

Optoelectronică, structuri și tehnologii

Curs 3
2016/2017

Disciplina 2016/2017

- ▶ 2C/1L Optoelectronică, structuri, tehnologii, circuite, **OSTC**
- ▶ **Minim 7 prezente curs + laborator**
- ▶ Curs – **sl. Radu Damian**
 - Joi 15–18, P5
 - E – 70% din nota
 - **20% test la curs**, saptamana 4–5?
 - probleme + (?1 subiect teorie) + (2p prez. Curs)
 - **2prez=0.5p**
 - toate materialele permise
- ▶ Laborator – **sl. Daniel Matasaru**
 - Joi 8-14 par
 - L – 15% din nota
 - C – 15% din nota

Orar 2016/2017

▶ Curs

- Joi 15–18, P5
- **2C ⇒ 3C**
 - $14 * 2/3 \approx 9.33$
 - $9 \div 10$ C

Fotografii



Date:

Grupa	5304 (2015/2016)
Specializarea	Tehnologii si sisteme de telecomunicatii
Marca	5184

[Trimite email acestui student](#) | [Adauga acest student la lista \(0\)](#)

Detalii curente

Finantare	Buget
Bursa	Fara Bursa

Observatii



Date:

Grupa	5304 (2015/2016)
Specializarea	Tehnologii si sisteme de telecomunicatii
Marca	5184

[Acceseaza ca acest student](#)

Note obtinute

Disciplina	Tip	Data	Descriere	Nota	Puncte	Obs.
TW	Tehnologii Web					
	N	17/01/2014	Nota finala	10	-	
	A	17/01/2014	Colocviu Tehnologii Web 2013/2014	10	7.55	
	B	17/01/2014	Laborator Tehnologii Web 2013/2014	9	-	
	D	17/01/2014	Tema Tehnologii Web 2013/2014	9	-	



Date:

Grupa	5304 (2015/2016)
Specializarea	Tehnologii si sisteme de telecomunicatii
Marca	5244

[Trimite email acestui student](#) | [Adauga acest student la lista \(0\)](#)

Detalii curente

Finantare	Buget
Bursa	Bursa de Studii

Observatii

Fotografii

Nr. Student	Student	Prezent	Nr. Student	Student	Prezent	Nr. Student	Student	Prezent
1	ANGHELUS IONUT-MARIUS	<input type="checkbox"/>	2	ANTIGHIN FLORIN-RAZVAN	<input checked="" type="checkbox"/>	3	ANTONICA BIANCA	<input type="checkbox"/>
4	APOSTOL PAVEL-MANUEL	<input type="checkbox"/>	5	BALASCA IULIAN-PETRU	<input type="checkbox"/>	6	BOSTAN ANDREI-PETRIKA	<input type="checkbox"/>
7	BOTEZAT EMANUEL	<input type="checkbox"/>	8	BUTUNOI GEORGE-MADALIN	<input type="checkbox"/>	9	CHILEA SALUCA-MARIA	<input type="checkbox"/>
10	CHIRITOIU ECATERINA	<input type="checkbox"/>	11	COJOC MARIUS	<input checked="" type="checkbox"/>	12	COJOCARI AURA-FLORINA	<input type="checkbox"/>

Nr. Student	Student	Prezent
2	ANTIGHIN FLORIN-RAZVAN	<input checked="" type="checkbox"/>

Fotografia nu exista

Prezent

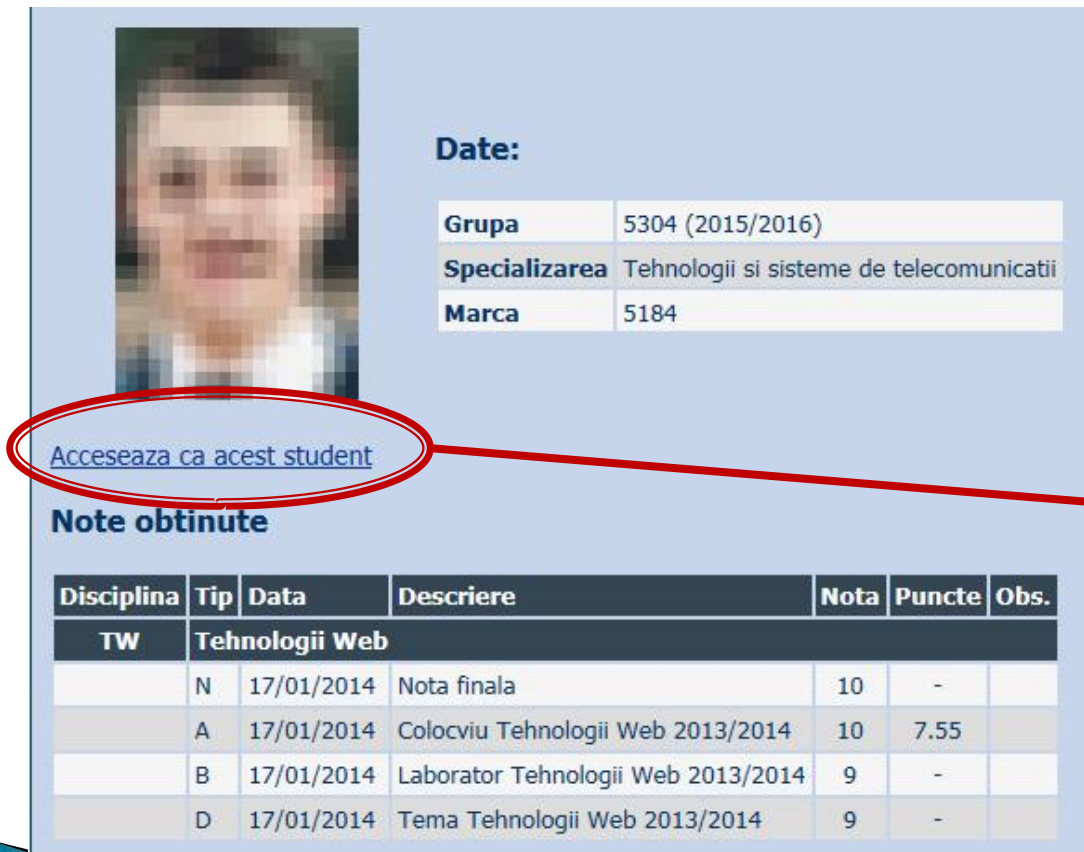
Puncte: 0

Nota: 0

Obs:

Acces

▶ Personalizat



Student profile card showing a blurred photo, a 'Date:' section with a table of personal information, and a 'Note obtinute' table. A red oval highlights the link 'Acceseaza ca acest student'.

Date:

Grupa	5304 (2015/2016)
Specializarea	Tehnologii si sisteme de telecomunicatii
Marca	5184

[Acceseaza ca acest student](#)

Note obtinute

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Login form with fields for Name, Email, and Verification Code. A red oval highlights the Email field, and another red oval highlights the Verification Code field. A red arrow points from the link in the student profile to the Email field. A verification code '344bd9f' is displayed below the code field, and a 'Trimite' button is at the bottom.

Nume

Email

Cod de verificare

344bd9f

Trimite

Reprezentare logaritmică

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Calculul atenuarii

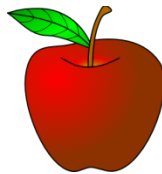
$$\text{Pierderi} = \frac{P_{out}}{P_{in}}$$

$$\text{Pierderi [dB]} = [-] 10 \cdot \log_{10} \left(\frac{P_{out}}{P_{in}} \right)$$

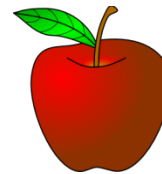
$$\text{Pierderi [dB]} = [-] (P_{out} [\text{dBm}] - P_{in} [\text{dBm}])$$



=



-



$$\text{Atenuare [dB/km]} = \frac{\text{Pierderi [dB]}}{\text{lungime [km]}}$$

Bonus

Disciplina: Optoelectronica, structuri, tehnologii, circuite
An: 2015/2016

Bonus-uri care se aplica la nota de la teza obtinute prin:

- prezenta la curs (0.5p / 3pr)
- 3 miniteste aplicate la curs (max. 3 X 1.5p)
- contributie la site rf-opto (foto <C5=1p, >C5=0.5p)

Nr.	Student	Grupa	Prezente curs	Bonus prezenta	Bonus foto	Bonus T1	Bonus T2	Bonus T3	Total Bonus	Obs.
1	CIOLPAN OCTAVIAN	5306	3	0.5					0.5	-
2	NITA COSTEL-CATALIN	5307	4	0.5	1				1.5	-
3	BARON BOGDAN-IONUT	5405	12	2	1	0.5		0.75	4.25	-

Prezenta

[Curs](#)
[Laborator](#)

Liste

[Studenti care nu pot intra in examen](#)
[Bonus-uri acumulate](#)

- ▶ **Minim** 7 prezente
- ▶ 0.5p/2(3)prez
- ▶ 3 teste
- ▶ foto

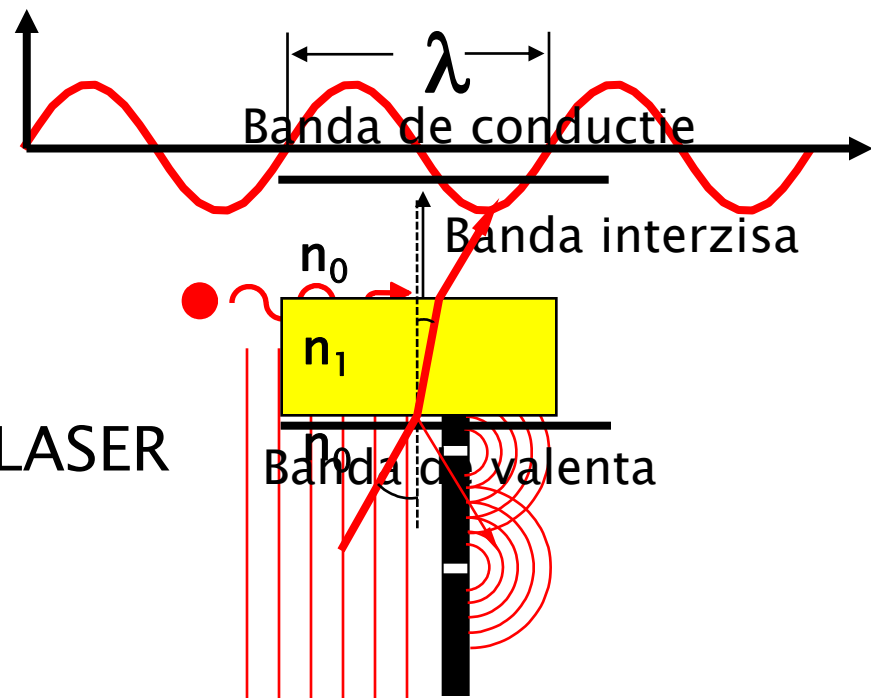
Recapitulare

Modelarea luminii

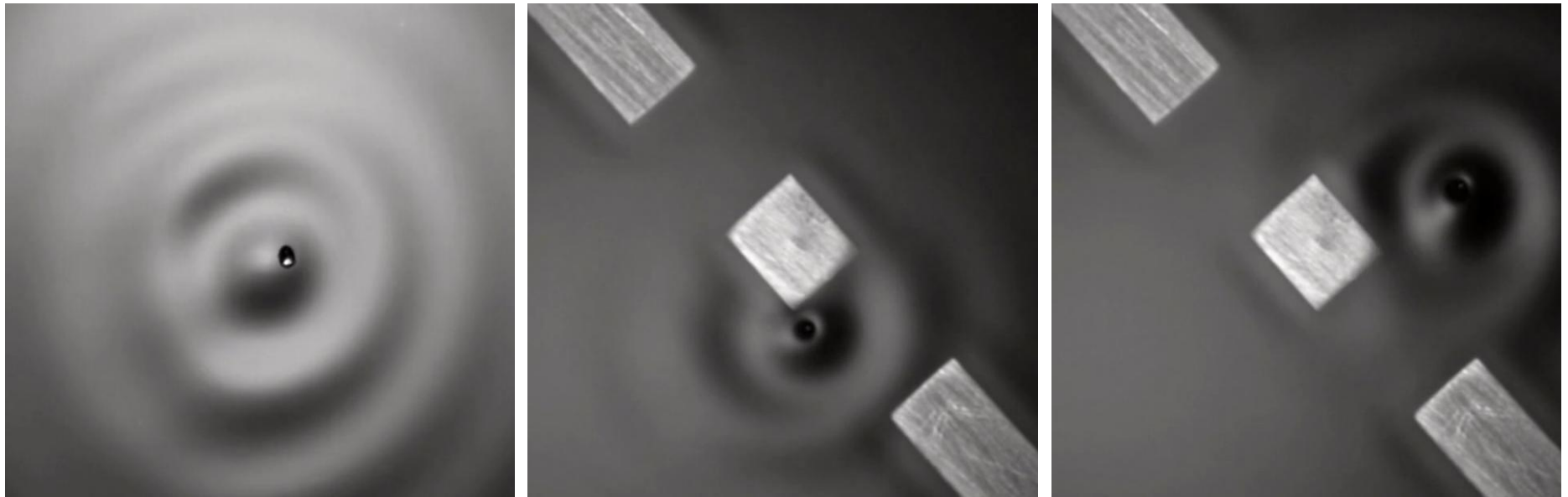
(tot) Capitolul 1

Modelarea luminii

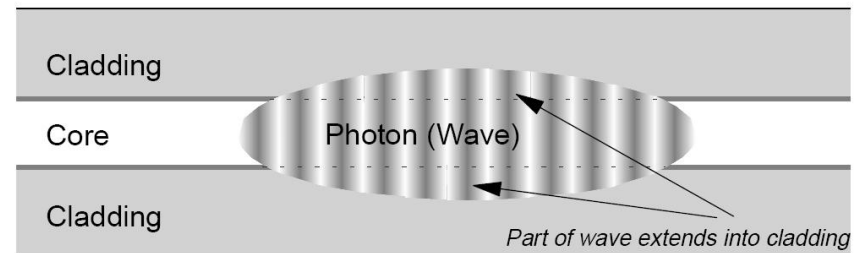
- ▶ Undă electromagnetică
 - Ecuațiile lui Maxwell
 - λ , ϵ , ω , f
- ▶ Teoria cuantică
 - Benzi energetice $E = h \nu$
 - fotoni, emisie stimulată, LASER
- ▶ Optică geometrică
 - n , θ
 - raze de lumină
 - intuitivă



Modelare



Through the Wormhole
S02E07 How Does the Universe Work



Lumina ca undă electromagnetică

Capitolul 2

Ecuatiile lui Maxwell

$$\nabla \times E = -\frac{\partial B}{\partial t}$$

$$\nabla \times H = \frac{\partial D}{\partial t} + J$$

$$\nabla \cdot D = \rho$$

$$\nabla \cdot B = 0$$

$$\nabla \cdot J = -\frac{\partial \rho}{\partial t}$$

▶ Ecuatii constitutive

$$D = \varepsilon \cdot E$$

$$B = \mu \cdot H$$

$$J = \sigma \cdot E$$

▶ In vid

$$\mu_0 = 4\pi \times 10^{-7} \text{ H/m}$$

$$\varepsilon_0 = 8,854 \times 10^{-12} \text{ F/m}$$

$$c_0 = \frac{1}{\sqrt{\varepsilon_0 \cdot \mu_0}} = 2,99790 \cdot 10^8 \text{ m/s}$$

Parametri, dependenta de mediu

$$\eta_0 = \sqrt{\frac{\mu_0}{\epsilon_0}} = 377\Omega$$

$$c_0 = \frac{1}{\sqrt{\epsilon_0 \cdot \mu_0}} = 2,99790 \cdot 10^8 \text{ m/s}$$

$n = 1$

$$T = \frac{2\pi}{\omega} = \frac{1}{f}$$

$$\lambda_0 = \frac{2\pi}{\beta} = \frac{c_0}{f}$$

$$\eta = \frac{\eta_0}{n}$$

$$c = \frac{c_0}{n}$$

$n = \sqrt{\epsilon_r}$

$$T = \frac{2\pi}{\omega} = \frac{1}{f}$$

$$\lambda = \frac{c_0}{n \cdot f} = \frac{\lambda_0}{n}$$

$$\lambda = \lambda(n)$$

$$f = \text{indep.}$$

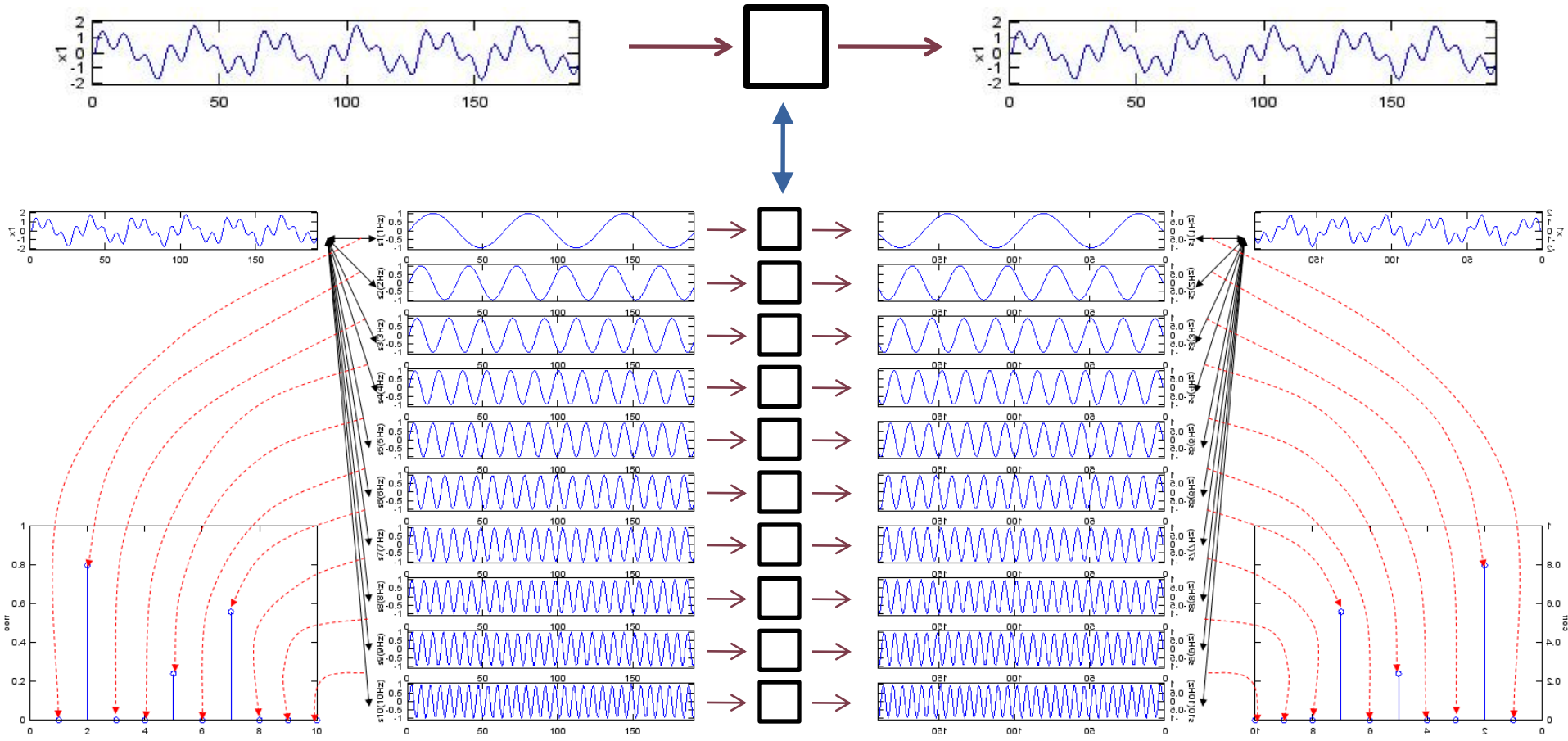
ITU G.692

"the allowed channel frequencies are based on a 50 GHz grid with the reference frequency at 193.10 THz"

SI

"a source that emits monochromatic radiation of frequency $540 \cdot 10^{12}$ Hz"

Modelle matematiche



$$g(\omega) = \int_{-\infty}^{\infty} f(t) \cdot e^{-j\omega t} dt$$

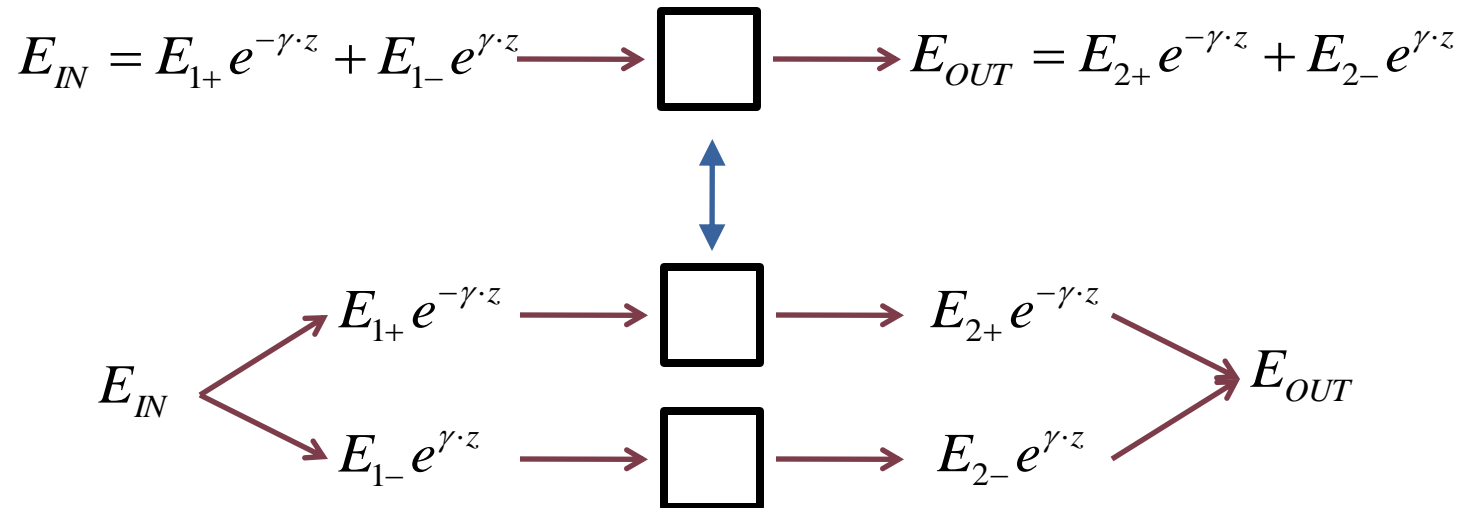
$$f(t) = \int_{-\infty}^{\infty} g(\omega) \cdot e^{j\omega t} d\omega$$

Modele matematice

► cazuri particulare in care exista rezolvare analitica

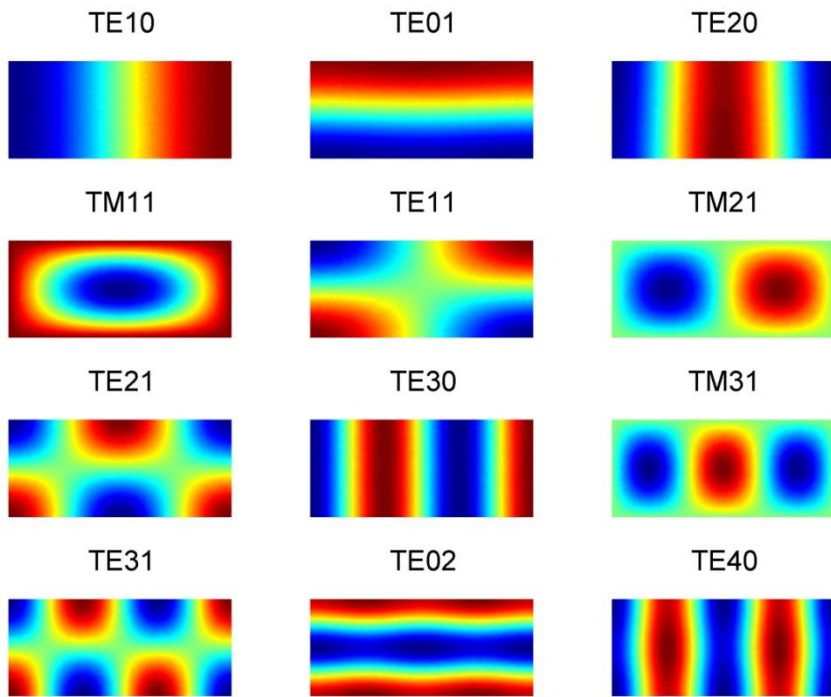
- unda
 - incidenta
 - reflectata
- unda
 - directa
 - inversa

$$E_y = E^+ \cdot e^{-\alpha \cdot z} \cdot e^{j(\omega t - \beta \cdot z)} + E^- \cdot e^{-\alpha \cdot z} \cdot e^{j(\omega t + \beta \cdot z)}$$

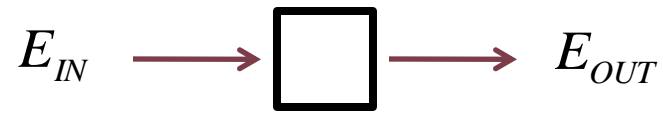


Modele matematice

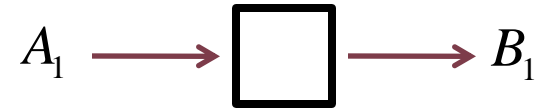
- ▶ cazuri particulare in care exista rezolvare analitica
 - moduri in medii delimitate



$$E = \sum_1^{\infty} A_i \cdot Mod_i \quad A_i = \langle E, Mod_i \rangle$$



$$A_i = \langle E_{IN}, Mod_i \rangle$$

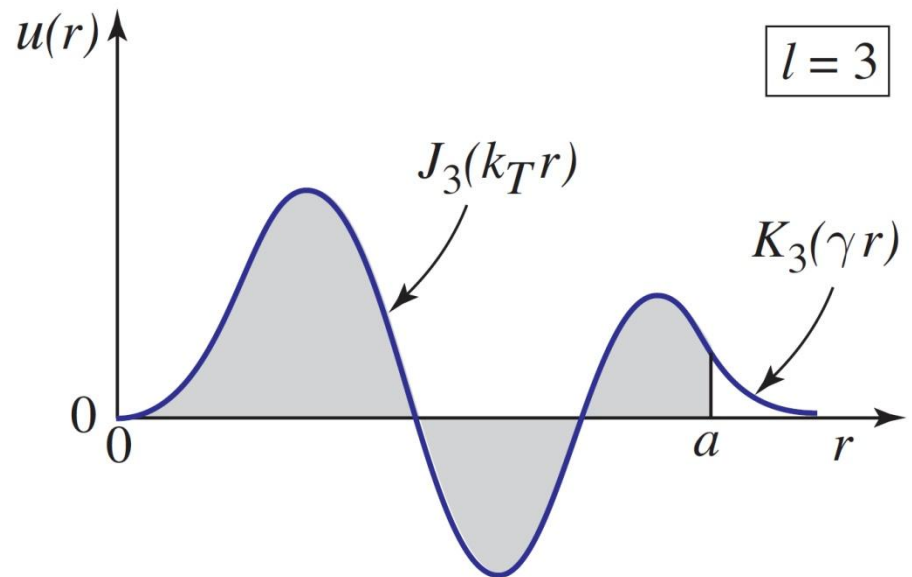
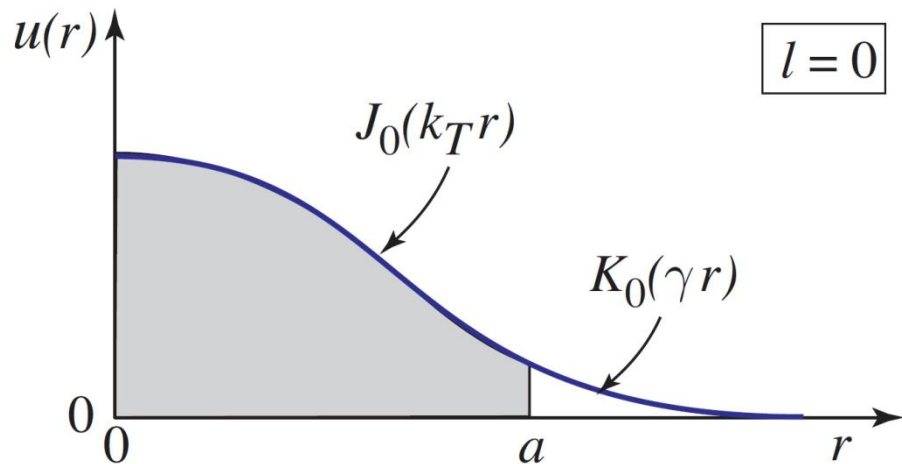


$$E_{OUT} = \sum_1^N B_i \cdot Mod_i$$

Ghid cilindric dielectric

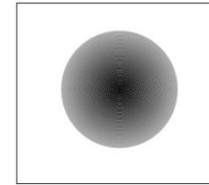
- ▶ solutii proportionale cu functii Bessel

$$u(r) \propto \begin{cases} J_l(k_T r), & r < a \quad (\text{core}) \\ K_l(\gamma r), & r > a \quad (\text{cladding}) \end{cases}$$

