

# Optoelectronică

Curs 4  
2020/2021

# Disciplina 2020/2021

- ▶ 2C/1L Optoelectronică **OPTO**
- ▶ **Minim 7 prezente curs + laborator**
- ▶ Curs – conf. **Radu Damian**
  - an IV  $\mu E$
  - Miercuri 11–14, online, Microsoft Teams
  - E – 70% din nota (50+20), online, rf-opto
    - **20% test la curs**, saptamana 4–5?
  - probleme + (? 1 subiect teorie) + (2p prez. curs)
  - toate materialele permise
- ▶ Laborator – **sl. Daniel Matasaru**
  - an IV  $\mu E$ 
    - Marti 10-14 impar/par
  - L – 30% din nota (+Caiet de laborator)

# Orar 2020/2021

## ▶ Curs

- Miercuri 11–14, online
- **2C ⇒ 3C**
  - $14 * 2/3 \approx 9.33$
  - $9 \div 10 C \approx 9C + E$

# Online

- ▶ acces la **examene** necesita **parola** primita prin **email**

English | Romana |

Start Didactic Master Colectiv Cercetare Stud

Note Lista Studenti Examene Fotografii

## POPESCU GOPO ION

**Fotografia nu exista**

**Date:**

|               |  |
|---------------|--|
| Grupa         | 5700 (2019/2020)                         |
| Specializarea | Inginerie electronica si telecomunicatii |
| Marca         | 7000021                                  |

Acceseaza ca acest student | [here acces la licente](#)

**Note obtinute**

Inca nu a fost notat.

Start Didactic Master Colectiv C

Note Lista Studenti Examene Fotografii

## Identificare

Introduceti numele si adresa de email utilizata la inscriere

Nume  
POPESCU GOPO

**E-mail/Parola**

Introduceti codul afisat mai jos

4db4457

Trimite

# Online

## ► acces email/parola

Start Didactic Master Colectiv

Note Lista Studenti Examene Fotografii

### POPESCU GOPO ION

Fotografia nu exista

Date:

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| Grupa         | 5700 (2019/2020)      |
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Se acceseaza site-ul [ca acest student!](#)

Start Didactic Master Colectiv

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### POPESCU GOPO ION

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|               |                         |
|---------------|-------------------------|
| Grupa         | 5700 (2019/2020)        |
| Specializarea | Inginerie electronica s |
| Marca         | 7000021                 |

Se acceseaza site-ul [ca acest student \(inclusiv examene\)!](#)

# Parola

## ▶ primita prin email

Important message from RF-OPTO

Inbox x



Radu-Florin Damian

to me, POPESCU

Romanian > English Translate message



Laboratorul de Microunde si Optoelectronica  
Facultatea de Electronica, Telecomunicatii si Tehnologia Informatiei  
Universitatea Tehnica "Gh. Asachi" Iasi

**In atentie: POPESCU GOPO ION**

Parola pentru a accesa examenele pe server-ul **rf-opto** este

Parola: [REDACTED]

Identificati-va pe [server](#), cu parola, cat mai rapid, pentru confirmare.

**Memorati** acest mesaj intr-un loc sigur, pentru utilizare ulterioara

**Attention: POPESCU GOPO ION**

The password to access the exams on the **rf-opto** server is

Password: [REDACTED]

Login to the [server](#), with this password, as soon as possible, for confirmation.

**Save** this message in a safe place for later use

Reply

Reply all

Forward

Subject

Important message from RF-OPTO

Validation of MIDCR exam from 02/05/2020

From: Me <rdamian@etti.tuiasi.ro>

Subject: Important message from RF-OPTO

To: [REDACTED]

Cc: Me <rdamian@etti.tuiasi.ro>

Correspondents

POPESCU GOPO ION

[REDACTED]

[REDACTED]

Laboratorul de Microunde si Optoelectronica  
Facultatea de Electronica, Telecomunicatii si Tehnologia Informatiei  
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**Save** this message in a safe place for later use


# Manual examen online

- ▶ Aplicatia de examen online utilizata intens la:
  - curs (prezenta)
  - miniteste
  - examen

## Materials

### Other data

[Manual examen on-line](#) (pdf, 2.65 MB, ro, )

[Simulare Examen](#) (video) (mp4, 65.12 MB, ro, )

## Microwave Devices and Circuits (Englis

# Examen online

- ▶ intotdeauna **contratimp**
  - perioada lunga (prezenta curs/rezultate laborator)
  - perioada scurta (teste: 15min, examen: 2h)

Start Didactic Master Colectiv Cercetare **Studenti**

Note Lista Studenti **Examene** Fotografii

**Anunț**  
17:28 (29/04/2020)

**Material suport**  
17:30 (29/04/2020)

**Subiecte**  
17:32 (29/04/2020)

**Rezultate**  
17:35 (29/04/2020)

**Finalizare**  
17:45 (29/04/2020)

**Confirmare**  
17:45 (30/04/2020)

Urmatorul interval de timp in:  
**01 m 08 s**  
[Reincarca acum](#)

## Anunț

In acest examen se verifica diverse actiuni ale studentilor pentru examen

## Ora pe server

Toate examenele sunt bazate pe fusul orar al server-ului (ar putea sa fie diferit de timpul local). Pentru referinta ora pe server este acum:

**29/04/2020 17:28:51**



# Introducere

## Capitolul 1

# Aplicatii majore

- ▶ Comunicatii

- Infrarosu (InGaAsP)

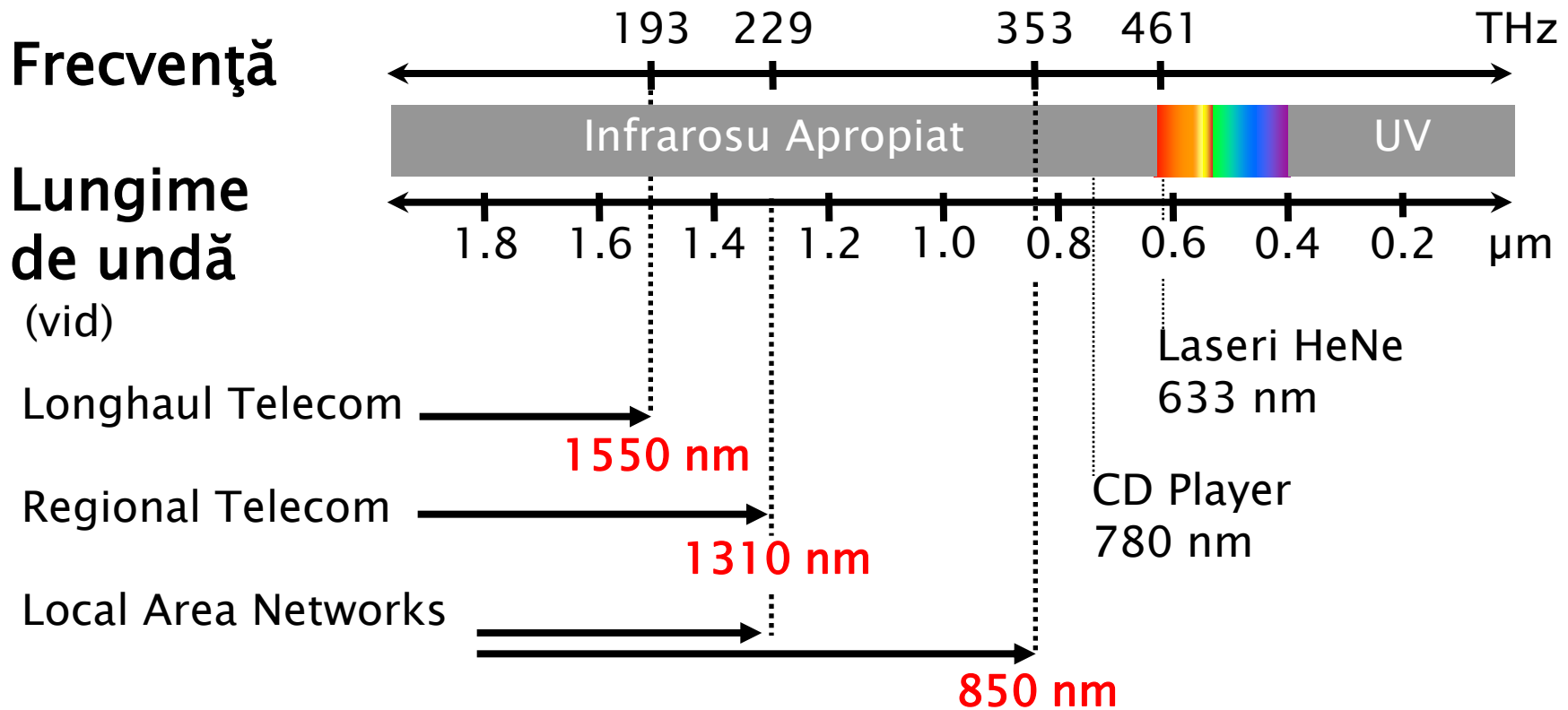
- ▶ Vizibil

- Spectru vizibil (GaAlAs)

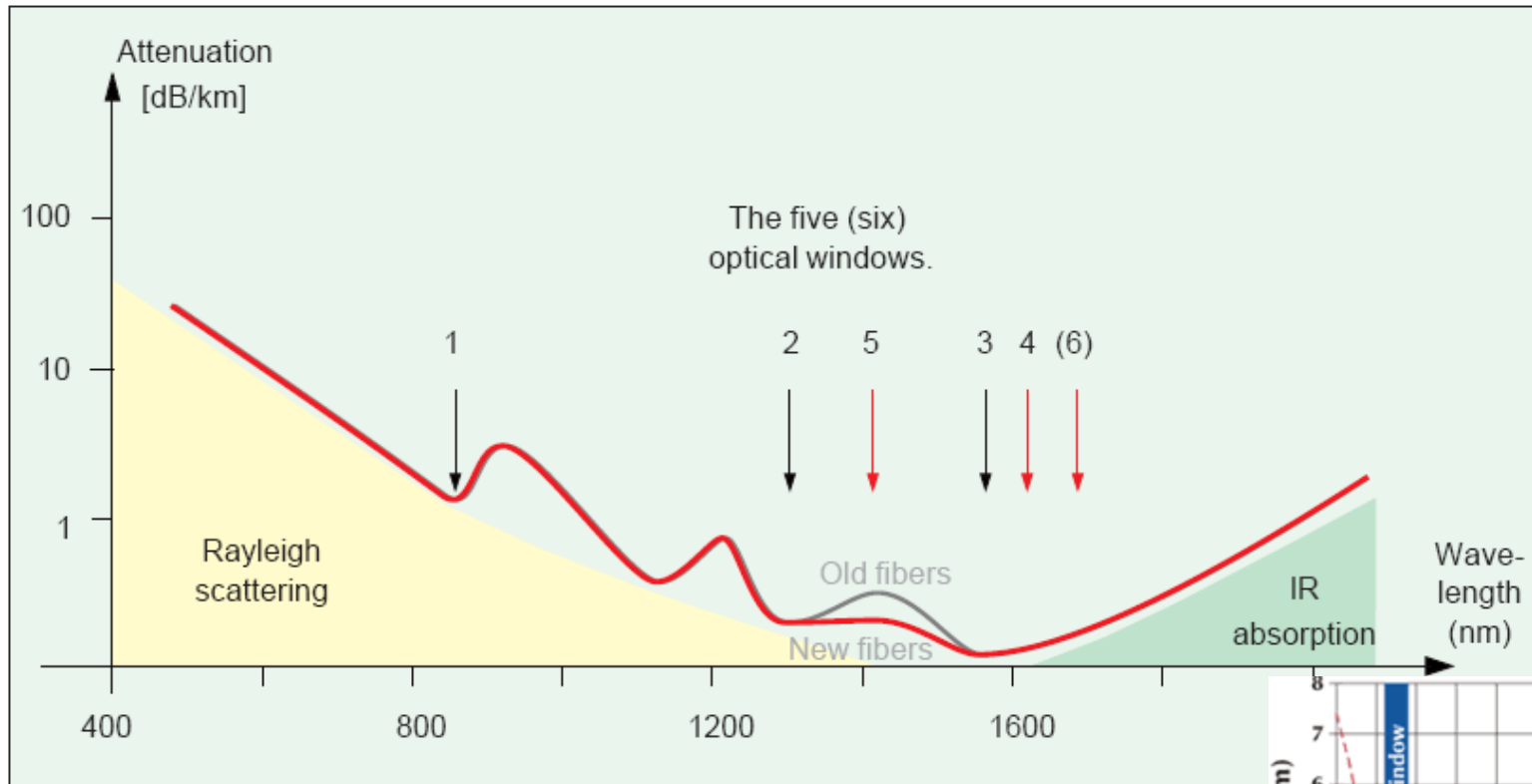
- ▶ Iluminare

- Putere ridicata, lumina alba (GaN)

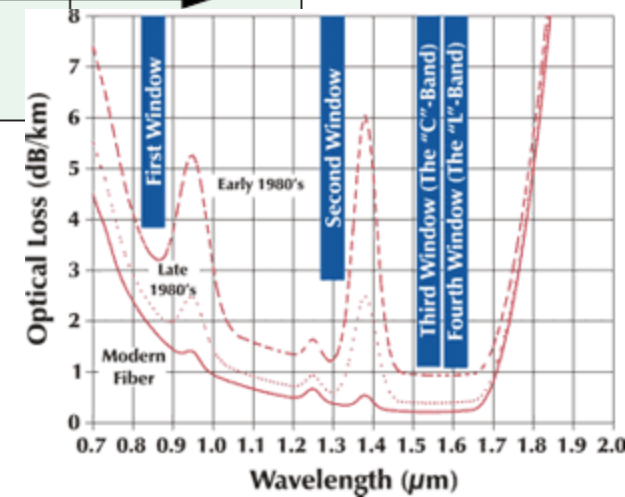
# Benzi de lucru in comunicațiile optice



# Atenuarea în fibra optică (SiO<sub>2</sub>)



850nm, 1310nm, 1550nm



# Aplicatii majore

- ▶ Comunicatii
  - Infrarosu (InGaAsP)
- ▶ Vizibil
  - Spectru vizibil (GaAlAs)
- ▶ Iluminare
  - Putere ridicata, lumina alba (GaN)

# Premiul Nobel, Fizica, 2014

Physics



The Nobel Prize in Physics 2014

Summary



The Nobel Prize in Physics 2014

Isamu Akasaki  
Hiroshi Amano  
Shuji Nakamura

Share this



## The Nobel Prize in Physics 2014



© Nobel Media AB. Photo: A. Mahmoud

**Isamu Akasaki**

Prize share: 1/3



© Nobel Media AB. Photo: A. Mahmoud

**Hiroshi Amano**

Prize share: 1/3



© Nobel Media AB. Photo: A. Mahmoud

**Shuji Nakamura**

Prize share: 1/3

The Nobel Prize in Physics 2014 was awarded jointly to Isamu Akasaki, Hiroshi Amano and Shuji Nakamura "for the invention of efficient blue light-emitting diodes which has enabled bright and energy-saving white light sources."

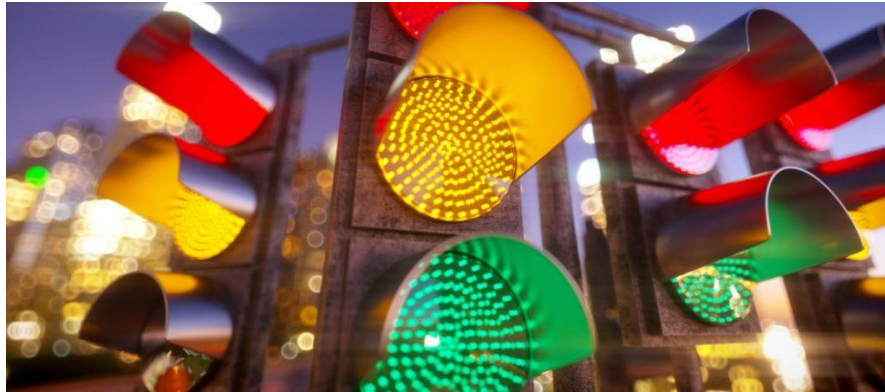
To cite this section

MLA style: The Nobel Prize in Physics 2014, NobelPrize.org, Nobel Media AB 2021. Tue, 2 Mar 2021.

# Aplicatii majore

- ▶ Comunicatii
  - Infrarosu (InGaAsP)
- ▶ Vizibil
  - Spectru vizibil (GaAlAs)
- ▶ Iluminare
  - Putere ridicata, lumina alba (GaInN)

# Spectru vizibil





# Reprezentare logaritmică

$$\text{dB} = 10 \cdot \log_{10} (P_2 / P_1)$$

$$\text{dBm} = 10 \cdot \log_{10} (P / 1 \text{ mW})$$

$$0 \text{ dB} = 1$$

$$+ 0.1 \text{ dB} = 1.023 (+2.3\%)$$

$$+ 3 \text{ dB} = 2$$

$$+ 5 \text{ dB} = 3$$

$$+ 10 \text{ dB} = 10$$

$$-3 \text{ dB} = 0.5$$

$$-10 \text{ dB} = 0.1$$

$$-20 \text{ dB} = 0.01$$

$$-30 \text{ dB} = 0.001$$

$$0 \text{ dBm} = 1 \text{ mW}$$

$$3 \text{ dBm} = 2 \text{ mW}$$

$$5 \text{ dBm} = 3 \text{ mW}$$

$$10 \text{ dBm} = 10 \text{ mW}$$

$$20 \text{ dBm} = 100 \text{ mW}$$

$$-3 \text{ dBm} = 0.5 \text{ mW}$$

$$-10 \text{ dBm} = 100 \mu\text{W}$$

$$-30 \text{ dBm} = 1 \mu\text{W}$$

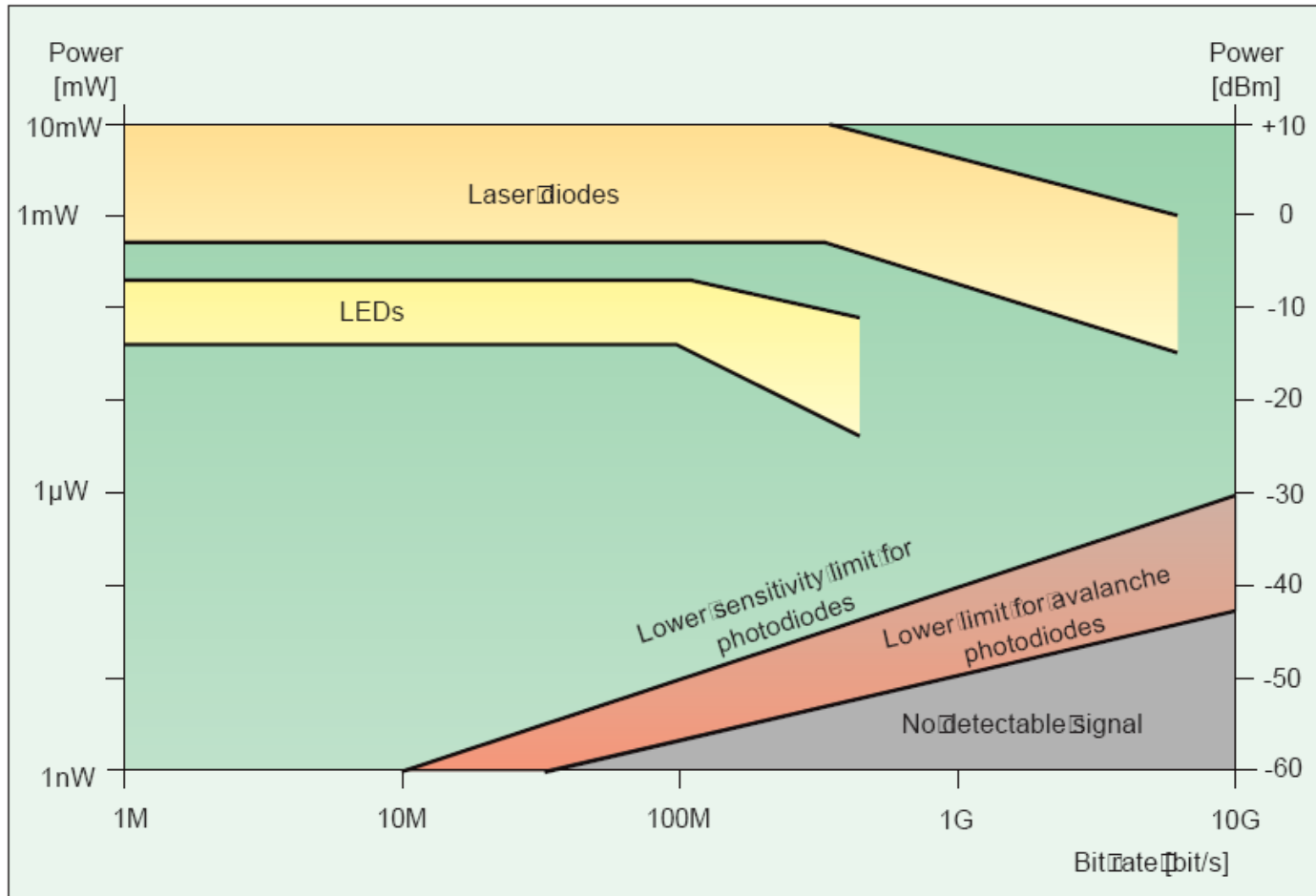
$$-60 \text{ dBm} = 1 \text{ nW}$$

$$[\text{dBm}] + [\text{dB}] = [\text{dBm}]$$

$$[\text{dBm/Hz}] + [\text{dB}] = [\text{dBm/Hz}]$$

$$[\text{x}] + [\text{dB}] = [\text{x}]$$

# Limite putere/bandă a dispozitivelor optoelectronice

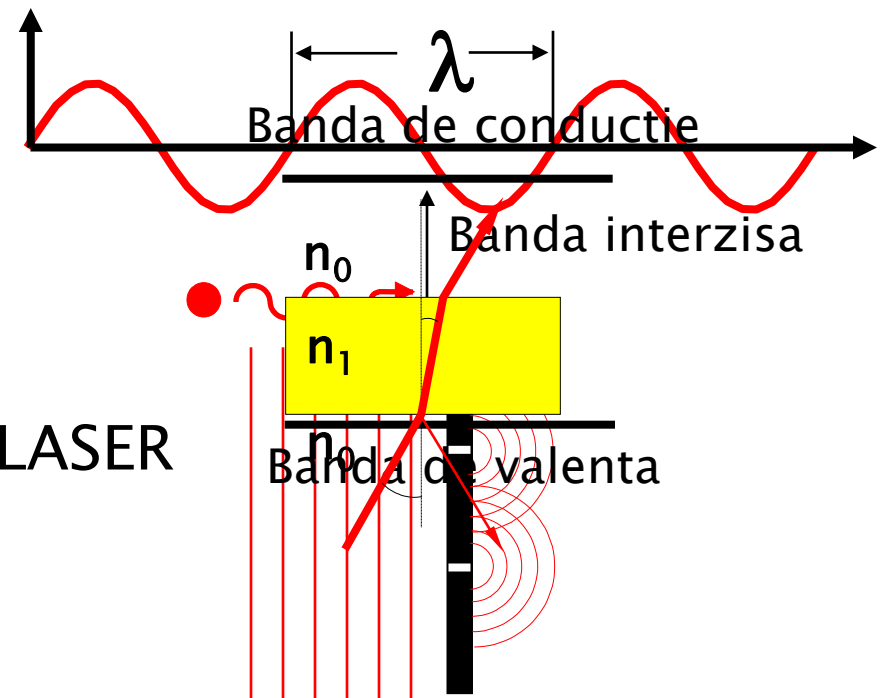


# Modelarea luminii

(tot) Capitolul 1

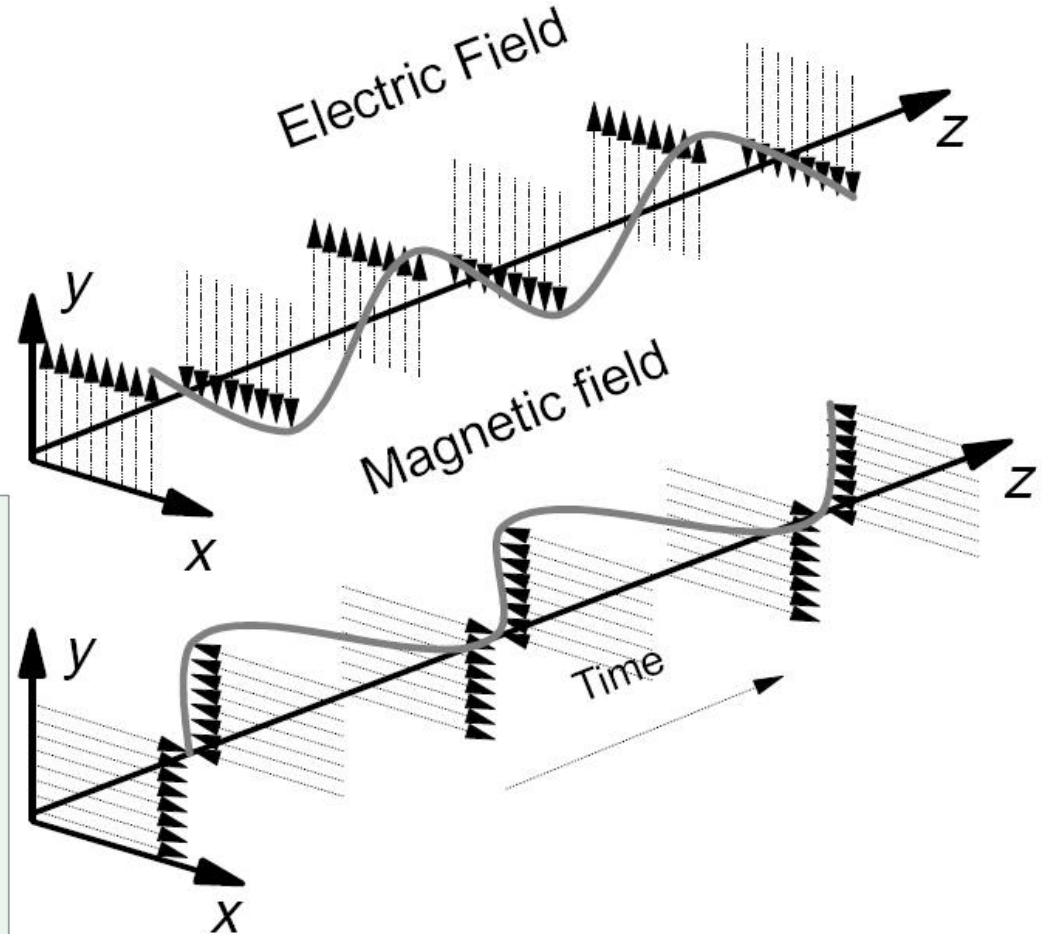
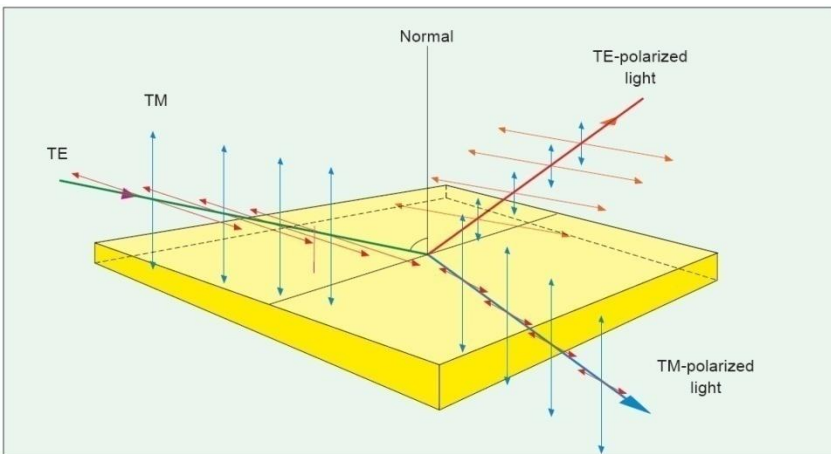
# Modelarea luminii

