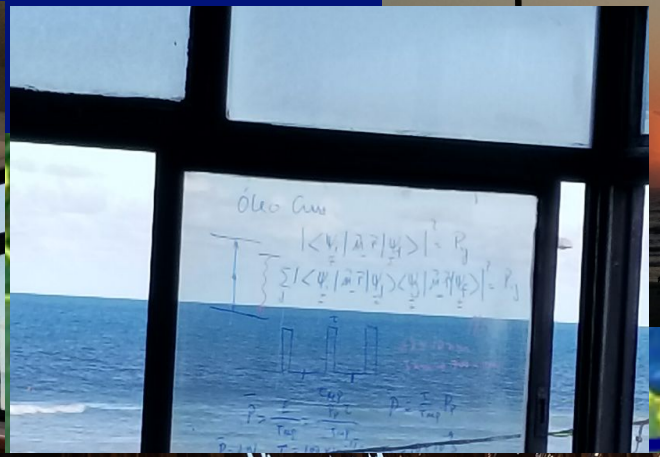
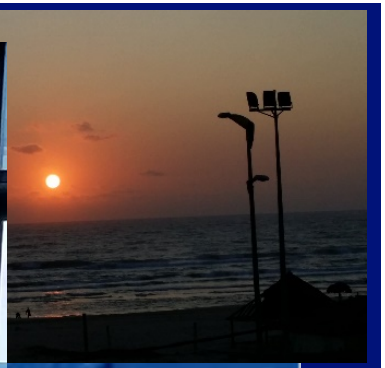
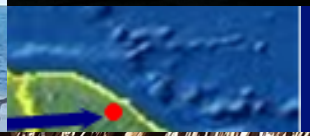
Elementos de Óptica