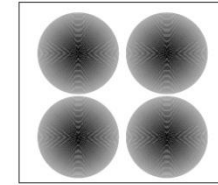


Moduri in fibra

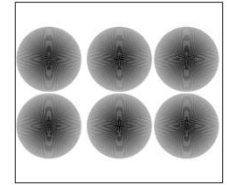
- ▶ Moduri in ghid rectangular



TEM₀₀

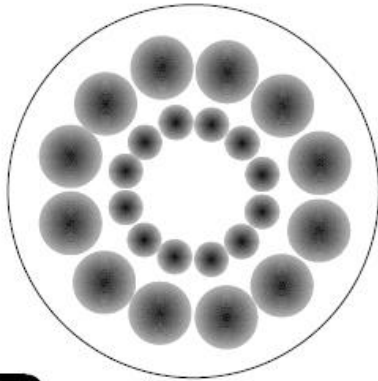


TEM₁₁

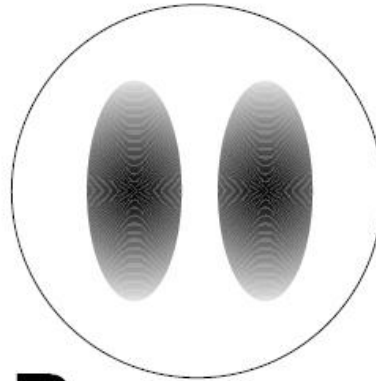


TEM₂₁

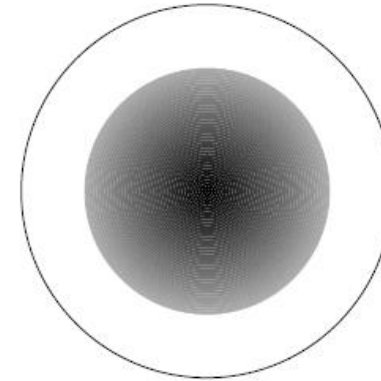
- ▶ Moduri linear polarizate in fibra



LP₆₂

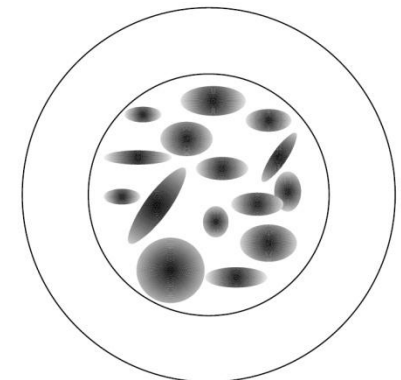


LP₁₁



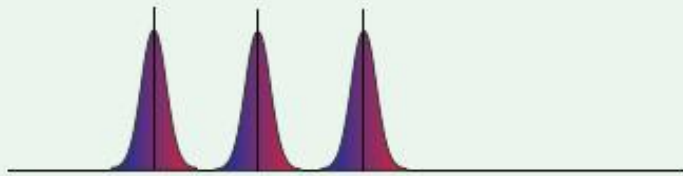
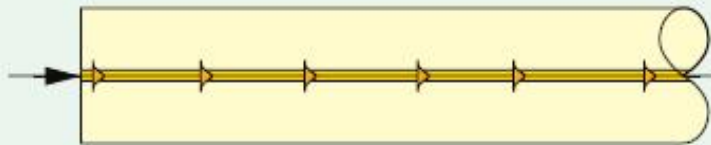
LP₀₁

“Sparkle” pattern

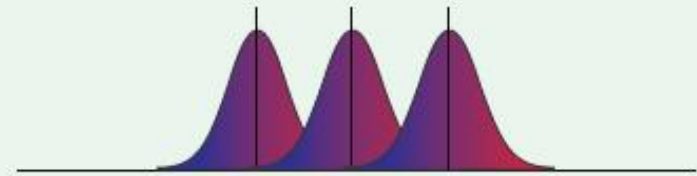
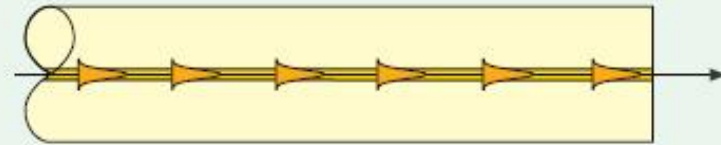


Dispersie

> 50 km Single-mode step index
< 10 km Multimode graded index
< 1 km Multimode step index



Transmission:
Well-defined pulses but not absolutely monochromatic.
Typical spectral width < 0.8 nm



Reception:
Pulse broadening caused by the laser's spectral width and the difference between the refractive indices of the red and blue ends of the light pulse.

Optică geometrică

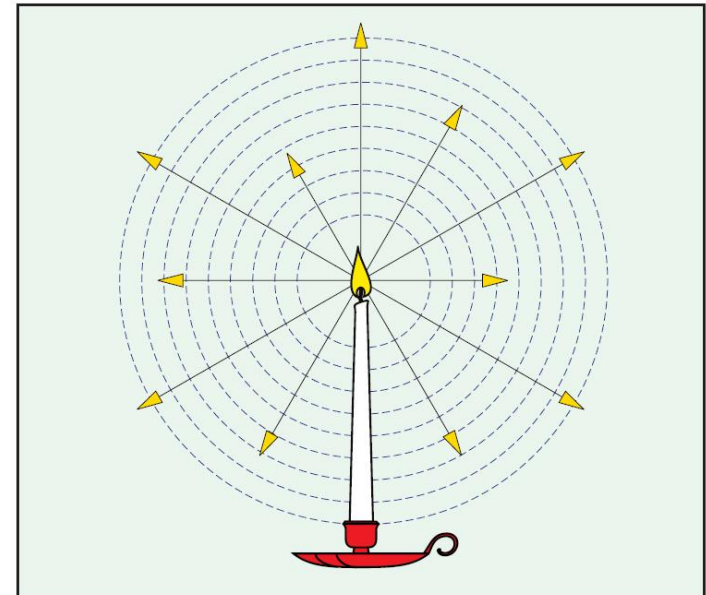
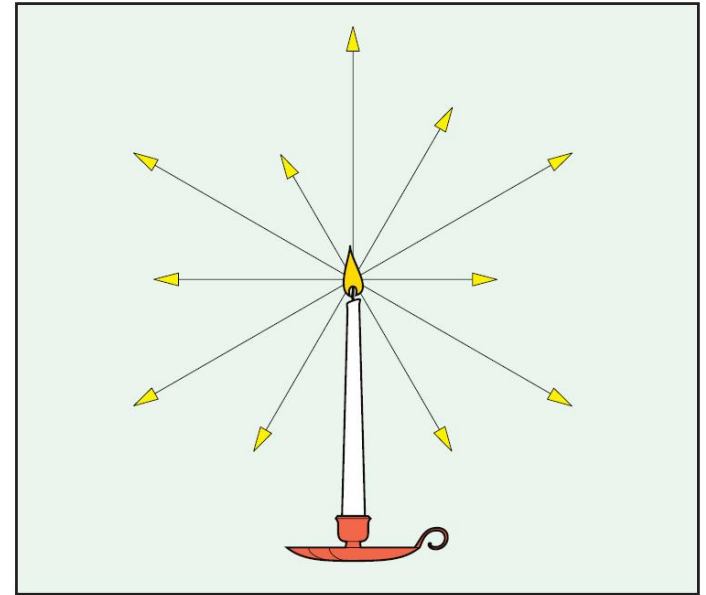
(tot) Capitolul 2

Raze de lumina

- ▶ Lumina este constituita din raze care se propaga in linie dreapta in medii omogene
- ▶ Sursa omnidirectionala: emite similar in toate directiile

- ▶ Energia luminoasa descreste invers proportional cu patratul distantei fata de sursa (energia se imparte uniform pe suprafata intregii sfere)

$$P = \frac{P_0}{r^2}$$



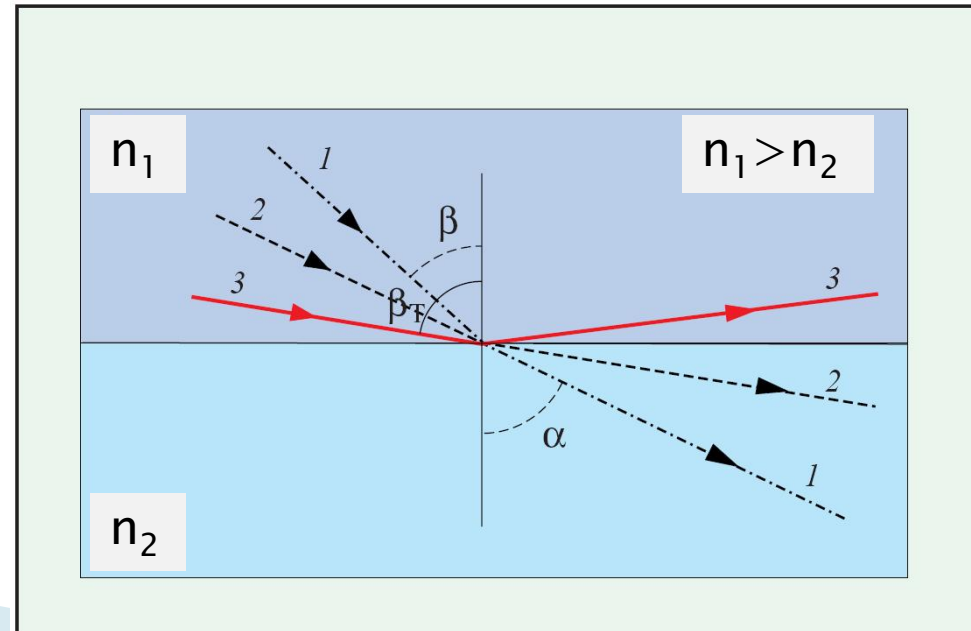
Reflexia totala

- ▶ Apare **numai când** lumina se propaga dintr-un mediu mai dens optic într-un mediu mai puțin dens
- ▶ La intersecția luminii cu suprafața de separație a doua medii se întâlnesc în general raze reflectate **și** raze refractate
- ▶ Pentru un unghi de incidență numit **unghi critic**, raza refractată se obține în lungul suprafeței de separație
- ▶ Pentru orice unghi mai mare decât unghiul critic există numai raza reflectată

$$n_1 > n_2; \quad \phi_R = 90^\circ$$

$$n_1 \cdot \sin \phi_C = n_2$$

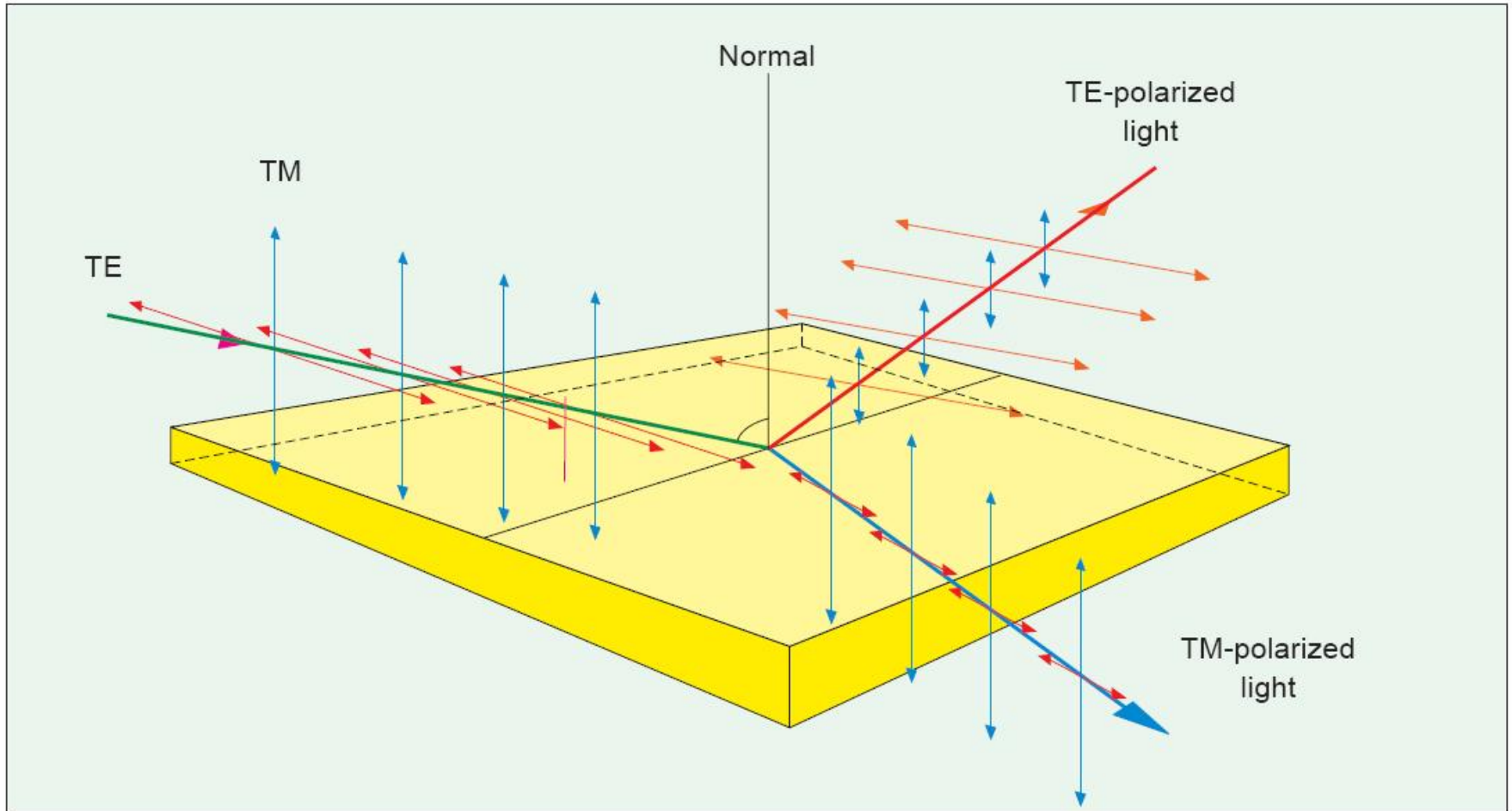
$$\phi_C = \arcsin\left(\frac{n_2}{n_1}\right)$$



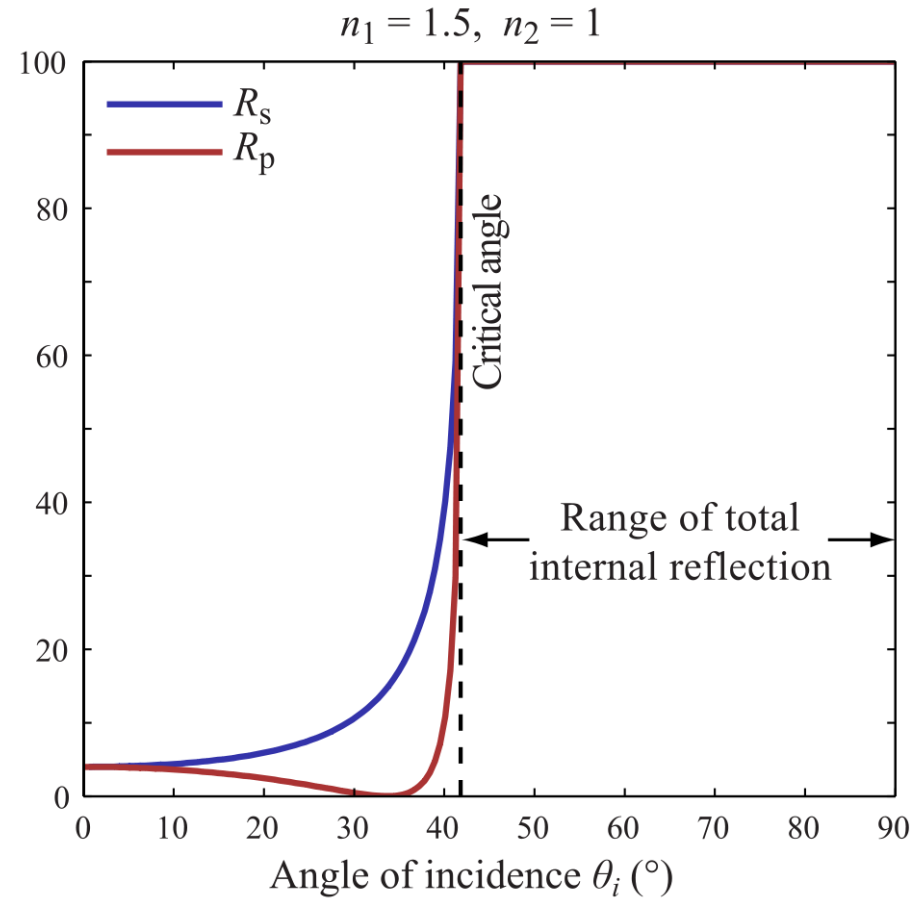
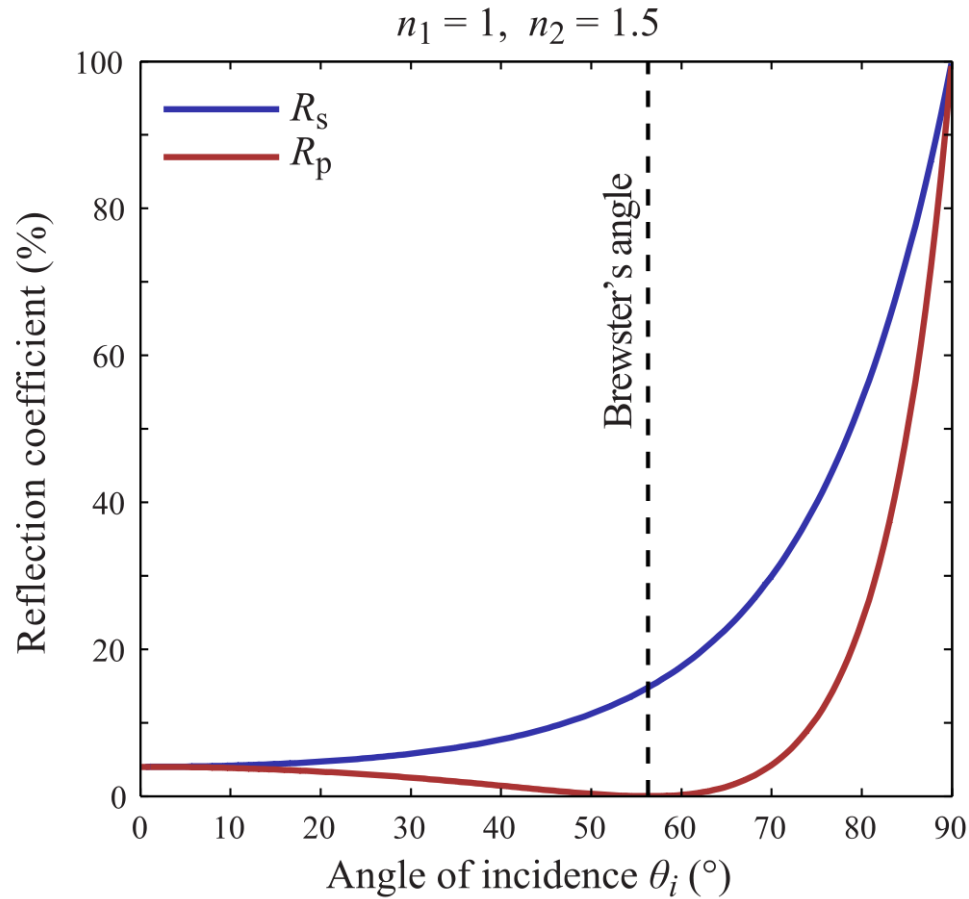
Lumina ca undă electromagnetică

(tot) Capitolul 2

Polarizarea luminii



Unghi Brewster



Introducere

Capitolul 1

Aplicatii majore

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

Continuare



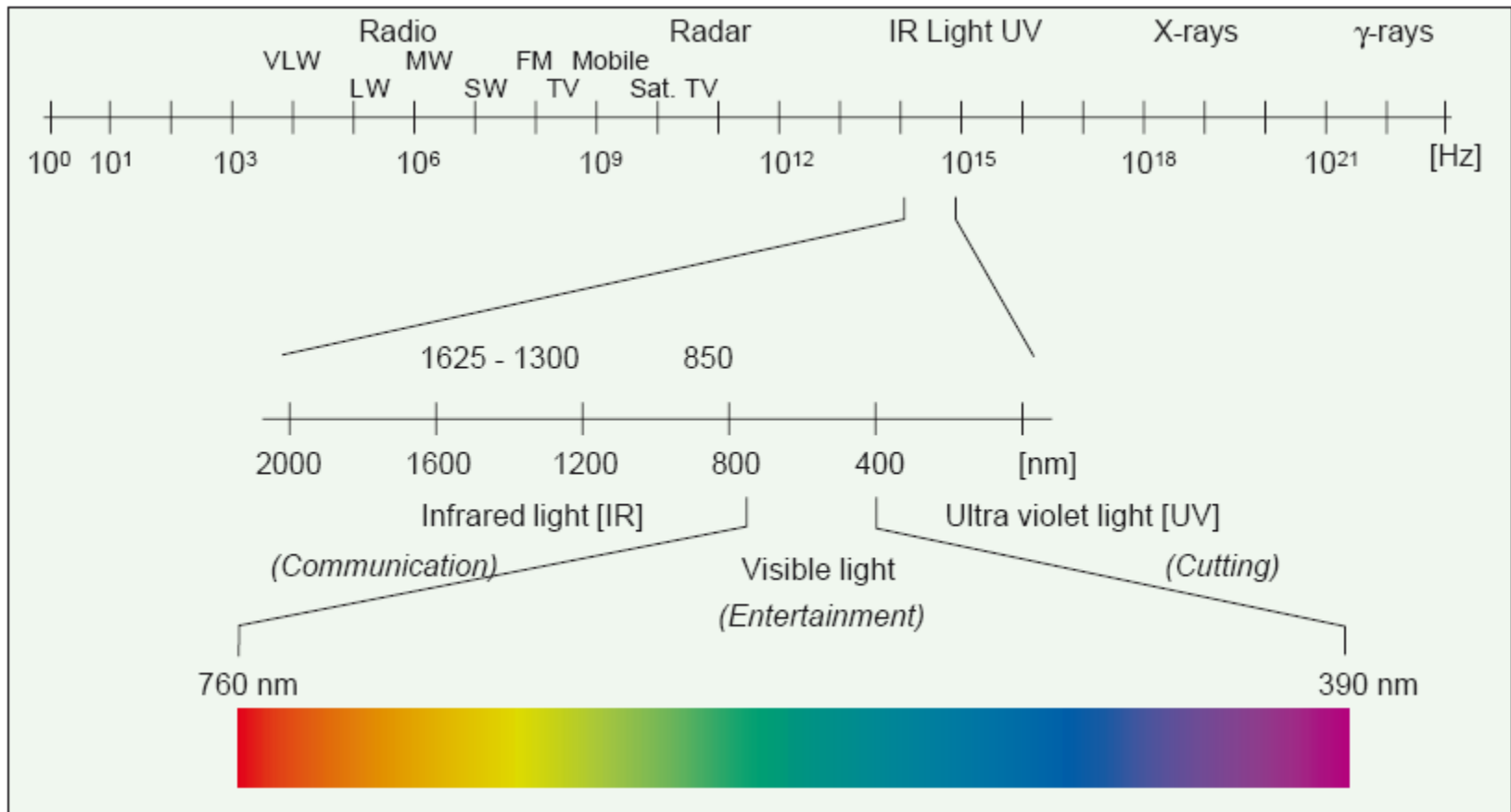
Fotometrie și radiometrie

Capitolul 3

Aplicatii majore

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

Spectrul electromagnetic



O alta dualitate

- ▶ In optoelectronica, lumina poate fi privita din doua puncte de vedere
 - energetic (efect asupra dispozitivului)
 - uman (efect asupra ochiului uman)
- ▶ 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