- ▶ Undă electromagnetică
  - Ecuațiile lui Maxwell
  - $\lambda$ ,  $\epsilon$ ,  $\omega$ ,  $f$
- ▶ Teoria cuantică
  - Benzi energetice  $E = h \nu$
  - fotoni, emisie stimulată, LASER
- ▶ Optică geometrică
  - $n$ ,  $\theta$
  - raze de lumină
  - intuitivă

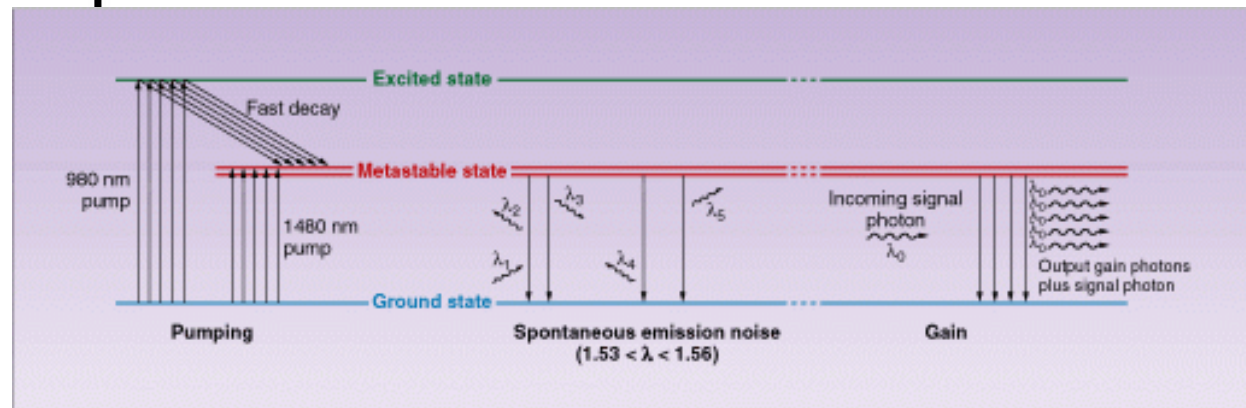
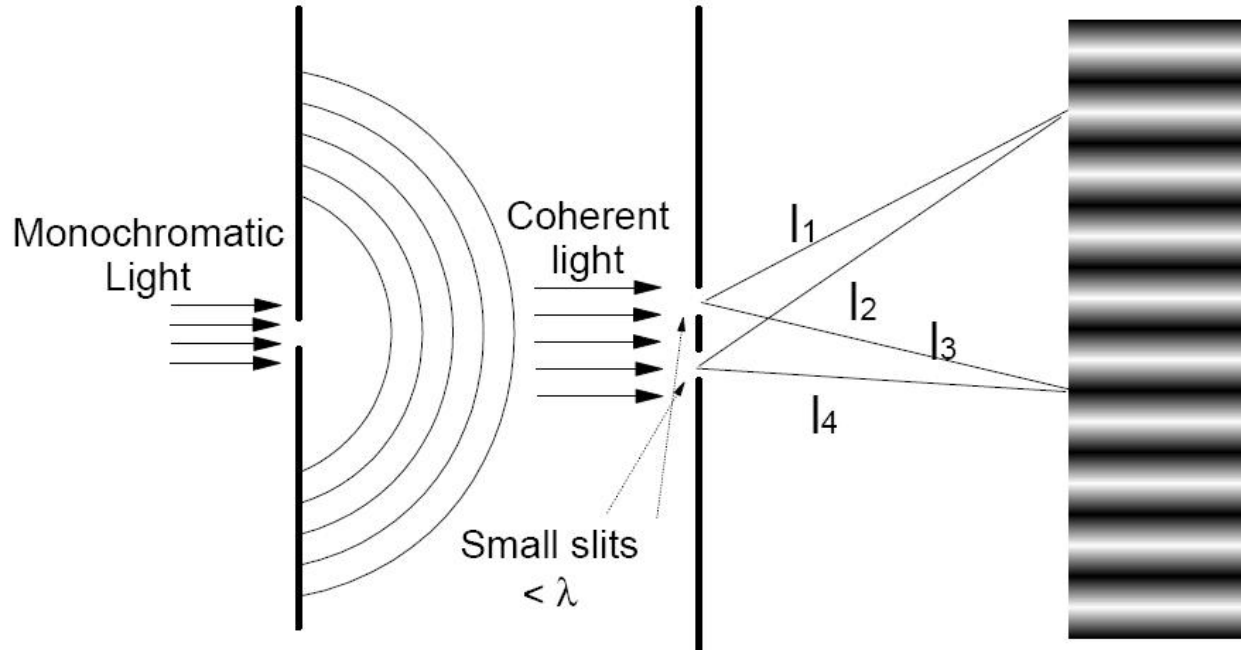


# Unda electromagnetica

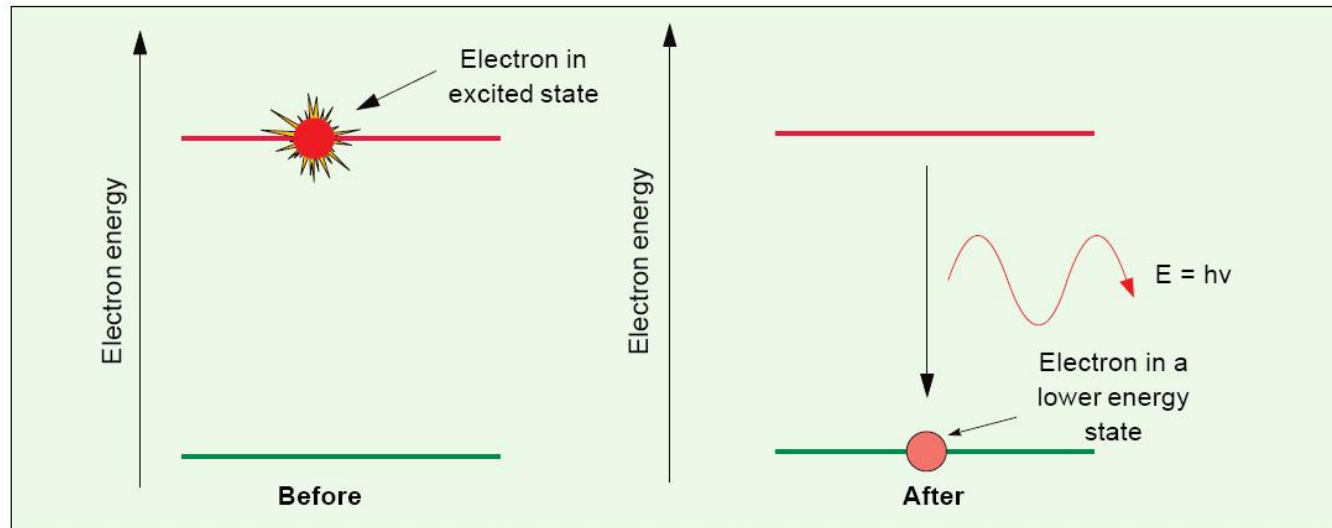
- ▶ Dispersie
- ▶ Fibre monomod
- ▶ Interferenta
- ▶ Polarizare



# Fotoni/Unda

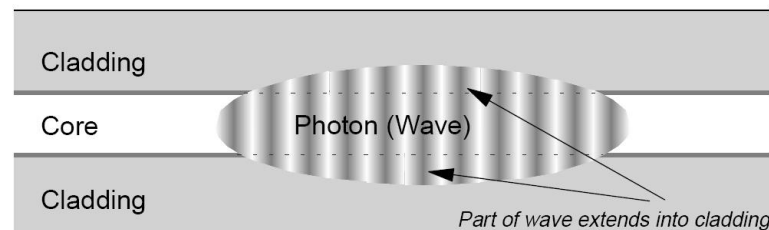


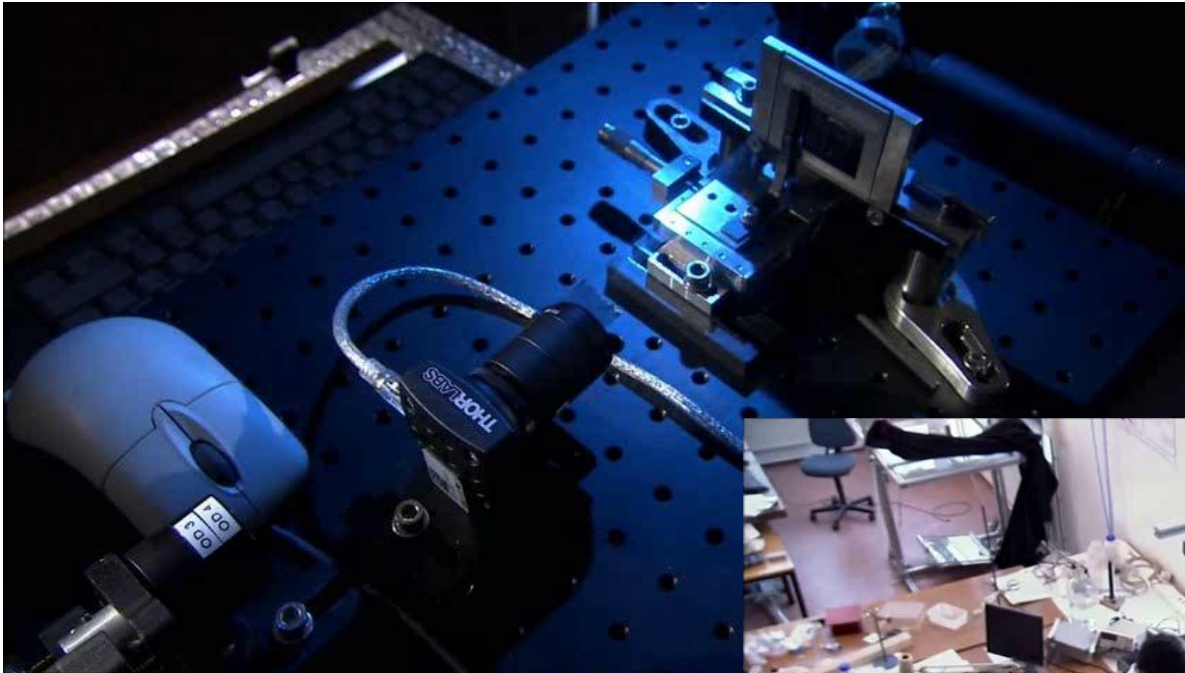
# Model cuantic – foton



$$E_g = h\nu; \quad \lambda = \frac{hc}{E_g}; \quad \lambda[\mu\text{m}] = \frac{1.240}{E_g[\text{eV}]}$$

- ▶  $h$  constanta lui Plank  
 $6.62 \cdot 10^{-32} \text{ Ws}^2$
- ▶  $c$  viteza luminii **in vid**  
 $2.998 \cdot 10^8 \text{ m/s}$

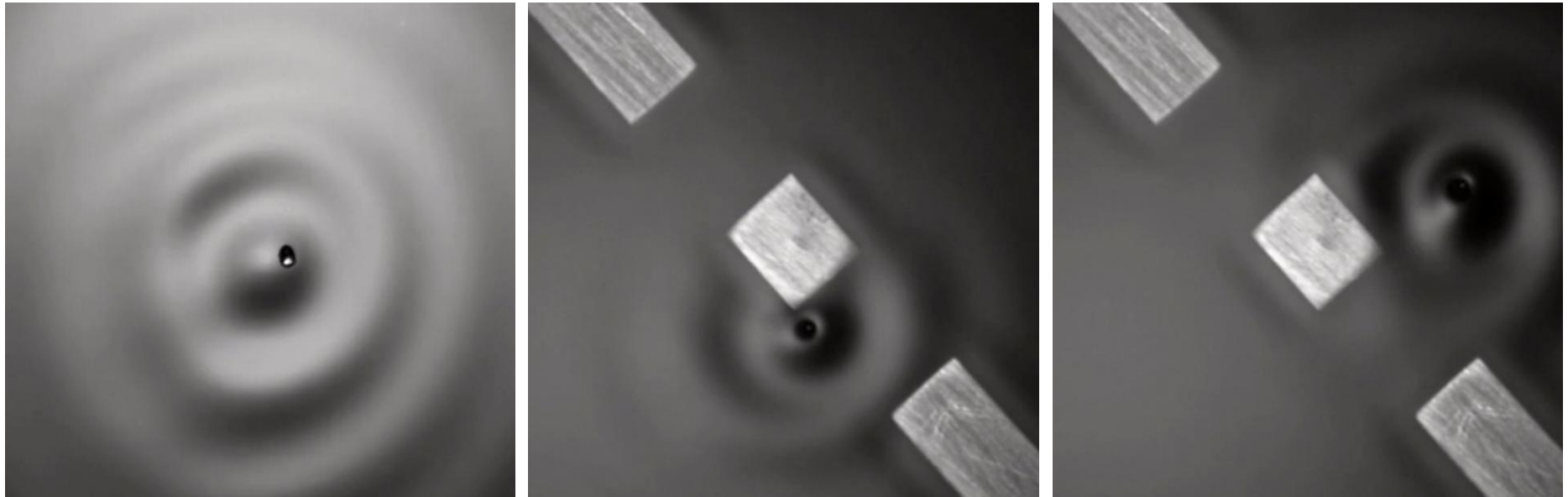




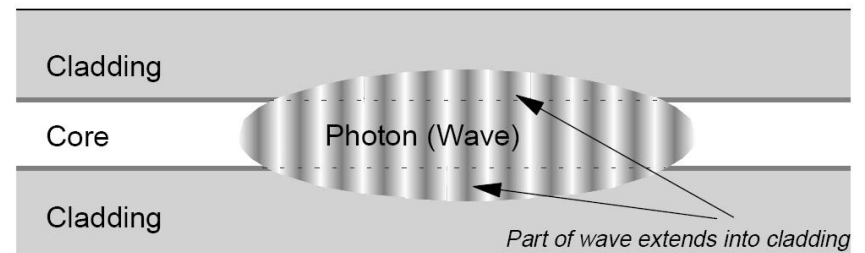
## Through the Wormhole S02E07 How Does the Universe Work



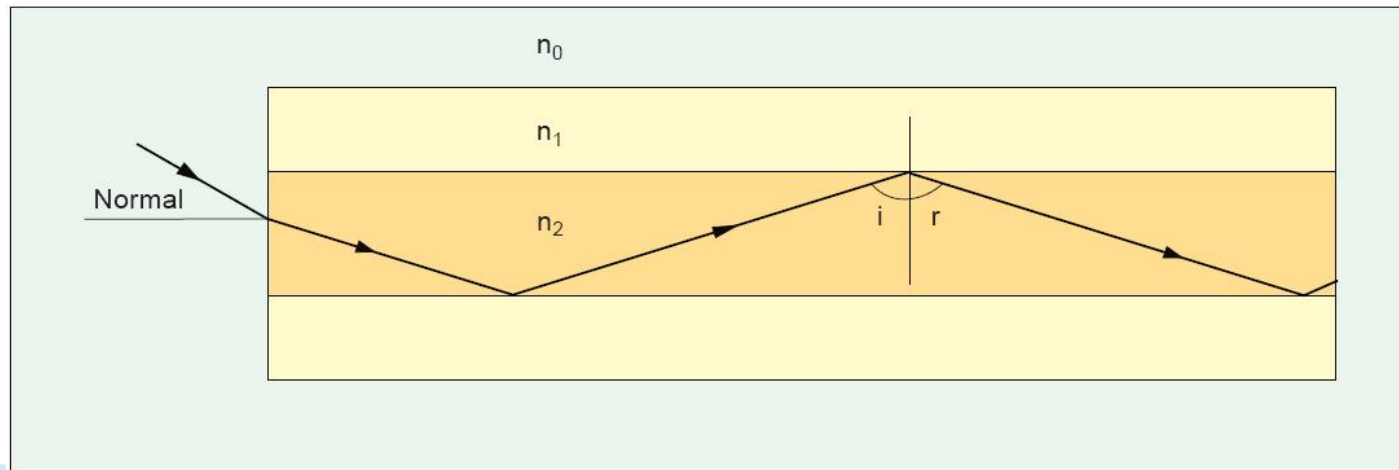
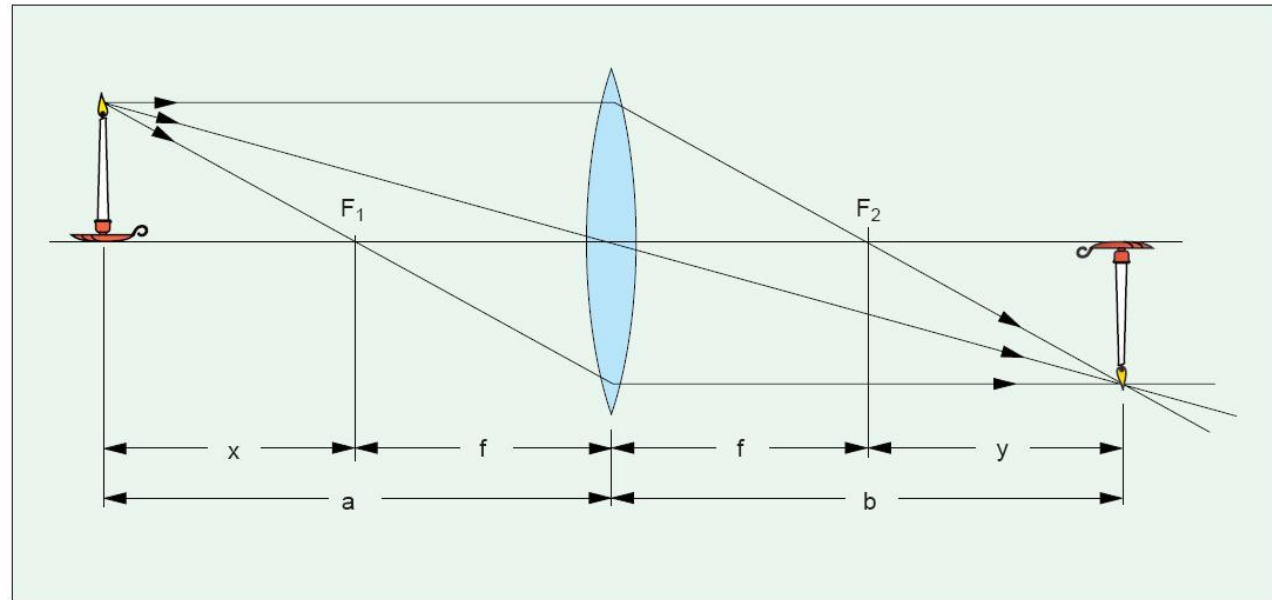
# Modelare



Through the Wormhole  
S02E07 How Does the Universe Work



# Optica geometrica



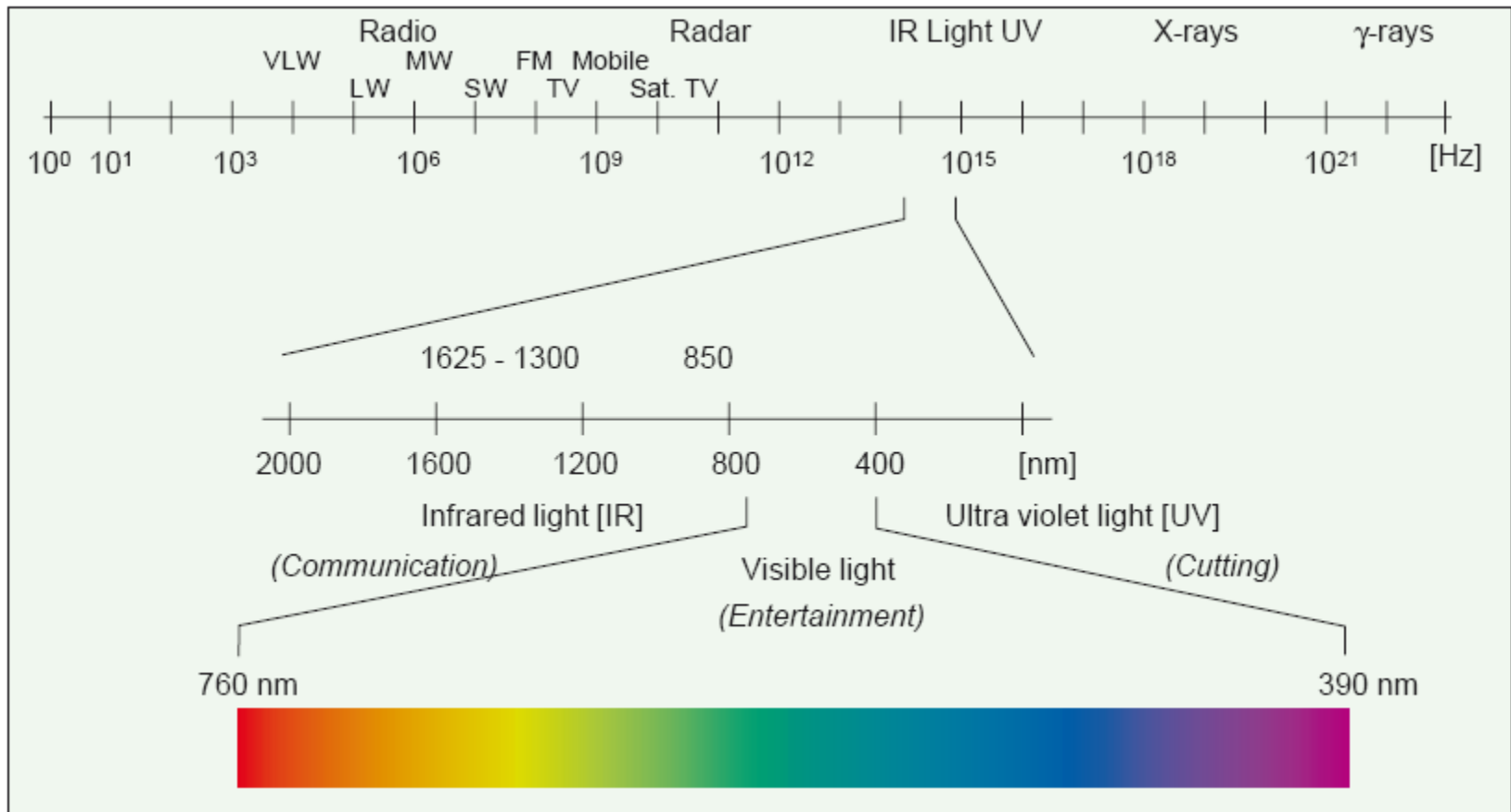
# Fotometrie și radiometrie

Capitolul 3

# Aplicatii majore

- ▶ Comunicatii
  - Infrarosu (InGaAsP)
- ▶ Vizibil
  - Spectru vizibil (GaAlAs)
- ▶ Iluminare
  - Putere ridicata, lumina alba (GaN)