Carlos Lenz Cesar: Departamento de Física UFC

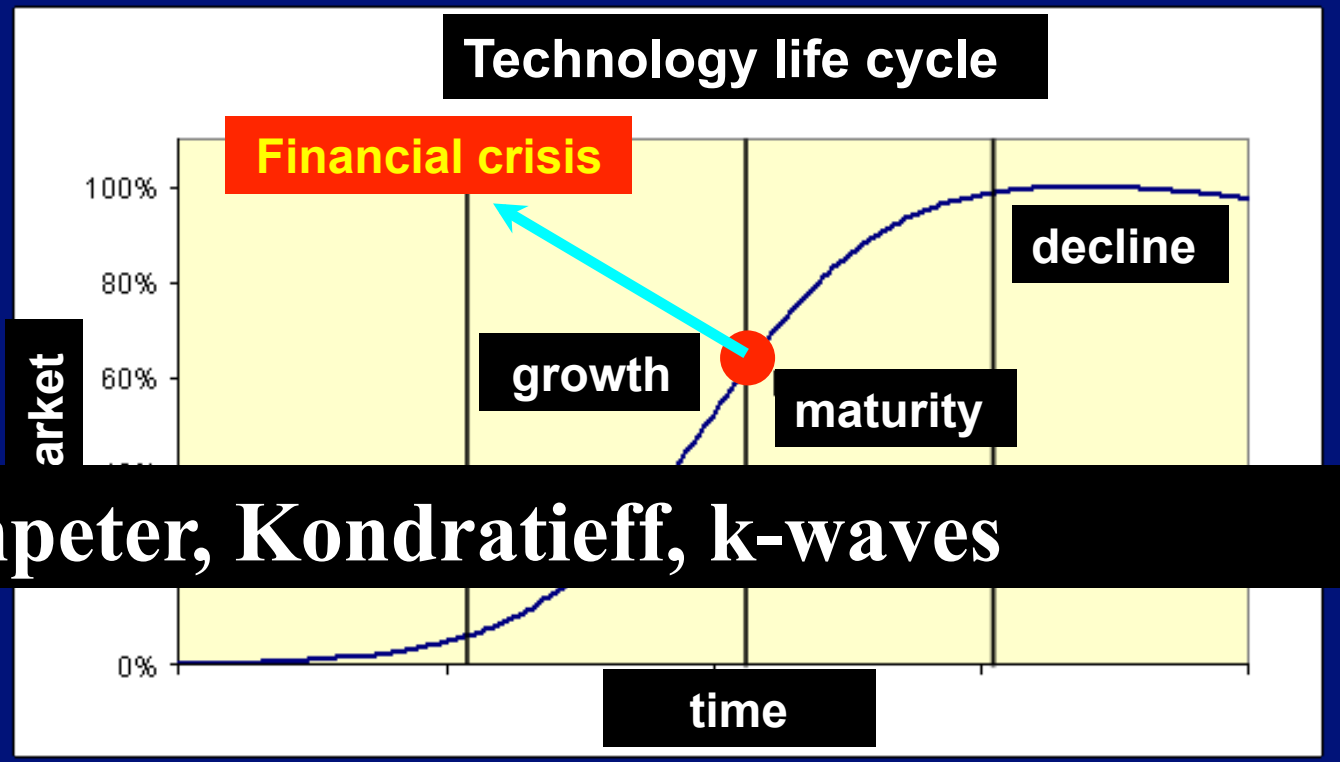






Brazil

Carlota Perez: Technological Revolutions and Financial Capital



Schumpeter, Kondratieff, k-waves

5 Revolutions - ~50- 60 years total cycle

1. Industrial Rev. – England – 1771

Trillion dollars question: Next Revolution???

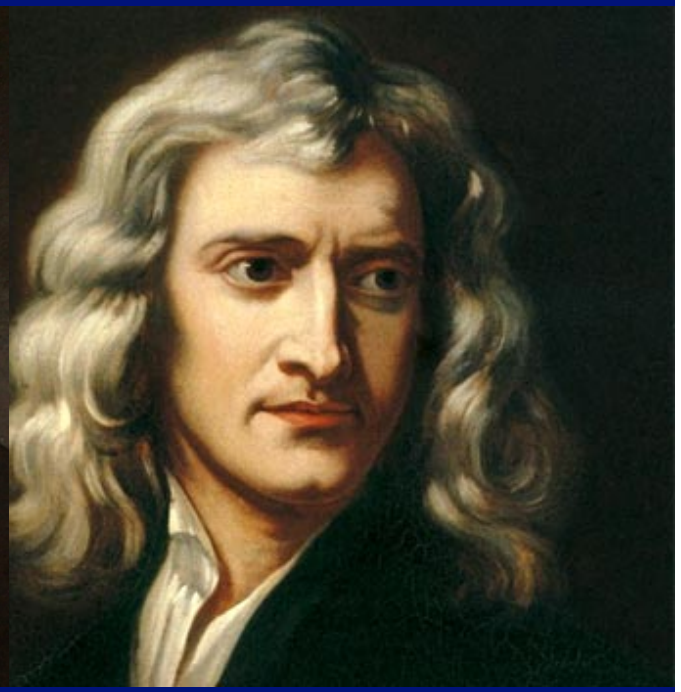
Our bet: control of biology at cell/molecular level

BIOECONOMY

XVII Century Science

Leeuwenhoek
1660-1670's
1632 - 1723

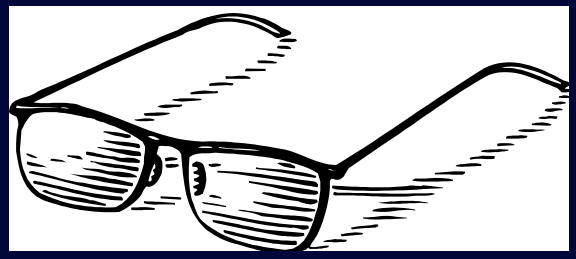
Robert Hooke
Micrographia 1665
1635 - 1703



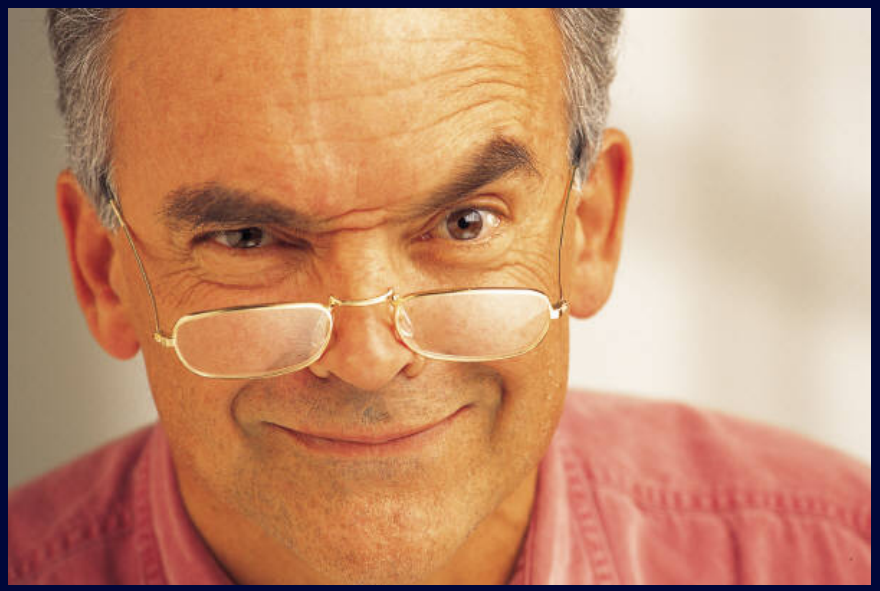
Isaac Newton
Principia 1687 (1665)
1643 - 1727