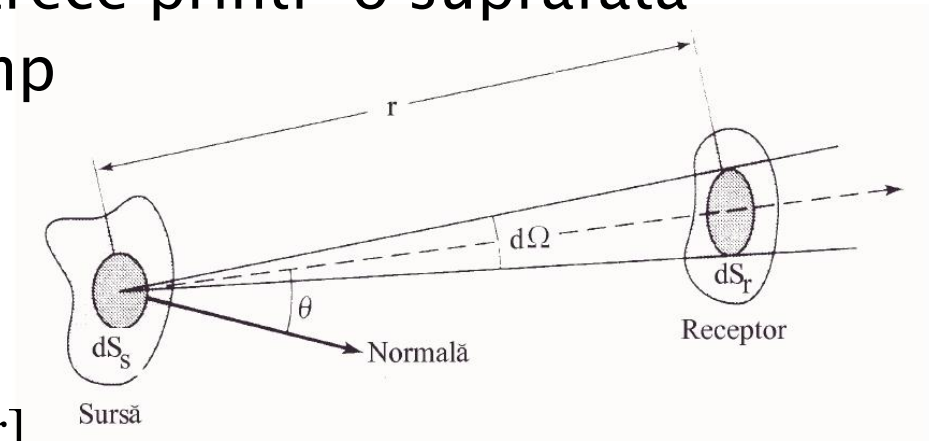
► Flux energetic al luminii

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

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

► Unghi solid

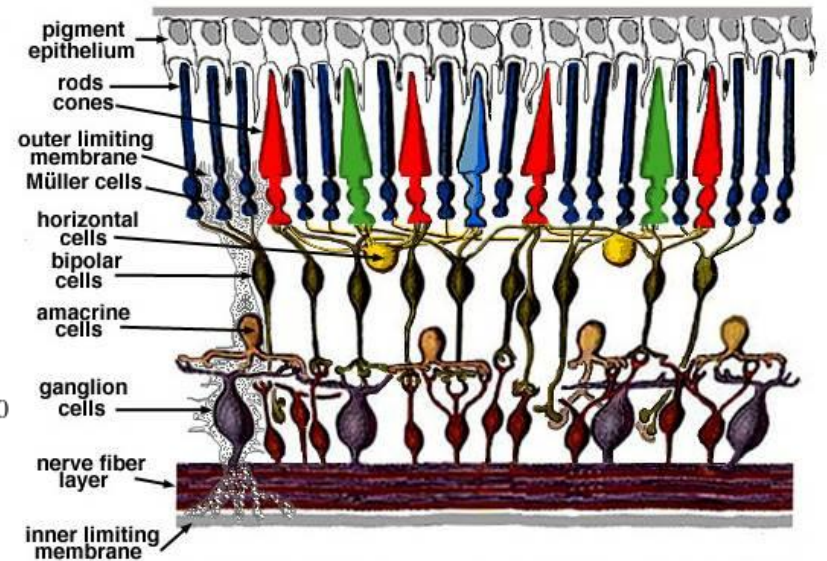
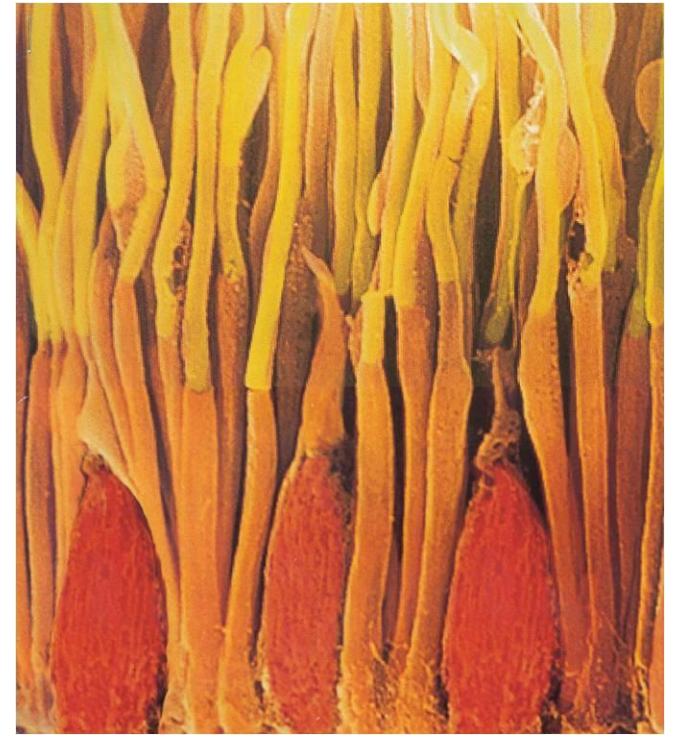
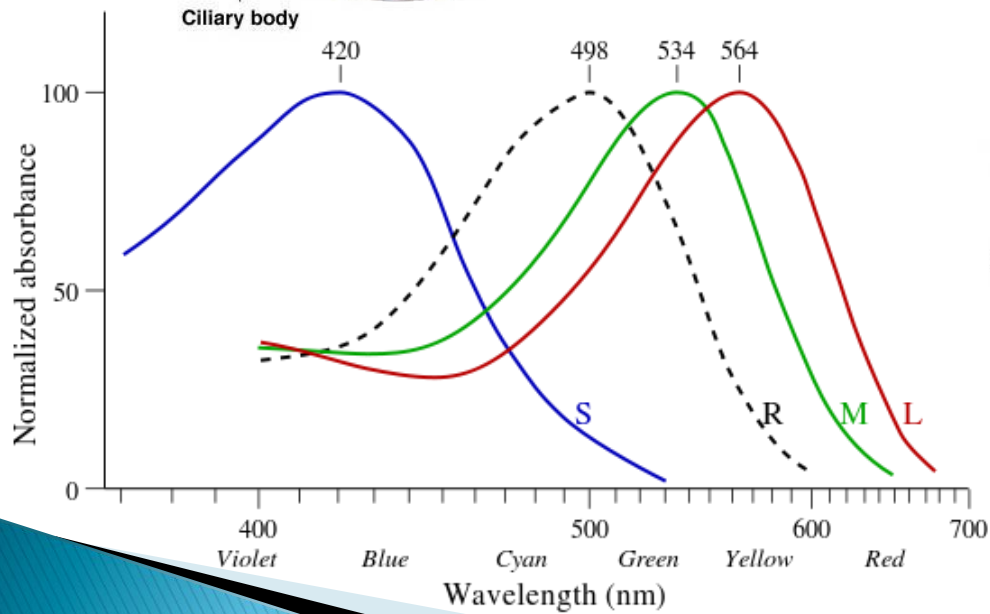
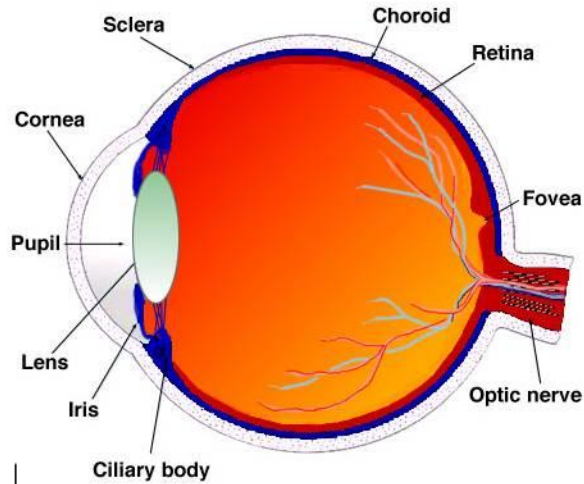
- definitie $\Omega = \frac{A}{r^2} \quad [sr]$
- valoarea maxima, sfera: $\Omega = 4\pi \text{ sr}$
- pentru con cu deschiderea la varf 2ϕ : $\Omega = 2\pi \cdot (1 - \cos \phi)$
- pentru unghiuri mici: $\Omega = \pi \cdot \phi^2$



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

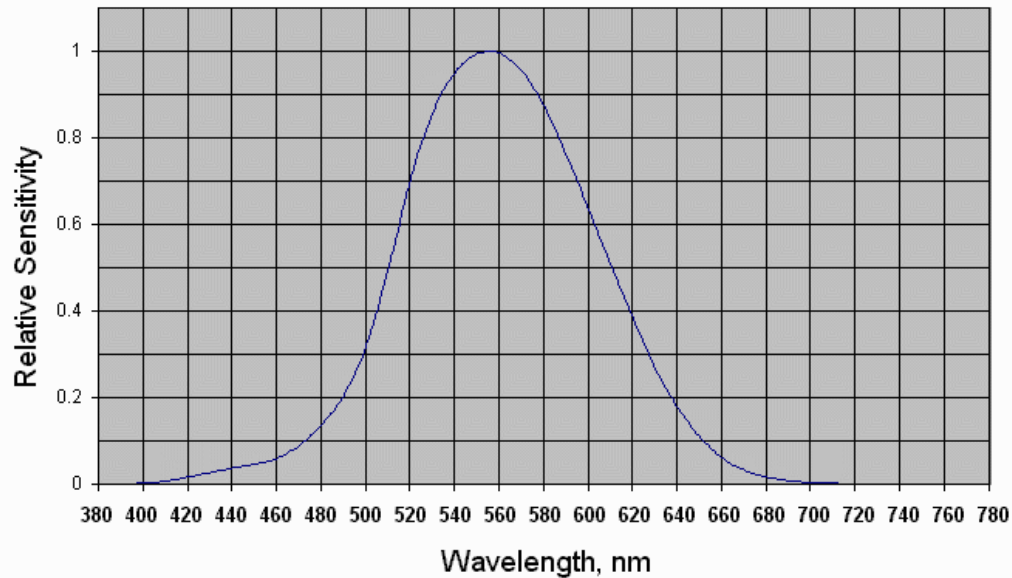
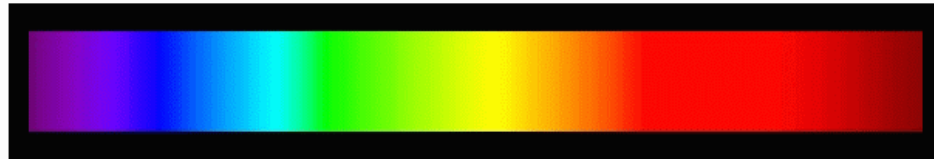
Ochiul uman



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)

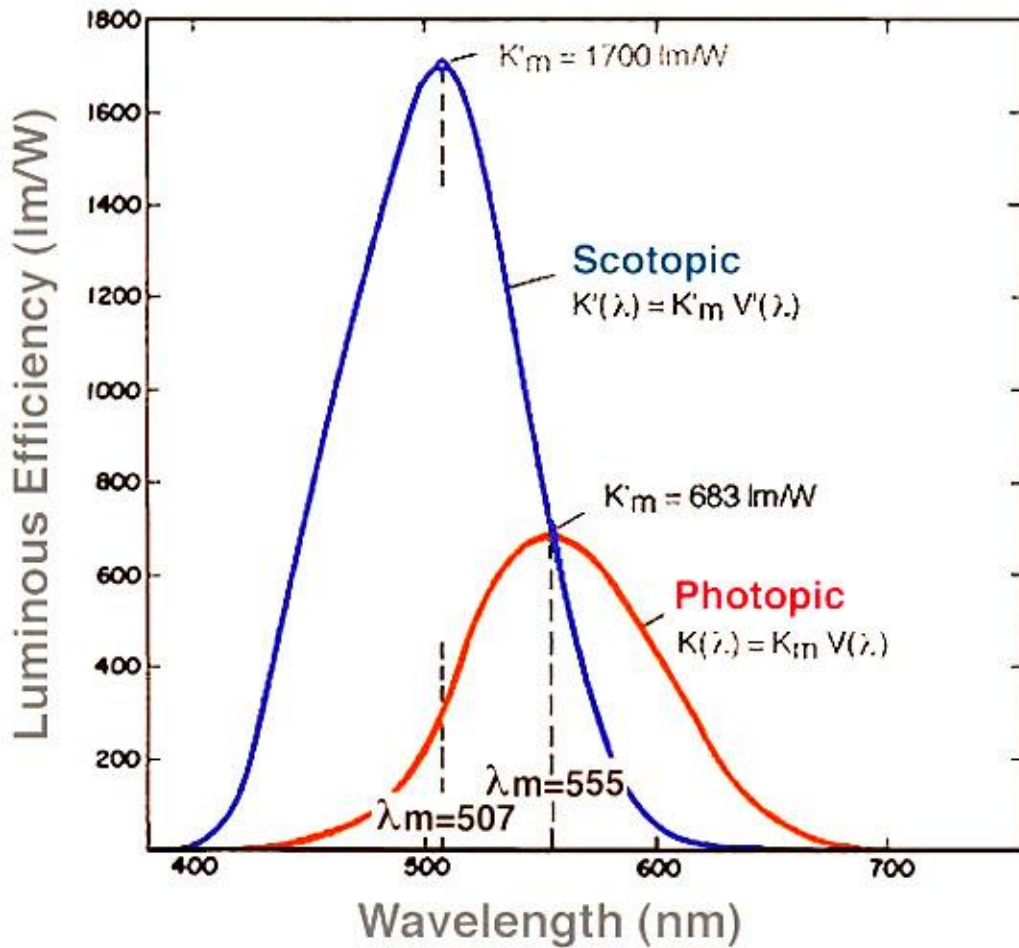


Figure 9. The scotopic and the photopic curves of spectral luminous efficacy (non-normalised values).

efect Purkinje

Curbe normalizate CIE

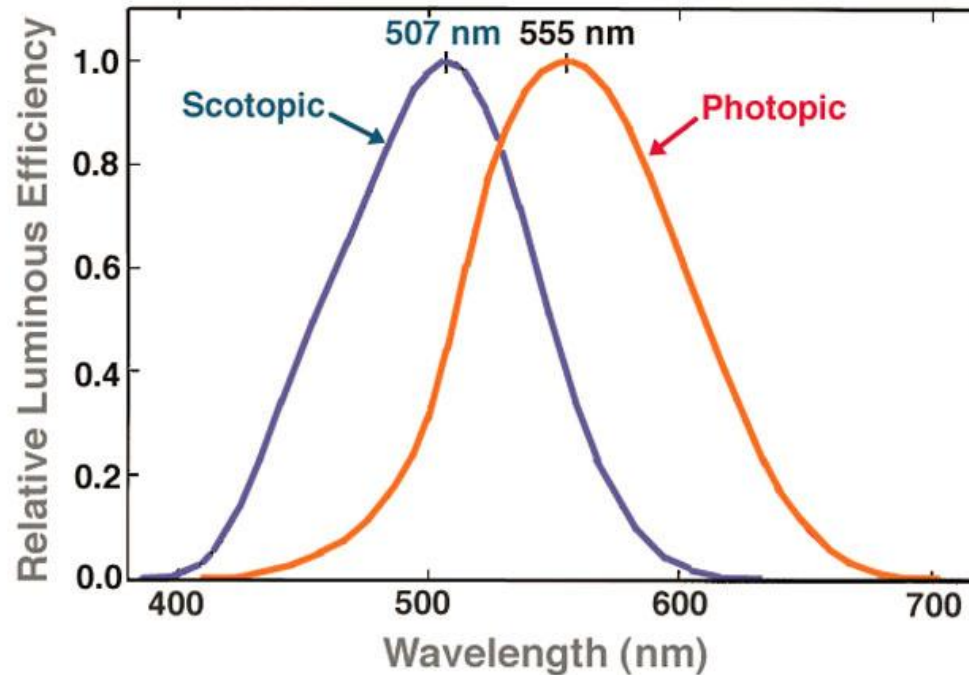


Figure 10. The scotopic and the photopic curves of relative spectral luminous efficiency as specified by the CIE (normalised values).

CIE $V(\lambda)$

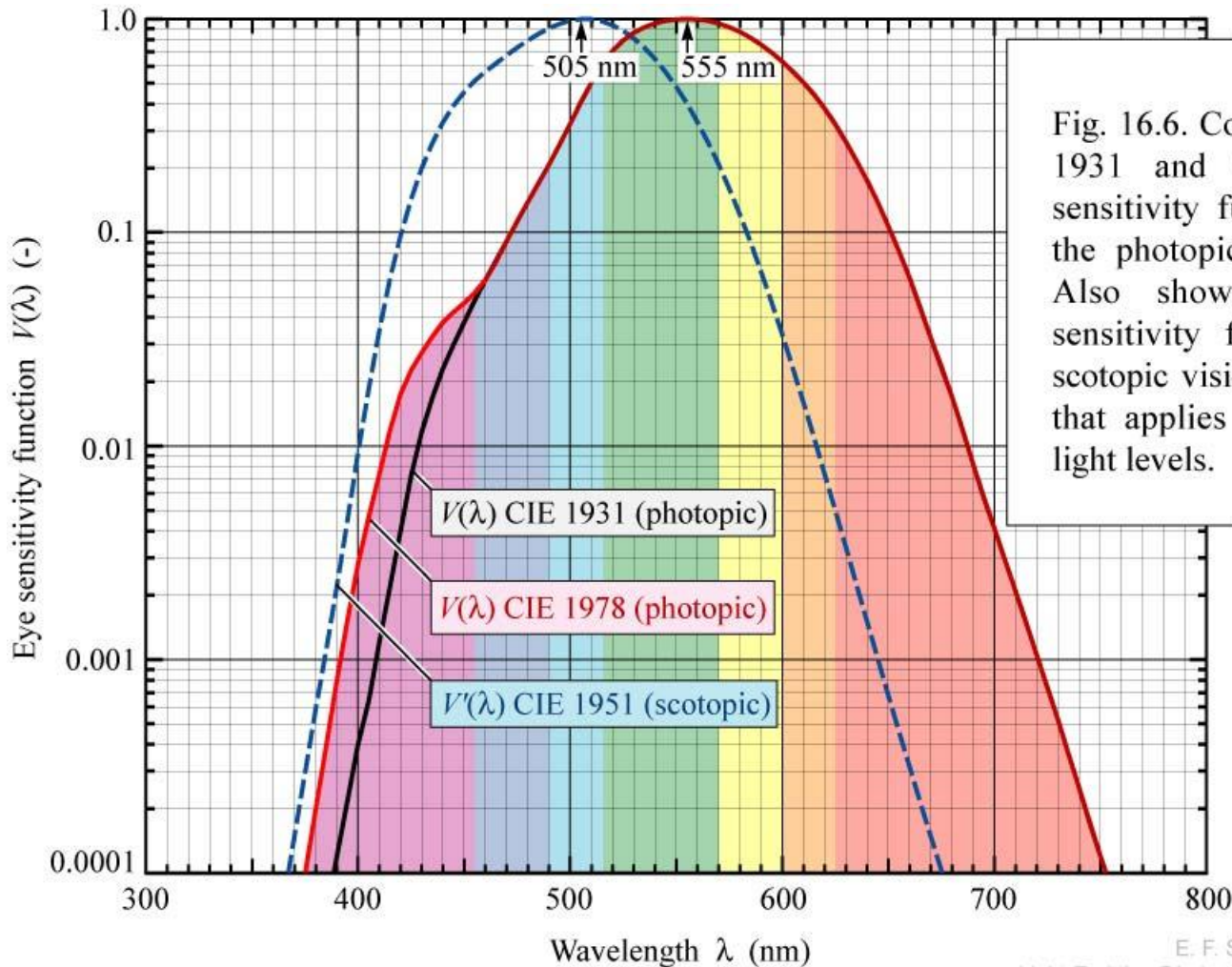
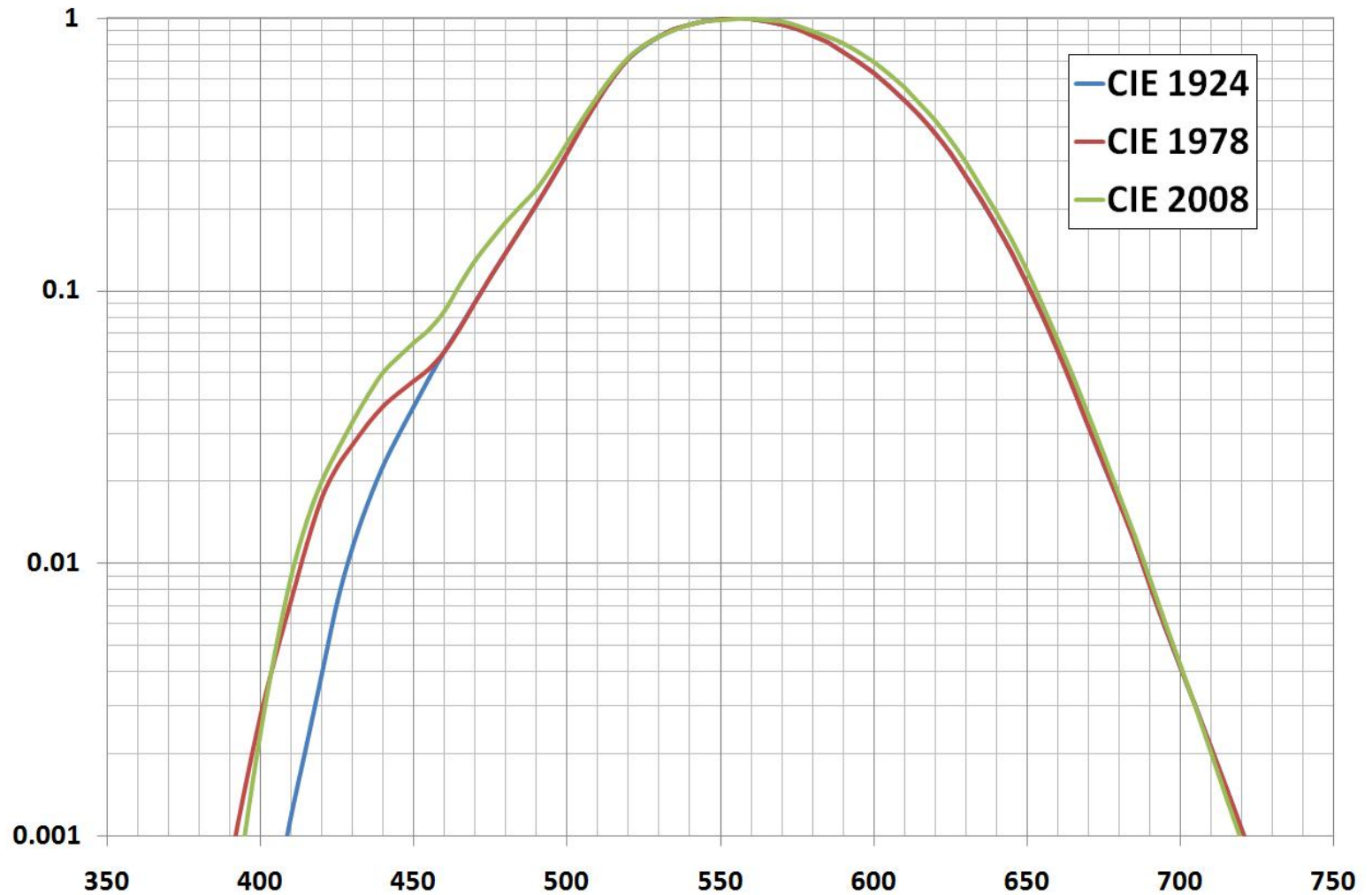
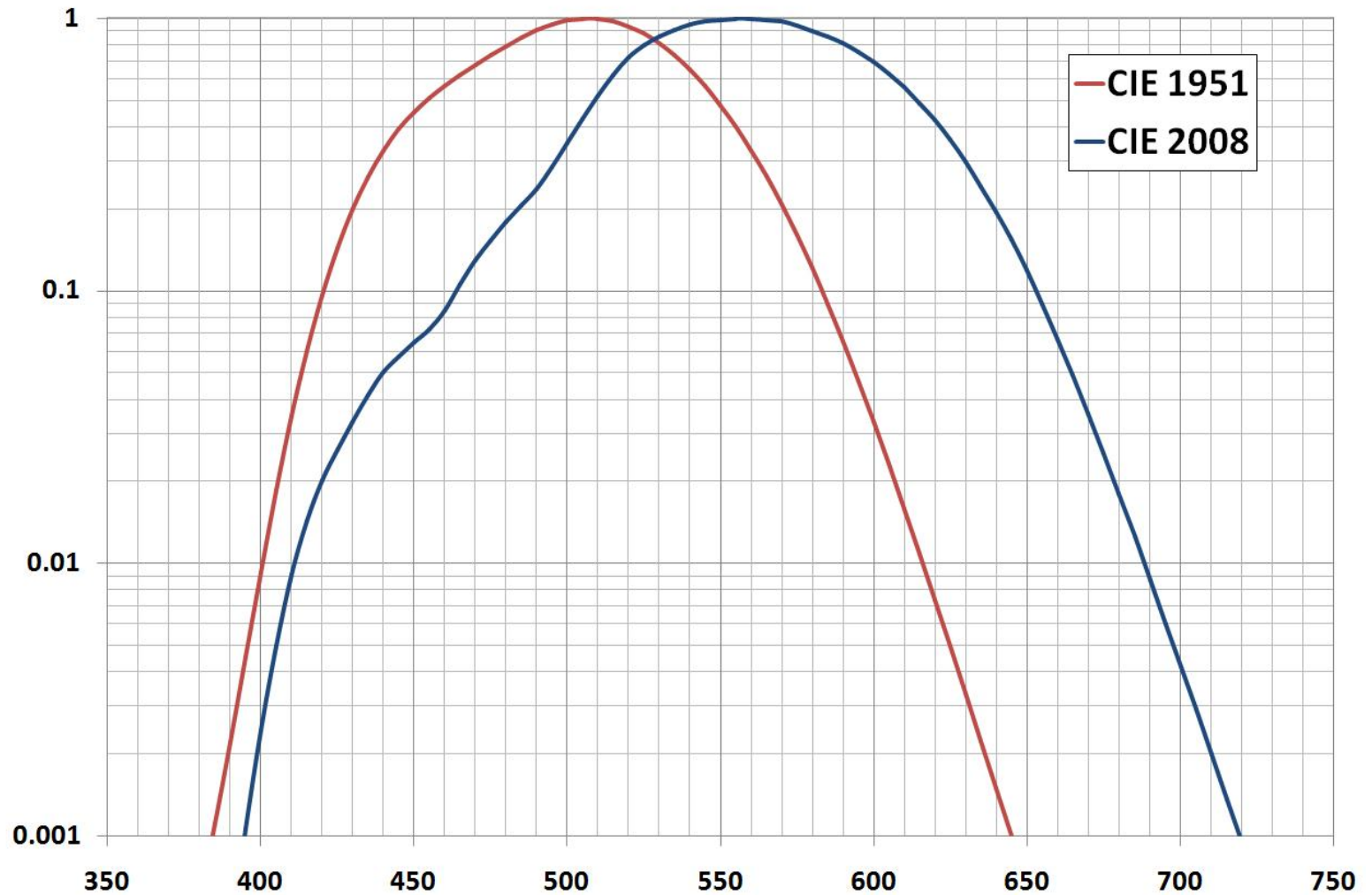


Fig. 16.6. Comparison of CIE 1931 and CIE 1978 eye sensitivity function $V(\lambda)$ for the photopic vision regime. Also shown is the eye sensitivity function for the scotopic vision regime, $V'(\lambda)$, that applies to low ambient light levels.