# Spectrul electromagnetic



# O alta dualitate

- ▶ In optoelectronica, lumina poate fi privita din doua puncte de vedere
  - energetic (efect asupra dispozitivului)
  - uman (efect asupra ochiului)
- ▶ Dualitatea mărimilor implicate
  - energetice
  - luminoase
- ▶ Candela (cd) **este** una din cele 7 mărimi fundamentale ale SI
  - Cd = intensitatea luminoasa a unei surse ce emite o radiație monocromatica cu frecventa  $540 \cdot 10^{12}$  Hz ( $\lambda = 555\text{nm}$  in vid) si are o intensitate radianta de  $1/683$  W/sr

# Flux energetic

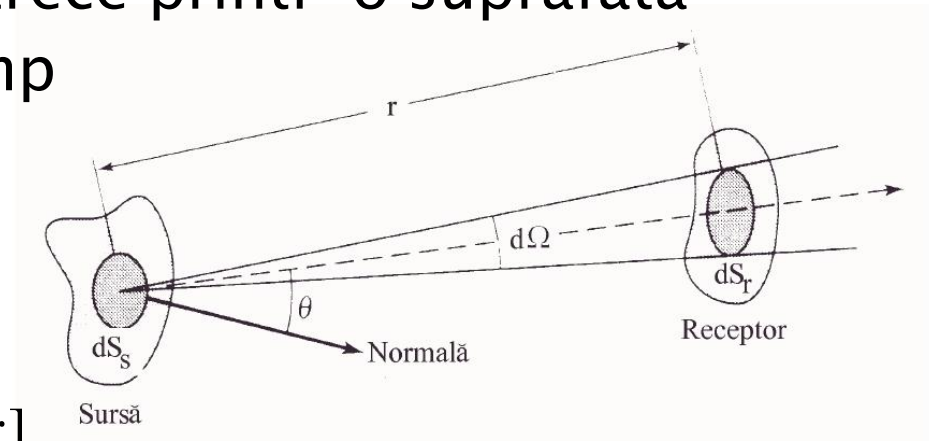
## ► Flux energetic al luminii

- viteza cu care energia trece printr-o suprafata
- energie/unitatea de timp
- unitatea SI – W

$$\Phi_e = \frac{dE}{dt} \quad [W]$$

## ► Unghi solid

- definitie  $\Omega = \frac{A}{r^2} \quad [sr]$
- valoarea maxima, sfera:  $\Omega = 4\pi \text{ sr}$
- pentru con cu deschiderea la varf  $2\phi$ :  $\Omega = 2\pi \cdot (1 - \cos \phi)$
- pentru unghiuri mici:  $\Omega = \pi \cdot \phi^2$



# Marimi globale vs. locale

- ▶ Flux energetic al luminii
  - viteza cu care energia trece printr-o suprafata
  - energie/unitatea de timp
  - unitatea SI – W

$$\Phi_e = \frac{dE}{dt} \quad [W]$$

- ▶ Putere electrica

$$P = \frac{dE}{dt} \quad [W]$$



# Marimi globale vs. locale

- ▶ Flux energetic al luminii
  - marime locala
  - este asociat unei anumite suprafete
- ▶ Putere electrica
  - marime globala
  - “suma fluxurilor pentru toate suprafetele disponibile”

$$P = \frac{dE}{dt} = \iint_S \frac{\partial^2 E}{\partial t \partial A} dA = \iint_S \frac{\partial \Phi_e}{\partial A} dA \quad [W]$$

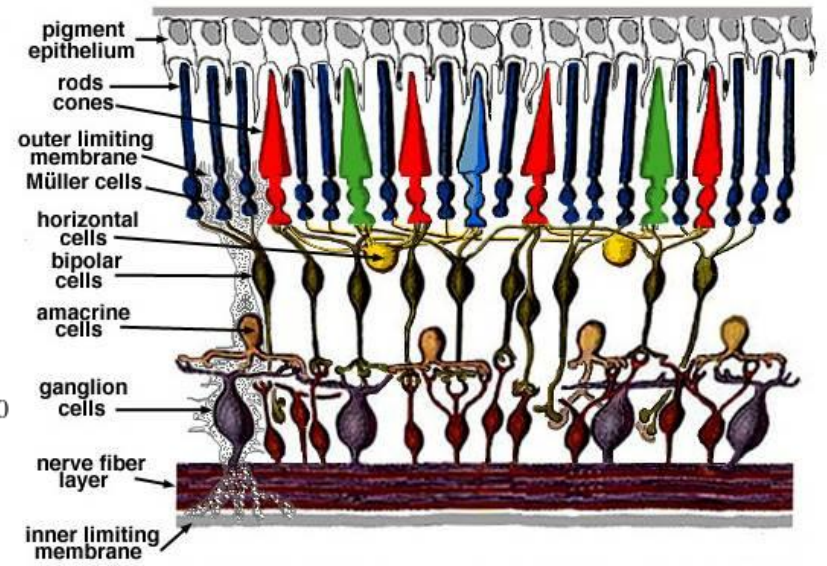
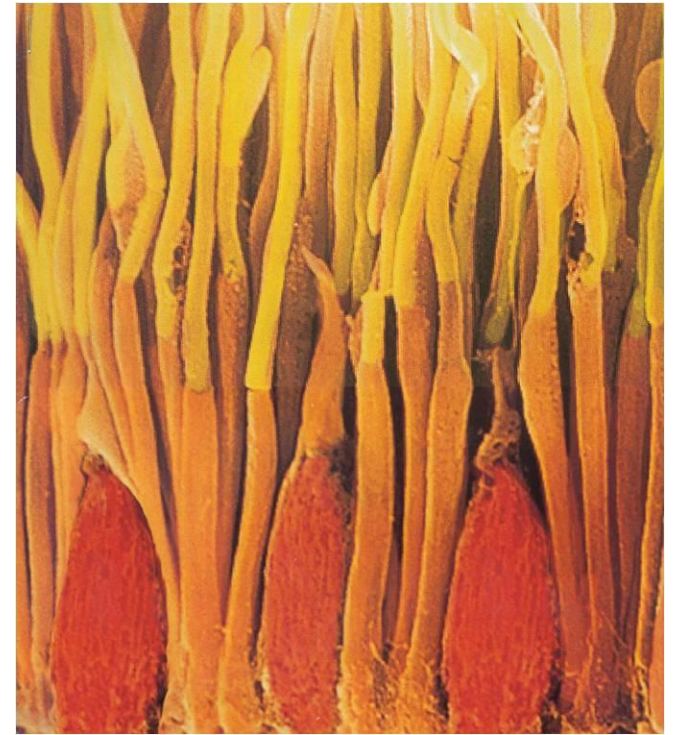
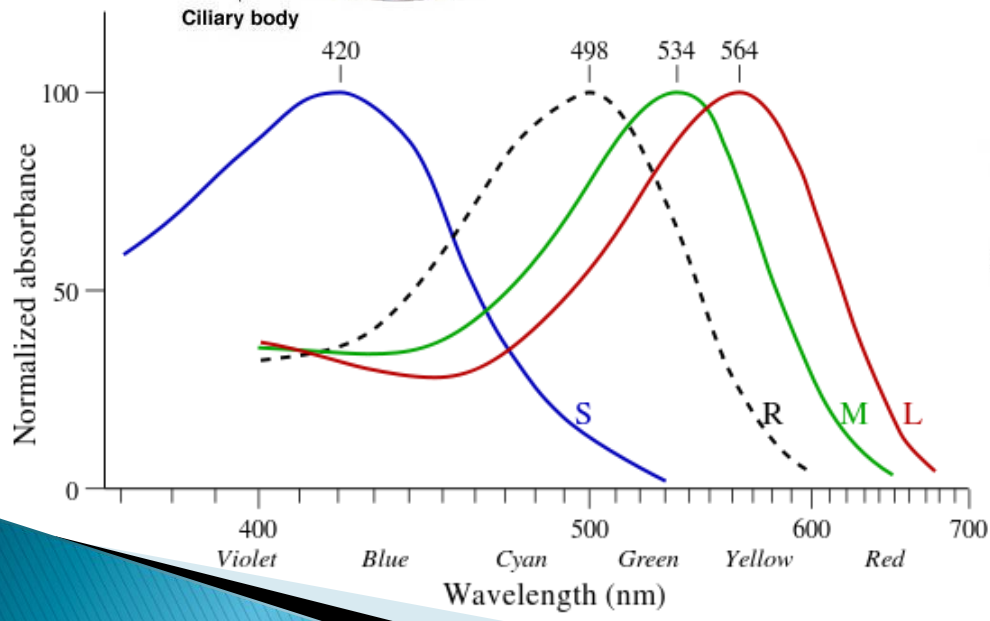
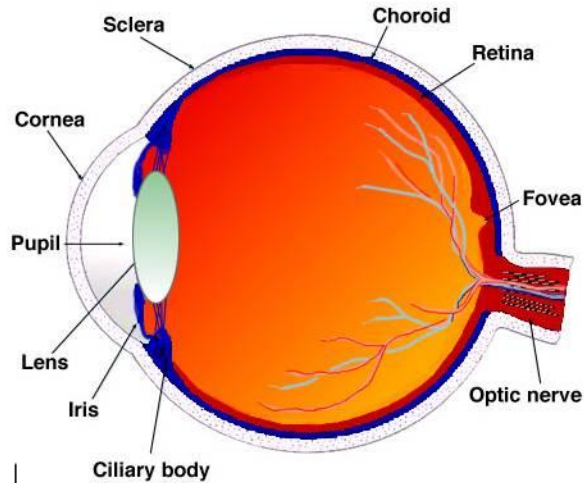
- ▶ Daca se poate considera emisie uniforma

$$\Phi_e \approx ct. \rightarrow P = \Phi_e \quad [W]$$

# Flux luminos

- ▶ Flux luminos, definitie
  - o masura a puterii luminoase percepute de om
- ▶ Unitate de masura –  $lm = \text{lumen}$ 
  - In SI de unitati **lumenul** este definit ca fluxul luminos al unei surse luminoase punctiforme cu intensitatea luminoasa de o candela intr-un unghi solid egal cu 1 sr.
  - la  $\lambda = 555\text{nm}$   $\Phi_e = 1\text{W} \Leftrightarrow \Phi_v = 683\text{ lm}$
- ▶ Dualitate pentru toate marimile implicate
  - radiometrie – indice “e”
  - fotometrie – indice “v”
- ▶ La alte lungimi de unda se tine cont de sensibilitatea relativa medie a ochiului uman

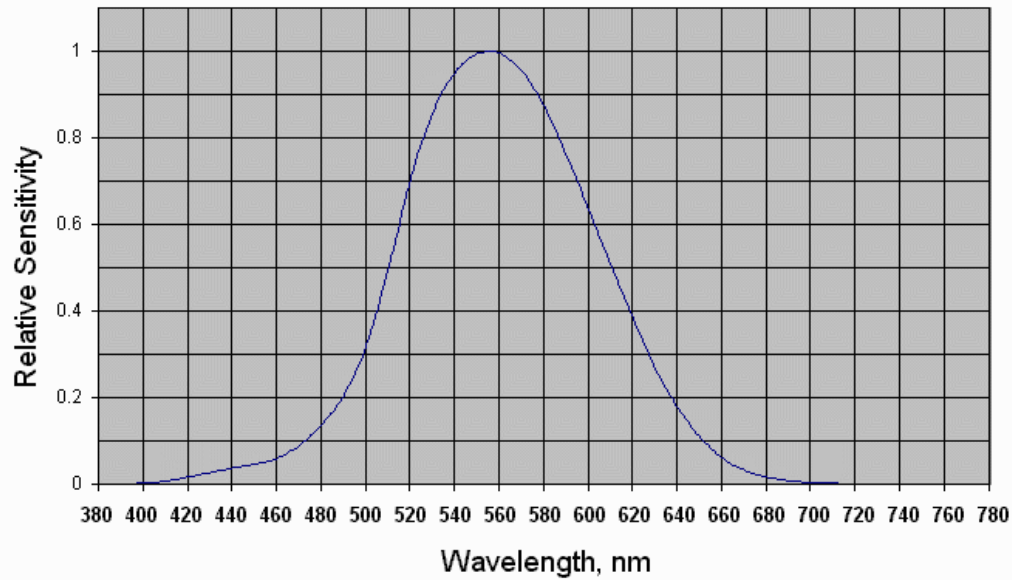
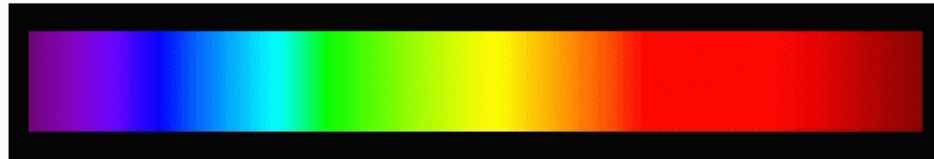
# Ochiul uman



# Standarde

- ▶ Se încearca definirea omului “standard”
- ▶ CIE – Commission Internationale de l'Éclairage
  - 1931 – luminozitatea relativa standard  $V(\lambda)$  – **fotopic**
  - 1951 – luminozitatea relativa standard  $V(\lambda)$  – **scotopic**
  - 1978 – Vos
  - 2005 – Sharpe, Stockman, Jagla, Jägle
  - 2008 – CIE  $V(\lambda)$  – fotopic (~Sharpe)
- ▶ Sensibilitatea maxima a ochiului uman
  - vedere diurna (**fotopic**),  $\lambda=555$  nm,  $\eta_v = 683$  lm/W
  - vedere nocturna (**scotopic**),  $\lambda=507$  nm,  $\eta_v = 1700$  lm/W

# CIE $V(\lambda)$



**Response of Human Eye Versus Wavelength**  
(Data from the 1988 C.I.E. Photopic Luminous Efficiency Function)

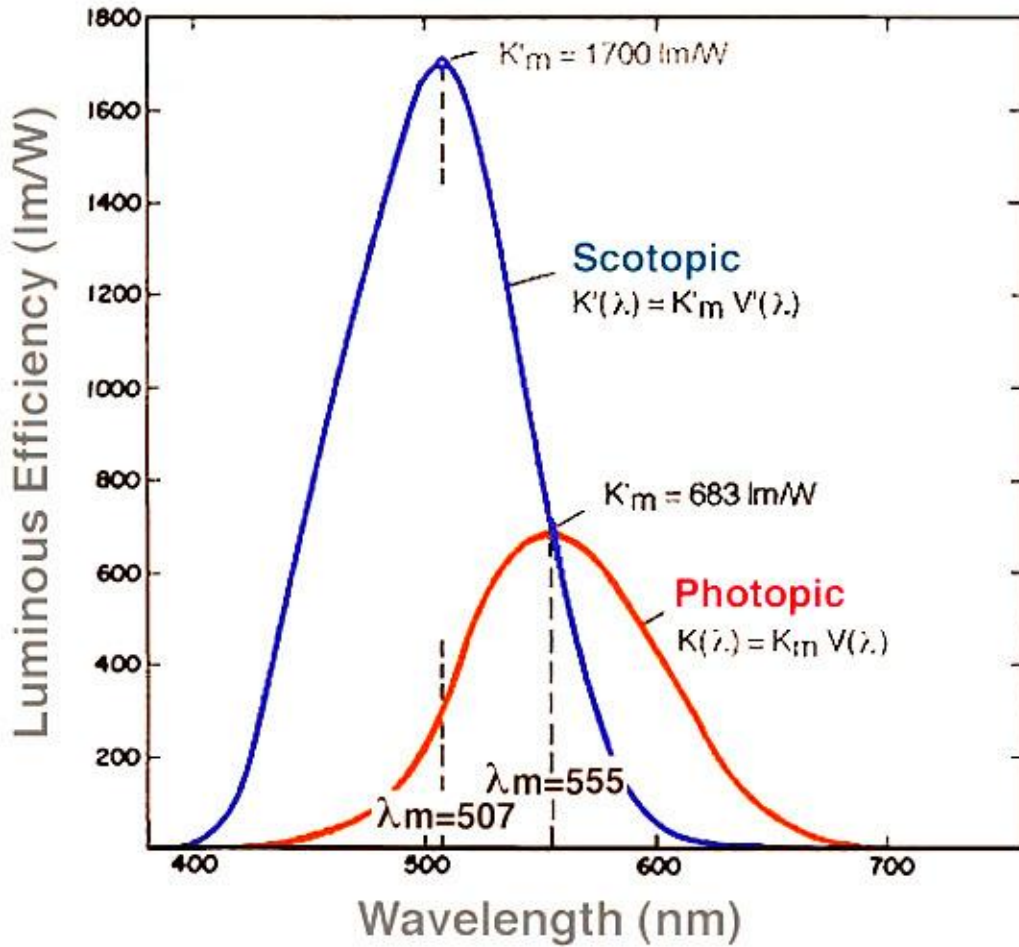


Figure 9. The scotopic and the photopic curves of spectral luminous efficacy (non-normalised values).

effect Purkinje

# Curbe normalizate CIE

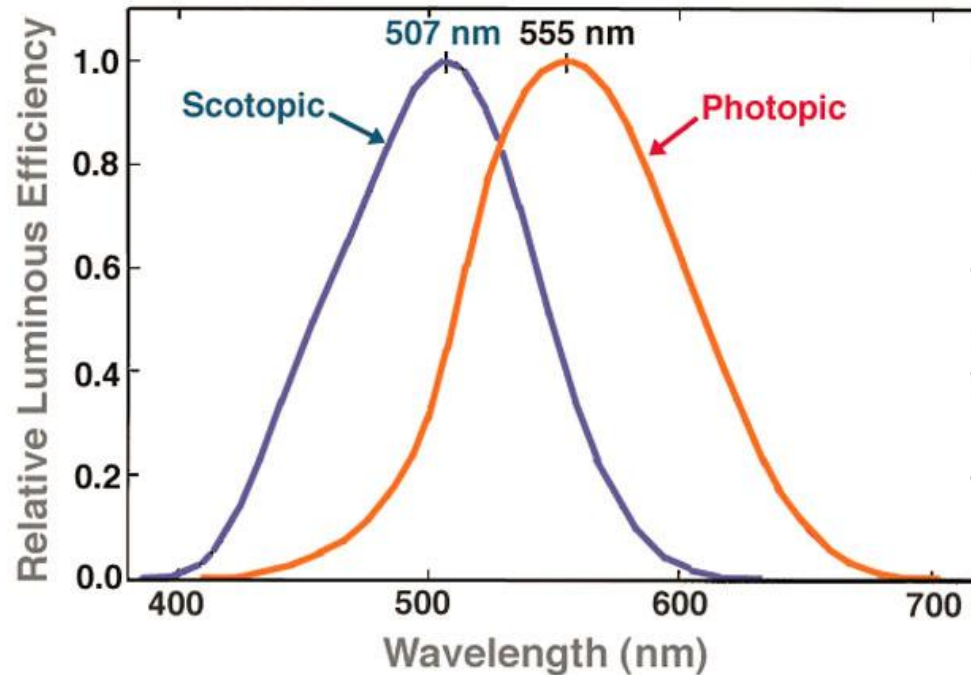


Figure 10. The scotopic and the photopic curves of relative spectral luminous efficiency as specified by the CIE (normalised values).

# CIE $V(\lambda)$

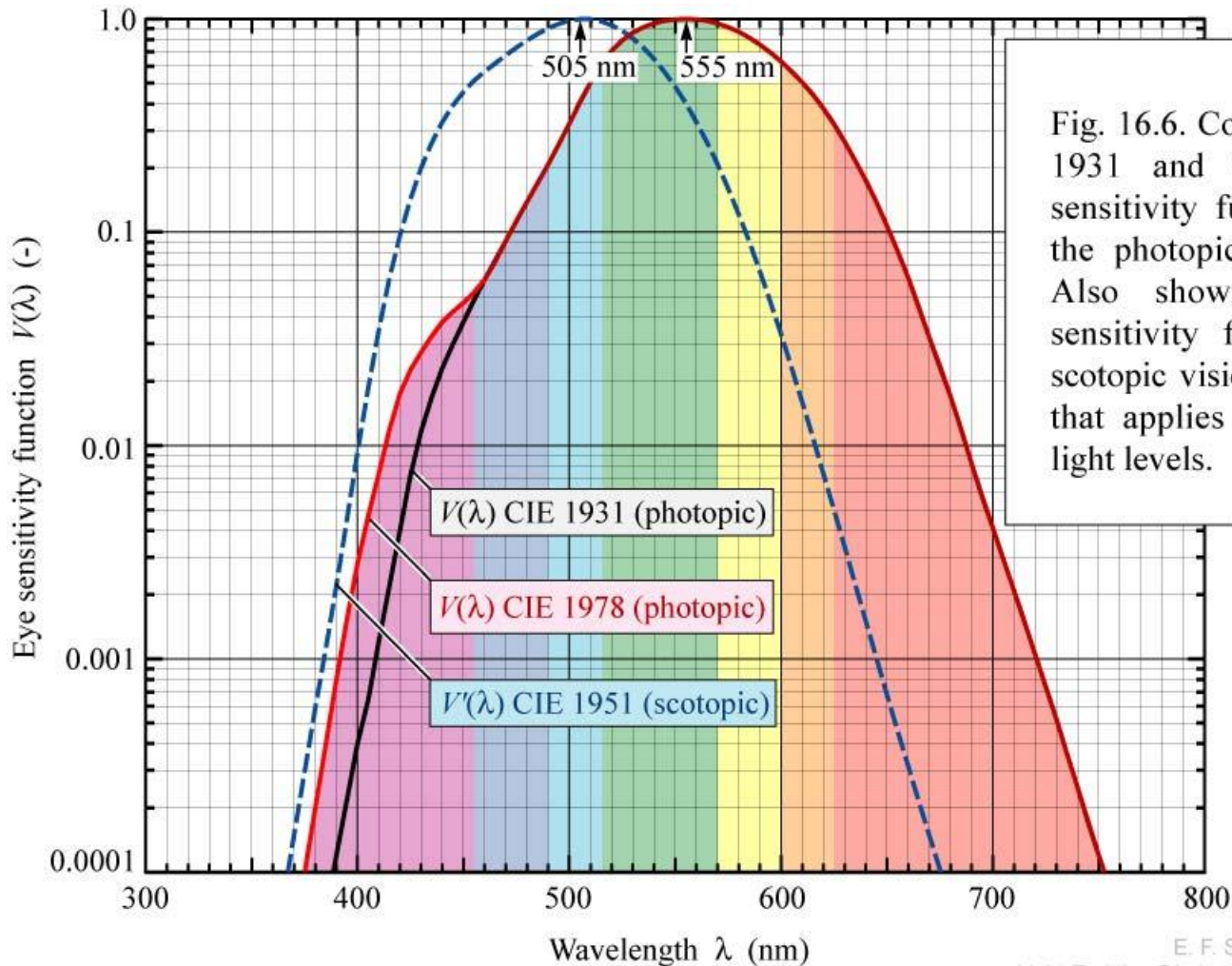
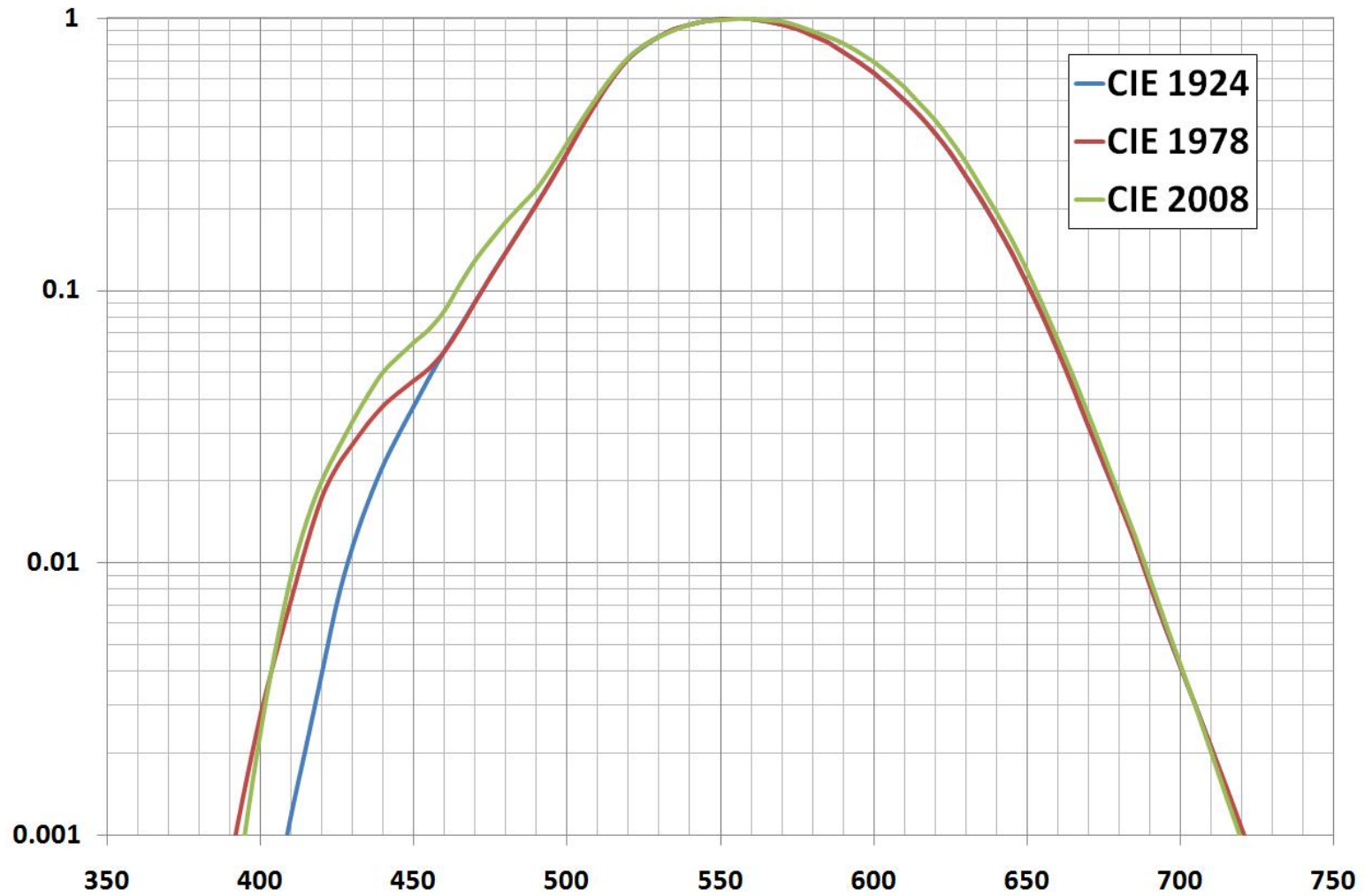


