customisation

Visione – ciò che non sappiamo misurare

- Texture e pattern

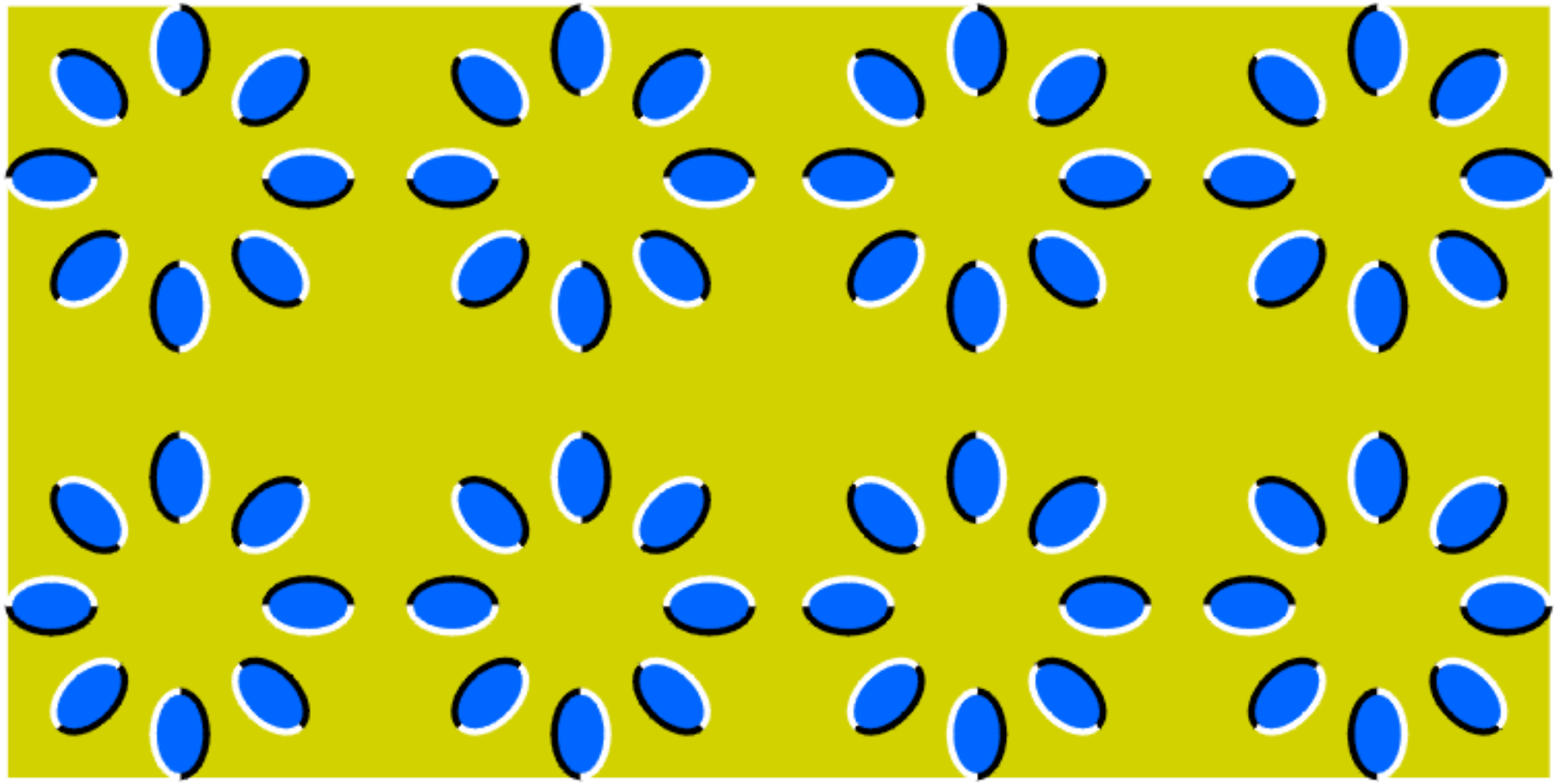
Visione–ciò che non sappiamo misurare

- Correlazione spaziale e temporale tra aspetti differenti

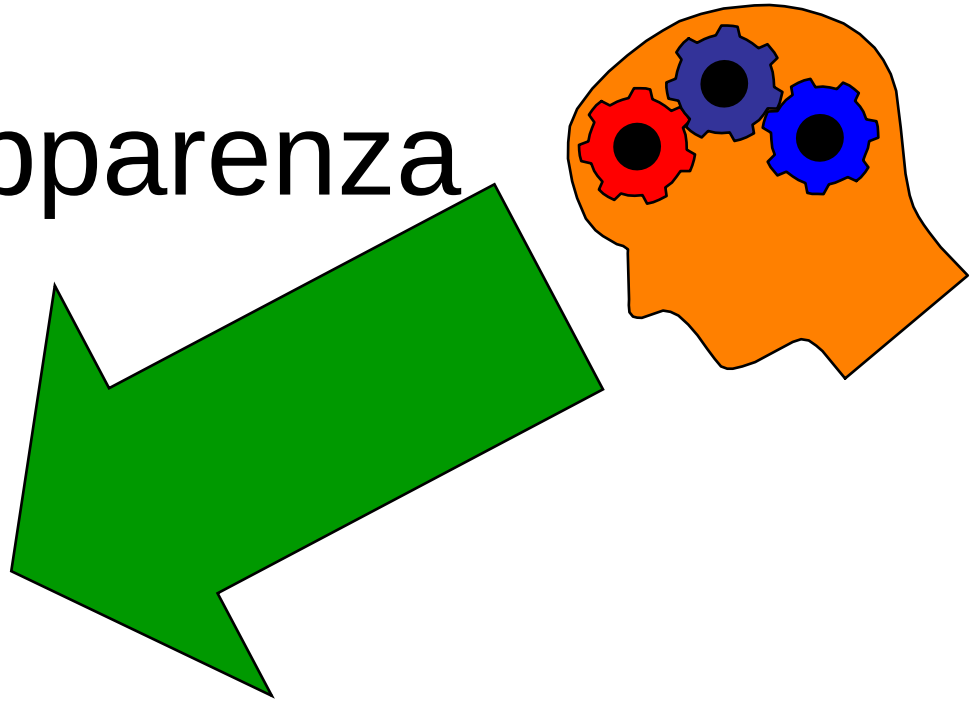
- Sensazioni fortemente emotive

© ChromaFlair