CIE $V(\lambda)$ fotopic



CIE $V(\lambda)$ fopic / scotopic



Sensibilitate luminoasa $V(\lambda)$

	λ	fotopic CIE 1924	fotopic CIE 2008	scotopic 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(λ) 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 μ)	Facteur de Visibilité relative(m μ)	Longueur d'onde	Facteur de Visibilité relative	Longueur d'onde (m μ)	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:

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

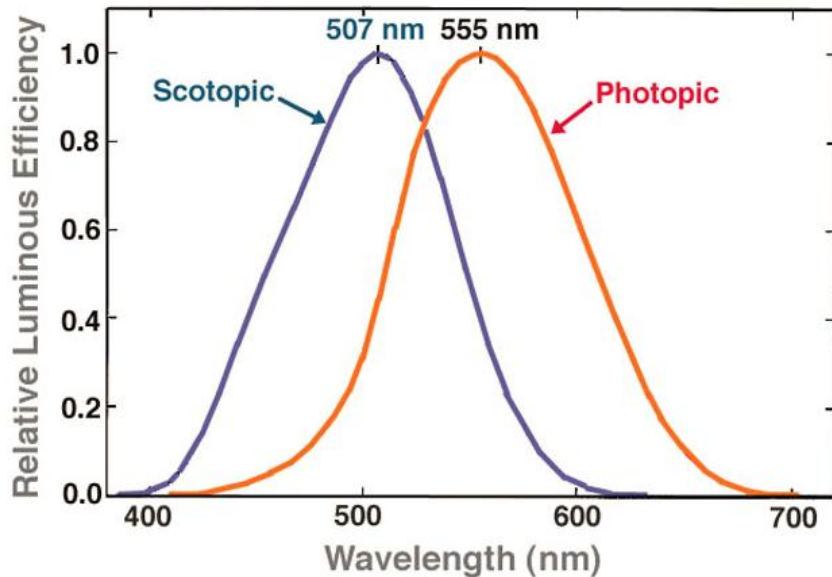
$$\Phi'_v = 1700 \frac{lm}{W} \int_0^{\infty} \frac{d\Phi_e}{d\lambda} \cdot V'(\lambda) d\lambda = 1700 \frac{lm}{W} \int_{390nm}^{830nm} \frac{d\Phi_e}{d\lambda} \cdot V'(\lambda) d\lambda \quad [lm]$$

- ▶ De cele mai multe ori, sursele sunt discrete, λ_i

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

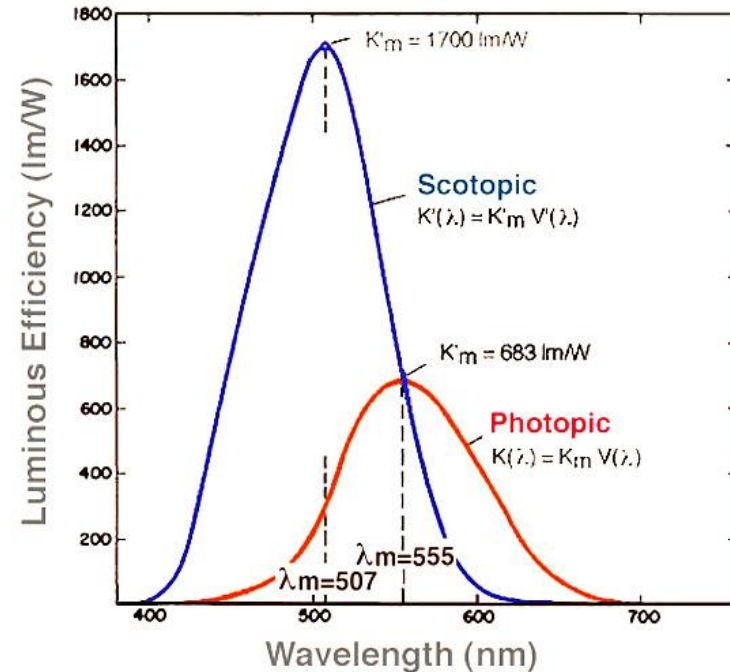
$$\Phi'_v = 1700 \frac{lm}{W} \cdot \sum_i \Phi_e(\lambda_i) \cdot V'(\lambda_i) \quad [lm]$$

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 relativa

Eficiența luminoasă, η_v [lm/W]

	λ	fotopic CIE 1924	Sharpe 2005	scotopic 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

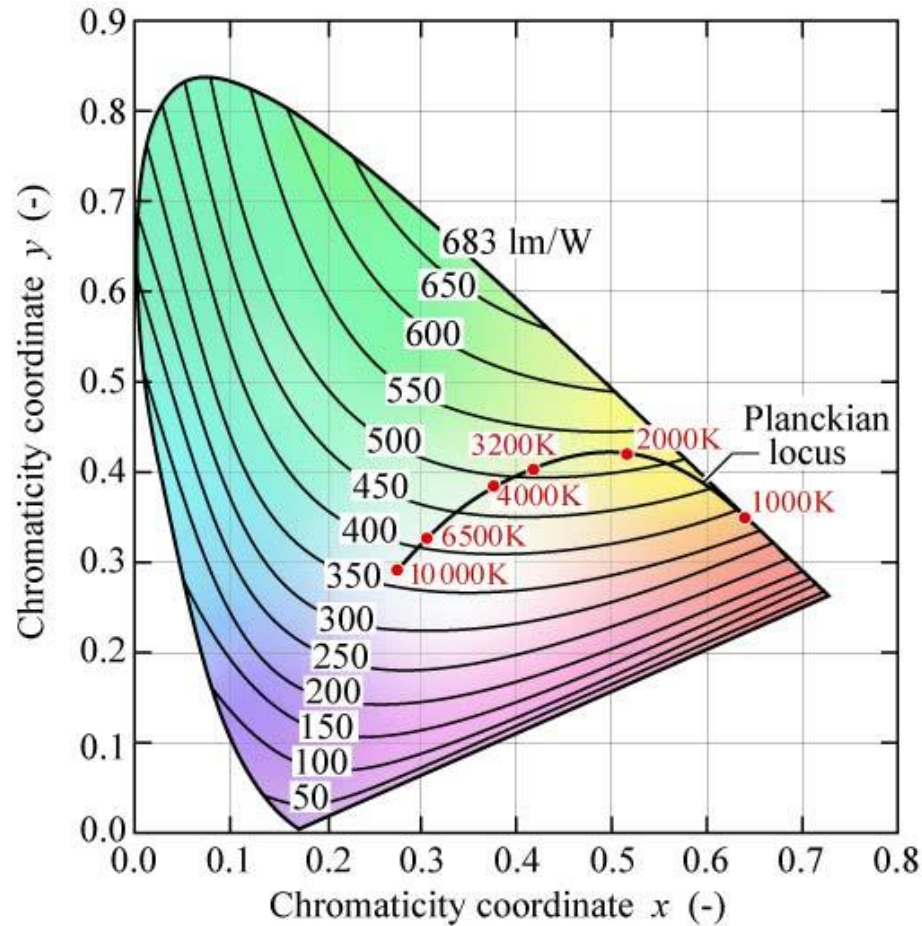
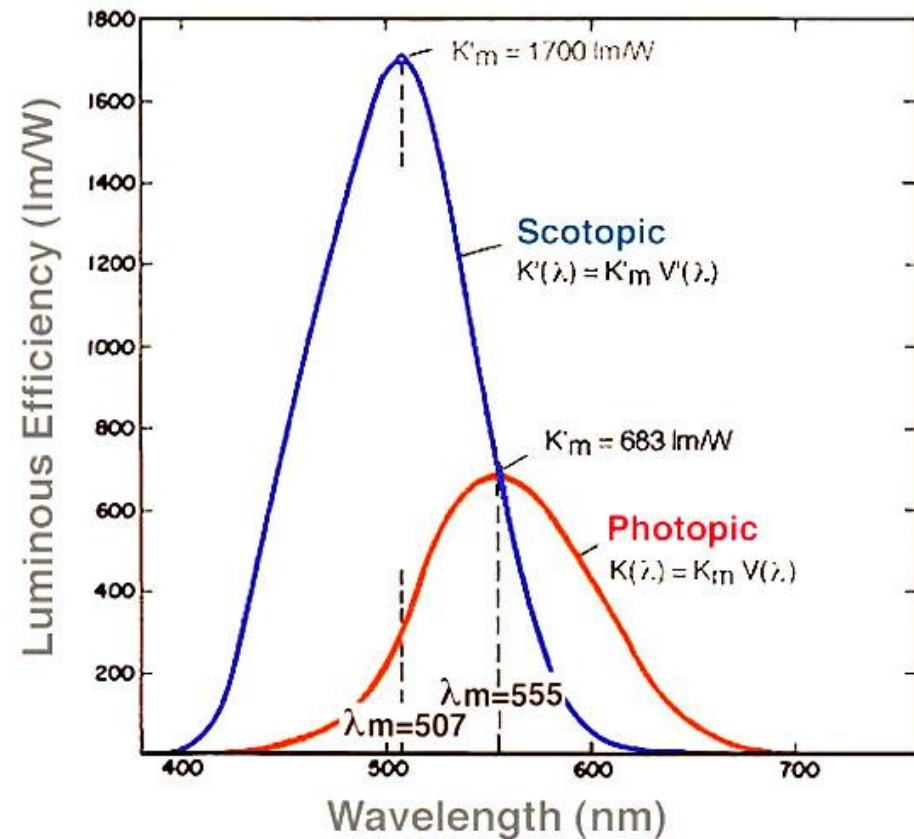
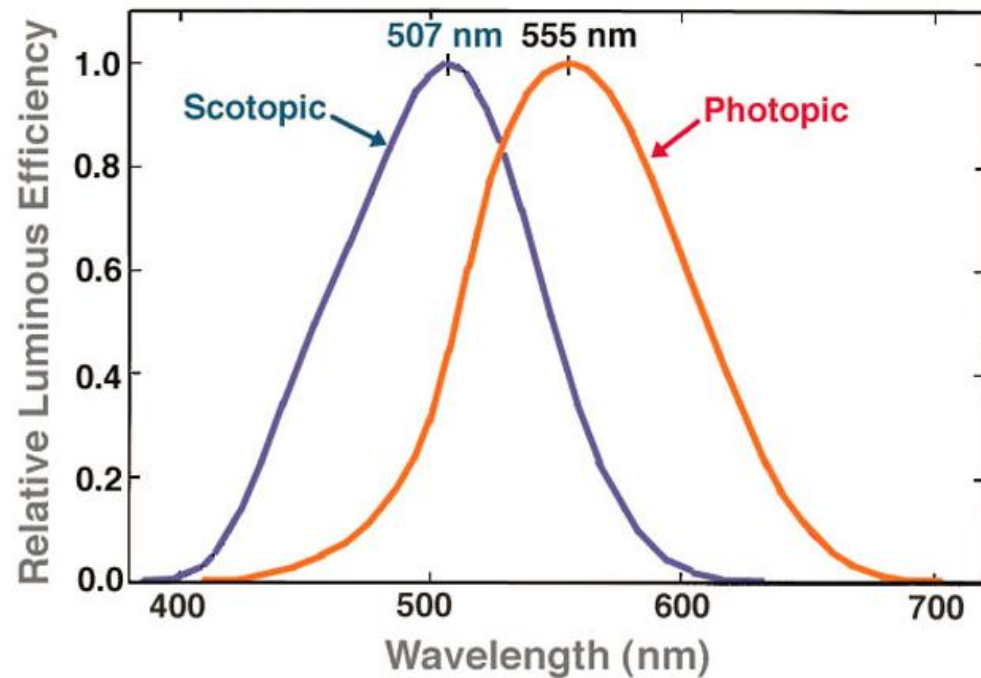


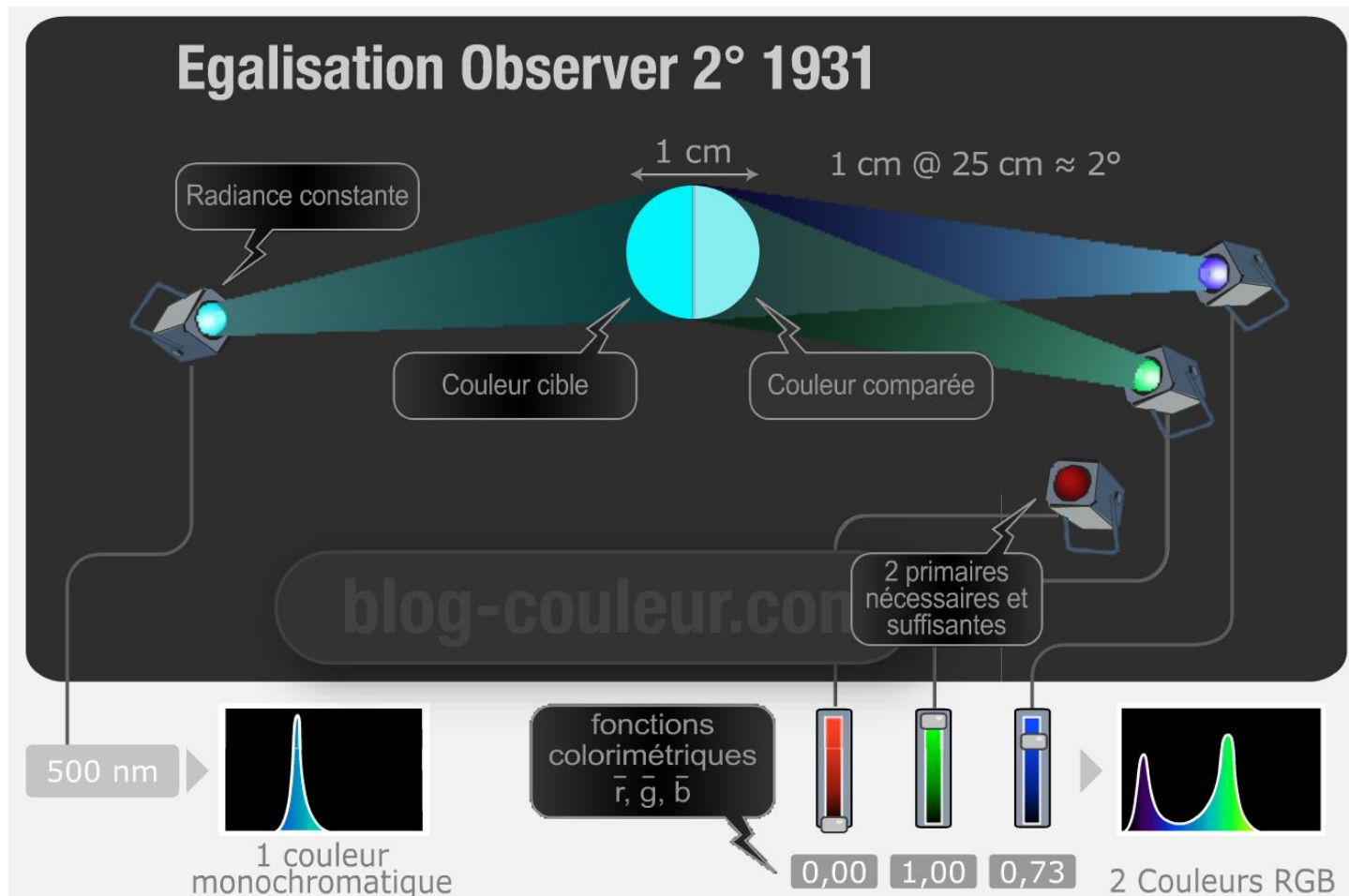
Fig. 16.8. Relation of maximum possible luminous efficacy (lumens per optical Watt) and chromaticity in the CIE 1931 x, y chromaticity diagram (adopted from MacAdam, 1950).

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

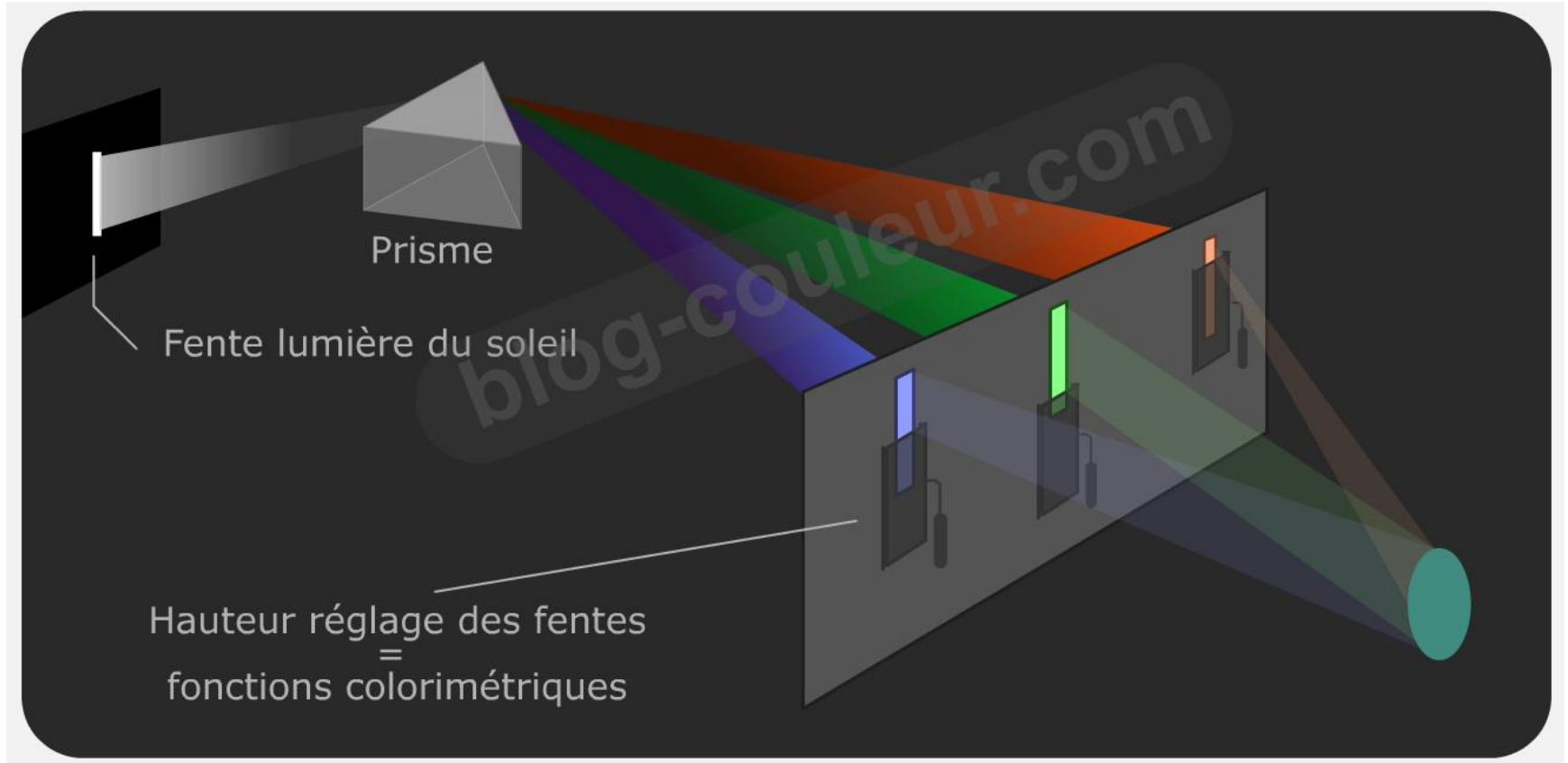
Relatie radiometrie/fotometrie



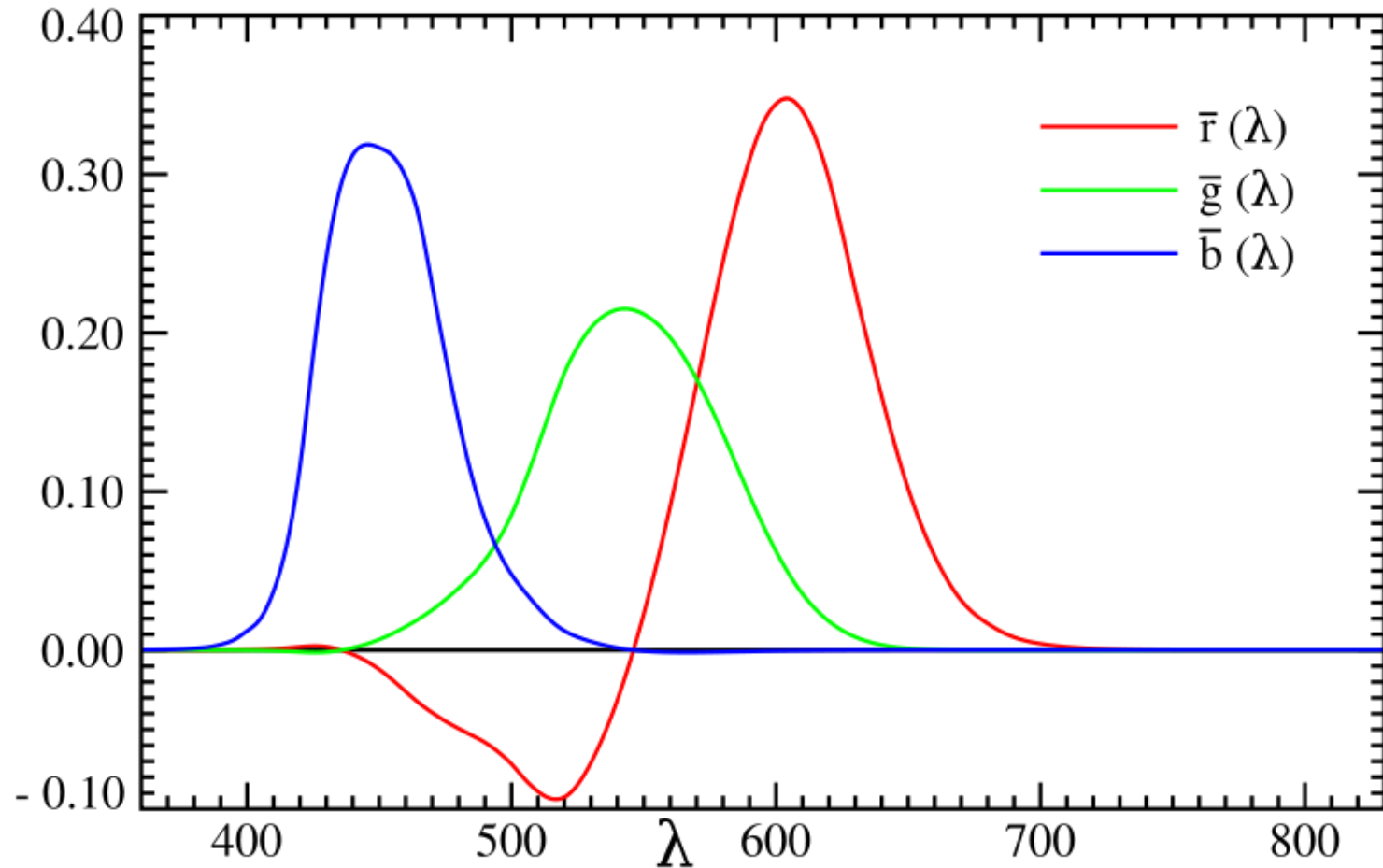
CIE xyz 1931



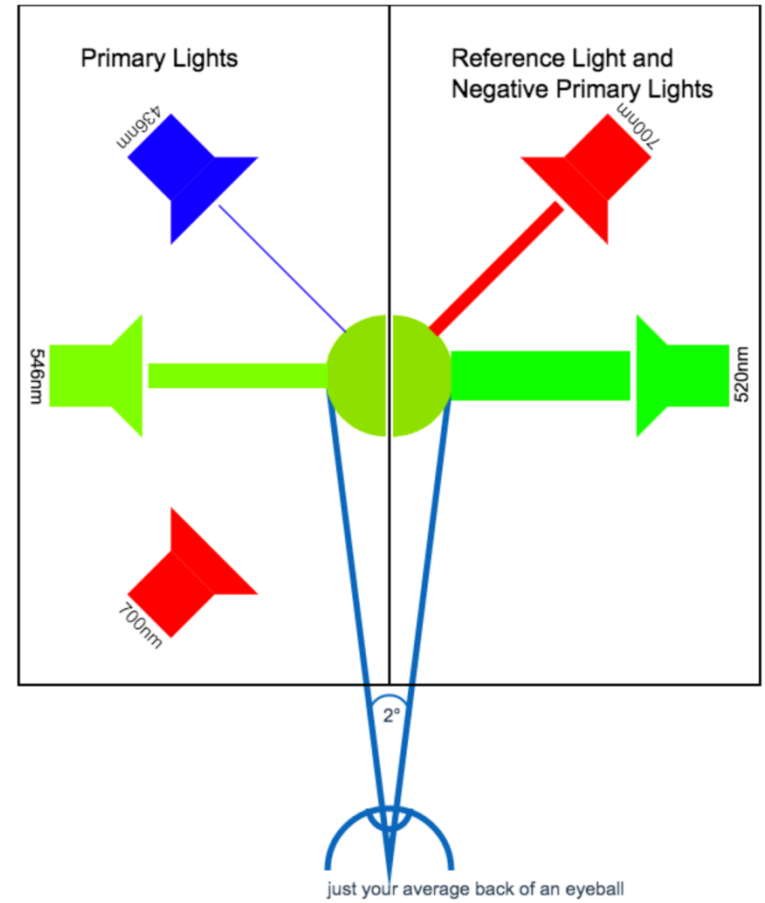
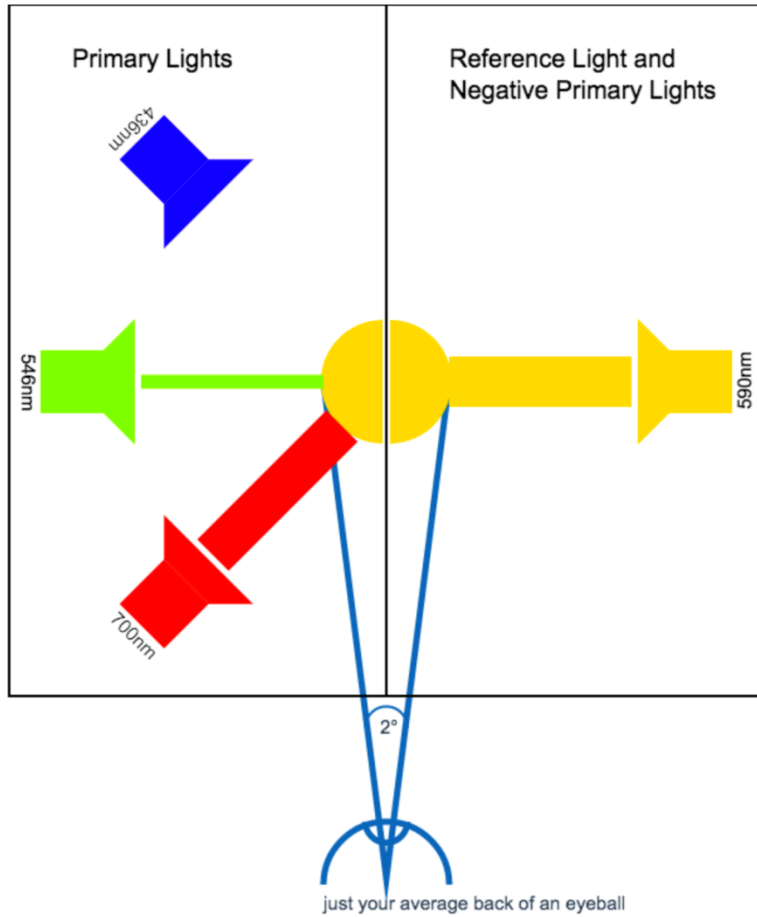
CIE xyz 1931