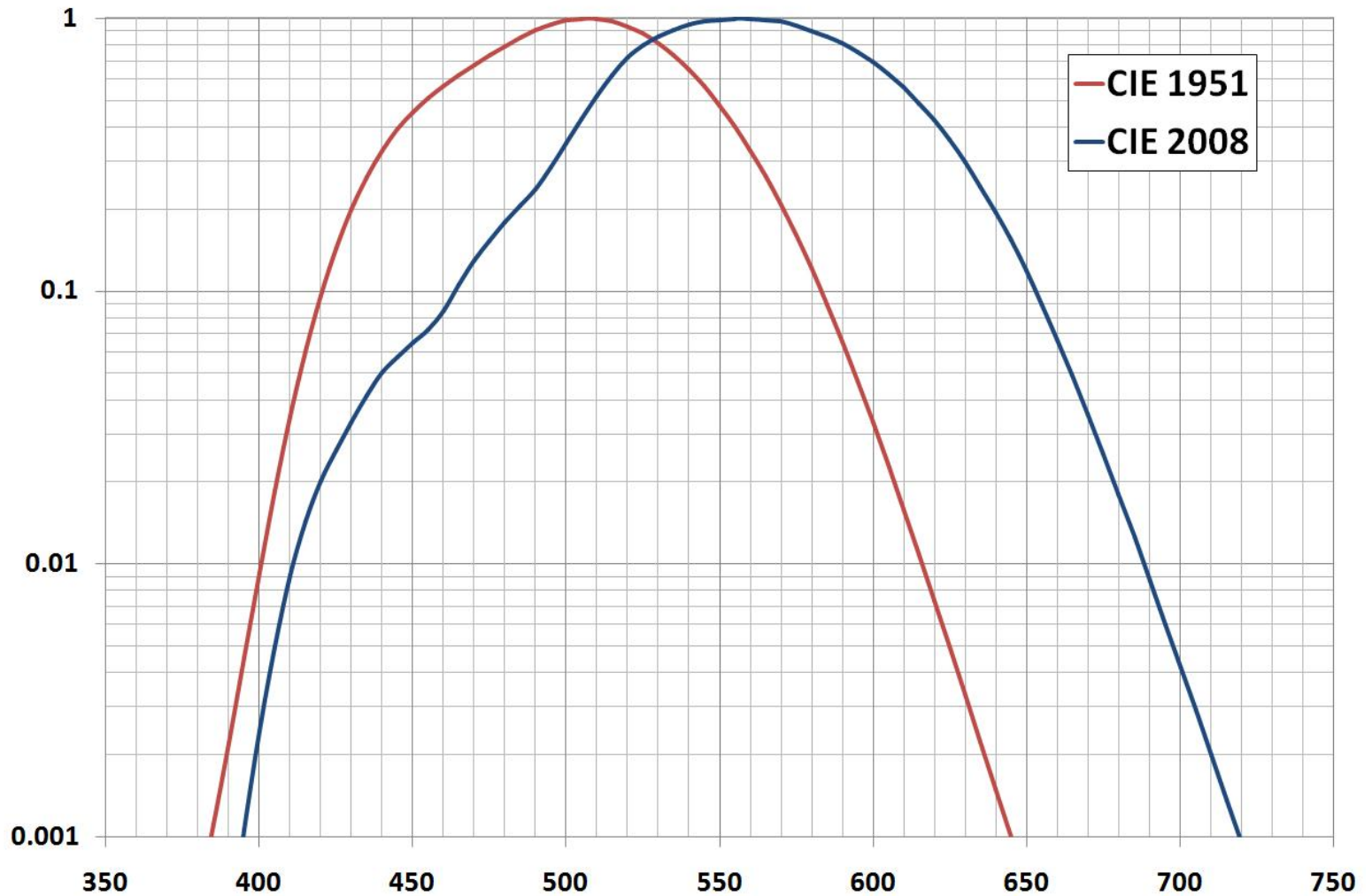
Fig. 16.6. Comparison of CIE 1931 and CIE 1978 eye sensitivity function  $V(\lambda)$  for the photopic vision regime. Also shown is the eye sensitivity function for the scotopic vision regime,  $V'(\lambda)$ , that applies to low ambient light levels.



# CIE $V(\lambda)$ fotopic



# CIE $V(\lambda)$ fotopic / scotopic



# Sensibilitate luminoasa $V(\lambda)$

|            | $\lambda$ | fotopic<br>CIE 1924 | fotopic<br>CIE 2008 | scotopic<br>CIE 1951 |
|------------|-----------|---------------------|---------------------|----------------------|
| Violet     | 400       | 0.000396            | 0.00245219          | 0.00929              |
| Indigo     | 445       | 0.0298              | 0.0574339           | 0.3931               |
| Albastru   | 475       | 0.1126              | 0.153507            | 0.734                |
| Verde      | 510       | 0.503               | 0.520497            | 0.997                |
| Galben     | 570       | 0.952               | 0.973261            | 0.2076               |
| Portocaliu | 590       | 0.757               | 0.811587            | 0.0655               |
| Rosu       | 650       | 0.107               | 0.119312            | 0.000677             |

# CIE V( $\lambda$ ) 1931

La Commission internationale de l'Éclairage recommande, pour l'usage général, les valeurs suivantes, comme valeurs provisoires pour le facteur de visibilité.

| Longueur d'onde (m $\mu$ ) | Facteur de Visibilité relative(m $\mu$ ) | Longueur d'onde | Facteur de Visibilité relative | Longueur d'onde (m $\mu$ ) | Facteur de Visibilité relative |
|----------------------------|--|-----------------|--------------------------------|----------------------------|--------------------------------|
| 400                        | 0.0004                                   | 530             | 0.862                          | 650                        | 0.107                          |
| 10                         | 0012                                     | 40              | 954                            | 60                         | 061                            |
| 20                         | 0040                                     | 550             | 995                            | 70                         | 032                            |
| 30                         | 0116                                     | 60              | 995                            | 80                         | 017                            |
| 40                         | 023                                      | 70              | 952                            | 90                         | 0082                           |
| 450                        | 038                                      | 80              | 870                            | 700                        | 0041                           |
| 60                         | 060                                      | 90              | 757                            | 10                         | 0021                           |
| 70                         | 091                                      | 600             | 631                            | 20                         | 00105                          |
| 80                         | 139                                      | 10              | 503                            | 30                         | 00052                          |
| 90                         | 208                                      | 20              | 381                            | 40                         | 00025                          |
| 500                        | 323                                      | 30              | 265                            | 750                        | 00012                          |
| 10                         | 503                                      | 40              | 175                            | 60                         | 00006                          |
| 20                         | 710                                      |                 |                                |                            |                                |

# Relatie radiometrie/fotometrie

- ▶ Pentru radiatii monocromatice

$$\Phi_v = 683 \frac{lm}{W} \cdot \Phi_e [W] \cdot V(\lambda) \quad [lm] \quad \Phi'_v = 1700 \frac{lm}{W} \cdot \Phi_e [W] \cdot V'(\lambda) \quad [lm]$$

- ▶ Pentru radiatii complexe:

$$\Phi_v = 683 \frac{lm}{W} \int_0^{\infty} \frac{d\Phi_e}{d\lambda} \cdot V(\lambda) d\lambda = 683 \frac{lm}{W} \int_{390nm}^{830nm} \frac{d\Phi_e}{d\lambda} \cdot V(\lambda) d\lambda \quad [lm]$$

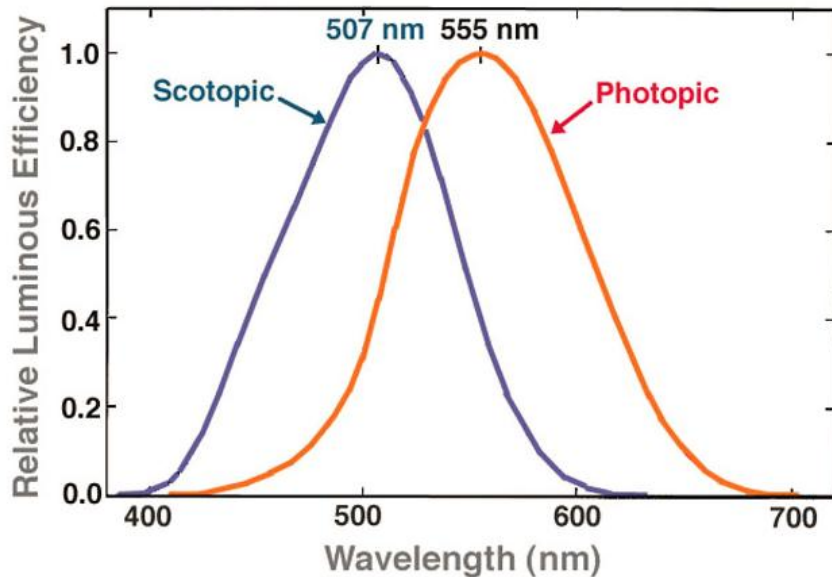
$$\Phi'_v = 1700 \frac{lm}{W} \int_0^{\infty} \frac{d\Phi_e}{d\lambda} \cdot V'(\lambda) d\lambda = 1700 \frac{lm}{W} \int_{390nm}^{830nm} \frac{d\Phi_e}{d\lambda} \cdot V'(\lambda) d\lambda \quad [lm]$$

- ▶ De cele mai multe ori, sursele sunt discrete,  $\lambda_i$

$$\Phi_v = 683 \frac{lm}{W} \cdot \sum_i \Phi_e(\lambda_i) \cdot V(\lambda_i) \quad [lm]$$

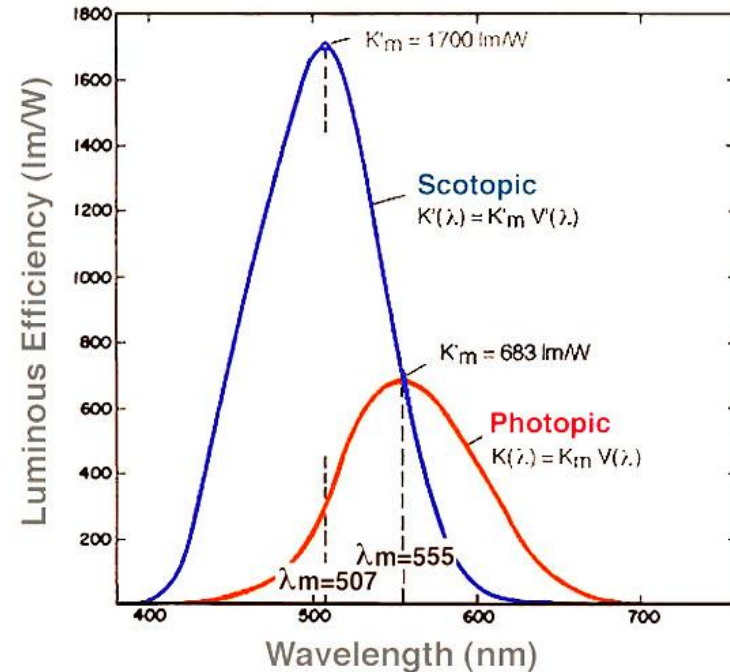
$$\Phi'_v = 1700 \frac{lm}{W} \cdot \sum_i \Phi_e(\lambda_i) \cdot V'(\lambda_i) \quad [lm]$$

# Relatie radiometrie/fotometrie



$$0 \leq V(\lambda) \leq 1$$

$$0 \leq V'(\lambda) \leq 1$$



$$0 \leq \eta_v \leq K_m = 683 \text{ lm/W}$$

$$0 \leq \eta'_v \leq K'_m = 1700 \text{ lm/W}$$

# Relatie radiometrie/fotometrie

## ▶ Eficienta luminoasa maxima

- scotopic:  $K_m' = 1700 \text{ lm/W @ } 505 \text{ nm}$
- fotopic:  $K_m = 683 \text{ lm/W @ } 555 \text{ nm}$ 
  - **683.002** lm/W;  $540 \cdot 10^{12} \text{ Hz}$  ( $\lambda = 555.016 \text{ nm}$ )

## ▶ Eficienta luminoasa

$$\eta_v = \frac{\Phi_v [\text{lm}]}{\Phi_e [\text{W}]} = K_m \cdot V(\lambda) = 683 \frac{\text{lm}}{\text{W}} \cdot V(\lambda)$$

$$\eta_v' = \frac{\Phi_v' [\text{lm}]}{\Phi_e [\text{W}]} = K_m' \cdot V'(\lambda) = 1700 \frac{\text{lm}}{\text{W}} \cdot V'(\lambda)$$

- ## ▶ Functiile de sensibilitate luminoasa $V(\lambda)$ , $V'(\lambda)$ sunt **normalizate** (valoarea 1 pentru sensibilitate maxima)
- Sensibilitate luminoasa = Eficienta luminoasa normalizata

# Eficiența luminoasă, $\eta_v$ [lm/W]

|            | $\lambda$ | fotopic<br>CIE 1924 | Sharpe<br>2005 | scotopic<br>CIE 1951 |
|------------|-----------|---------------------|----------------|----------------------|
| Violet     | 400       | 0                   | 2              | 16                   |
| Indigo     | 445       | 20                  | 40             | 668                  |
| Albastru   | 475       | 77                  | 108            | 1248                 |
| Verde      | 510       | 344                 | 361            | 1695                 |
| Galben     | 570       | 650                 | 659            | 353                  |
| Portocaliu | 590       | 517                 | 541            | 111                  |
| Rosu       | 650       | 73                  | 77             | 1                    |



# Radiometrie / fotometrie – fotopic

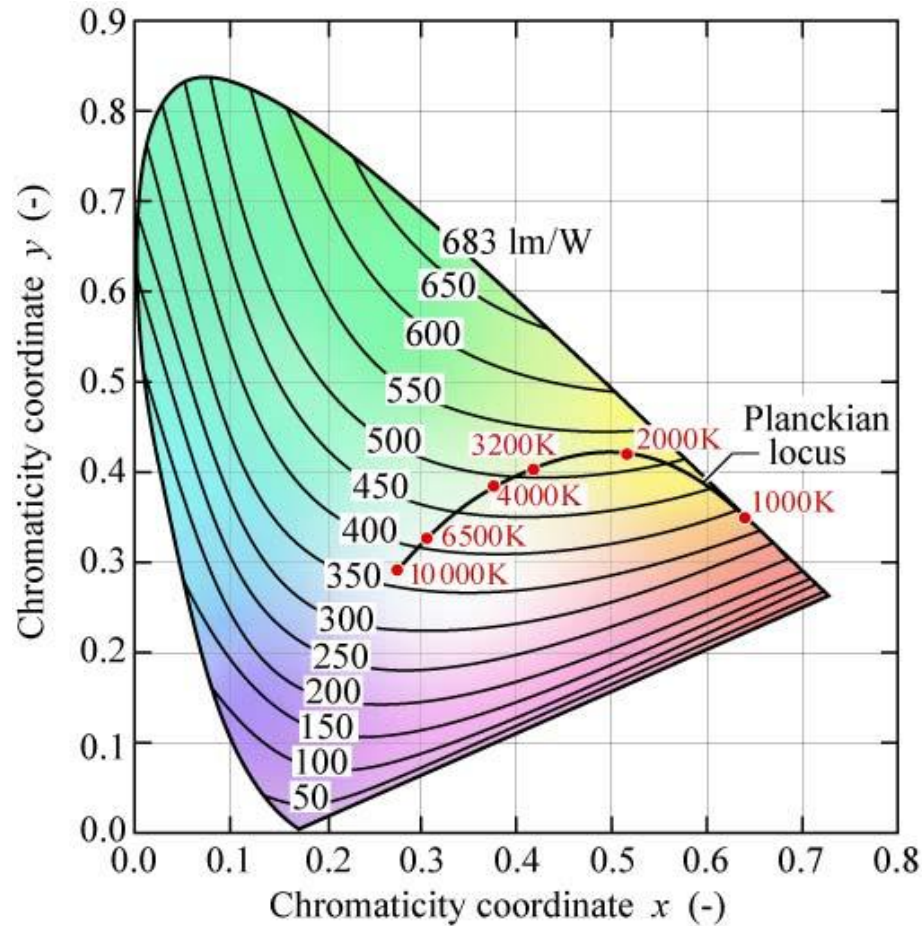
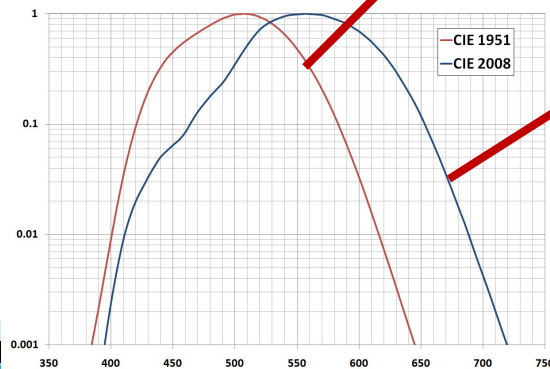
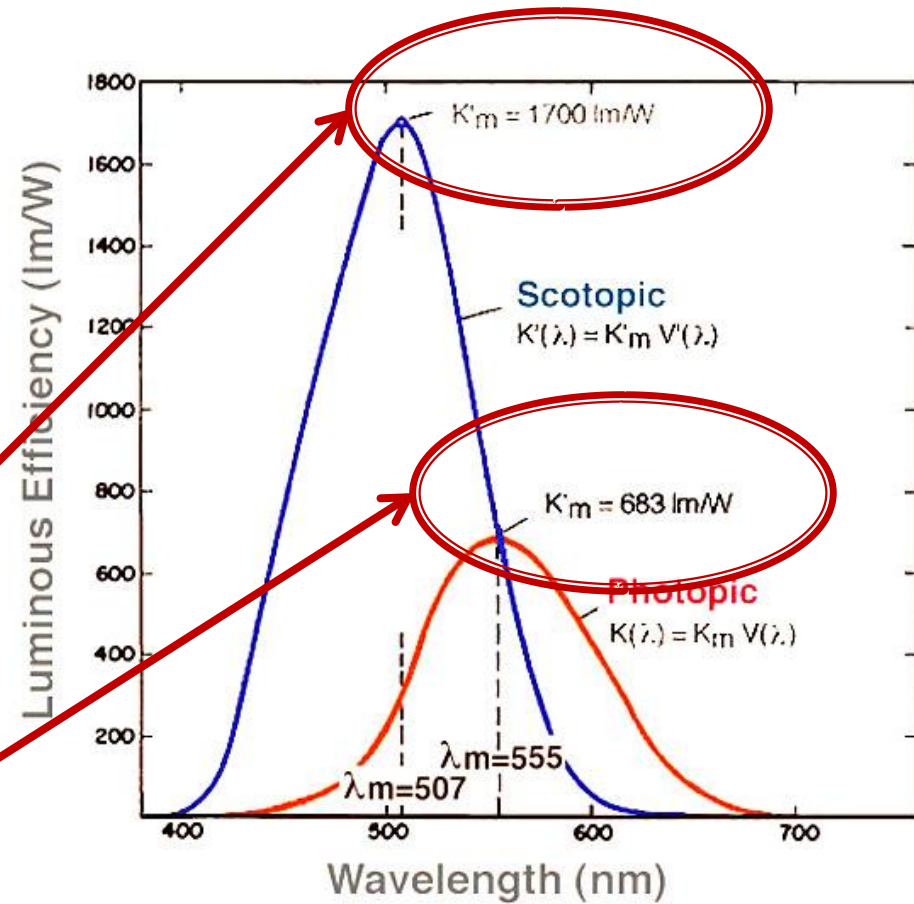
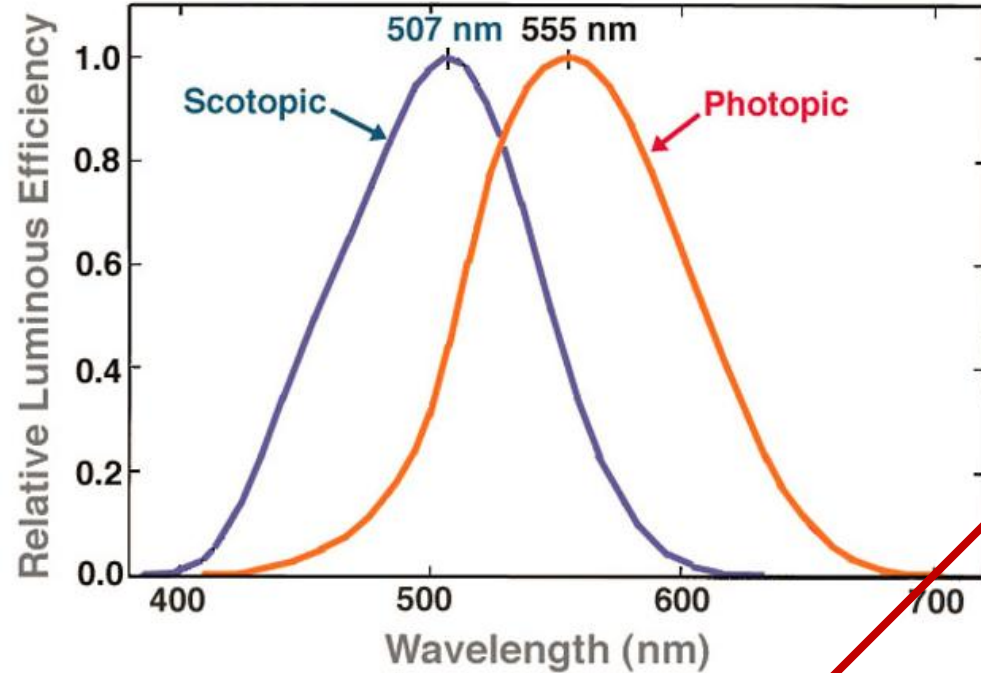


Fig. 16.8. Relation of maximum possible luminous efficacy (lumens per optical Watt) and chromaticity in the CIE 1931  $x, y$  chromaticity diagram (adopted from MacAdam, 1950).

$$\eta_v(\lambda) \quad [\text{lm/W}]$$

# Relatie radiometrie/fotometrie



# Marimi luminoase

## ► Intensitatea

- raportul dintre fluxul care părăsește sursa și se propagă într-un element de unghi solid ce conține direcția de propagare și elementul de unghi solid.
- o masura a puterii emise de o sursa într-un element de unghi solid

| Intensitatea                    |        |                                 |          |
|---------------------------------|--------|---------------------------------|----------|
| Fotometrie                      |        | Radiometrie                     |          |
| $I_v = \frac{d\Phi_v}{d\Omega}$ | SI: cd | $I_e = \frac{d\Phi_e}{d\Omega}$ | SI: W/sr |