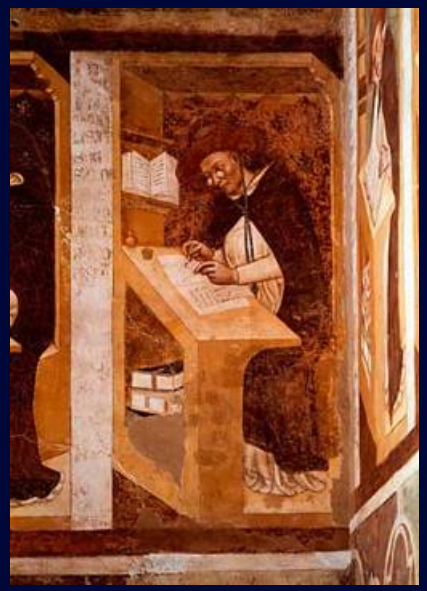
A revolução dos óculos – início: 1280-1300

Uma das invenções mais importantes dos últimos 2000 anos [Newsweek 1999]



Artesãos, médicos … com mais de 40 anos continuaram trabalhando

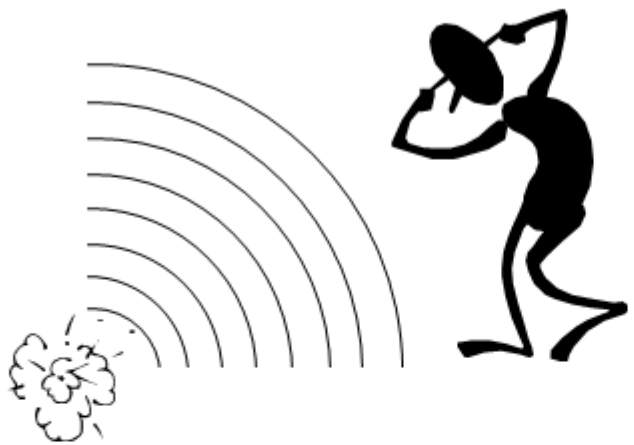




Primeira pintura de uma pessoa usando óculos: Tommaso da Modena 1352

ONDAS

Através das ondas nos escutamos



Ondas acústicas

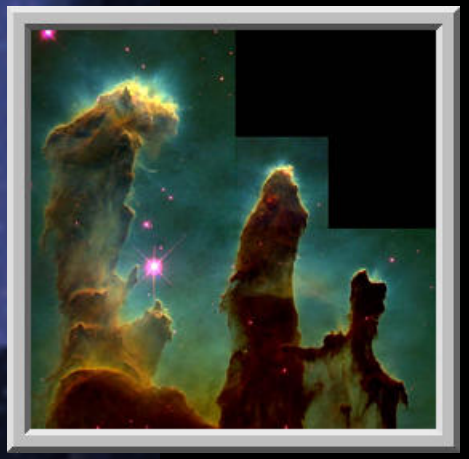
e enxergamos

Ondas eletromagnéticas

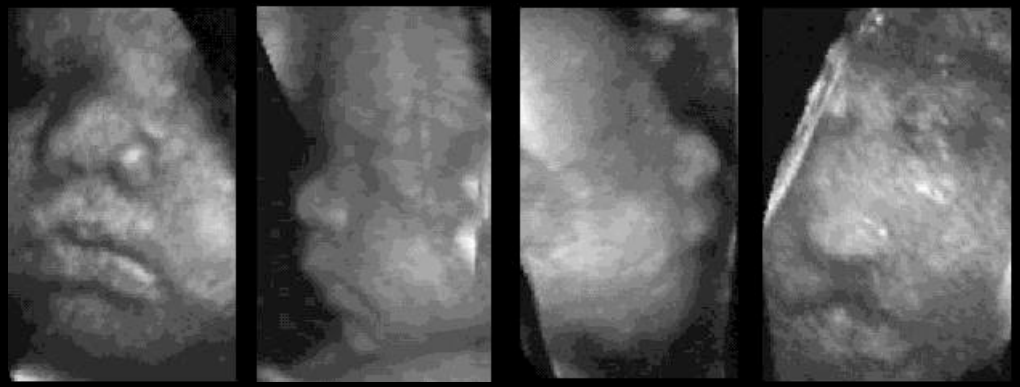
Sempre que a distância é grande utilizamos ondas.