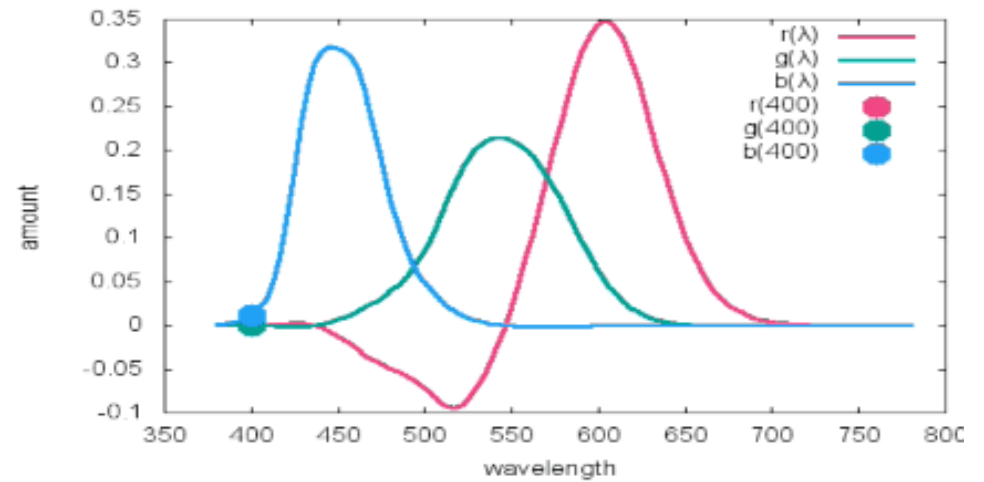
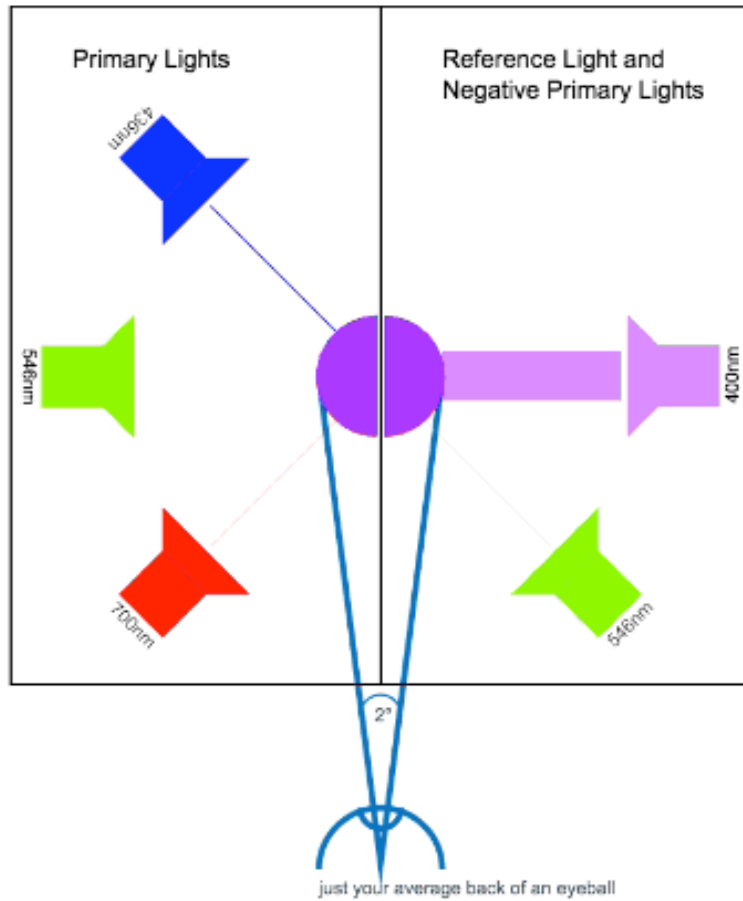
Cantitatea din culorile primare pentru aceeași senzație de culoare



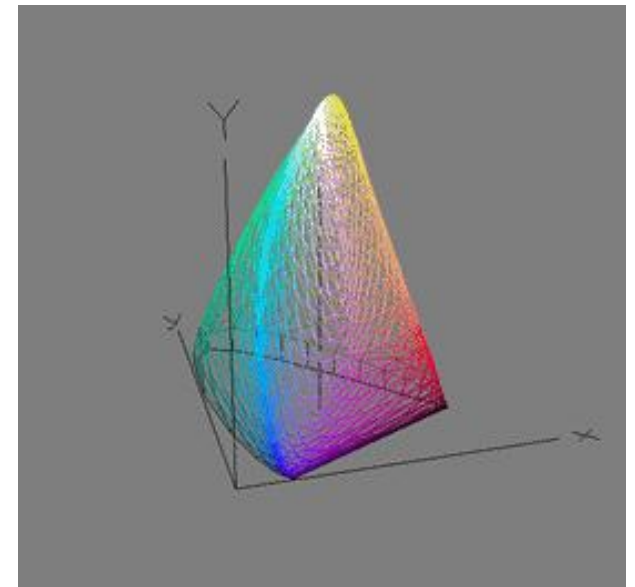
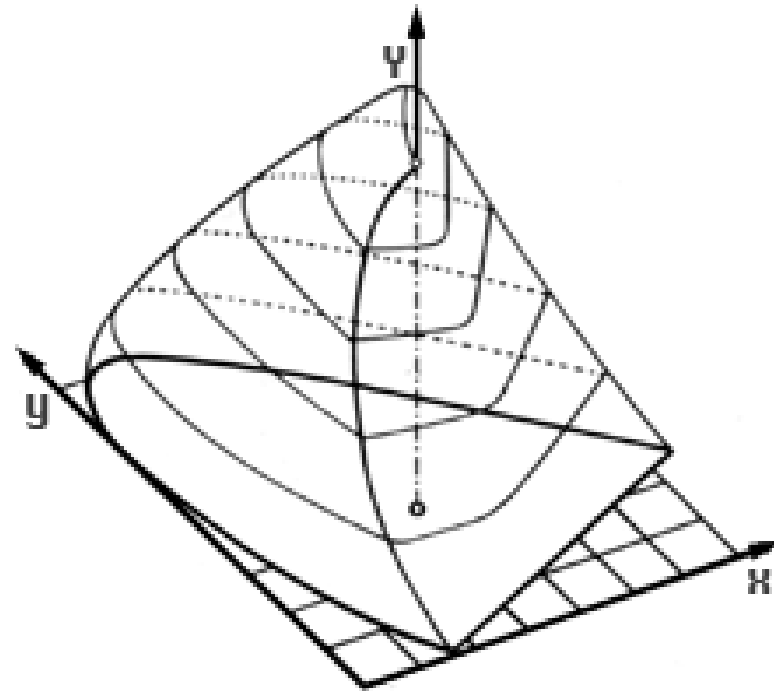
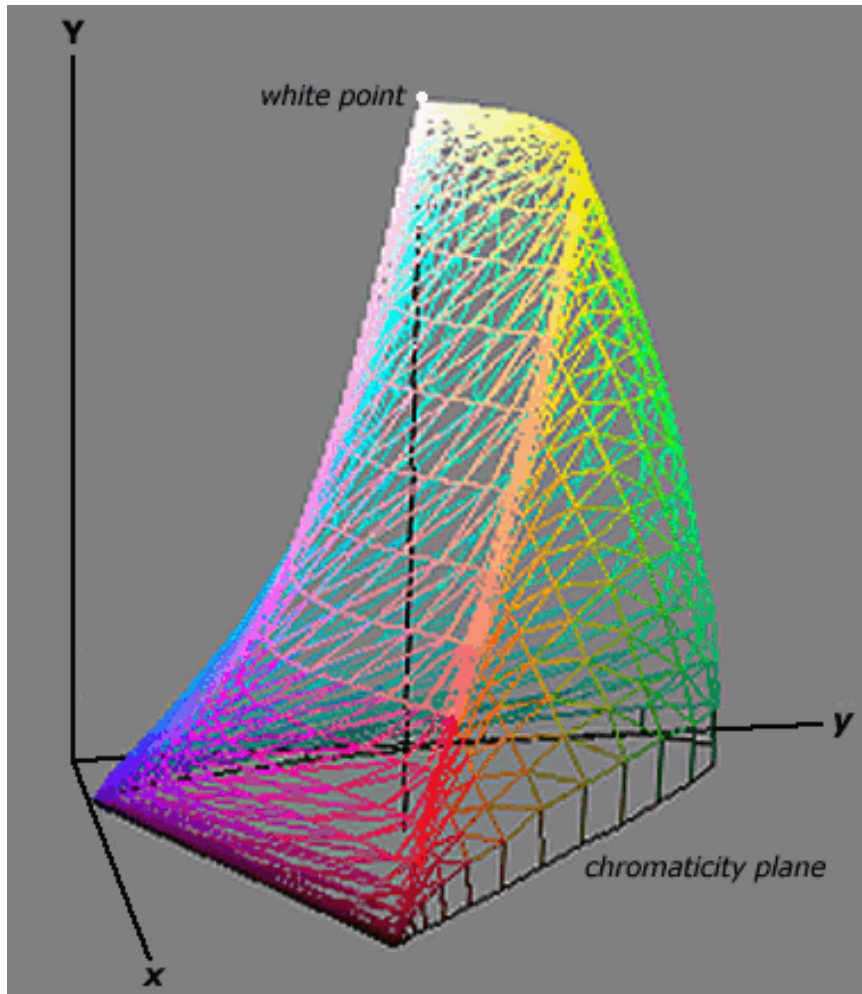
CIE xyz1931



CIE 1931

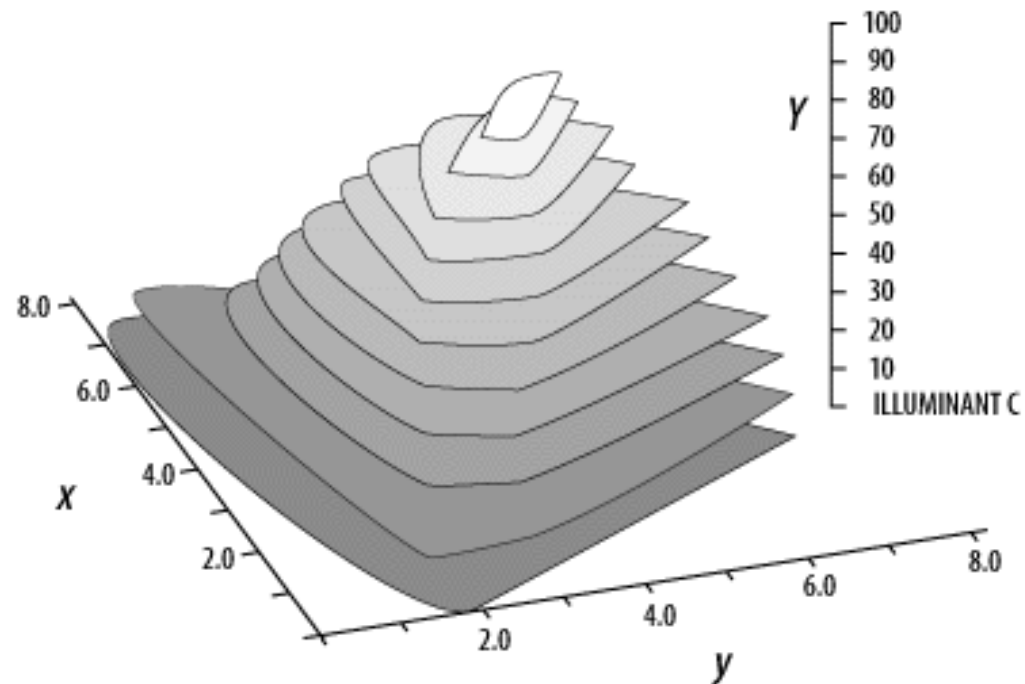


CIE xyz 1931

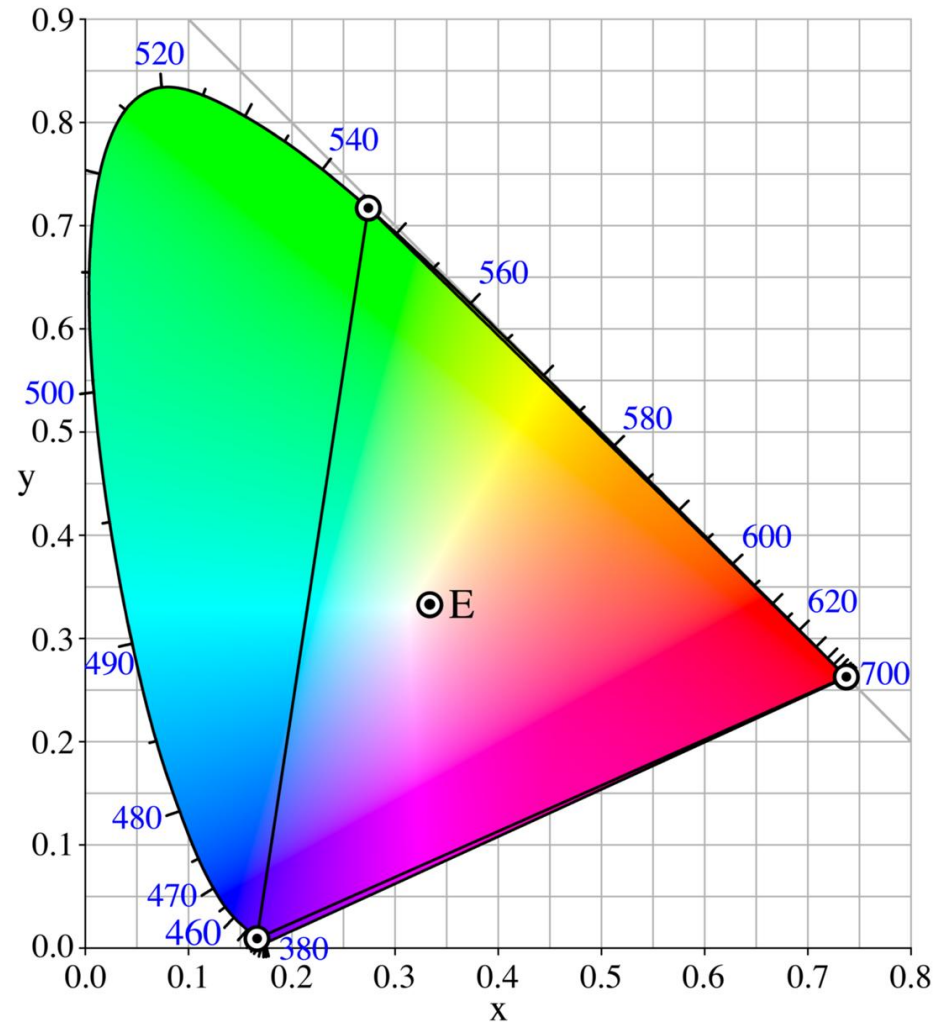
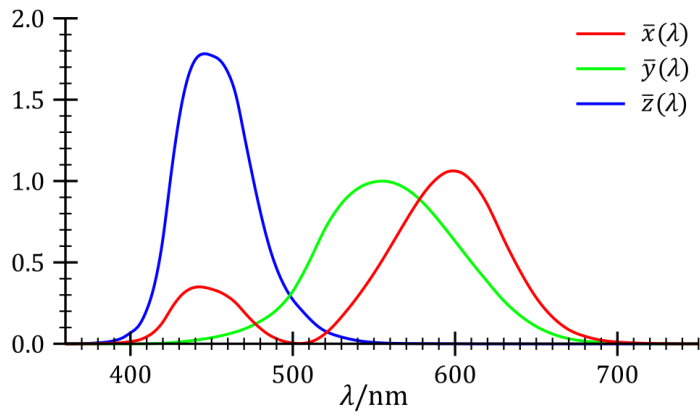


CIE xyz 1931

- ▶ 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

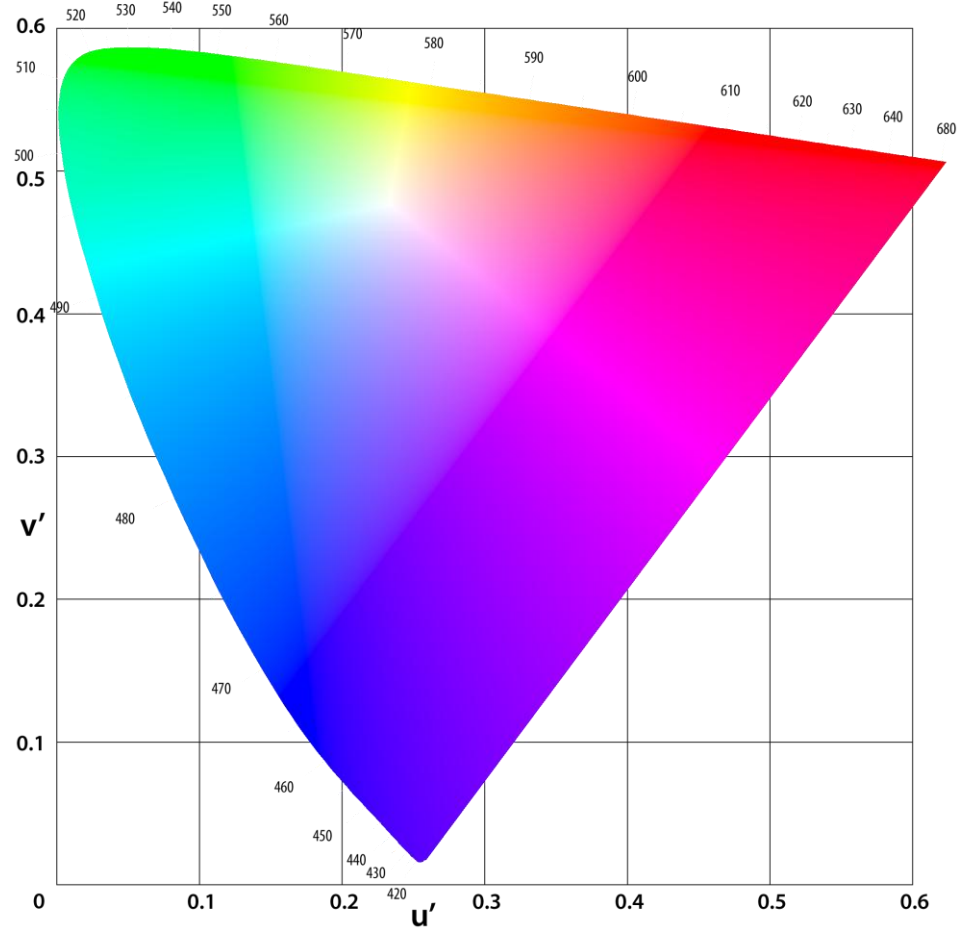


CIE xy 1931



CIELUV 1976

- ▶ uniformitatea percepției, a "diferenței de culoare"



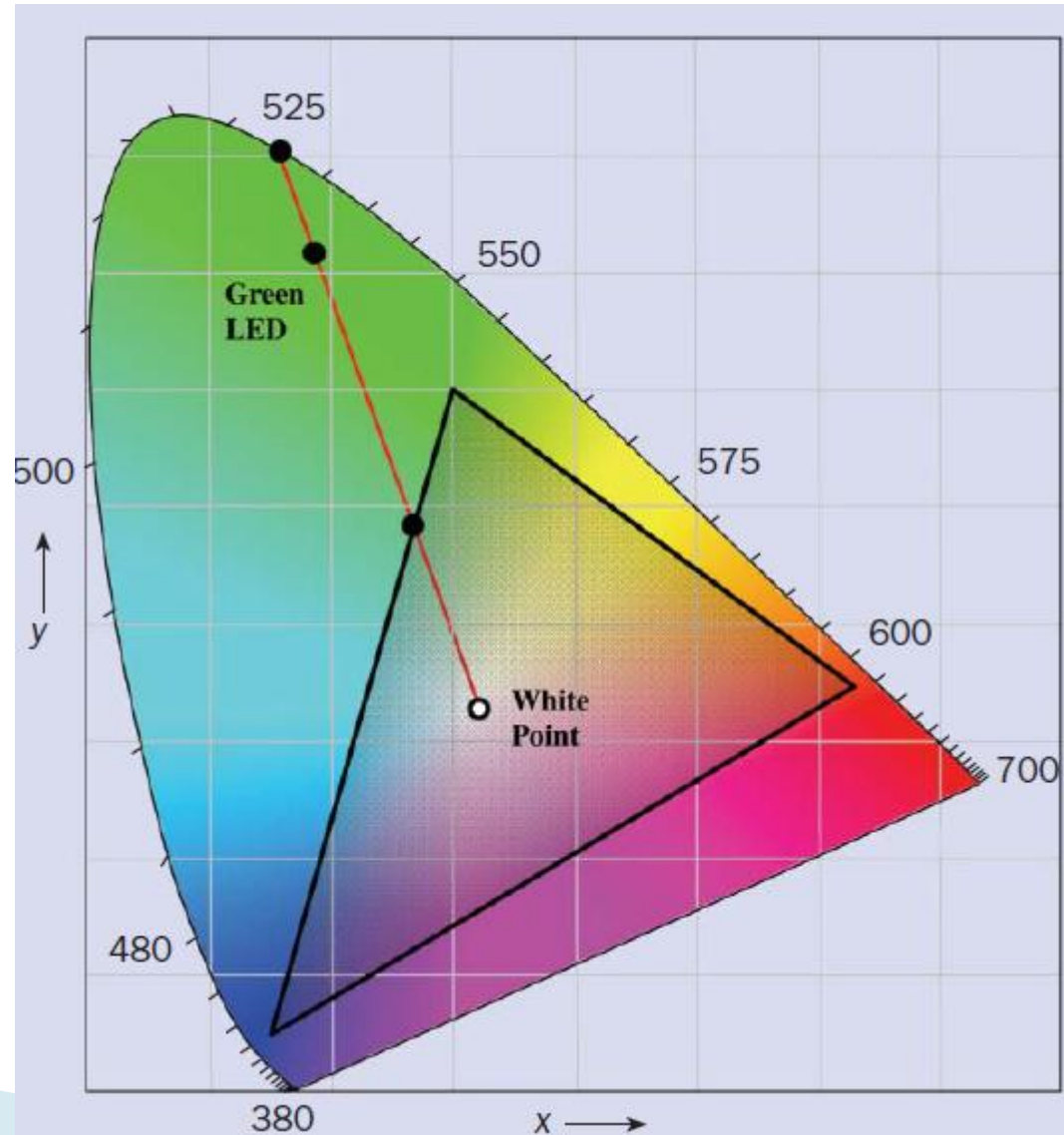
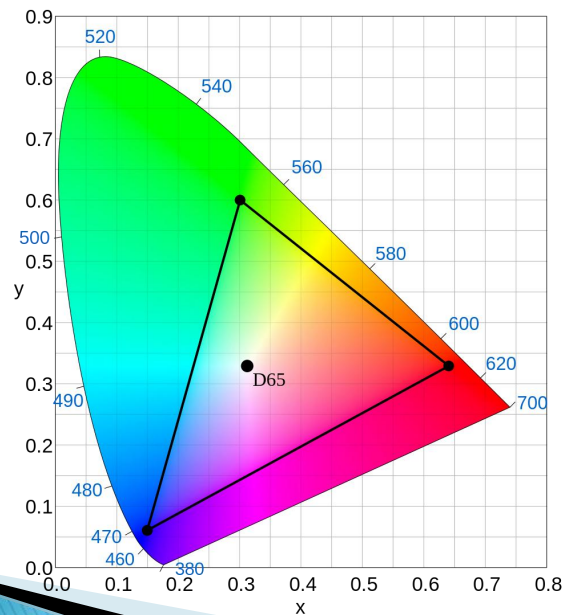
ITU-R BT.709



ITU-R BT.709 phosphor properties

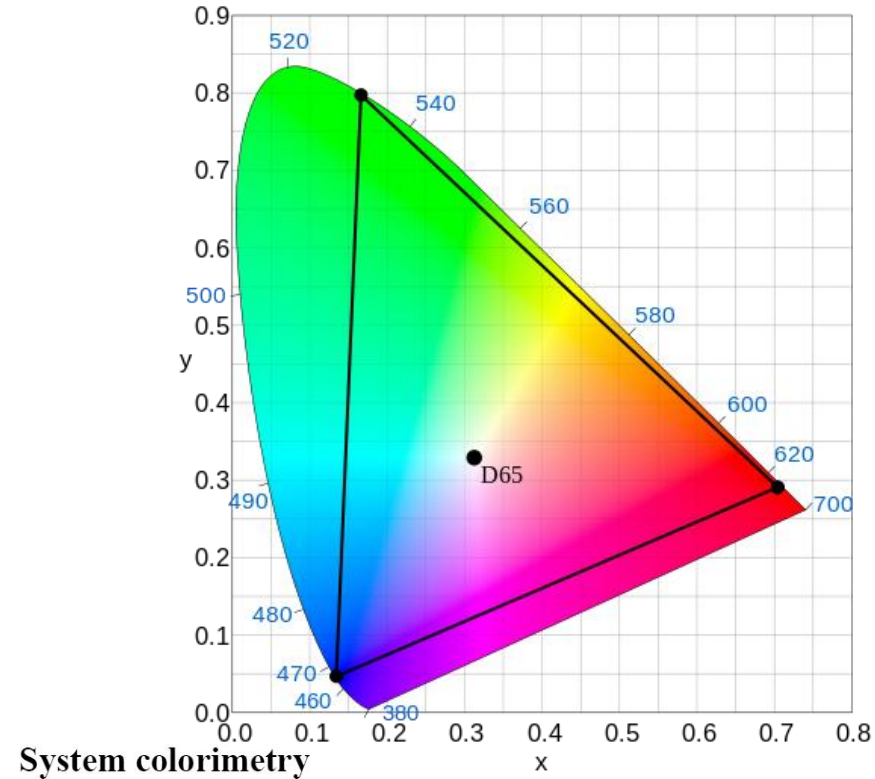
Phosphor	x	y
Red	0.640	0.330
Green	0.300	0.600
Blue	0.150	0.060

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

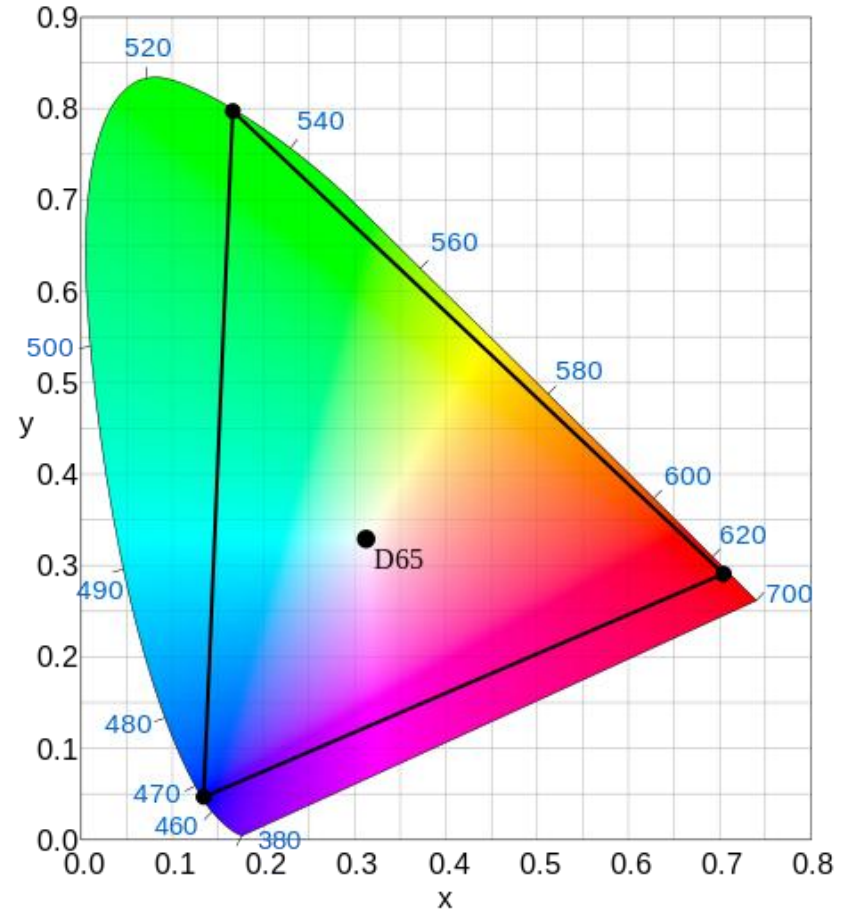
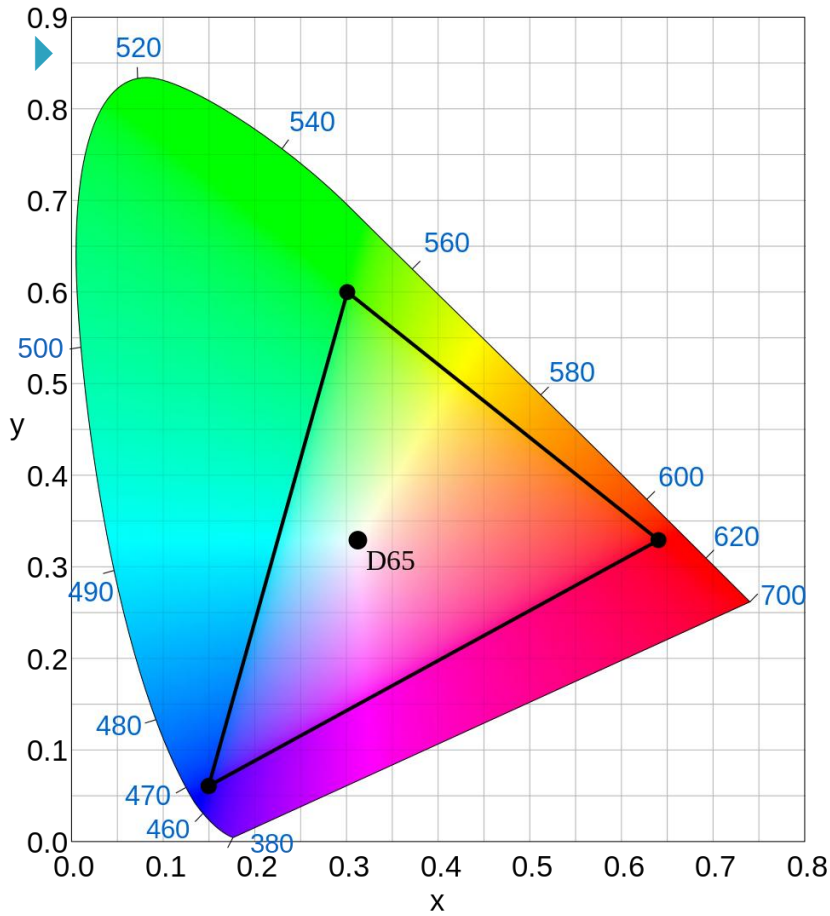
- ▶ Parameter values for ultra-high definition television systems
- ▶ UHDTV