# Marimi luminoase

## ► Iluminarea

- raportul dintre fluxul primit de un element de suprafață conținând punctul și aria acestui element (definita într-un punct al unei suprafețe la **receptie**):
- o masura a intensitatii luminii incidente pe o suprafata

| Iluminarea                 |        |                            |                      |
|----------------------------|--------|----------------------------|----------------------|
| Fotometrie                 |        | Radiometrie                |                      |
| $E_v = \frac{d\Phi_v}{dS}$ | SI: lx | $E_e = \frac{d\Phi_e}{dS}$ | SI: W/m <sup>2</sup> |

# Marimi luminoase

## ► Excitanța

- raportul dintre fluxul care părăsește un element de suprafață conținând punctul și aria elementului de suprafață (definita într-un punct al unei suprafețe la emisie):
- o masura a intensitatii luminii emise de o suprafata

| Excitanța                  |                       |                            |                      |
|----------------------------|-----------------------|----------------------------|----------------------|
| Fotometrie                 |                       | Radiometrie                |                      |
| $M_v = \frac{d\Phi_v}{dS}$ | SI: lm/m <sup>2</sup> | $M_e = \frac{d\Phi_e}{dS}$ | SI: W/m <sup>2</sup> |

# Marimi luminoase

## ▶ Luminanța

- raportul dintre fluxul care părăsește, atinge sau traversează un element de suprafață și care se propagă în direcții conținute într-un con elementar,  $d\Omega$ , conținând direcția dată, și produsul dintre unghiul solid al conului și aria proiecției ortogonale a elementului de suprafață pe un plan perpendicular pe direcția dată,  $dS$  (definita într-o direcție, într-un punct de pe suprafața unei surse sau unui receptor, sau într-un punct pe traiectul unui fascicol):
- o masura a densitatii de intensitate luminoasa într-o anumita directie

| Luminanța                                  |                       |  |                          |
|--|-----------------------|--|--------------------------|
| Fotometrie                                 |                       | Radiometrie                                |                          |
| $L_v = \frac{d^2\Phi_v}{d\Omega \cdot dS}$ | SI: cd/m <sup>2</sup> | $L_e = \frac{d^2\Phi_e}{d\Omega \cdot dS}$ | SI: W/m <sup>2</sup> /sr |

# Directivitatea radiatiei exterioare

## ▶ SLED

- radiatia este emisa cu simetrie circulara, in interiorul unui con cu unghi la varf tipic de  $60^\circ$
- Viewing Half Angle  $\sim 10 \div 15^\circ$

## ▶ ELED

- radiatia emisa nesimetric in forma de con eliptic
  - perpendicular pe jonctiune  $\sim 60^\circ$
  - paralel cu jonctiunea  $\sim 30^\circ$

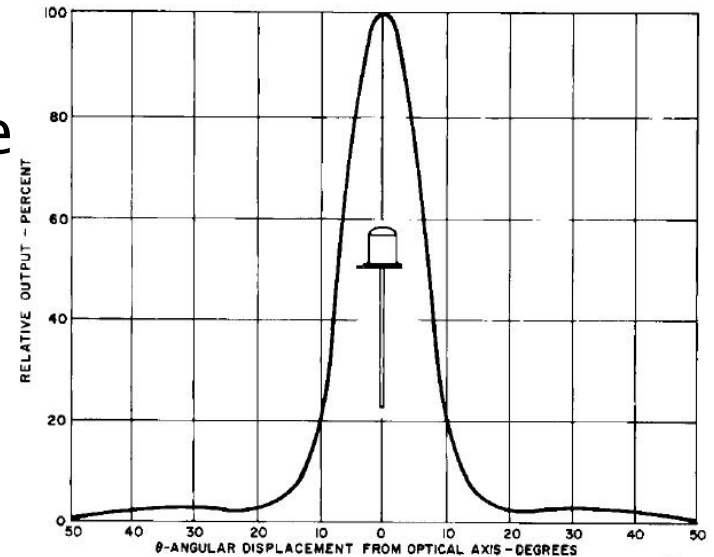
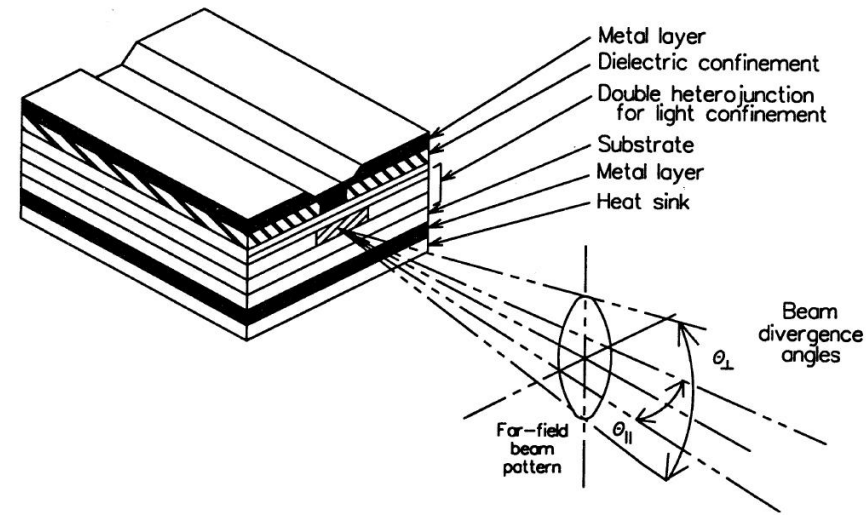


Fig. 5. Typical Radiation Pattern

ST1054



# Directivitatea radiatiei exterioare

- ▶ Sursa lambertiana

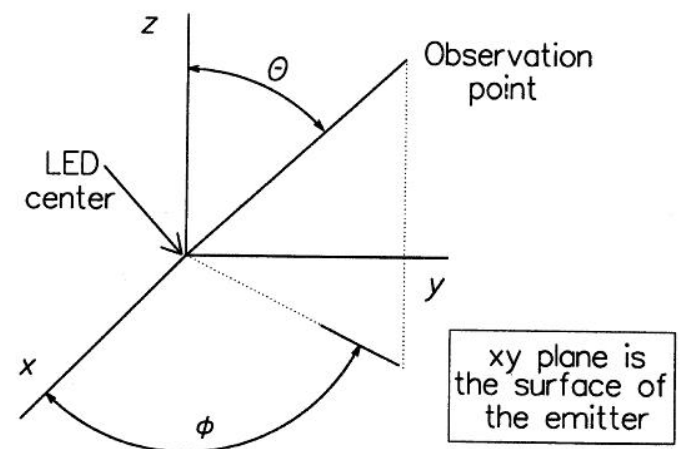
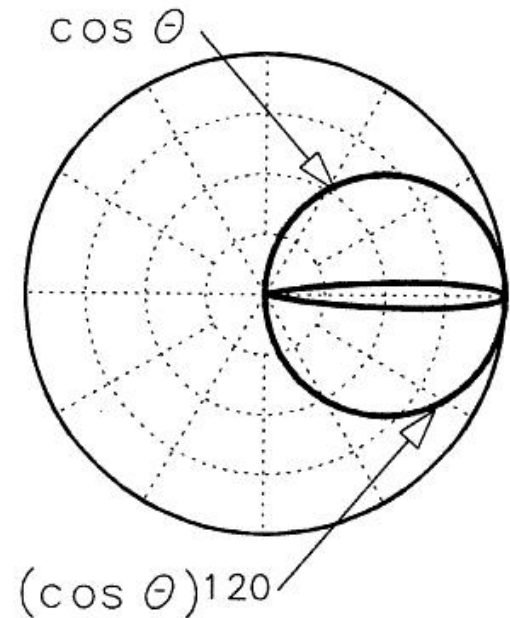
$$P(\theta) = P_0 \cdot \cos \theta$$

- ▶ Aproximatie Lambertiana pentru surse cu directivitate crescuta

$$P(\theta) = P_0 \cdot \cos^n \theta$$

- ▶ Surse cu emisie asimetrica

$$P(\theta) = \frac{P_0}{\frac{\sin^2 \phi}{\cos^T \theta} + \frac{\cos^2 \phi}{\cos^L \theta}}$$





# Marimi luminoase

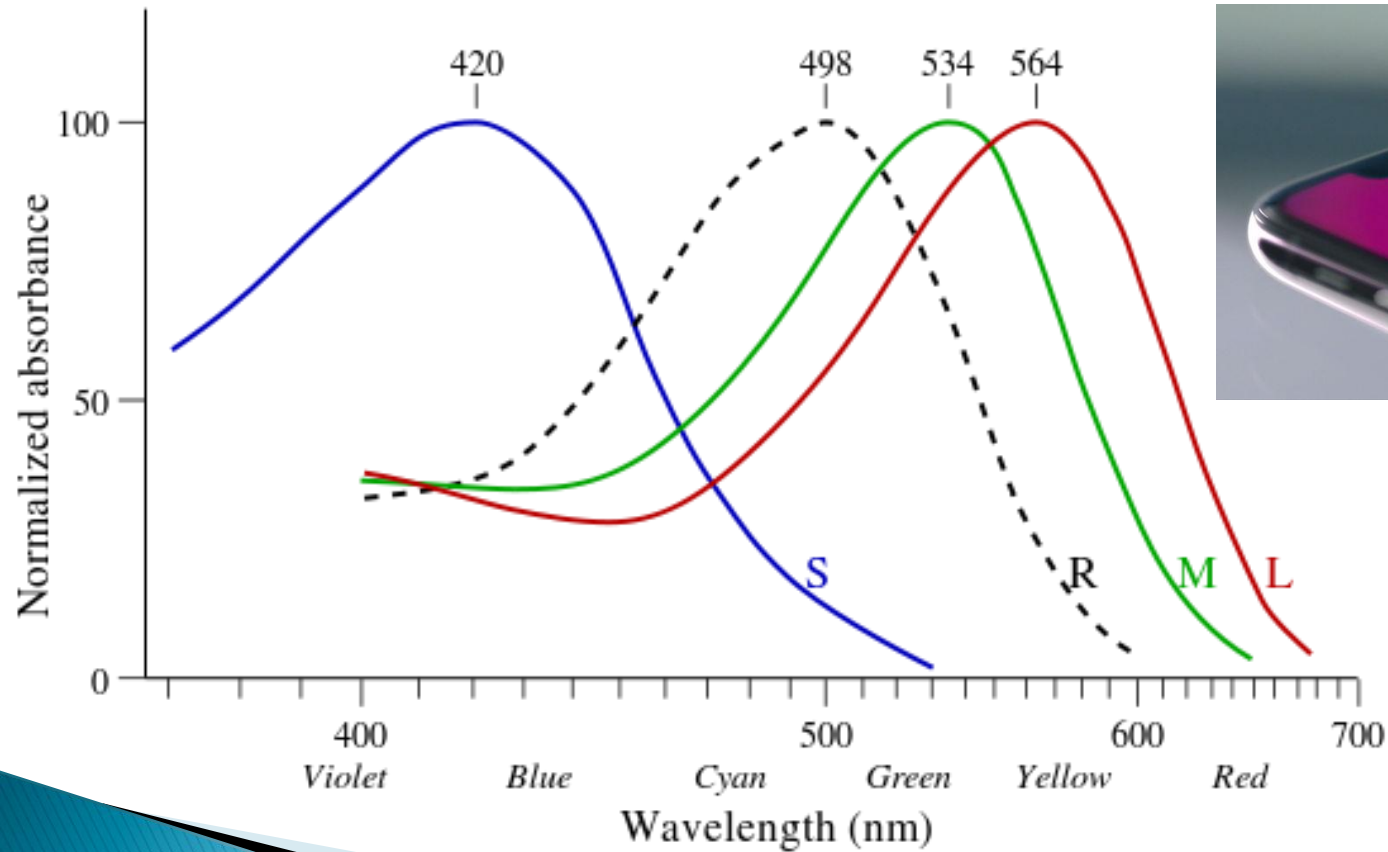
- ▶ Standardele pentru surse luminoase (de ex. semne de circulatie), iluminarea spatiilor de lucru/odihna
  - sunt concepute cu marimi luminoase
  - lm, cd, lx, cd/m<sup>2</sup> etc.
- ▶ de multe ori se adapteaza relatiile pentru surse mai simple:

$$I_v = \frac{d\Phi_v}{d\Omega} \rightarrow I_v = \frac{\Phi_v}{\Omega} \Big|_{I_v \approx ct. \text{ in } \Omega} \quad E_v = \frac{d\Phi_v}{dS} \rightarrow E_v = \frac{\Phi_v}{S} \Big|_{\Phi_v \approx ct. \text{ pe } S}$$

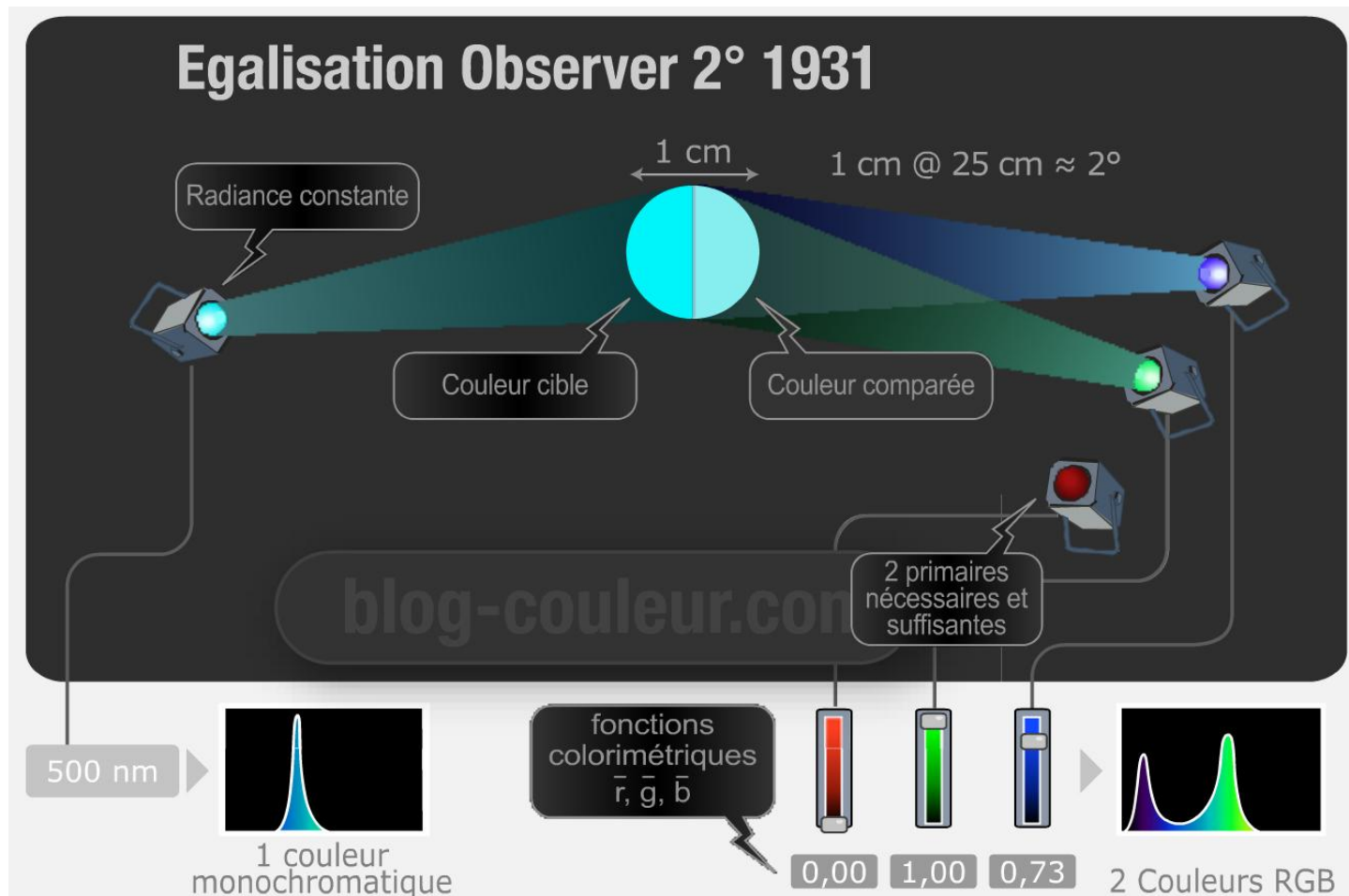
$$\Phi_v = 683 \frac{lm}{W} \int_{390nm}^{830nm} \frac{d\Phi_e}{d\lambda} \cdot V(\lambda) d\lambda \rightarrow \Phi_v = 683 \frac{lm}{W} \cdot \sum_i \Phi_e(\lambda_i) \cdot V(\lambda_i)$$