Akiyoshi KITAOKA, Japan



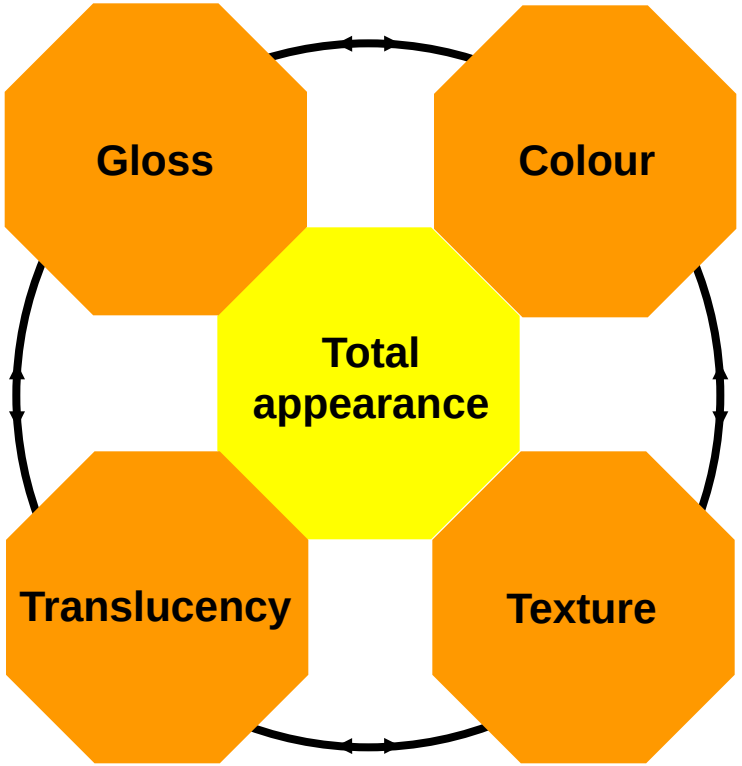
Misuratore di apparenza



Misuratore di apparenza

APPEARANCE METER

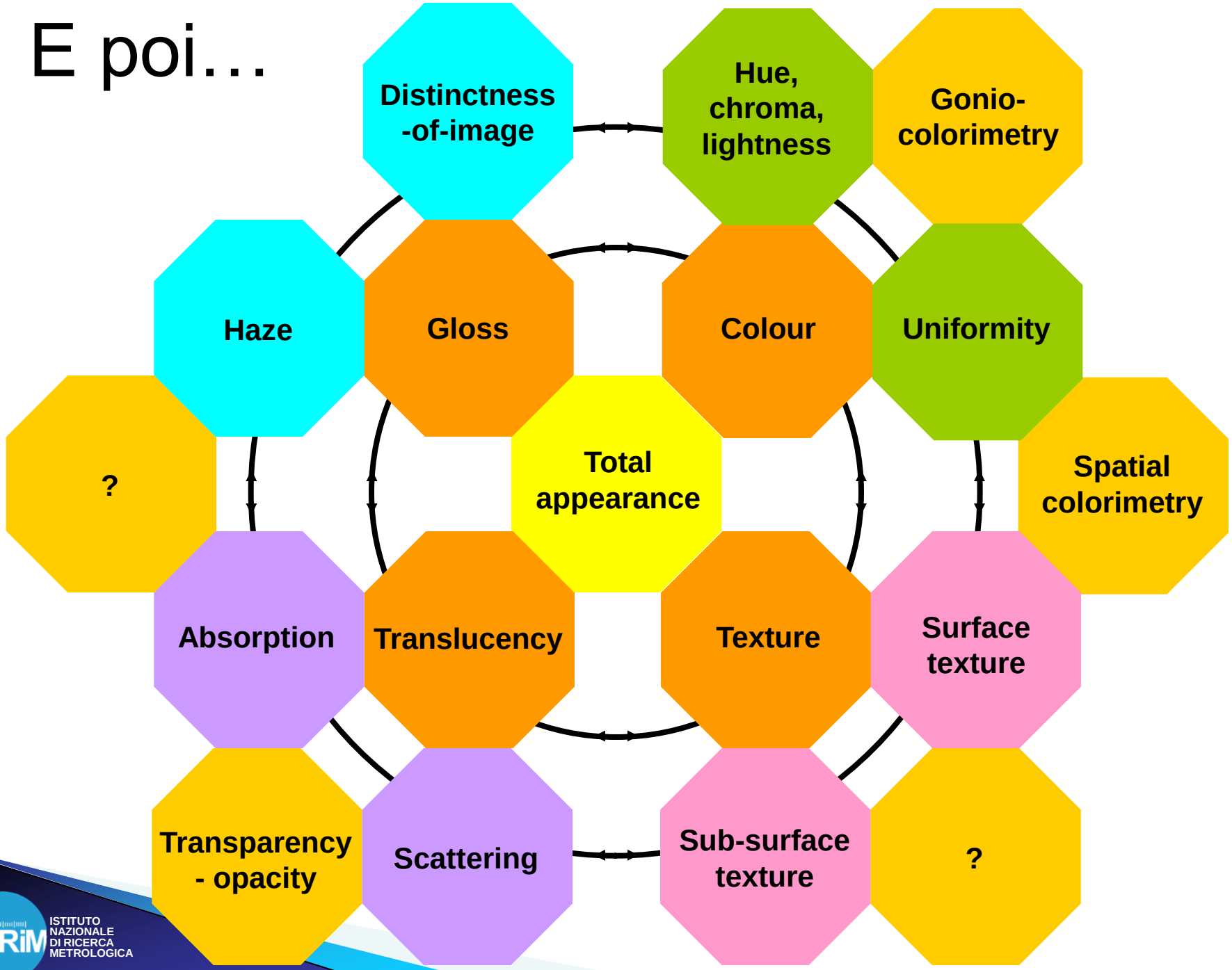
Il primo passo …



Il secondo . . .

Distinctness -of-image
Hue, chroma, lightness
Haze
Gloss
Colour
Uniformity
Total appearance
Absorption
Translucency
Texture
Surface texture
Scattering
Sub surface texture

E poi…


Distinctness -of-image
Hue, chroma, lightness
Gonio-colorimetry
Haze
Gloss
Colour
Uniformity
?
Total appearance
Spatial colorimetry
Absorption
Translucency
Texture
Surface texture
Transparency - opacity
Scattering
Sub-surface texture
?