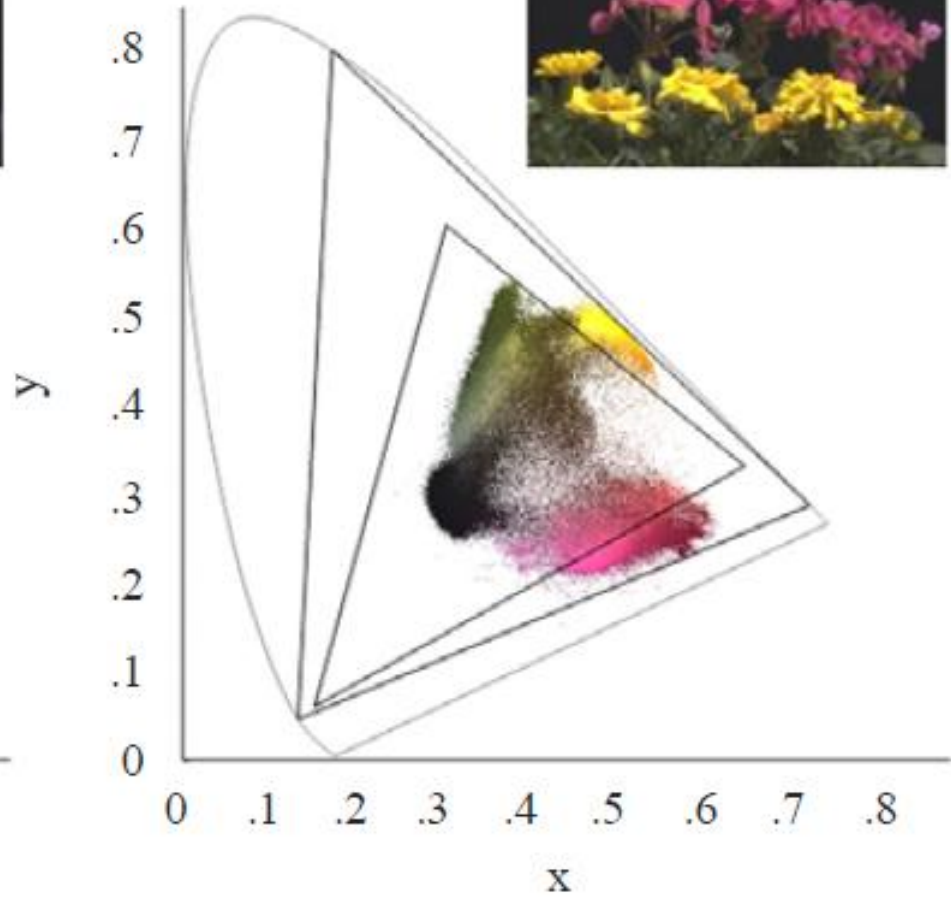
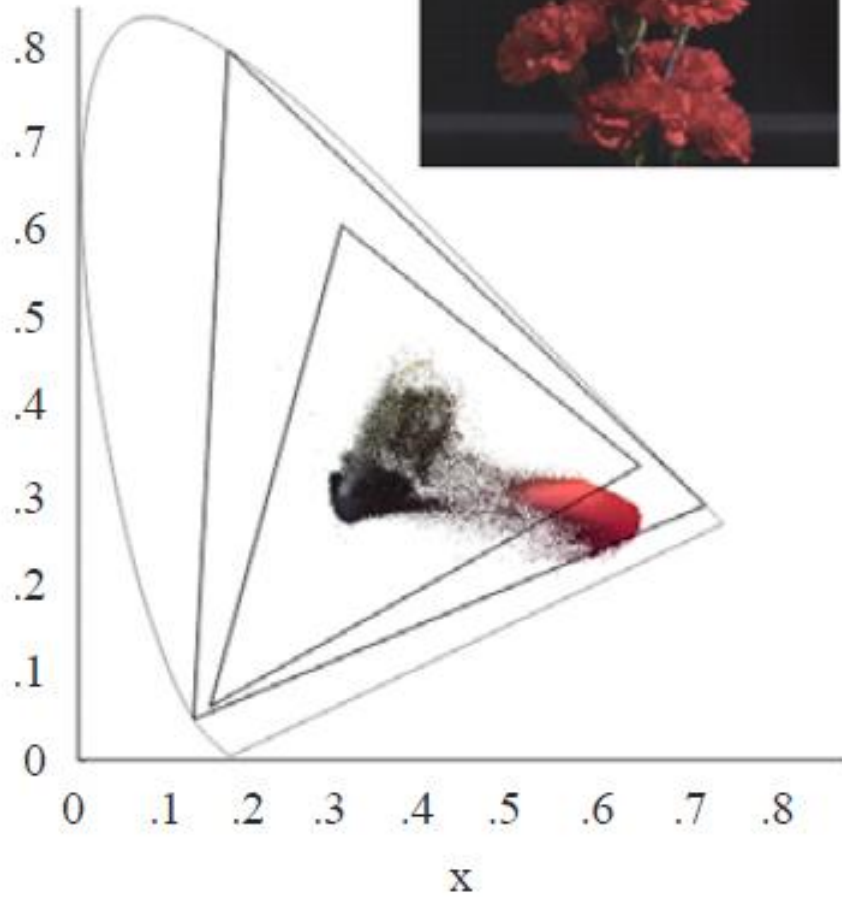
Parameter	Values		
Opto-electronic transfer characteristics before non-linear pre-correction	Assumed linear ⁽¹⁾		
Primary colours and reference white ⁽²⁾	Chromaticity coordinates (CIE, 1931)	x	y
	Red primary (R)	0.708	0.292
	Green primary (G)	0.170	0.797
	Blue primary (B)	0.131	0.046
	Reference white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

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

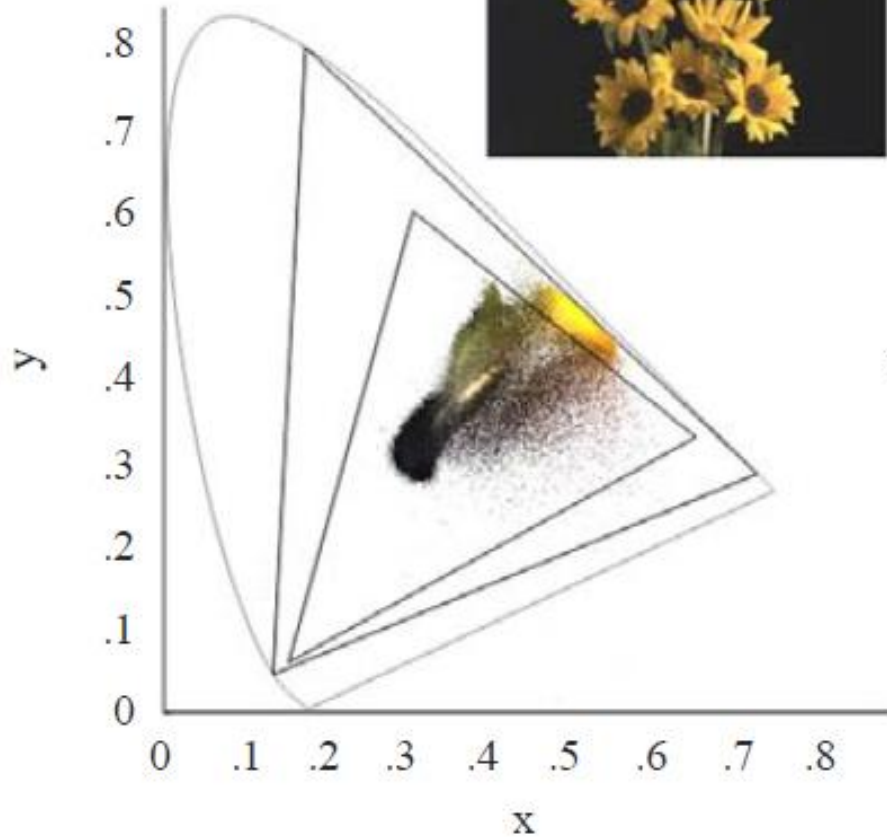
ITU-R BT.709/.2020



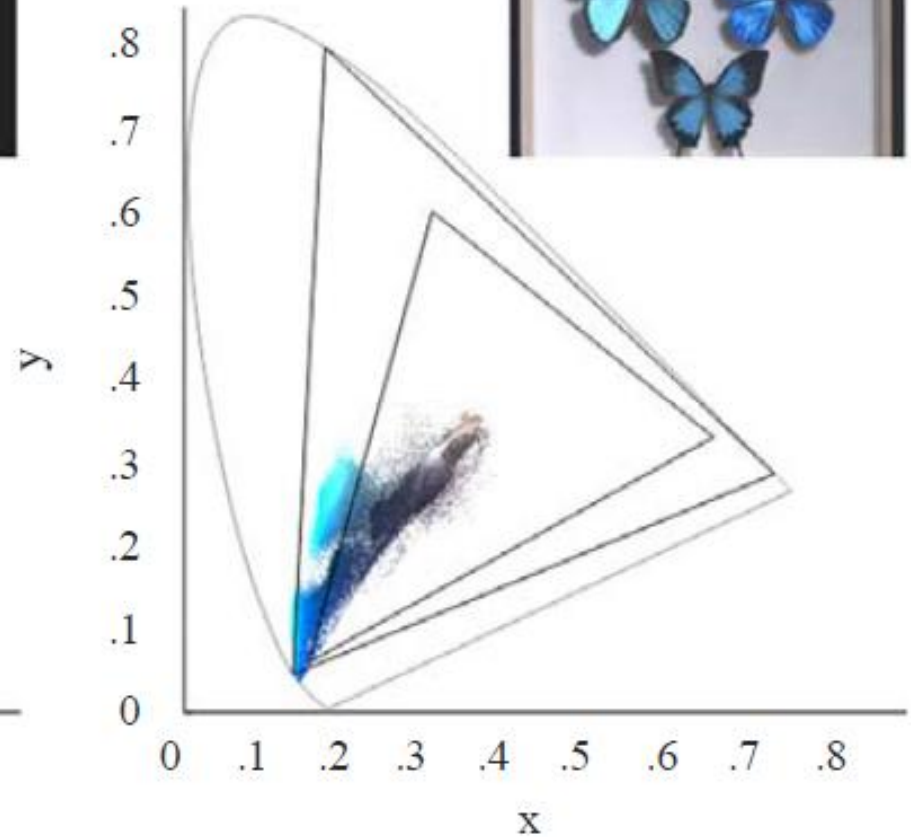
ITU-R BT.709/.2020



ITU-R BT.709/.2020



c) Sunflower



(d) Butterfly

Determinarea lungimii de unda dominante

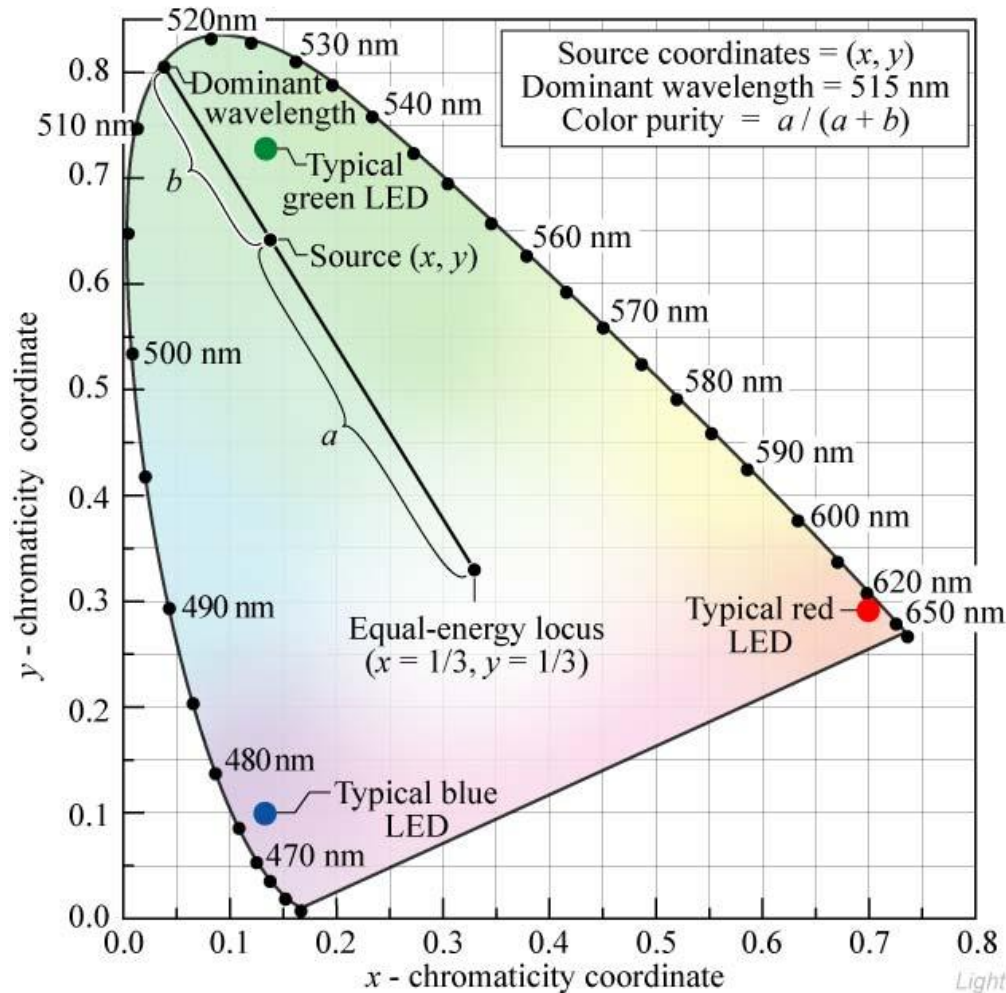
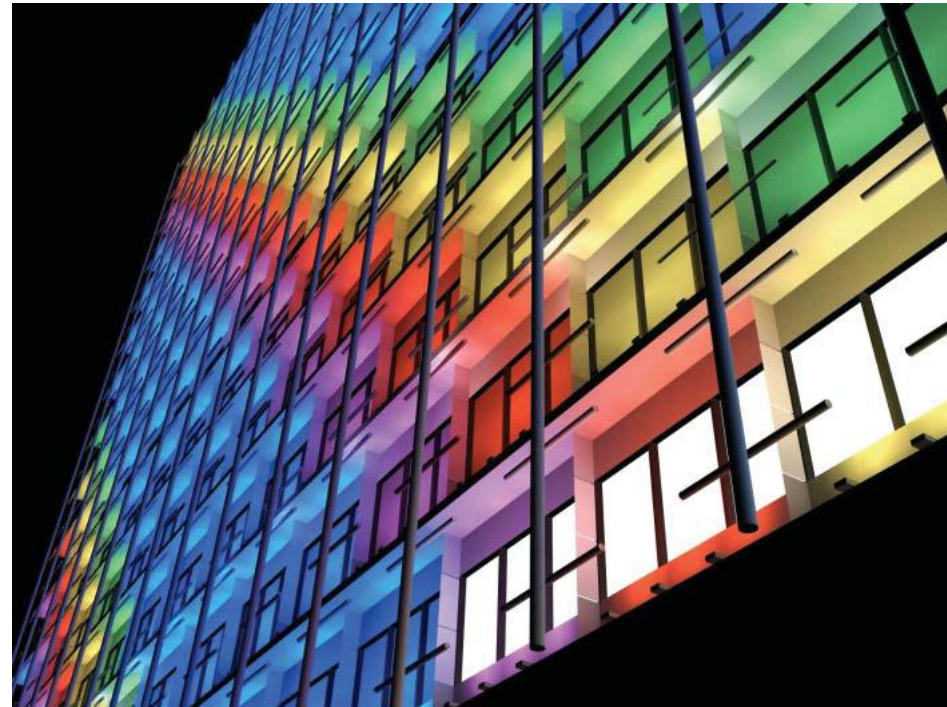


Fig. 17.8. Chromaticity diagram showing the determination of the *dominant color* and *color purity* of a light source with chromaticity coordinates (x, y) using the equal-energy locus ($x = 1/3, y = 1/3$) as the white-light reference. Also shown are typical locations of blue, green, and red LEDs.

ITU-R BT.709

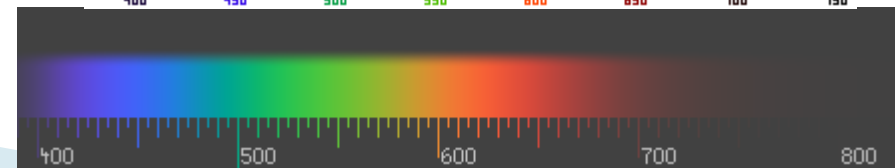
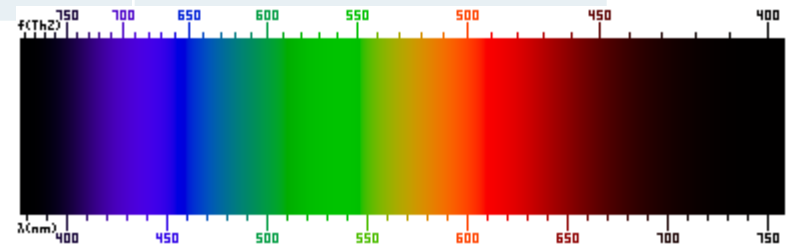


RGB values for Luxeon LEDs

LED color	Dominant wavelength λ_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

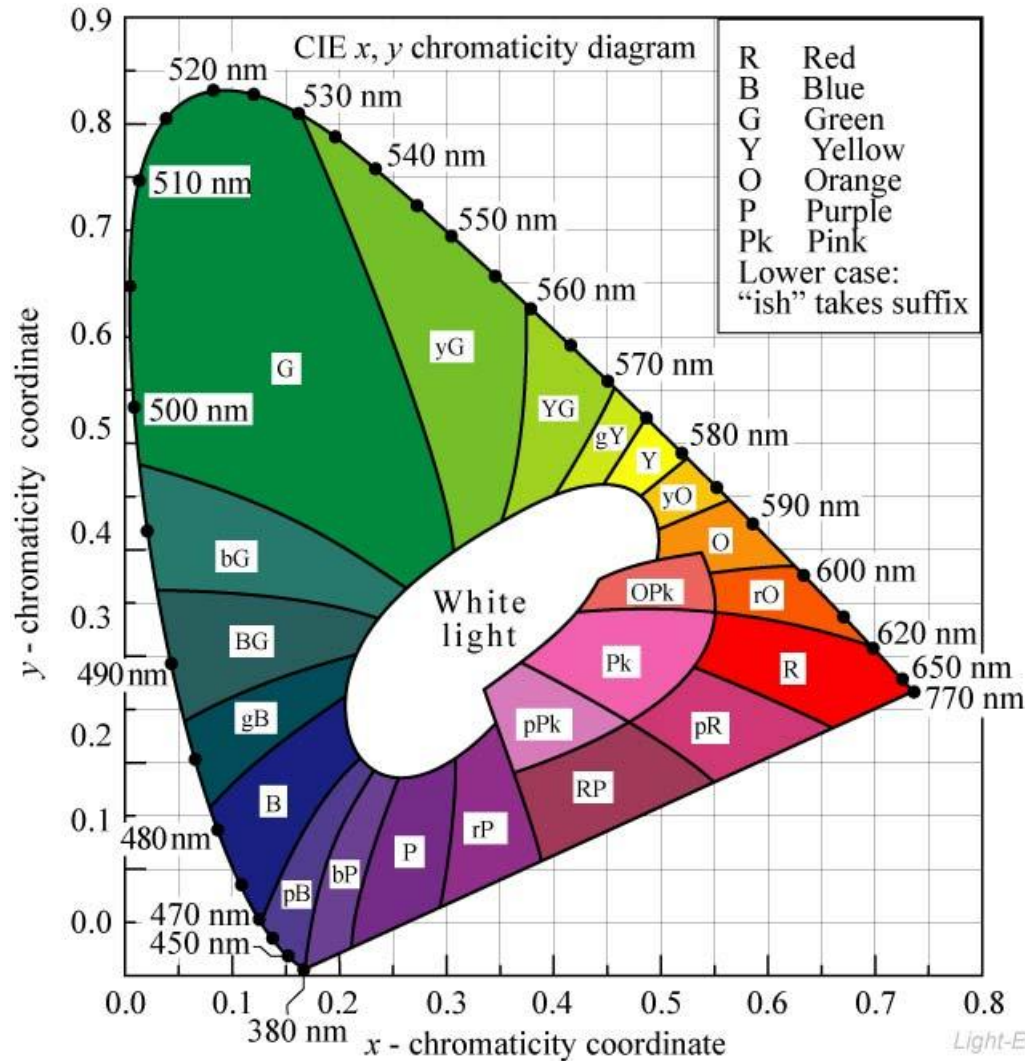


Fig. 17.3. 1931 CIE chromaticity diagram with areas attributed to distinct colors (adopted from Gage *et al.*, 1977).

Interpretarea standard a culorilor

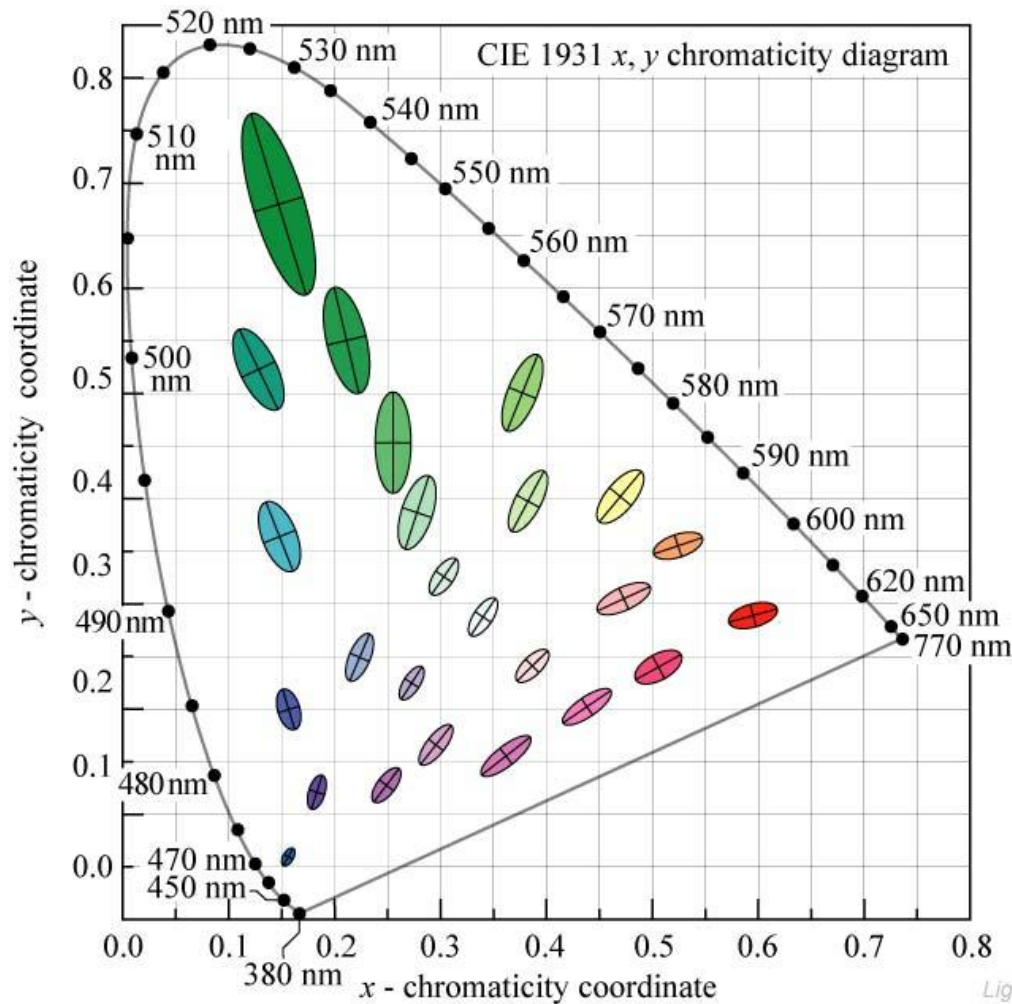


Fig. 17.5. MacAdam ellipses plotted in the CIE 1931 (x , y) chromaticity diagram. The axes of the ellipses are ten times their actual lengths (after MacAdam, 1943; Wright, 1943; MacAdam, 1993).