# Ochiul uman – culoare

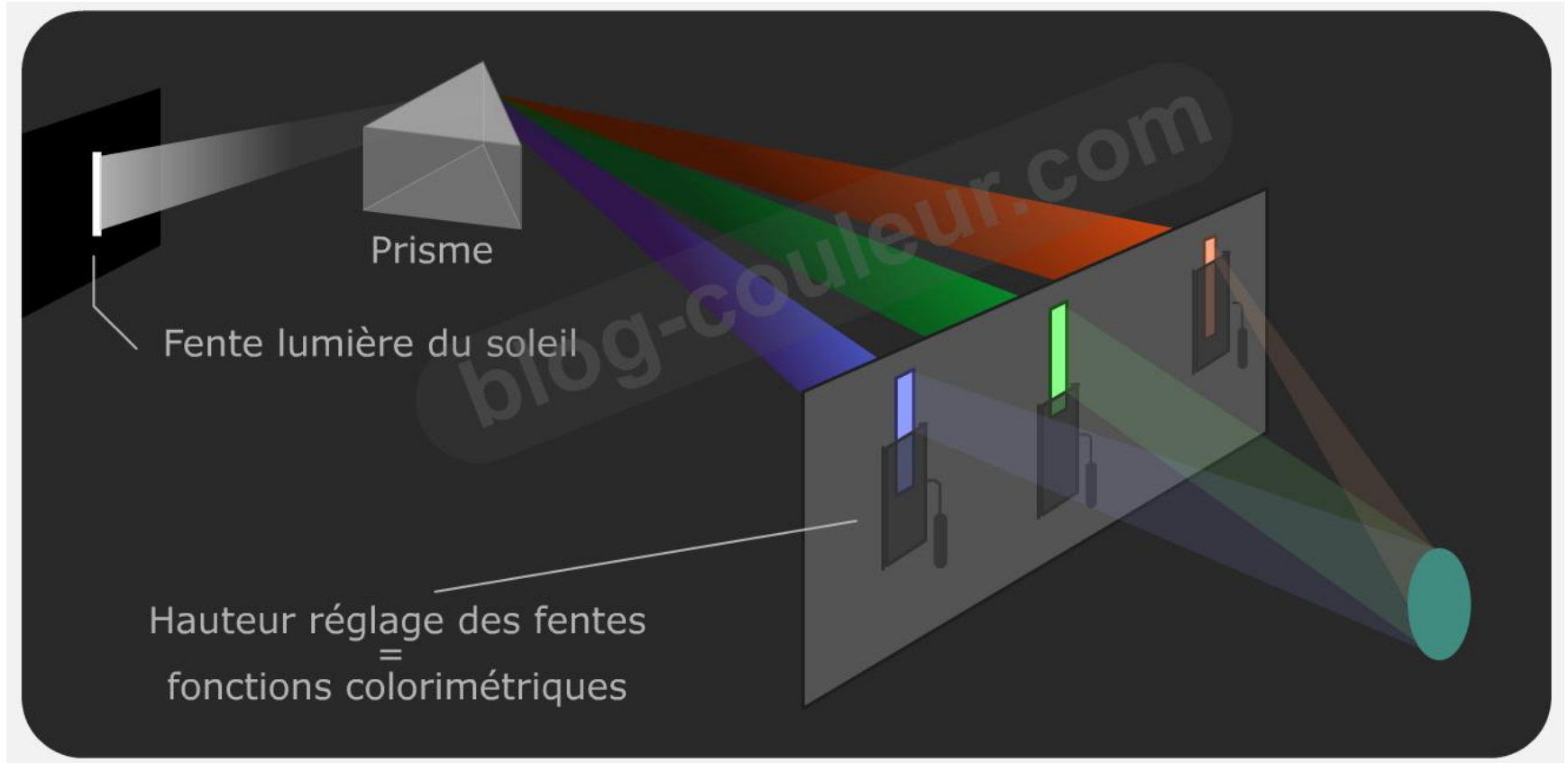
- ▶ culoare ~ lungime de unda



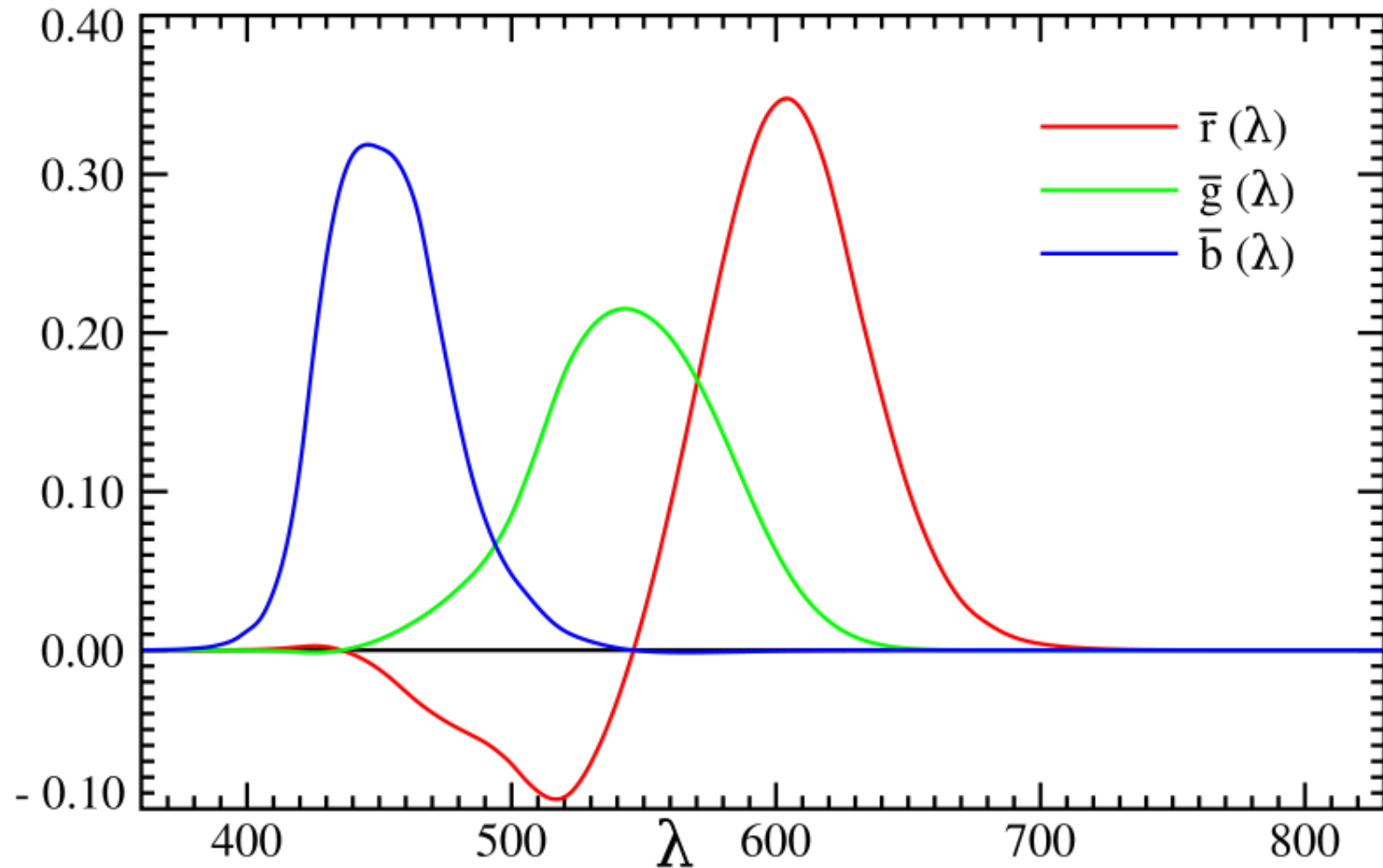
# CIE xyz 1931



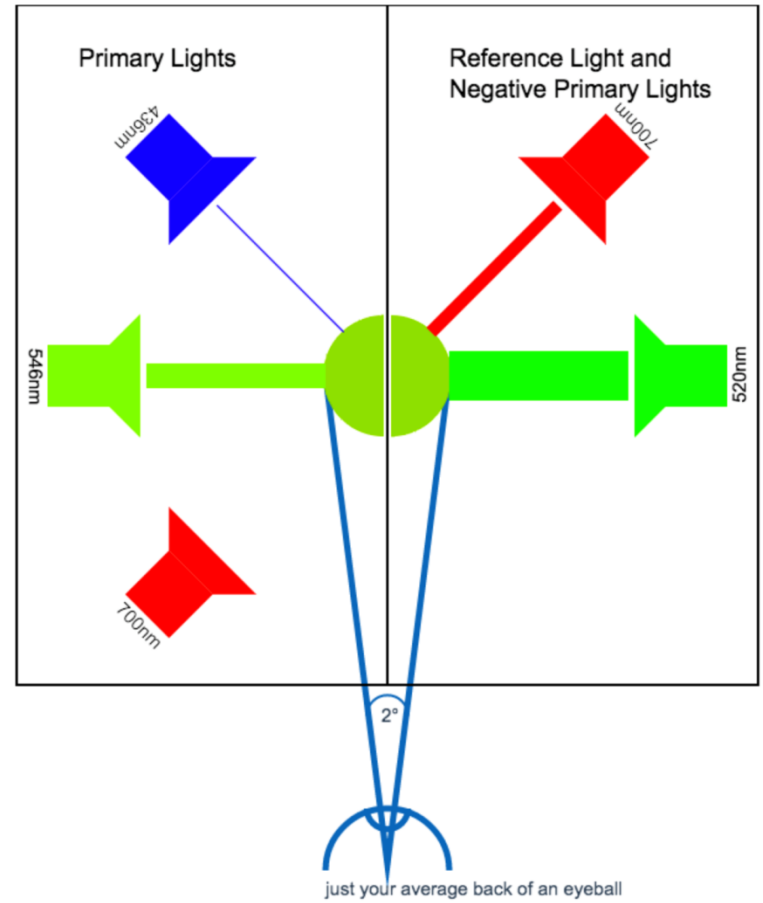
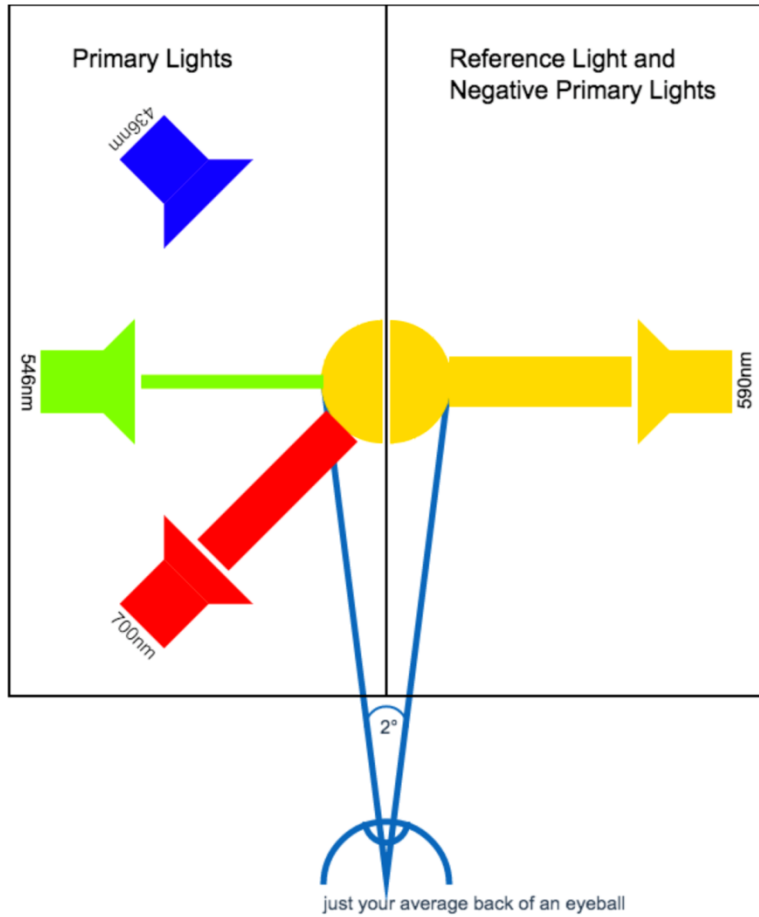
# CIE xyz 1931



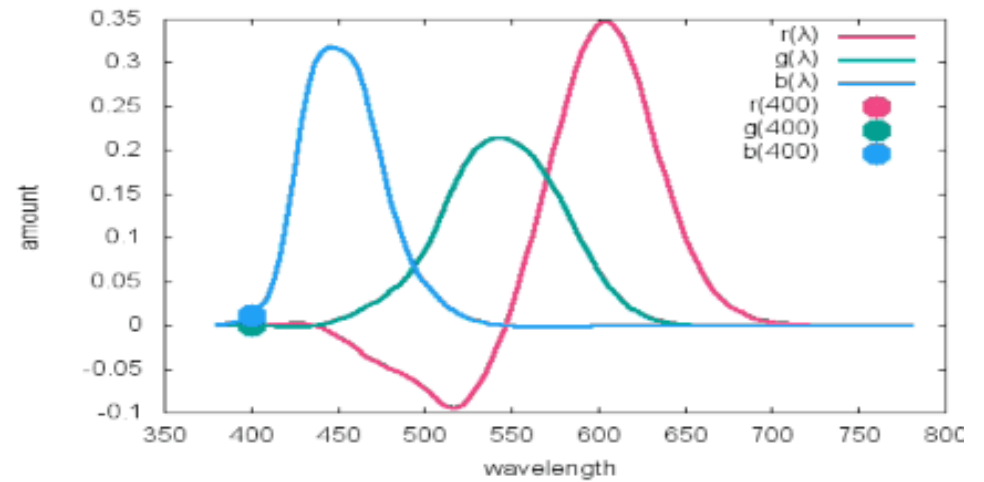
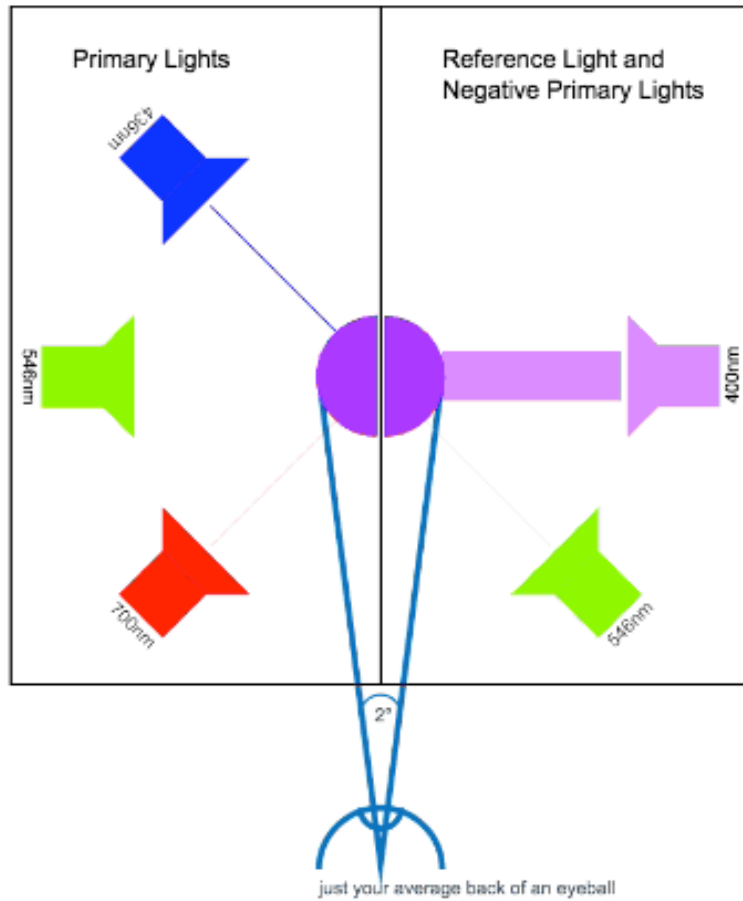
# Cantitatea din culorile primare pentru aceeași senzație de culoare



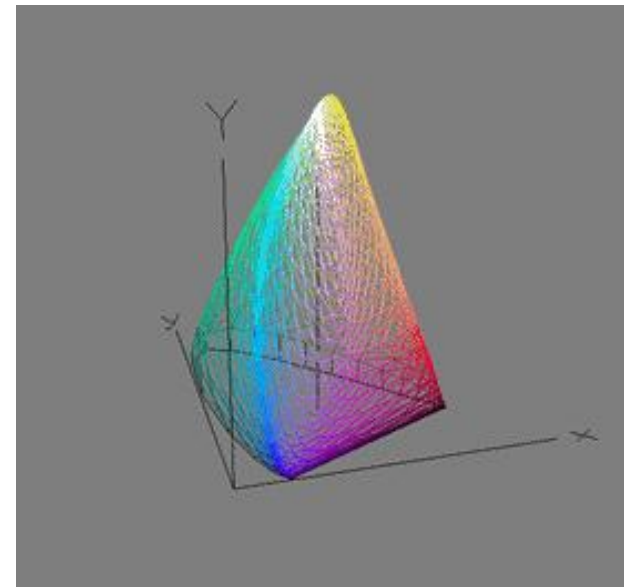
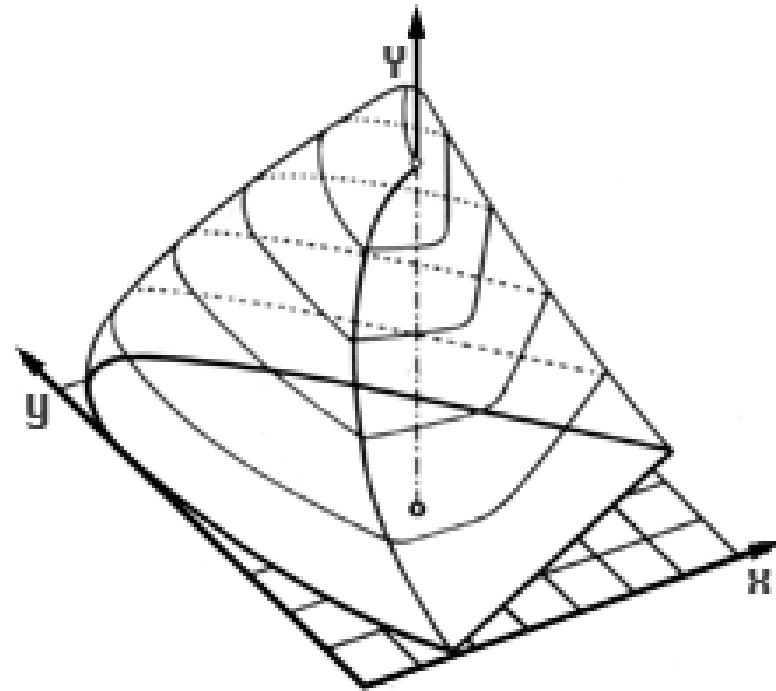
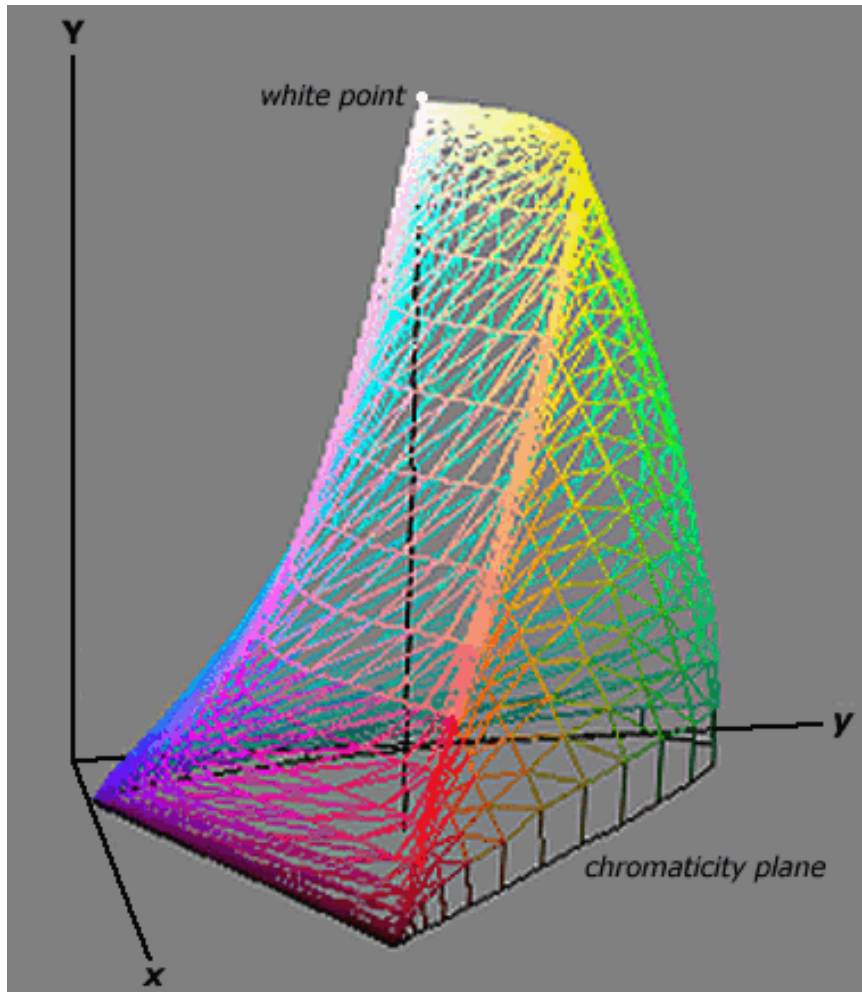
# CIE xyz1931



# CIE 1931



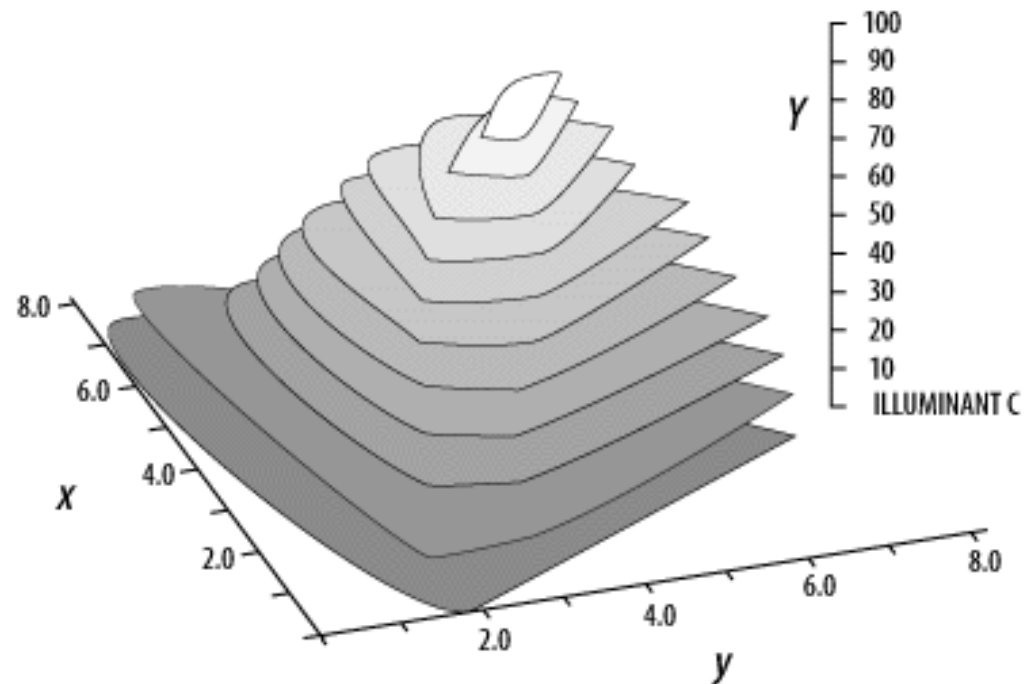
# CIE xyz 1931



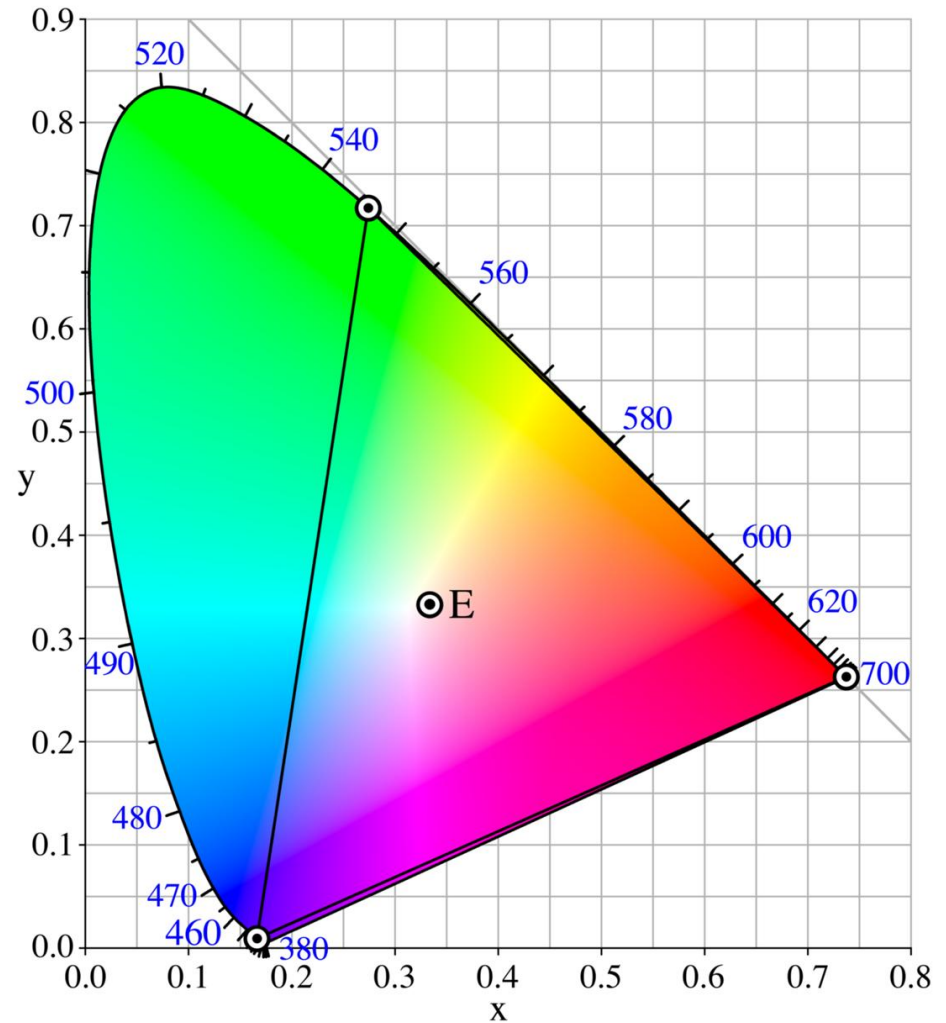
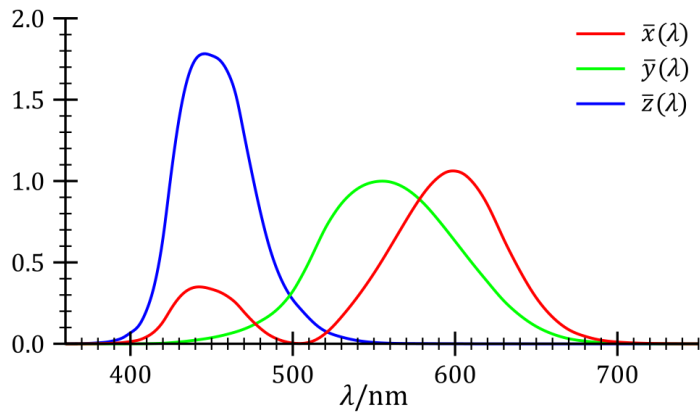


# CIE xyz 1931

- ▶ Se alege una din axe ( $xyY \rightarrow Y$ ) ca fiind cea a luminozitatii culorii
  - gri si alb sunt culori diferite
  - gri este un “alb” de luminozitate scazuta

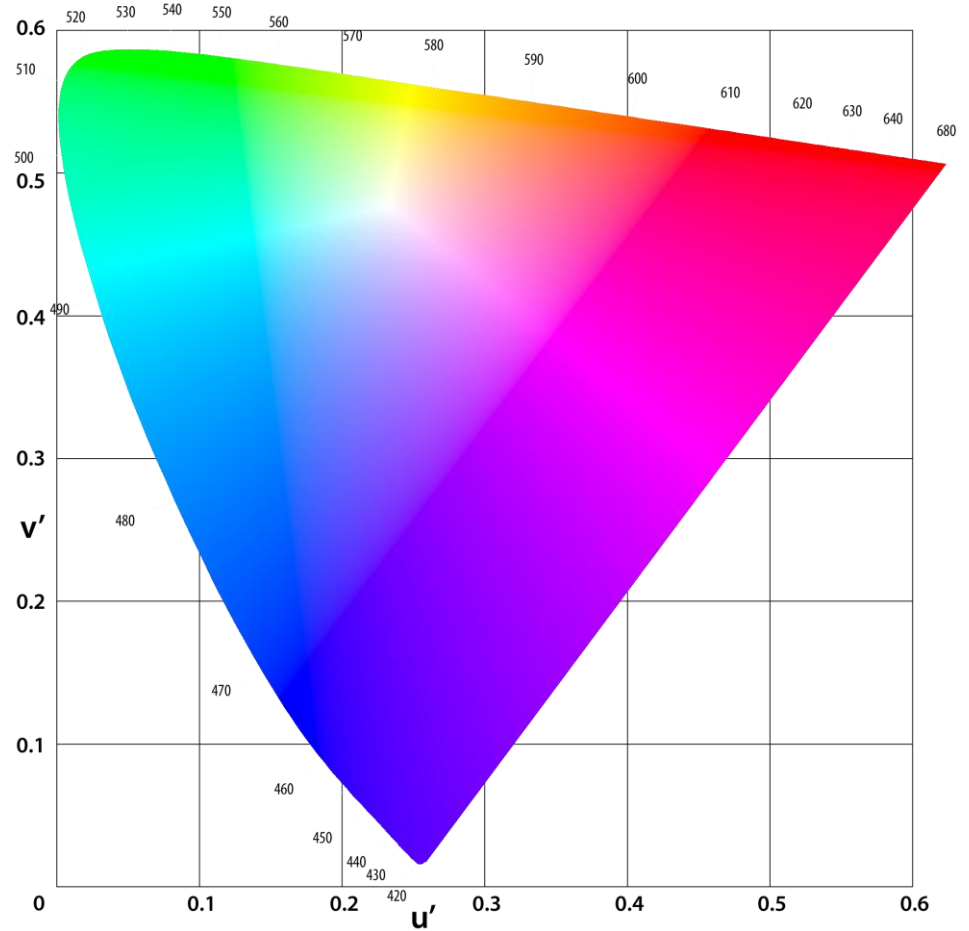


# CIE xy 1931



# CIELUV 1976

- ▶ uniformitatea percepției, a "diferenței de culoare"