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

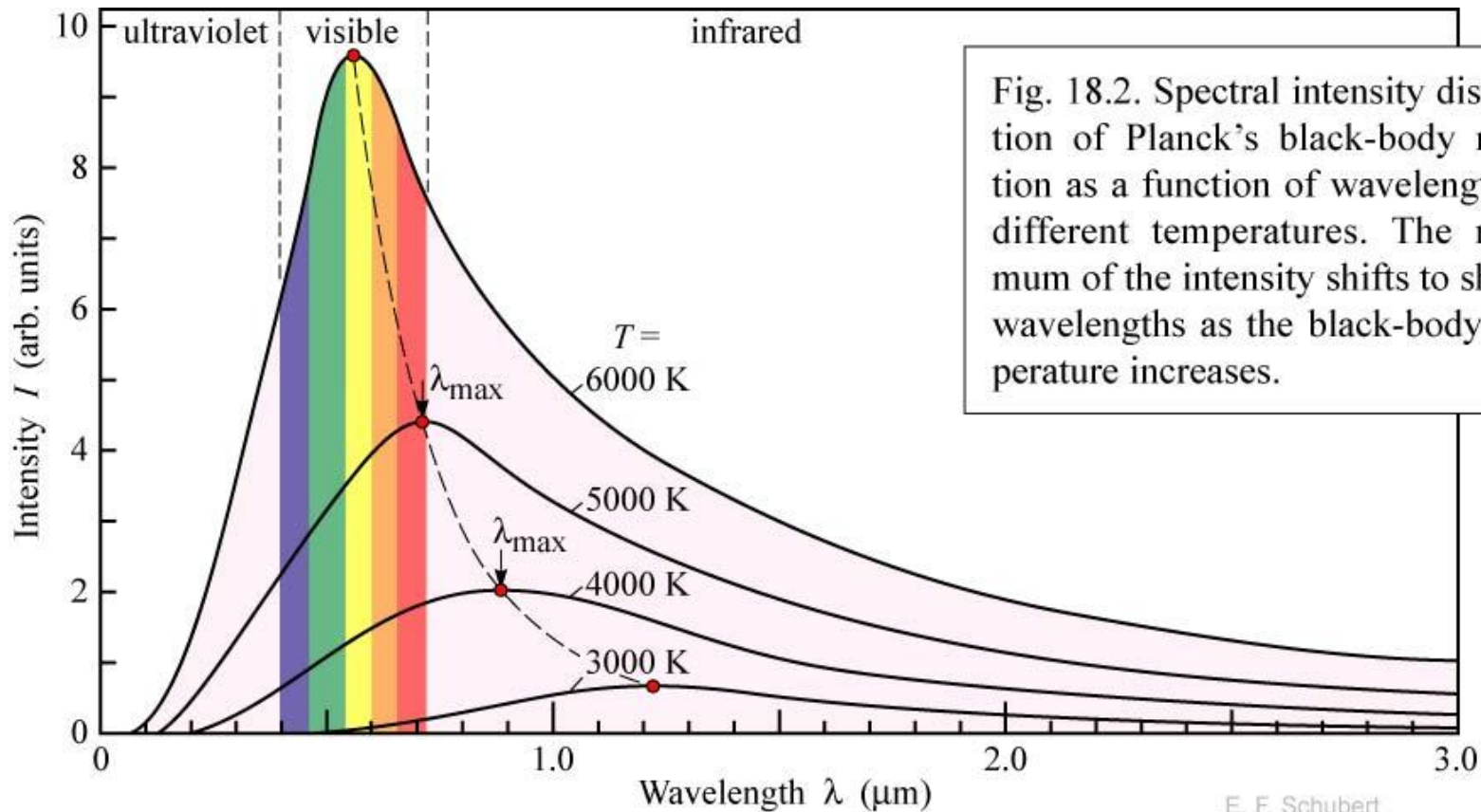
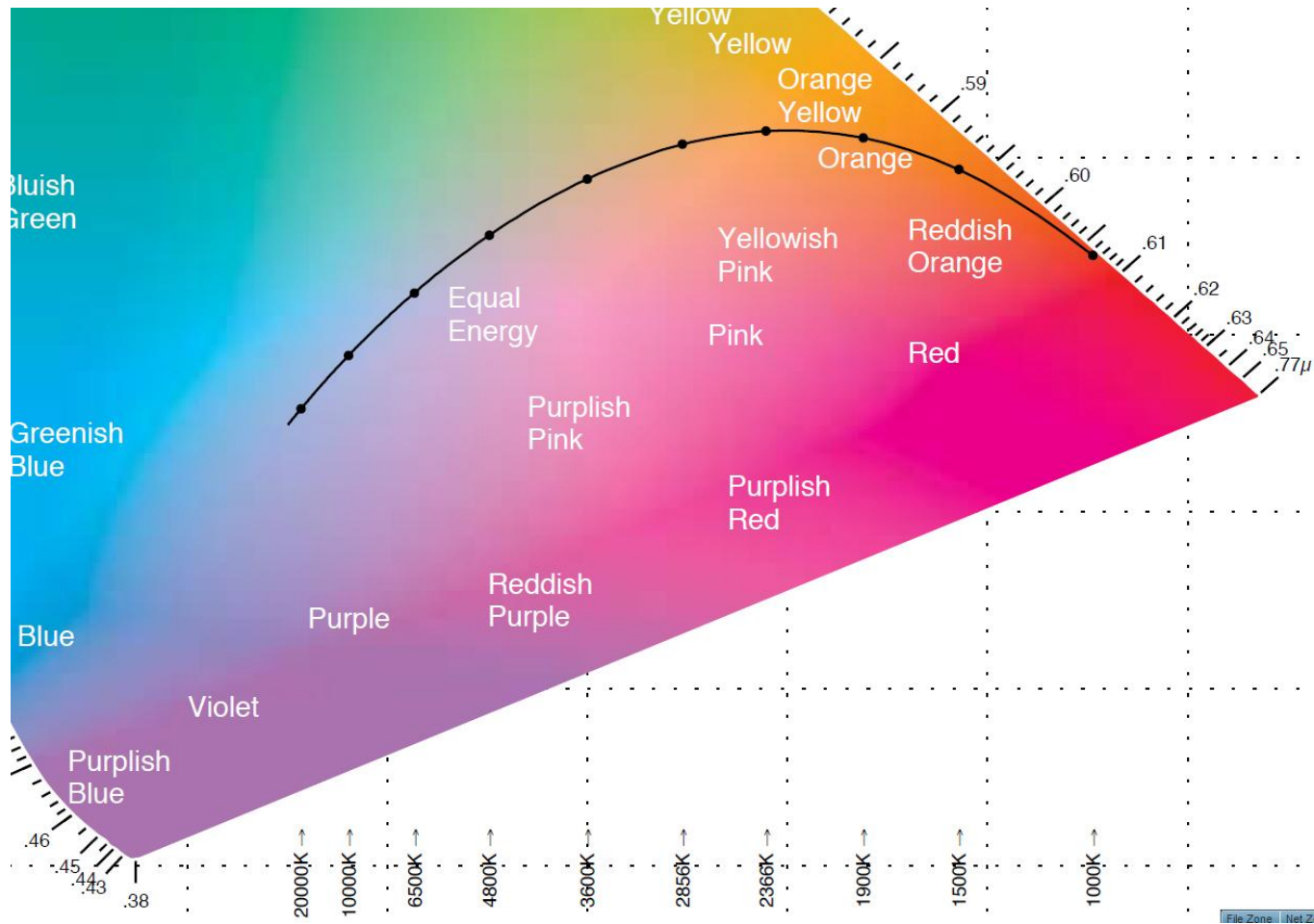


Fig. 18.2. Spectral intensity distribution of Planck's black-body radiation as a function of wavelength for different temperatures. The maximum of the intensity shifts to shorter wavelengths as the black-body temperature increases.

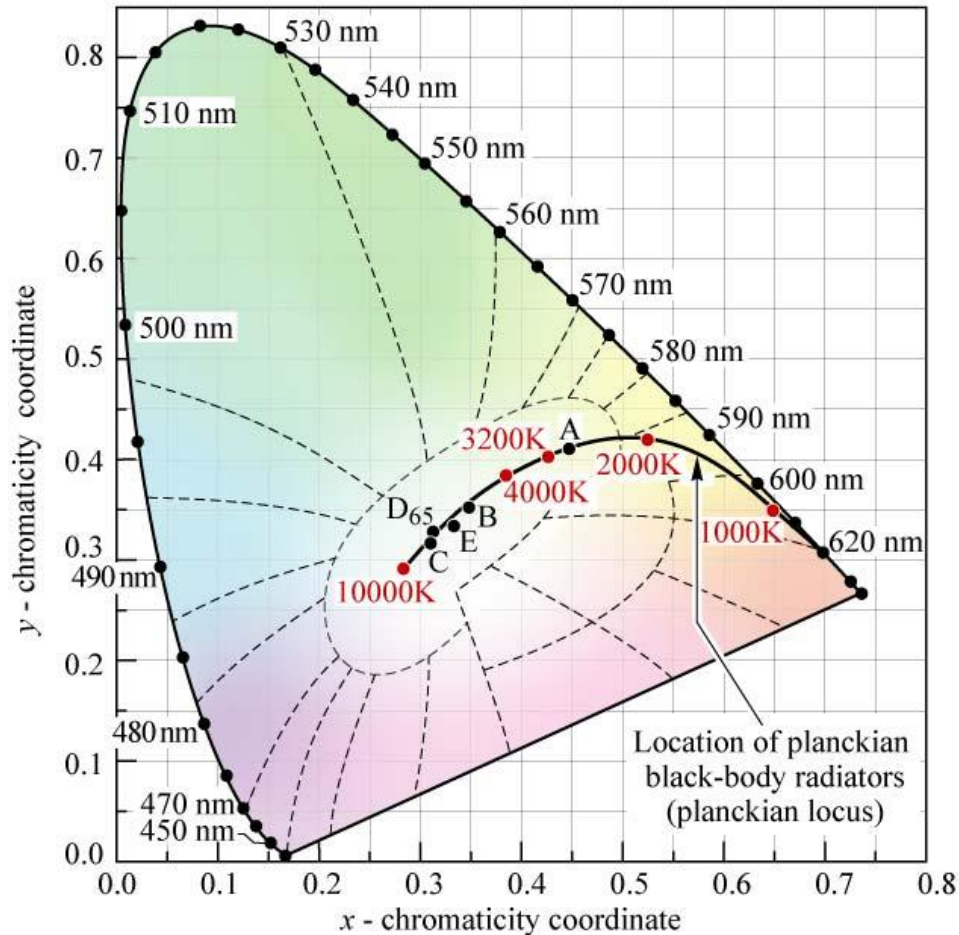
E. F. Schubert
Light-Emitting Diodes (Cambridge Univ. Press)
www.LightEmittingDiodes.org



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 D₆₅
 $(x, y) = (0.3128, 0.3292)$
 (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, D₆₅, 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

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 ²

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 ²	$M_e = \frac{d\Phi_e}{dS}$	SI: W/m ²

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 ²	$L_e = \frac{d^2\Phi_e}{d\Omega \cdot dS}$	SI: W/m ² /sr

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/m² etc.
- ▶ de multe ori se adapteaza relatiile pentru surse mai simple:

$$I_v = \frac{d\Phi_v}{d\Omega} \rightarrow I_v = \frac{\Phi_v}{\Omega} \Big|_{I_v \approx ct. \text{ in } \Omega}$$

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

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>

Fibra optică

Capitolul 4

Aplicatii majore

- ▶ Comunicatii

- Infrarosu (InGaAsP)

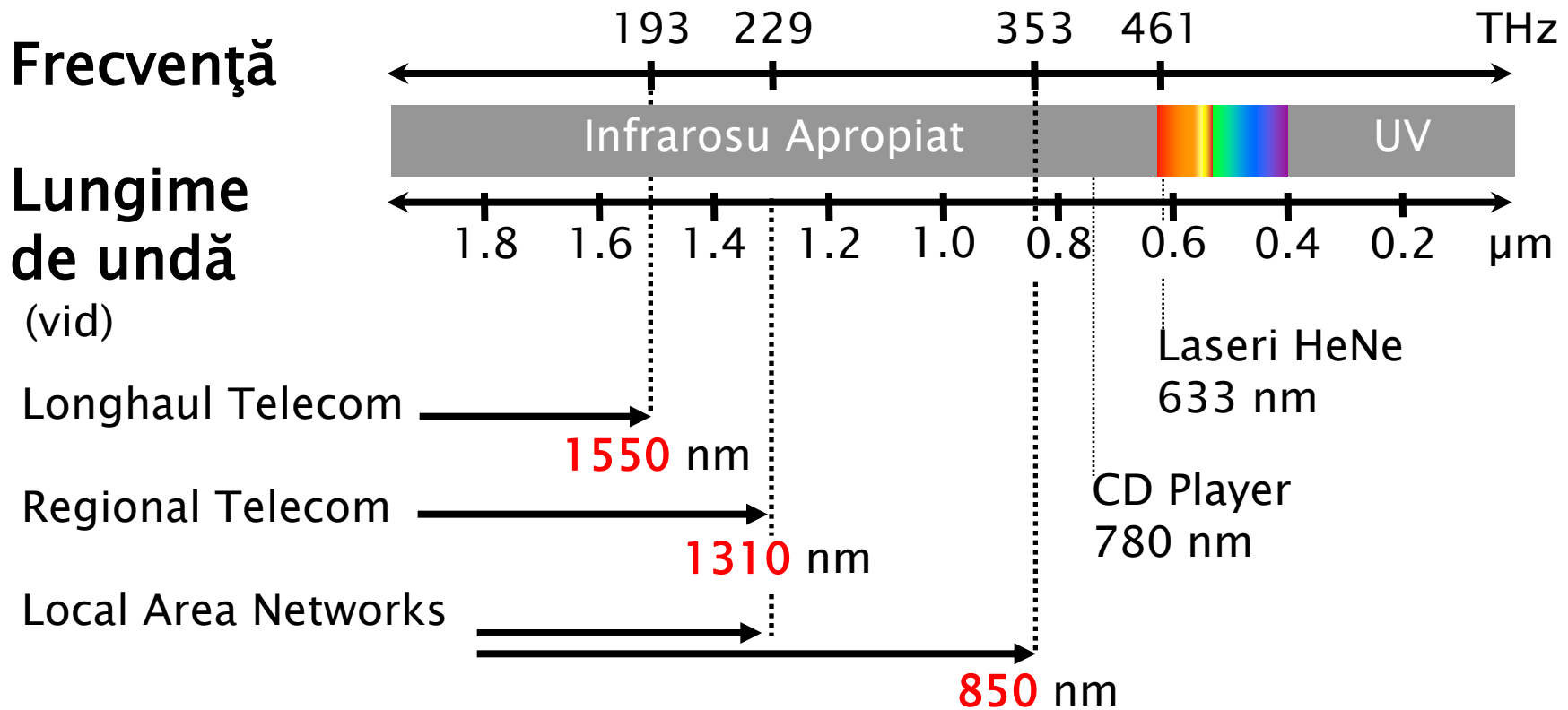
- ▶ Vizibil

- Spectru vizibil (GaAlAs)

- ▶ Iluminare

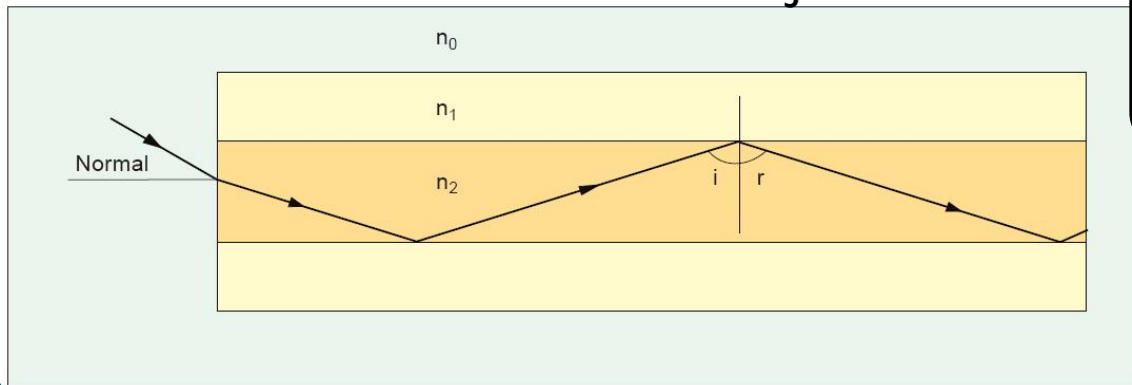
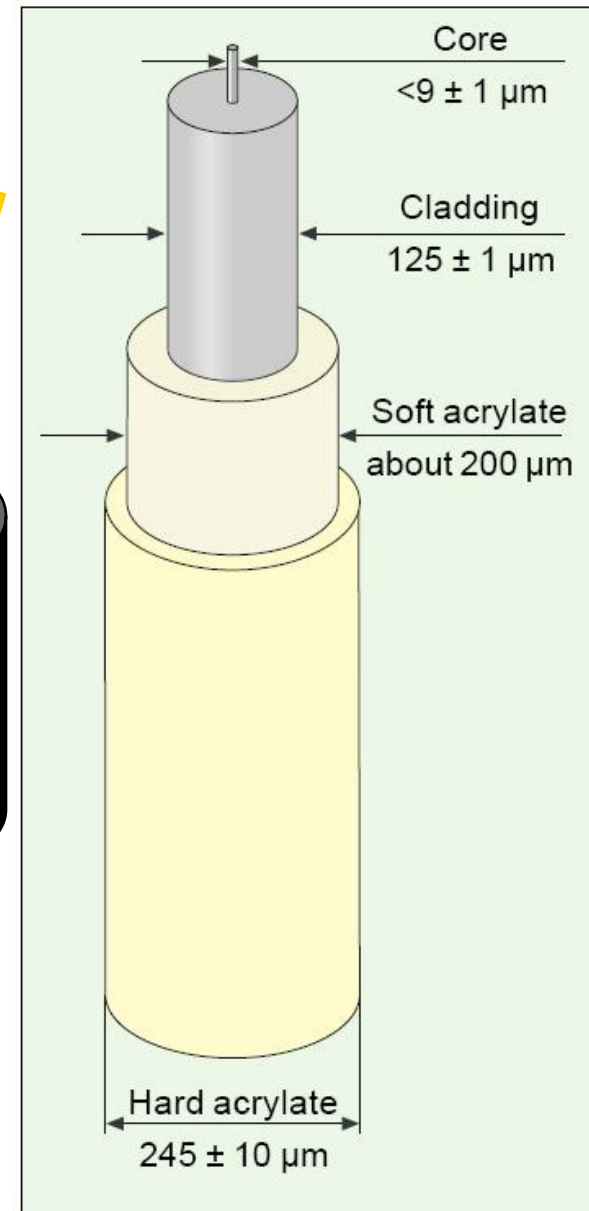
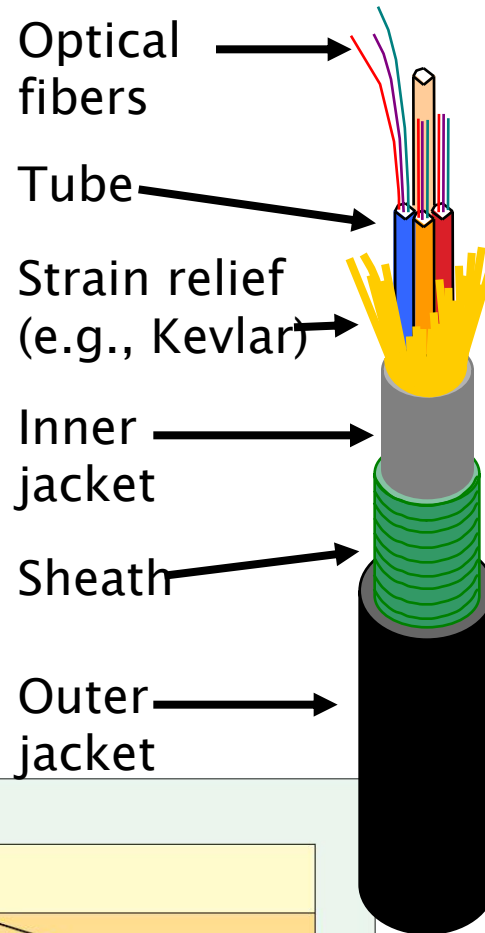
- Putere ridicata, lumina alba (GaInN)

Benzi de lucru in comunicațiile optice



Fibra optica

- ▶ un ghid de unda dielectric
 - miez
 - teaca



Unghi de acceptanta, apertura numerica

- ▶ Unghi de acceptanta

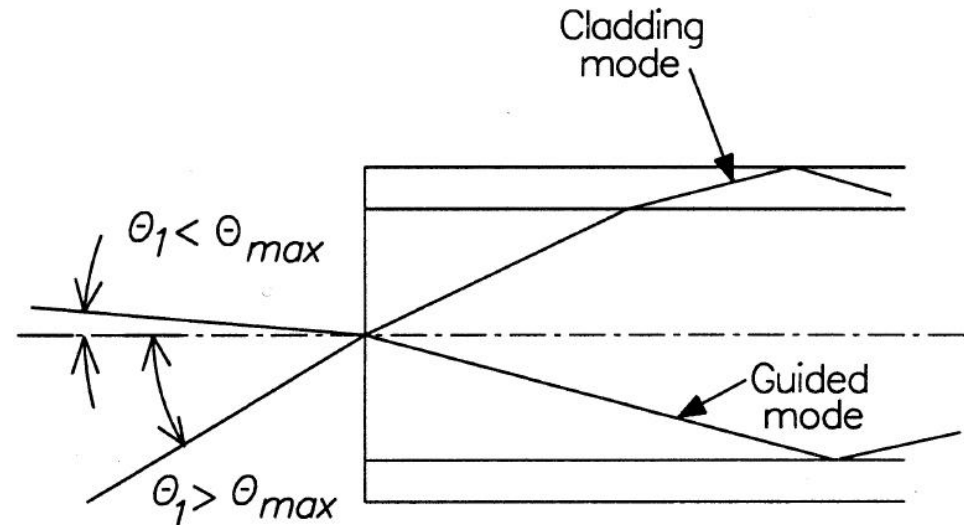
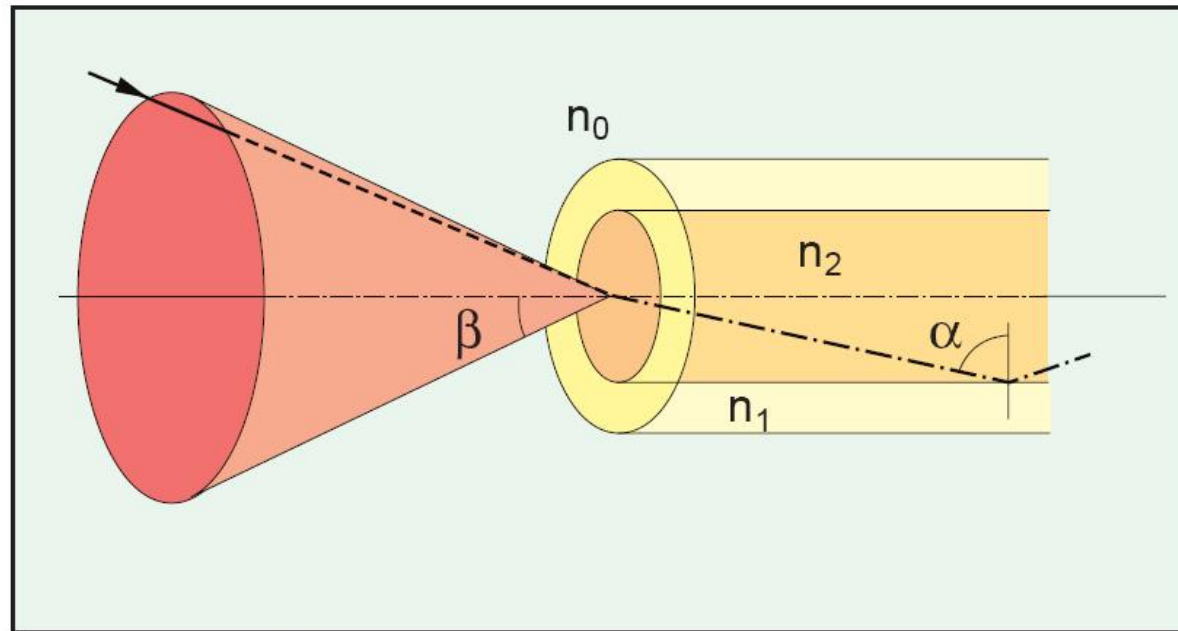
$$n_0 \cdot \sin \theta_{ACC} = n_2 \cdot \sin \phi_c$$

- ▶ Apertura numerica

$$NA = n_0 \cdot \sin \theta_{ACC}$$

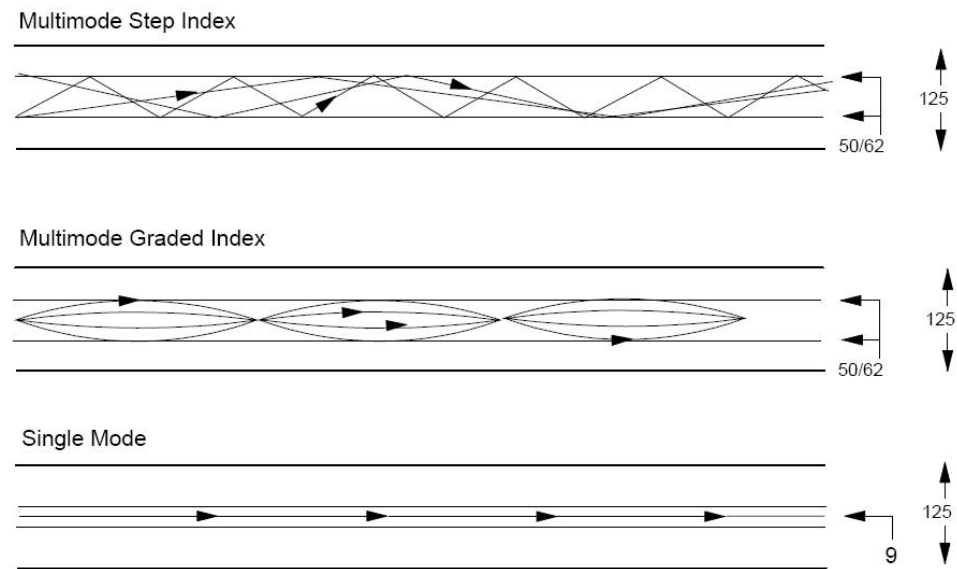
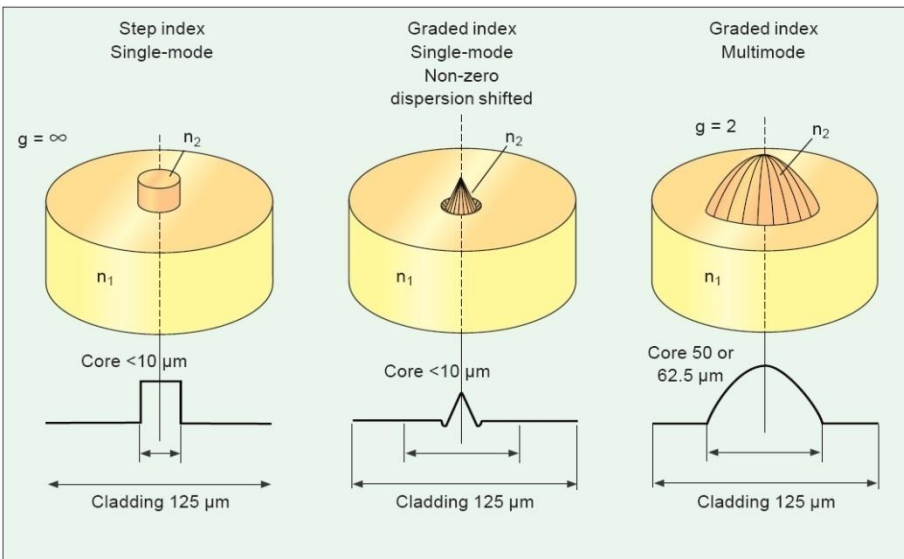
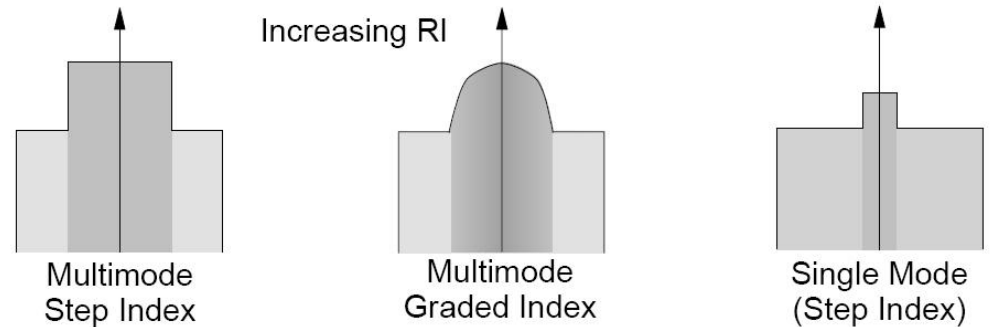
$$NA = n_2 \sqrt{\frac{n_2^2 - n_1^2}{n_2^2}} = \sqrt{n_2^2 - n_1^2}$$

n_2 - miez
 n_1 - teaca
 $n_2 > n_1$!!