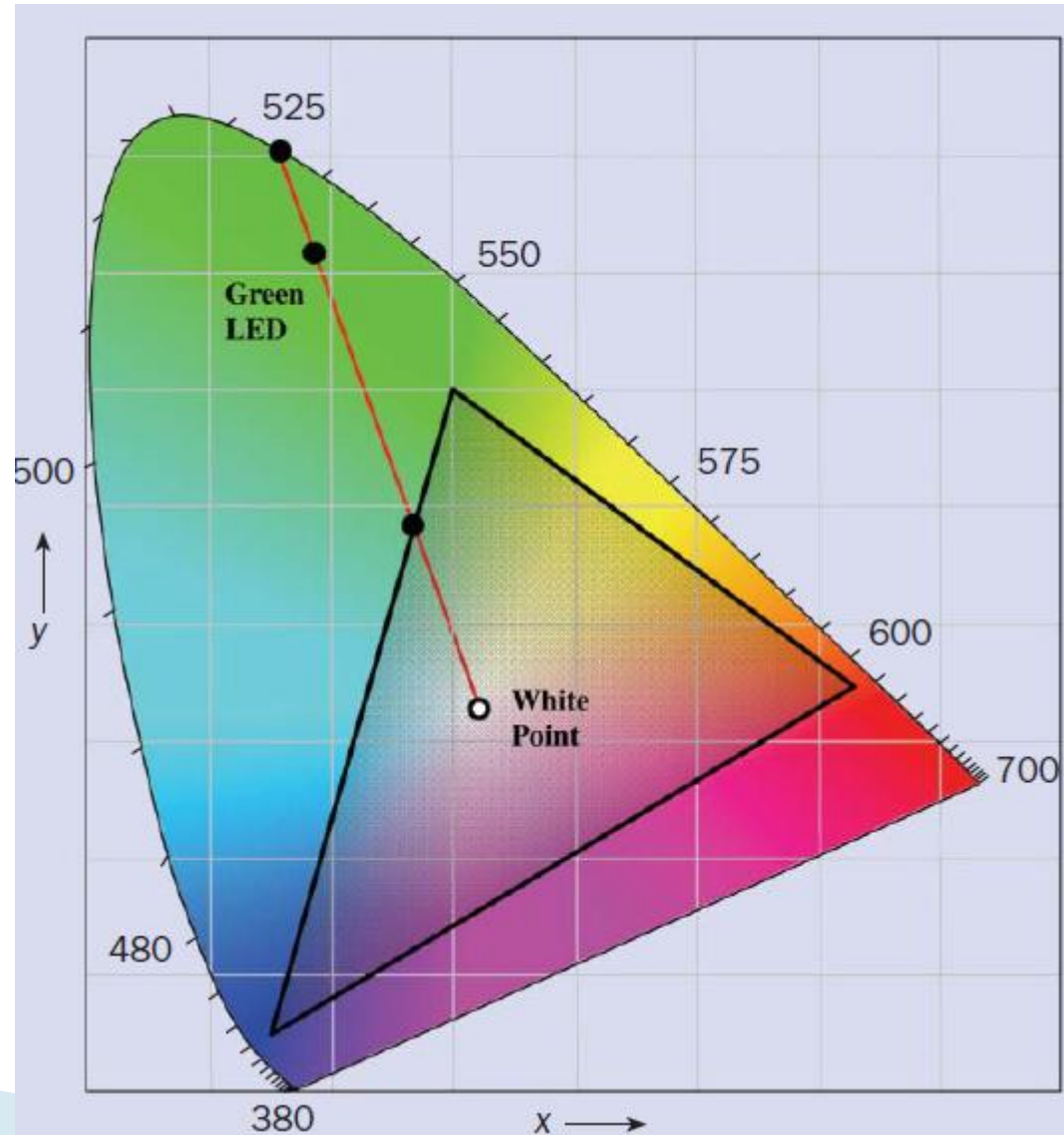
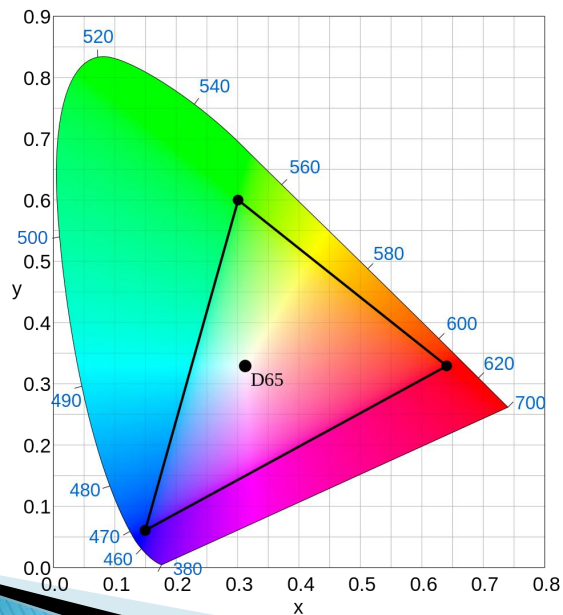


# ITU-R BT.709

## ITU-R BT.709 phosphor properties

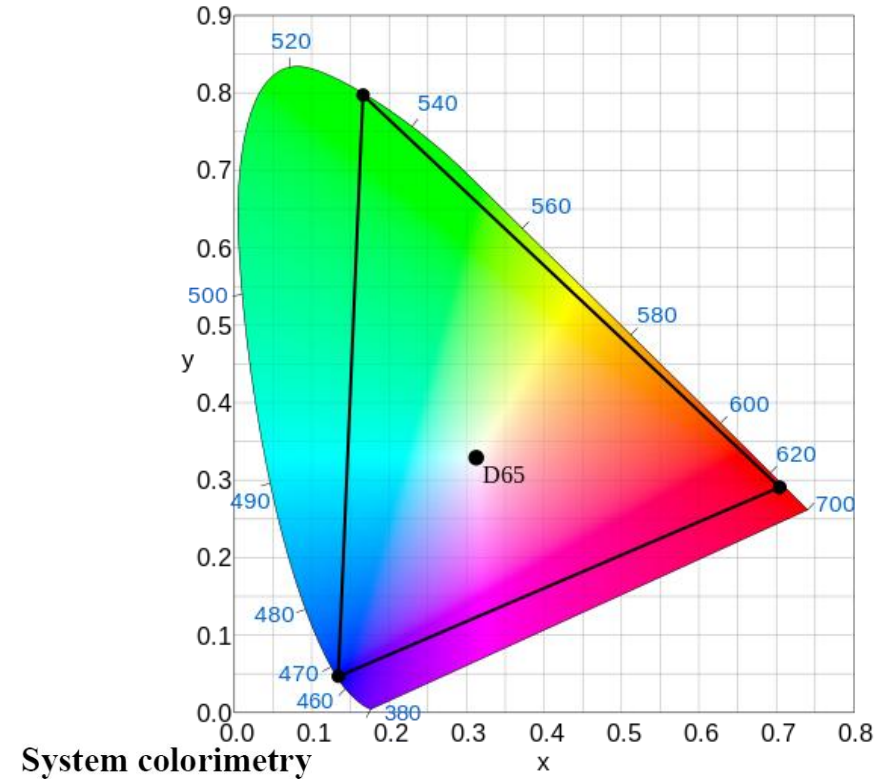
| Phosphor | x     | y     |
|----------|-------|-------|
| Red      | 0.640 | 0.330 |
| Green    | 0.300 | 0.600 |
| Blue     | 0.150 | 0.060 |

Data refers to xy chromaticity co-ordinates of ITU-R BT.709 phosphors which are used in most CRT displays [1].



# ITU-R BT.2020

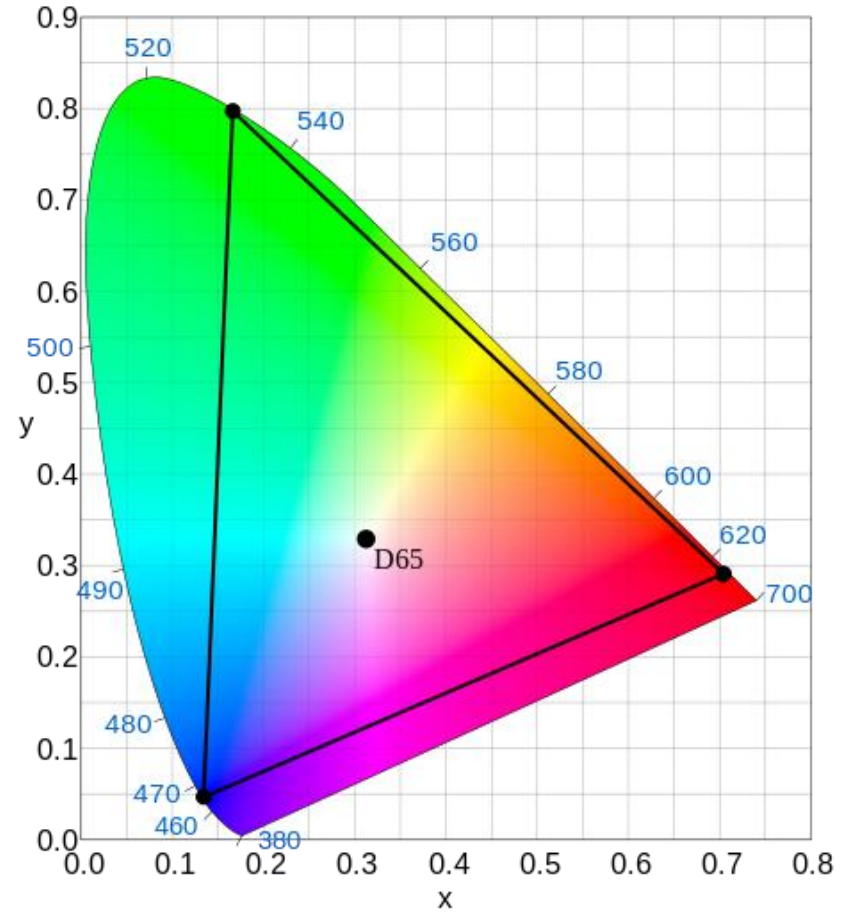
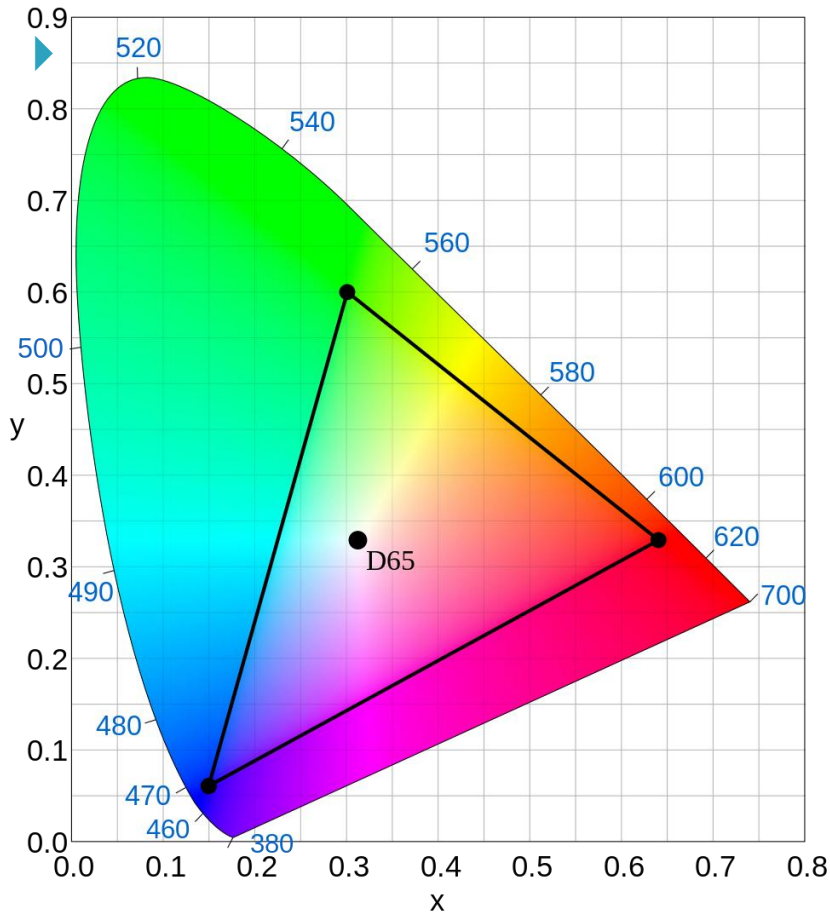
- ▶ Parameter values for ultra-high definition television systems
- ▶ UHDTV



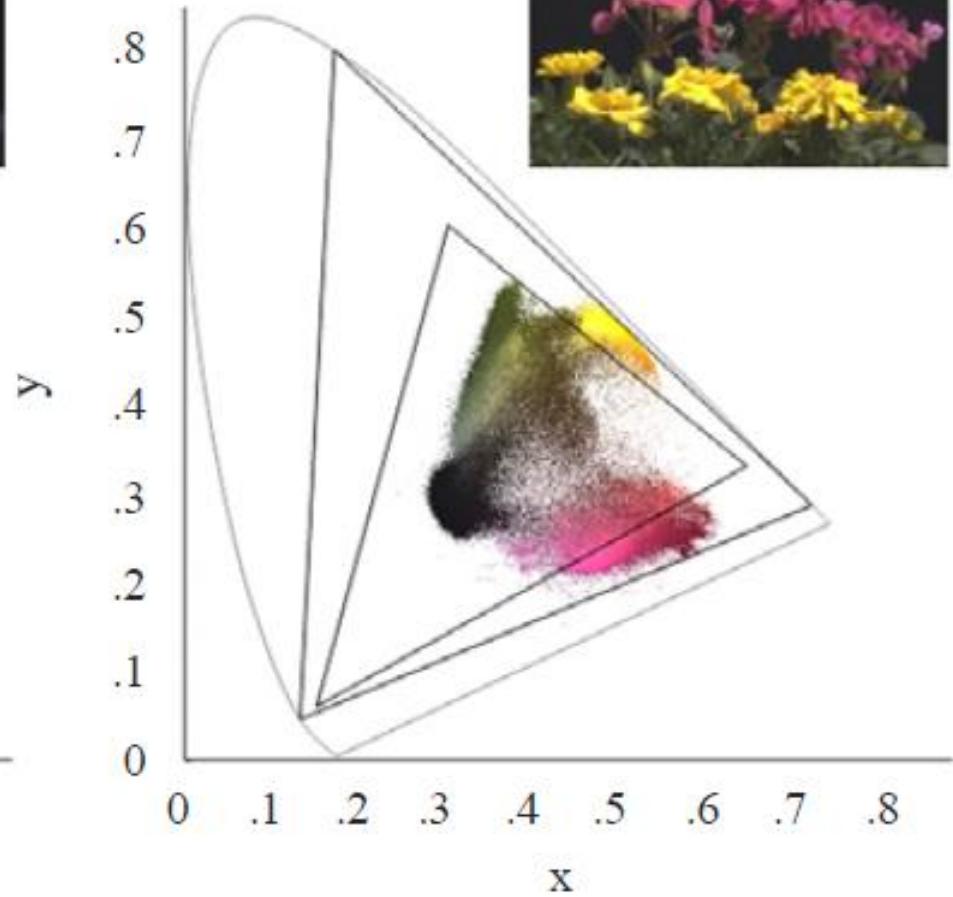
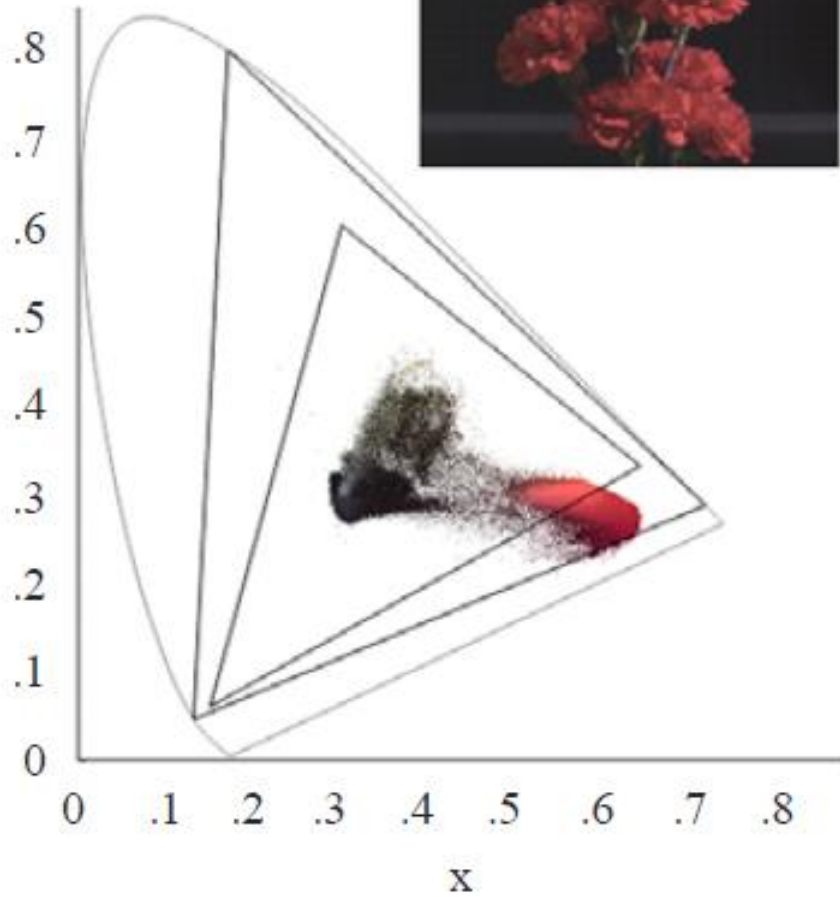
| Parameter   | Values                               |        |        |
|---|--------------------------------------|--------|--------|
| Opto-electronic transfer characteristics before non-linear pre-correction | Assumed linear <sup>(1)</sup>        |        |        |
| Primary colours and reference white <sup>(2)</sup>                        | Chromaticity coordinates (CIE, 1931) | x      | y      |
|   | Red primary (R)                      | 0.708  | 0.292  |
|   | Green primary (G)                    | 0.170  | 0.797  |
|   | Blue primary (B)                     | 0.131  | 0.046  |
|   | Reference white (D65)                | 0.3127 | 0.3290 |

<sup>(1)</sup> Picture information can be linearly indicated by the tristimulus values of RGB in the range of 0-1.

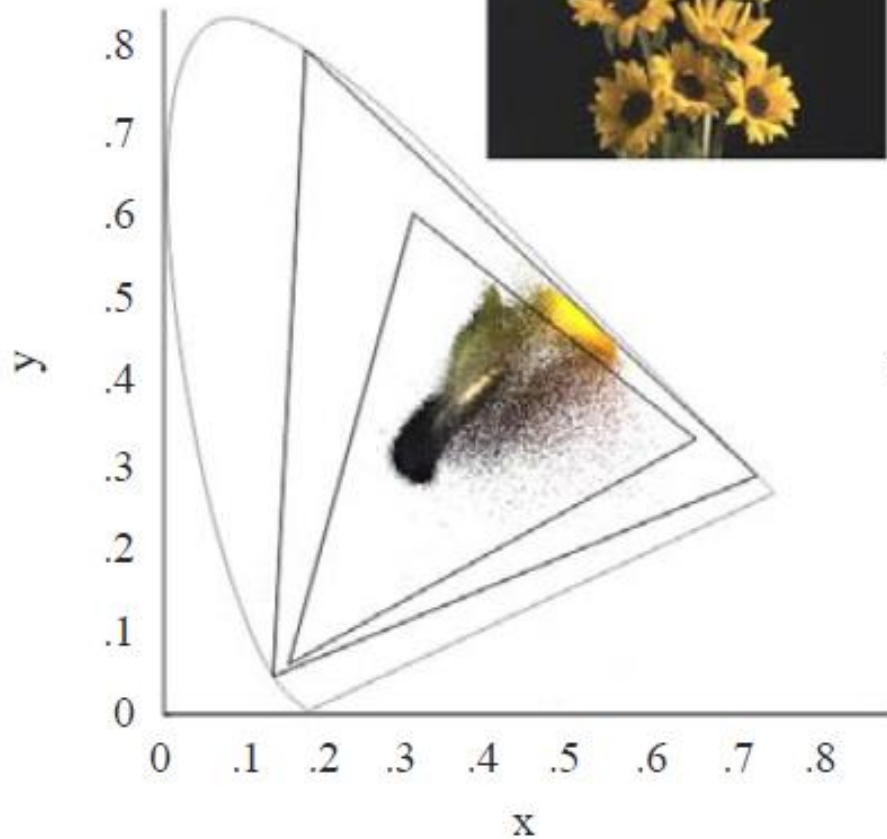
# ITU-R BT.709/.2020



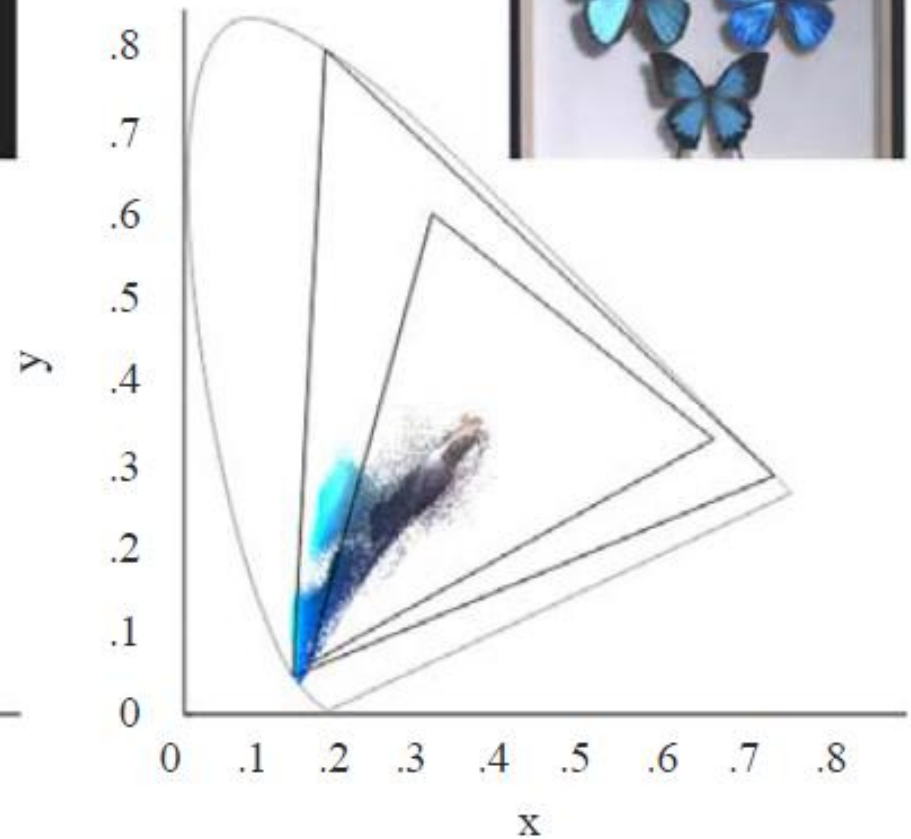
# ITU-R BT.709/.2020



# ITU-R BT.709/.2020



c) Sunflower



(d) Butterfly



# Determinarea lungimii de unda dominante

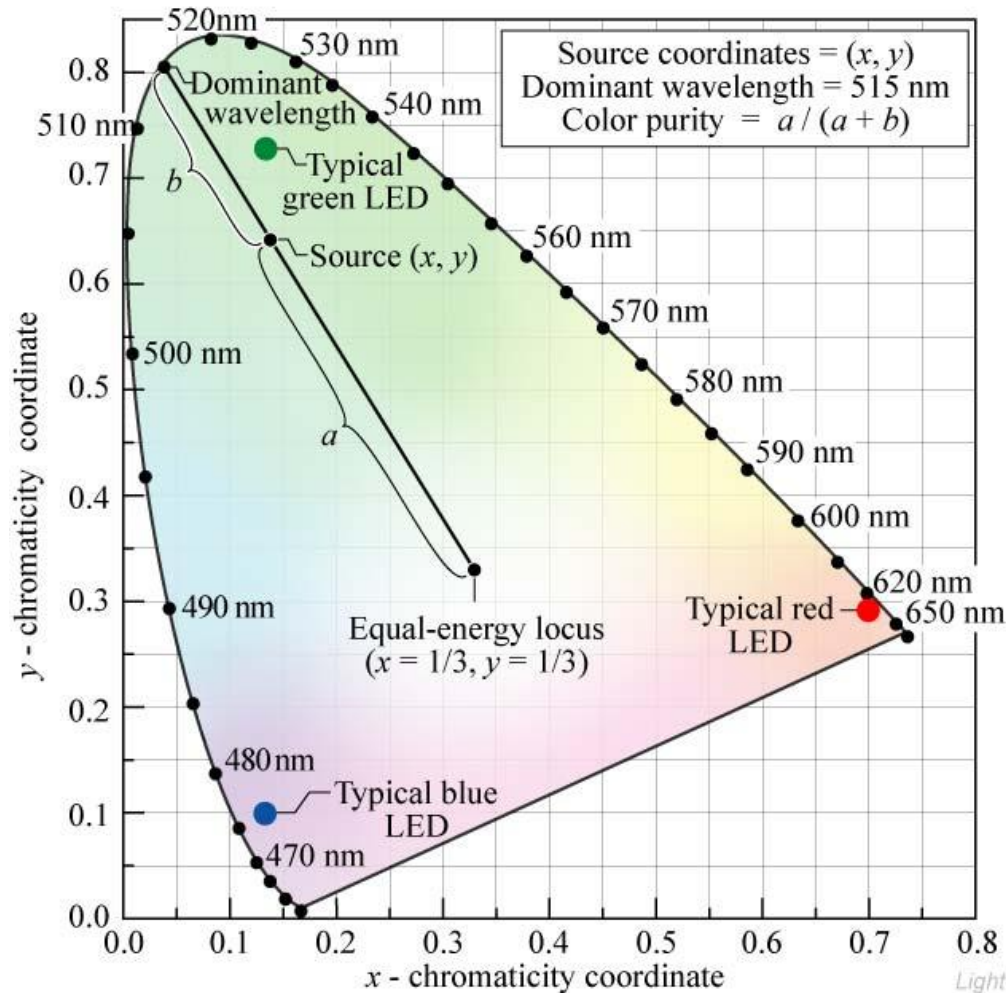


Fig. 17.8. Chromaticity diagram showing the determination of the *dominant color* and *color purity* of a light source with chromaticity coordinates  $(x, y)$  using the equal-energy locus ( $x = 1/3, y = 1/3$ ) as the white-light reference. Also shown are typical locations of blue, green, and red LEDs.