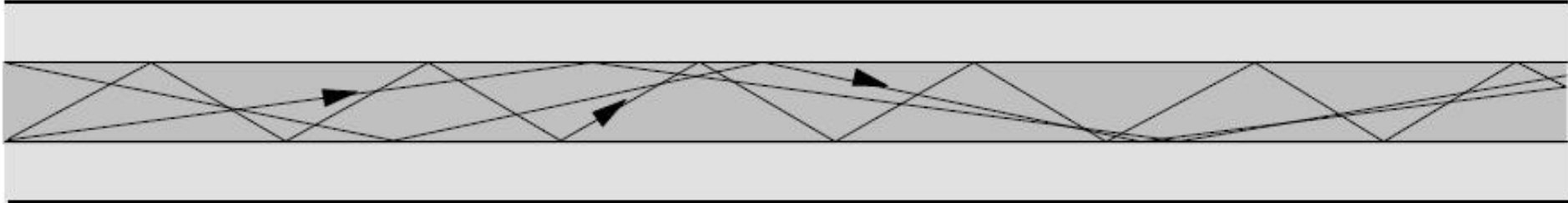


Tipuri de fibra

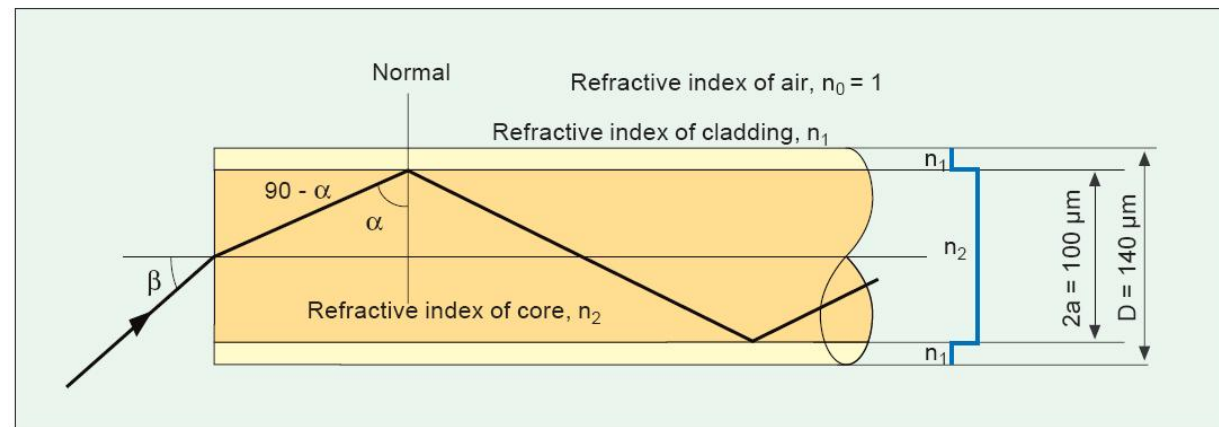
- ▶ Monomod
- ▶ Multimod
 - cu salt de indice
 - cu indice gradat



Fibre multimod cu salt de indice

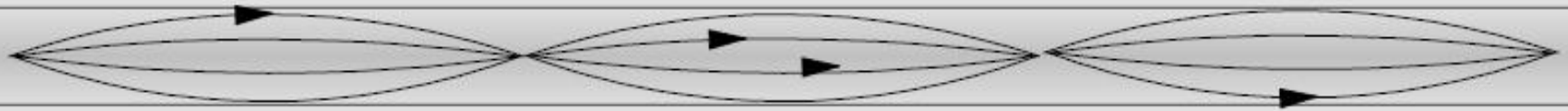


- ▶ 50/125 sau 62.5/125 (μm)
- ▶ 15–50 MHz · km

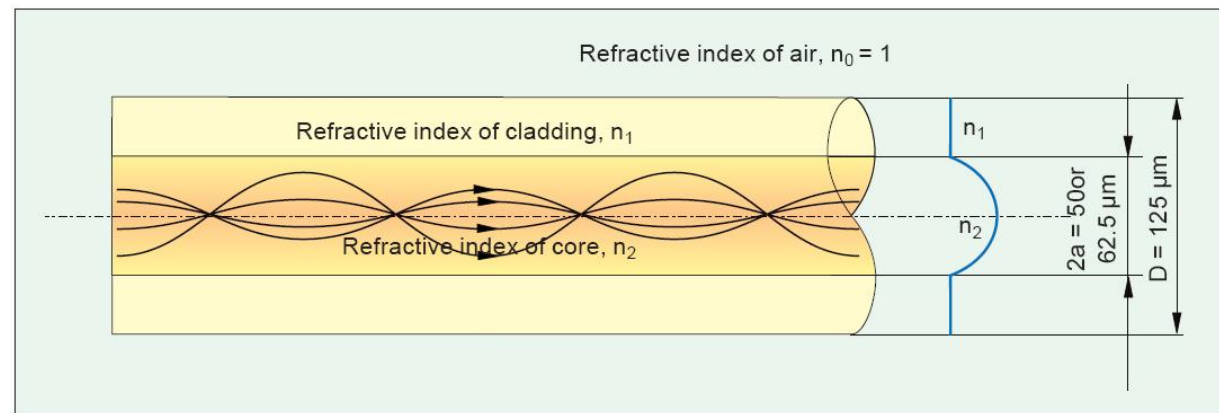


	glass	plastic
core diameter $2a$	100 μm	980 μm
cladding diameter D	140 μm	1000 μm
core refractive index n_2	1.48	
cladding refractive index n_1	1.45	

Fibre multimod cu indice gradat

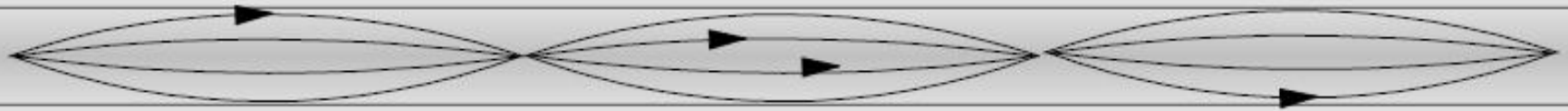


- ▶ 50/125 sau 62.5/125 (μm)
- ▶ 700–1200 MHz · km



Core diameter $2a$	50 or 62.5 μm
Cladding diameter D	125 μm
Maximum refractive index, core	1.46
Relative differential refractive index	0.010

Fibre multimod cu indice gradat

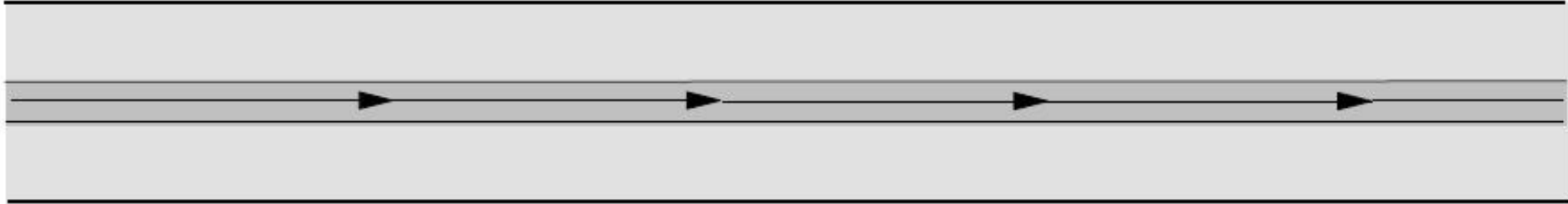


$$n(r) = n_2 \left[1 - \Delta \left(\frac{r}{a} \right)^g \right]$$

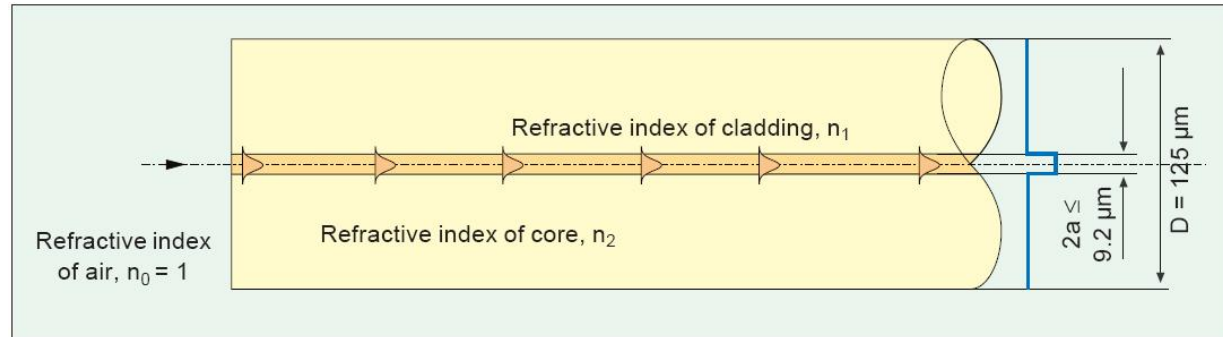
$$\Delta = \frac{NA^2}{2n_2^2} = \frac{n_2^2 - n_1^2}{2n_2^2} \approx \frac{n_2 - n_1}{n_2} \approx \frac{\Delta n}{n} \quad \text{for } \Delta \ll 1$$

- ▶ $g = 1$ - indice gradat triunghiular
- ▶ $g = 2$ - indice gradat parabolic
- ▶ $g = \infty$ - salt de indice

Fibre monomod



- ▶ 6–8/125 (μm)
- ▶ MHz · km
nerelevant
- ▶ MFD – Mode
Field Diameter



Cladding diameter D	125 μm
Core refractive index n_2	1.4485
Cladding refractive index n_1	1.4440
Refractive index differential	0.003 = 0.3%

Ghid cilindric dielectric

► Ecuatiile lui Maxwell in coordonate cilindrice

$$\frac{\partial^2 U}{\partial r^2} + \frac{1}{r} \frac{\partial U}{\partial r} + \frac{1}{r^2} \frac{\partial^2 U}{\partial \phi^2} + \frac{\partial^2 U}{\partial z^2} + n^2 k_o^2 U = 0$$

a – raza miezului
U – E(r) sau H(r)

$$U(r, \phi, z) = u(r) e^{-jl\phi} e^{-j\beta z}, \quad l = 0, \pm 1, \pm 2, \dots$$

$$\frac{d^2 u}{dr^2} + \frac{1}{r} \frac{du}{dr} + \left(n^2(r) k_o^2 - \beta^2 - \frac{l^2}{r^2} \right) u = 0$$

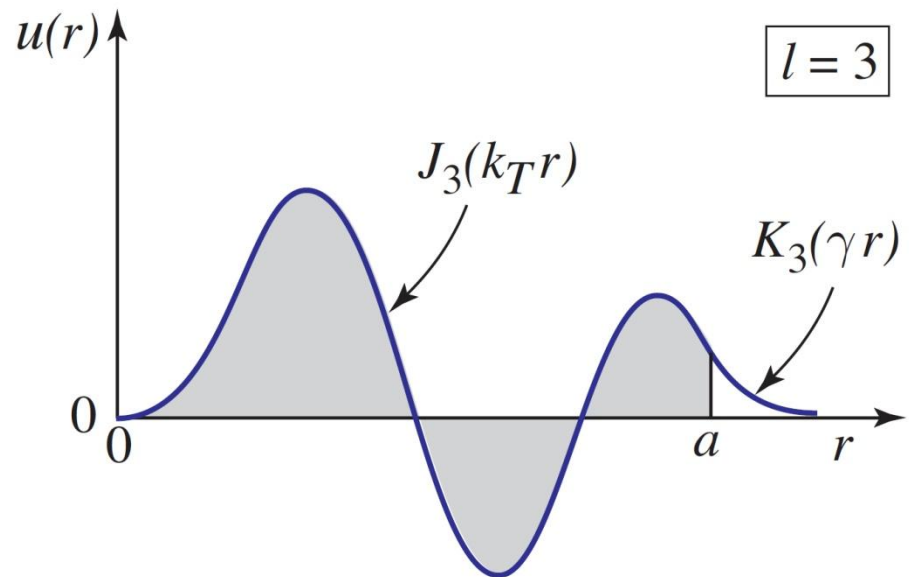
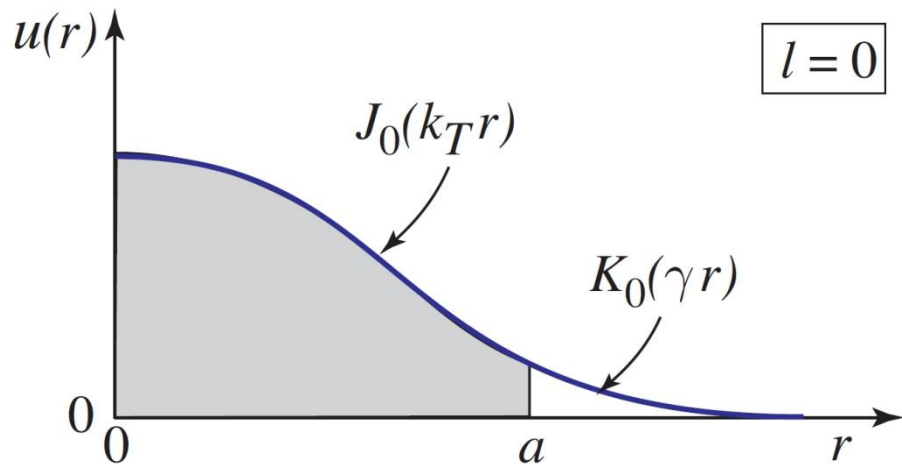
$$\frac{d^2 u}{dr^2} + \frac{1}{r} \frac{du}{dr} + \left(k_T^2 - \frac{l^2}{r^2} \right) u = 0, \quad r < a$$

$$\frac{d^2 u}{dr^2} + \frac{1}{r} \frac{du}{dr} - \left(\gamma^2 + \frac{l^2}{r^2} \right) u = 0, \quad r > a$$

Ghid cilindric dielectric

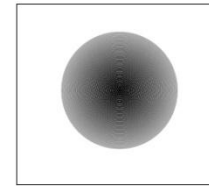
- ▶ solutii proportionale cu functii Bessel

$$u(r) \propto \begin{cases} J_l(k_T r), & r < a \quad (\text{core}) \\ K_l(\gamma r), & r > a \quad (\text{cladding}) \end{cases}$$

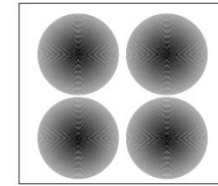


Moduri in fibra

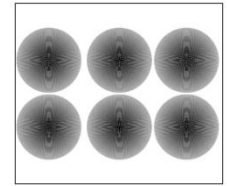
- ▶ Moduri in ghid rectangular



TEM₀₀

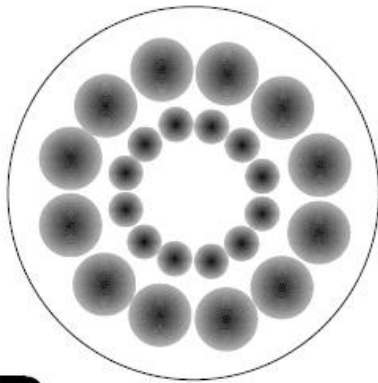


TEM₁₁

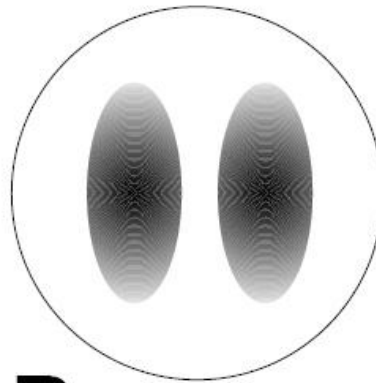


TEM₂₁

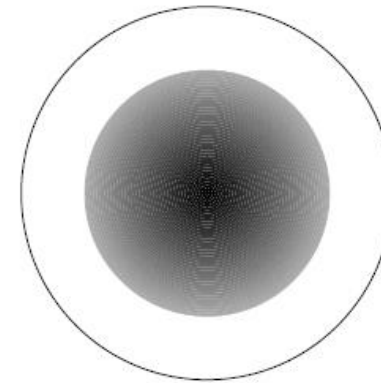
- ▶ Moduri linear polarizate in fibra



LP₆₂

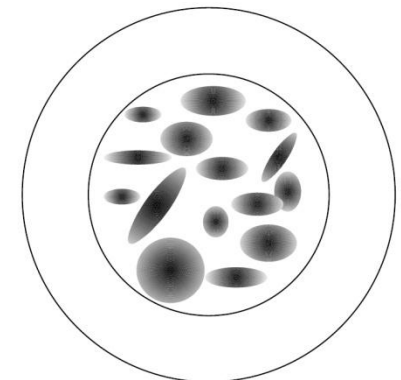


LP₁₁



LP₀₁

“Sparkle” pattern



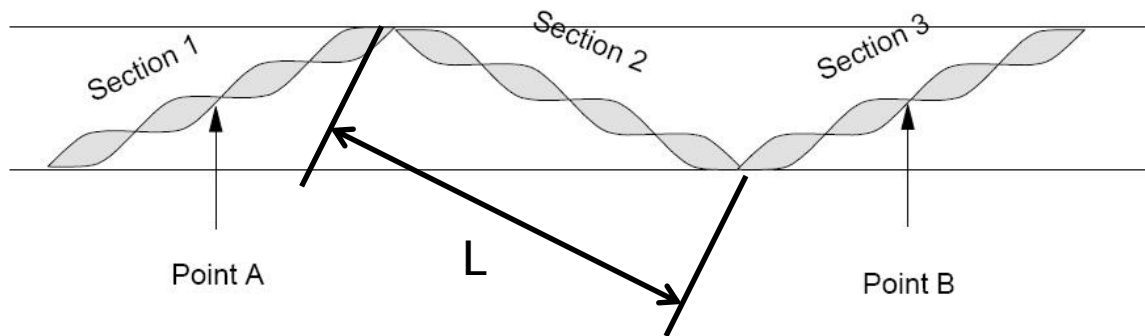
Frecventa normalizata

▶ Frecventa normalizata

$$V = 2\pi \frac{a}{\lambda} NA = k \cdot a \cdot NA \quad a - \text{raza miezului}$$

$$k = \frac{2\pi}{\lambda}$$

▶ Numar de moduri

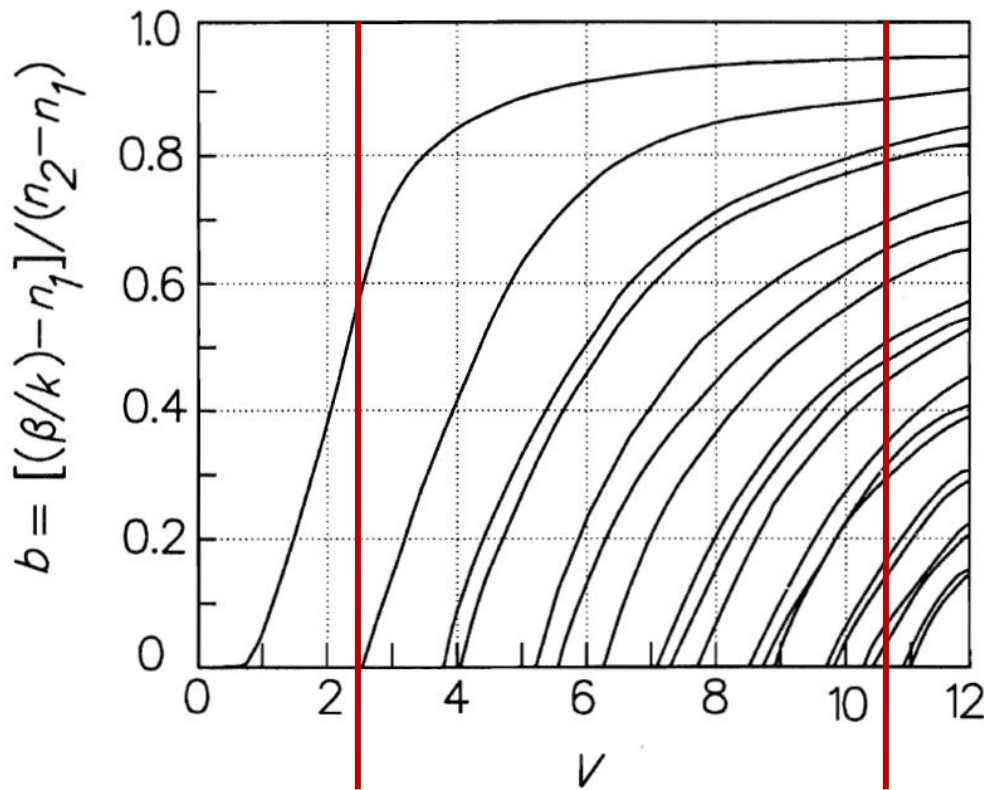


$$L = m \cdot \lambda$$

$$N \approx \frac{V^2}{2} \cdot \frac{g}{g+2}$$

Frecventa normalizata – monomod

► Fibre monomod



b – coeficient de propagare modal relativ

$$V \leq V_c = 2.405$$

exista un singur mod (solutii fc. Bessel)

$$\lambda \geq \lambda_c = \pi \frac{2a}{V_c} NA = \pi \frac{2a}{2.405} NA$$

Exemplu:

$$2a = 8.5 \mu\text{m}$$

$$NA = 0.11$$

$$\lambda_c = \pi \frac{8.5}{2.405} 0.11 = 1210 \text{nm}$$

Frecventa normalizata

- ▶ Numar de moduri
 - Multimod cu salt de indice

$$g = \infty \Rightarrow N \approx \frac{V^2}{2}$$

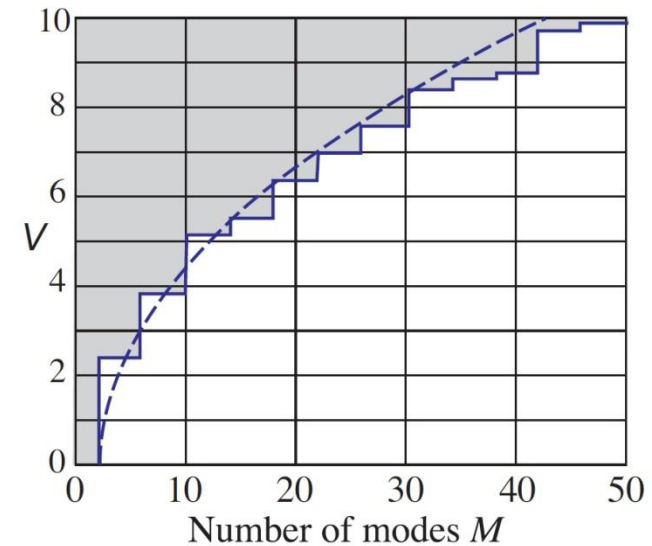
- Multimod cu indice gradat

$$g = 2 \Rightarrow N \approx \frac{V^2}{4}$$

- Monomod

$V \leq V_c = 2.405$ exista un singur mod (solutii fc. Bessel)

$$N \approx \frac{V^2}{2} \cdot \frac{g}{g+2}$$



Exemplu

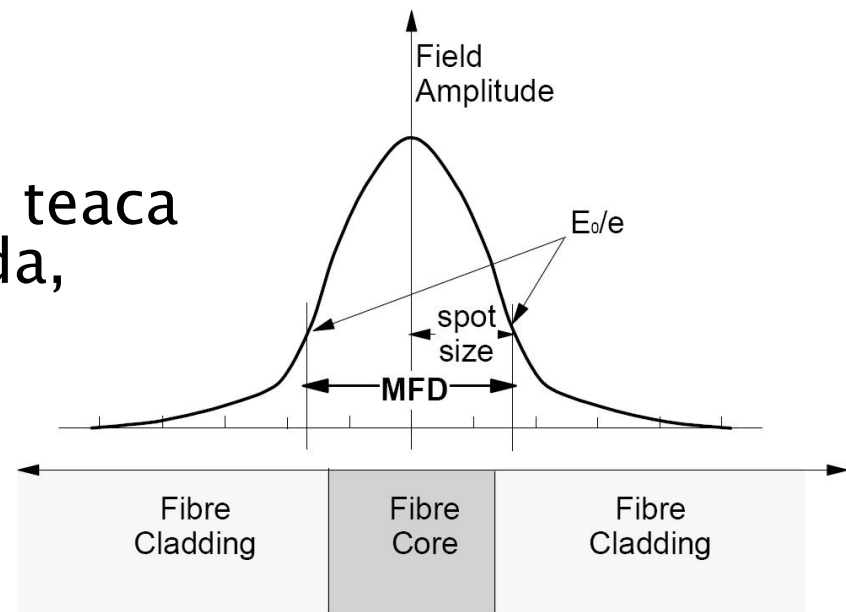
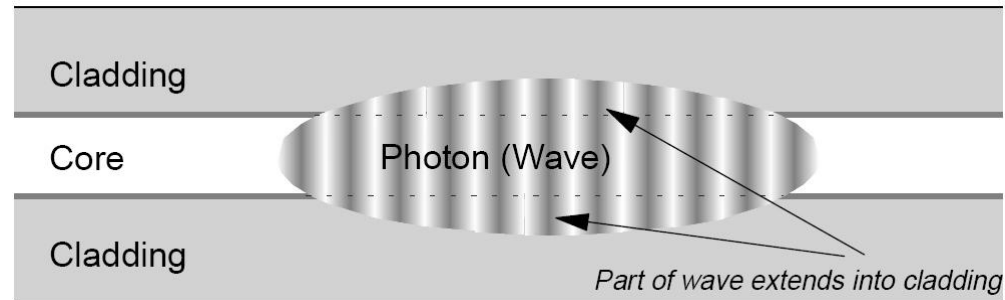
- ▶ fibra tipica multimod
 - $g=2$
 - $2a = 50\mu\text{m} \rightarrow a = 25\mu\text{m}$
 - $NA = 0.2$ la $\lambda = 1\mu\text{m}$

$$V = 2\pi \frac{a}{\lambda} NA = 2\pi \frac{25}{1} 0.2 = 2 \cdot \pi \cdot 5 \approx 31.4$$

$$g = 2 \Rightarrow N = \frac{V^2}{4} = \frac{31.4^2}{4} = 247$$

Propagarea in fibra monomod

- ▶ Propagarea luminii poate fi explicata doar prin teoria electromagnetica
- ▶ Energia campului se extinde in teaca (diametrul efectiv al spotului luminos – MFD, Mode Field Diameter)
- ▶ $MFD > 2a$
- ▶ Adancimea de patrundere in teaca depinde de lungimea de unda, generand dispersia de ghid



Contact

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- ▶ rdamian@etti.tuiasi.ro