# ITU-R BT.709

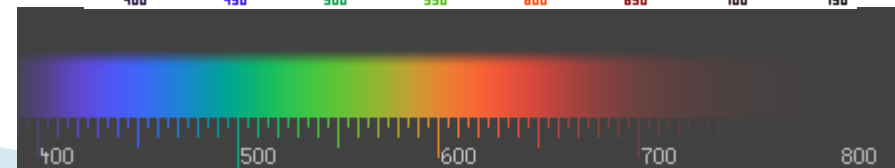
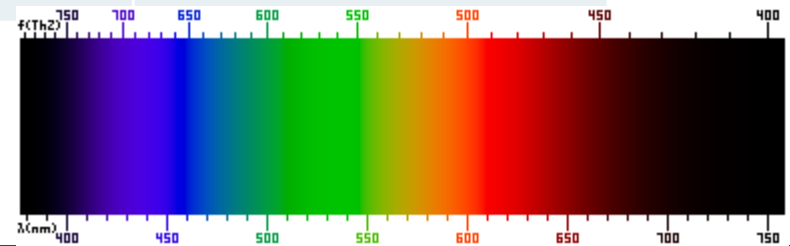


## RGB values for Luxeon LEDs

| LED color  | Dominant wavelength<br>$\lambda_D$ (nm) | RGB values       |
|------------|---|------------------|
| Royal blue | 455                                     | 0.05, 0.00, 0.95 |
| Blue       | 470                                     | 0.00, 0.11, 0.89 |
| Cyan       | 505                                     | 0.00, 0.63, 0.37 |
| Green      | 530                                     | 0.00, 0.77, 0.23 |
| Amber      | 590                                     | 0.70, 0.30, 0.00 |
| Red-orange | 615                                     | 0.97, 0.00, 0.03 |
| Red        | 625                                     | 0.92, 0.00, 0.08 |

# Culori – lungime de unda

| Culoare    | Lungime de unda | Frecventa     |
|------------|-----------------|---------------|
| Rosu       | ~ 700-630 nm    | ~ 430-480 THz |
| Portocaliu | ~ 630-590 nm    | ~ 480-510 THz |
| Galben     | ~ 590-560 nm    | ~ 510-540 THz |
| Verde      | ~ 560-490 nm    | ~ 540-610 THz |
| Albastru   | ~ 490-450 nm    | ~ 610-670 THz |
| Violet     | ~ 450-400 nm    | ~ 670-750 THz |



# Interpretarea standard a culorilor

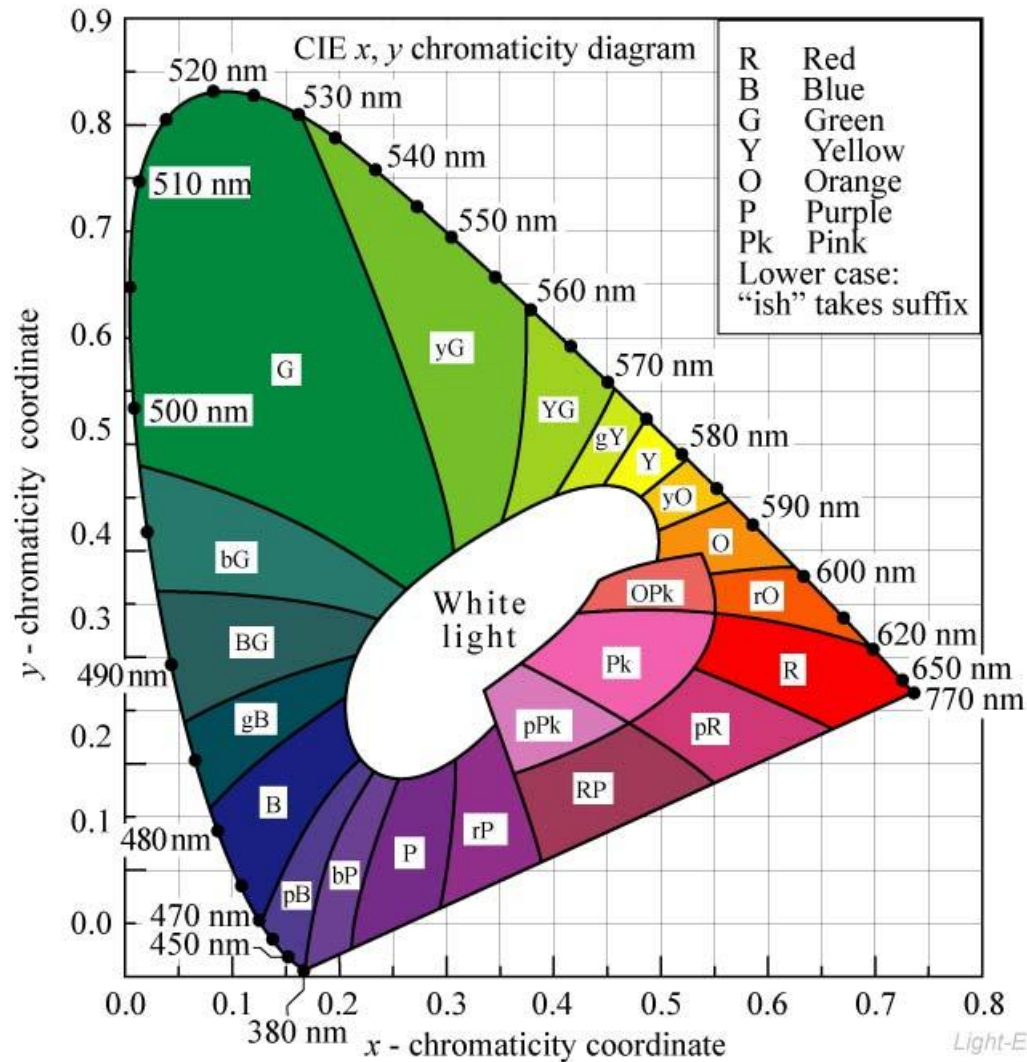


Fig. 17.3. 1931 CIE chromaticity diagram with areas attributed to distinct colors (adopted from Gage *et al.*, 1977).

# Interpretarea standard a culorilor

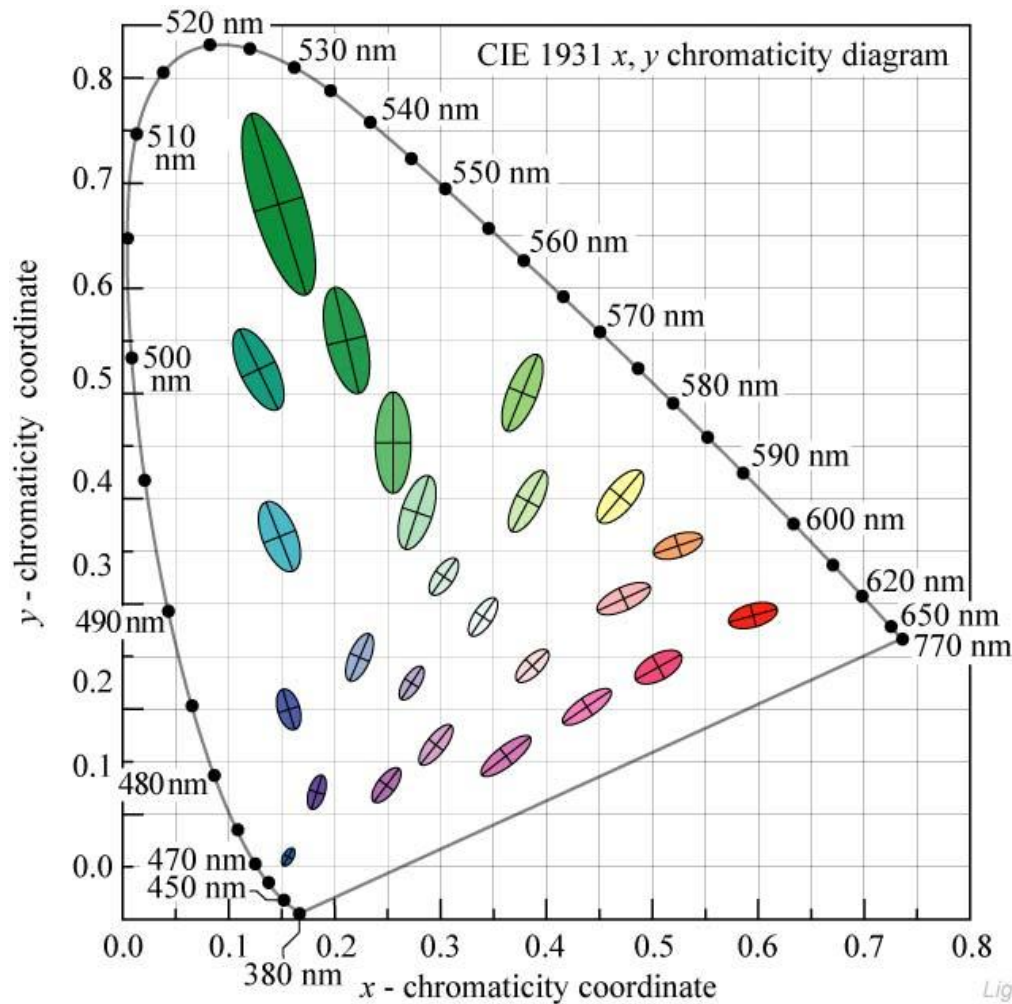


Fig. 17.5. MacAdam ellipses plotted in the CIE 1931 ( $x$ ,  $y$ ) chromaticity diagram. The axes of the ellipses are ten times their actual lengths (after MacAdam, 1943; Wright, 1943; MacAdam, 1993).

# Black body

## ▶ Legea lui Planck

- Intensitatea radiatiei electromagnetice (radianta spectrala) a corpului absolut negru (absoarbe in totalitate radiatiile incidente)
- Lege universală, independentă de material, forma etc.

$$I_{\lambda}(\lambda, T) = \frac{2 \cdot h \cdot c^2}{\lambda^5} \cdot \frac{1}{e^{\frac{h \cdot c}{k \cdot T \cdot \lambda}} - 1}$$

# Temperatura de culoare

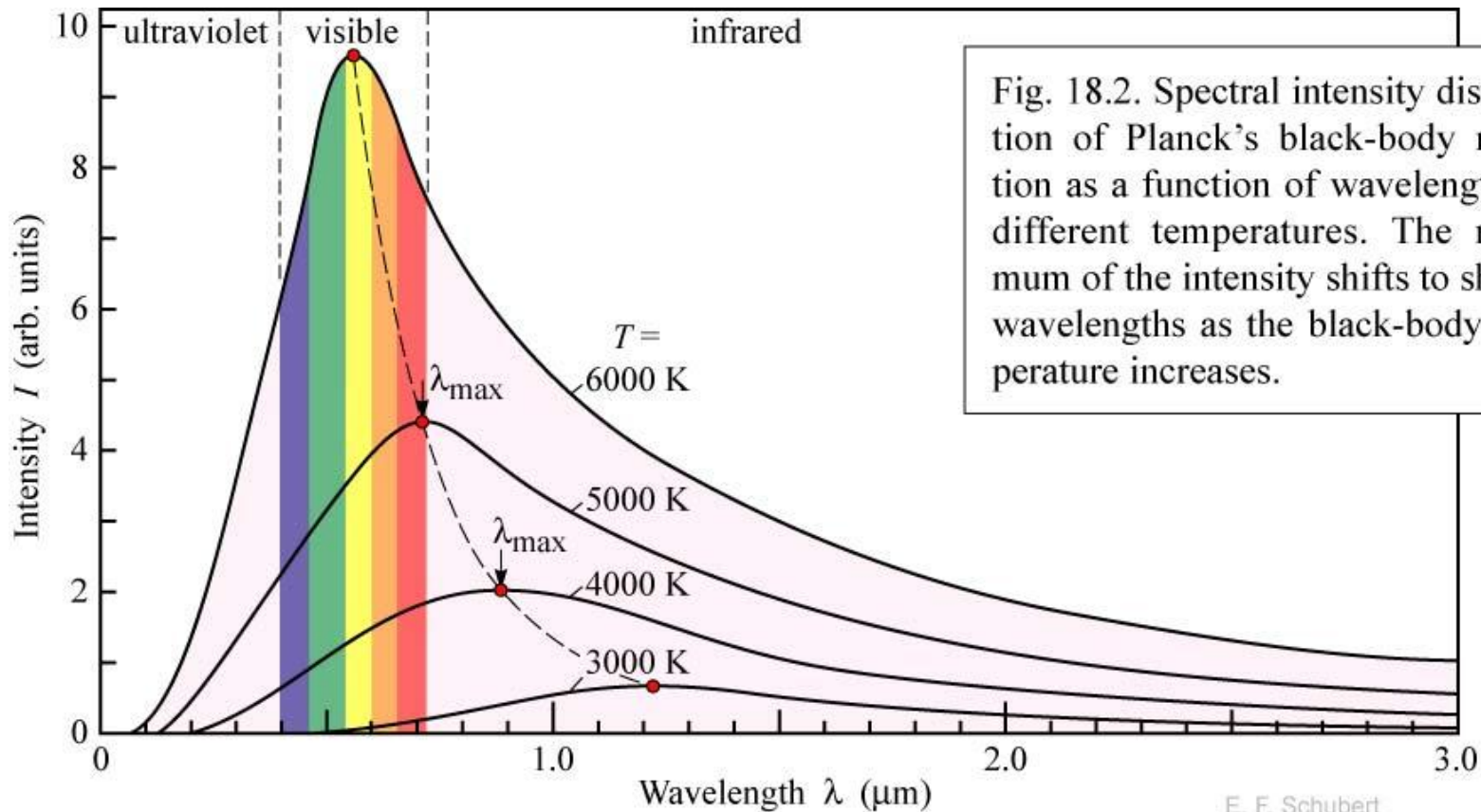
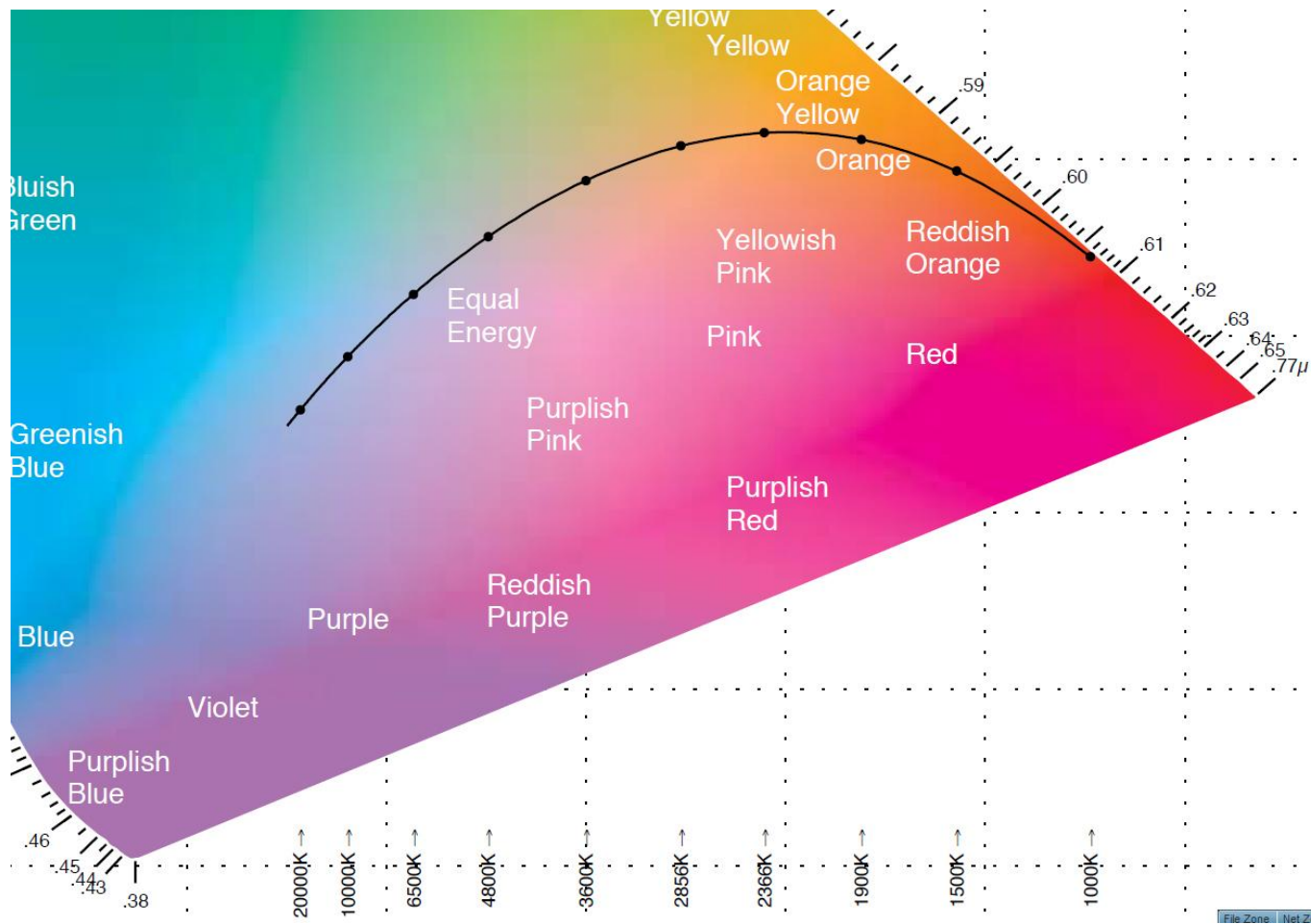


Fig. 18.2. Spectral intensity distribution of Planck's black-body radiation as a function of wavelength for different temperatures. The maximum of the intensity shifts to shorter wavelengths as the black-body temperature increases.

E. F. Schubert  
*Light-Emitting Diodes* (Cambridge Univ. Press)  
[www.LightEmittingDiodes.org](http://www.LightEmittingDiodes.org)

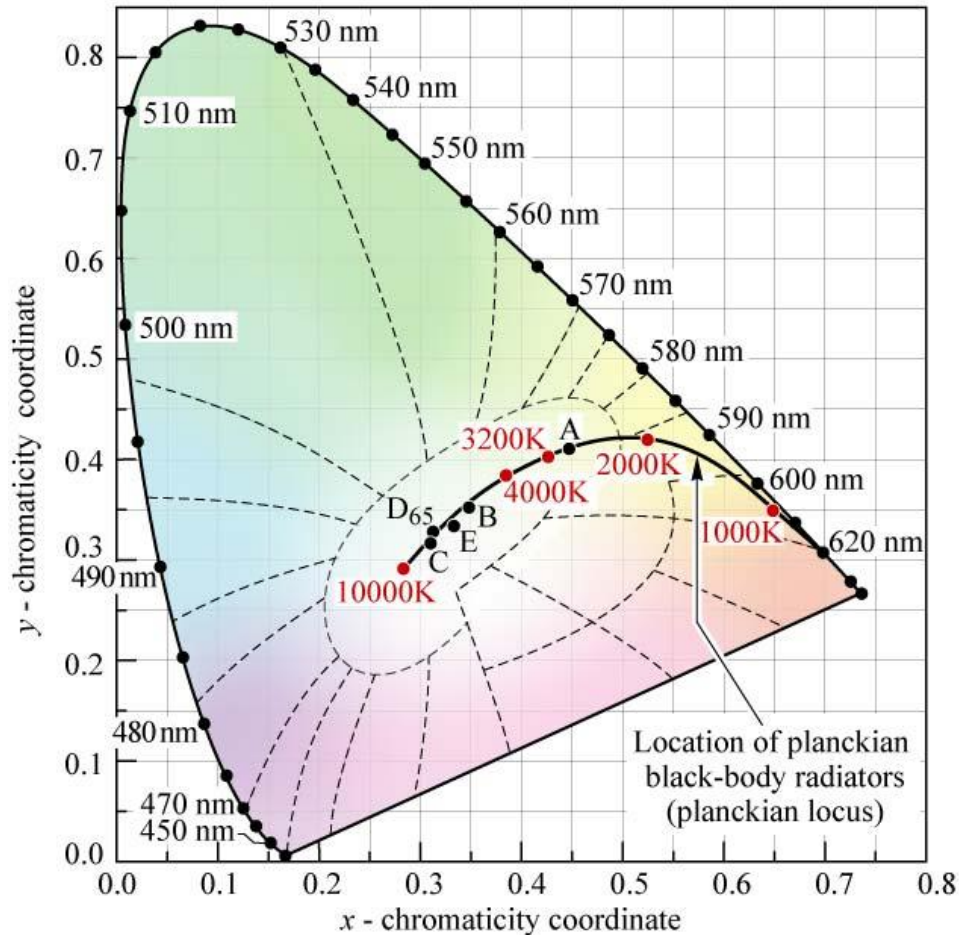


# CIE xy 1931





# Temperatura de culoare



**Illuminant A**  
 $(x, y) = (0.4476, 0.4074)$   
 (Incandescent source,  $T = 2856$  K)

**Illuminant B**  
 $(x, y) = (0.3484, 0.3516)$   
 (Direct sunlight,  $T = 4870$  K)


**Illuminant C**  
 $(x, y) = (0.3101, 0.3162)$   
 (Overcast source,  $T = 6770$  K)

**Illuminant D<sub>65</sub>**  
 $(x, y) = (0.3128, 0.3292)$   
 (Daylight,  $T = 6500$  K)

**Illuminant E (equal-energy point)**  
 $(x, y) = (0.3333, 0.3333)$

Fig. 18.3. Chromaticity diagram showing planckian locus, the standardized white Illuminants A, B, C, D<sub>65</sub>, and E, and their color temperature (after CIE, 1978).

# Lungimi de unda tipice – LED



| Wavelength (nm) | Color Name            |
|-----------------|-----------------------|
| 940             | Infrared              |
| 880             | Infrared              |
| 850             | Infrared              |
| 660             | Ultra Red             |
| 635             | High Eff. Red         |
| 633             | Super Red             |
| 620             | Super Orange          |
| 612             | Super Orange          |
| 605             | Orange                |
| 595             | Super Yellow          |
| 592             | Super Pure Yellow     |
| 585             | Yellow                |
| 4500K           | "Incandescent" White  |
| 6500K           | Pale White            |
| 8000K           | Cool White            |
| 574             | Super Lime Yellow     |
| 570             | Super Lime Green      |
| 565             | High Efficiency Green |
| 560             | Super Pure Green      |
| 555             | Pure Green            |
| 525             | Aqua Green            |
| 505             | Blue Green            |
| 470             | Super Blue            |
| 430             | Ultra Blue            |

# Probleme

- ▶ Panoul unui dispozitiv conține două LED-uri de semnalizare, unul de culoare verde și unul roșu standard. Doriți ca ambele să ofere aceeași luminozitate relativă și cât mai mare posibilă. Dacă ambele LED-uri acceptă un curent maxim de 50 mA, calculați curentul prin cele două LED-uri.
- ▶ Rezolvari: <http://rf-opto.etti.tuiasi.ro>

# Probleme

- ▶ Trebuie să proiectați un semafor cu LED-uri. LED-urile care intră în componența sa sunt caracterizate de eficiență cuantică egală (aceeași tehnologie), iar parametrii de catalog pentru LED-ul roșu sunt ...
- ▶ Proiectați semaforul, pentru a obține o iluminare la 5m, pe direcție normală, de 50 lx pe timp de zi și 2 lx pe timp de noapte.
- ▶ Cerințe: luminozitate egală pentru cele 3 culori, alegerea numărului de LED-uri (considerente electronice/practice), necesitățile de curent ale fiecărui LED, parametrii pentru sursa de alimentare, parametrii unui sistem de control a intensității luminoase pentru reglare zi/noapte.
- ▶ Rezolvari: <http://rf-opto.etti.tuiasi.ro>

# Probleme

- ▶ O instalație de semnalizare diurnă monocoloră trebuie realizată cu LED-uri. Cerințele sunt exprimate în parametri luminoși (lm, lx, cd, etc.). Aveți posibilitatea să alegeți între 4 LED-uri care au majoritatea parametrilor identici, valorile diferite fiind cele din tabel:

| Nr. | Lungime de undă [nm] | Putere optică emisă [mW] | Preț |
|-----|----------------------|--------------------------|------|
| 1   | 645                  | 2.55                     | 1.39 |
| 2   | 550                  | 2.30                     | 1.09 |
| 3   | 645                  | 1.35                     | 1.18 |
| 4   | 645                  | 2.90                     | 1.24 |

# Probleme

- ▶ Se presupune că numărul de LED-uri necesar în instalație este suficient de mare astfel încât rotunjirea la număr întreg să nu modifice semnificativ rezultatele.
  - Alegeți componenta care vă permite să obțineți prețul total cel mai mic. Justificați. (3.5p)
  - Dacă instalația este prevăzută să funcționeze pe timp de noapte, se schimbă alegerea? Justificați. (1.5p)
- ▶ Rezolvari: <http://rf-opto.etti.tuiasi.ro>

# Contact

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