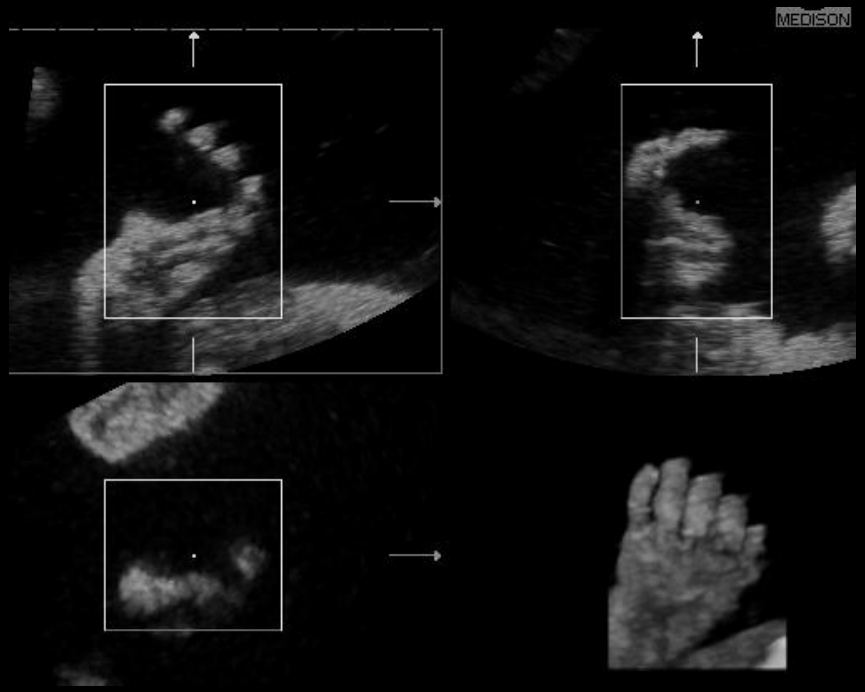
TV - Rádio - Telefone

Observando o céu:
descobrindo o que existe nas estrelas



Usando o Ultrassom - bêbe ainda na barriga da mãe





Advantages of Waves:

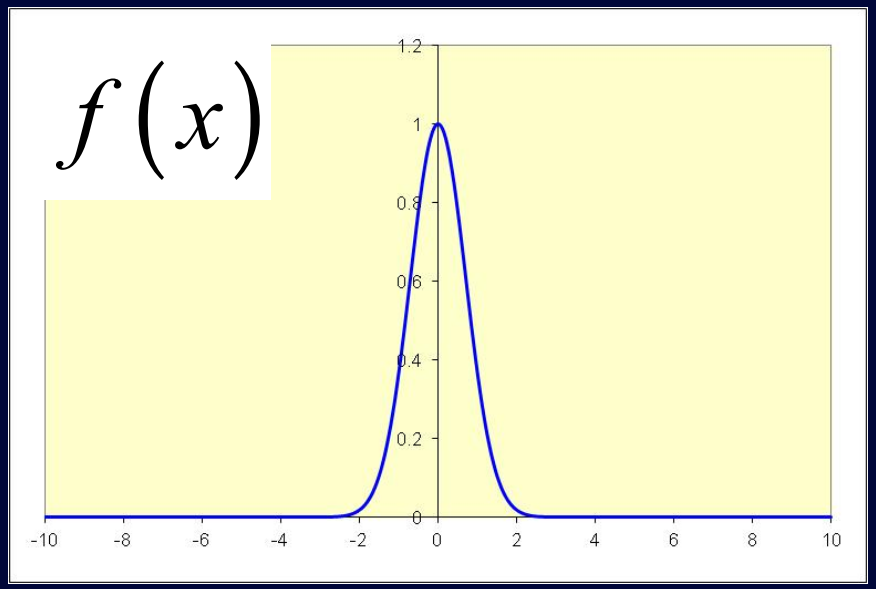
Can be detected very far away

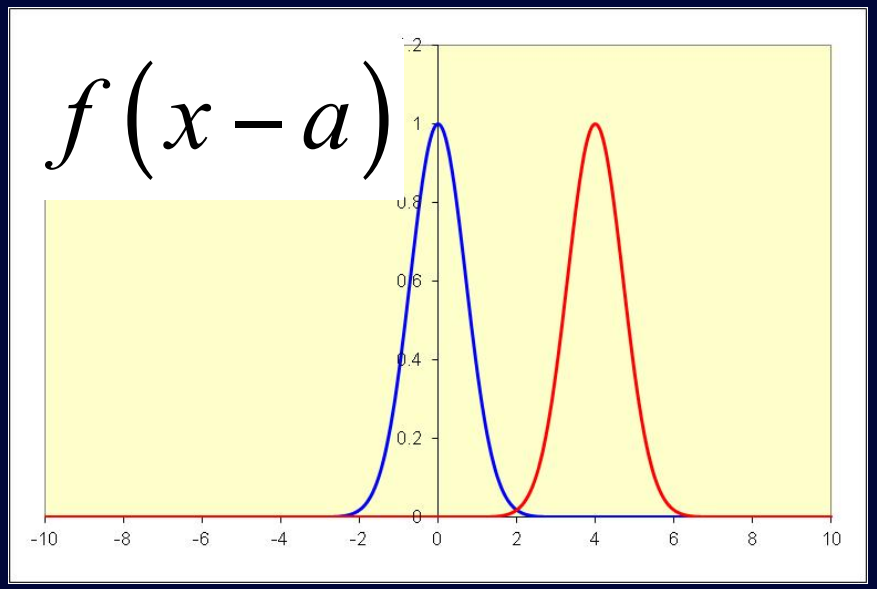
Capable to transpass materials

Non destructive observation

The sonar

ONDA

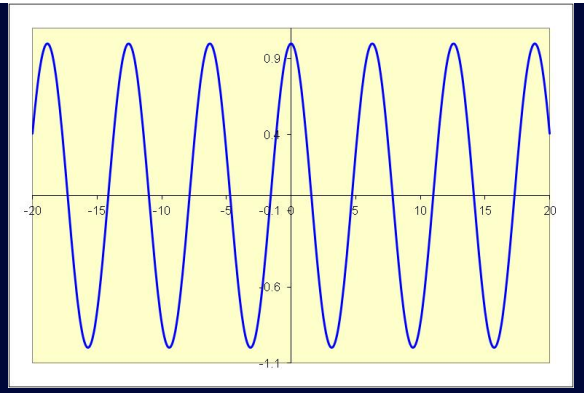




$$f(x - \mathrm{v}\,t)$$

ONDA HARMÔNICA

$$f\left(x - \mathrm{v}\,t\right) = A\cos\left[k\,x - \omega t\right]$$



Velocidade da Onda: $f\left(x - \mathrm{v}\,t\right) = \cos\left[k\left(x - \dfrac{\omega}{k}t\right)\right]$ $\mathrm{v} = \dfrac{\omega}{k}$

Onda se repete em λ [comprimento de onda]

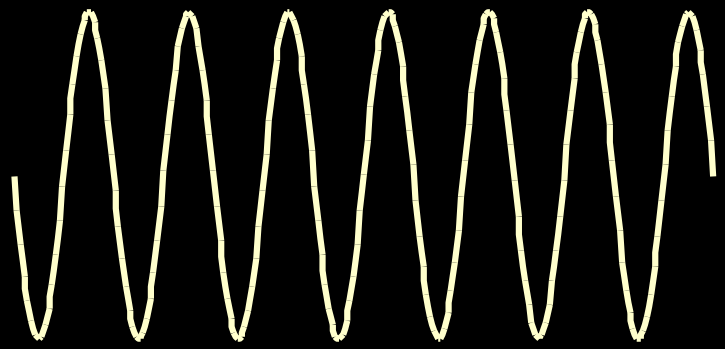
$$k\lambda = 2\pi \rightarrow k = \frac{2\pi}{\lambda}$$

Onda se repete em τ [período da onda]

$$\omega\tau = 2\pi \rightarrow \omega = \frac{2\pi}{\tau}$$

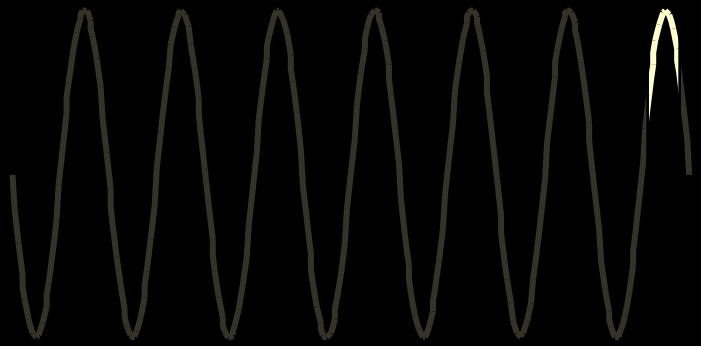
$$\lambda = \mathrm{v}\,\tau$$

Caracterizando uma Onda



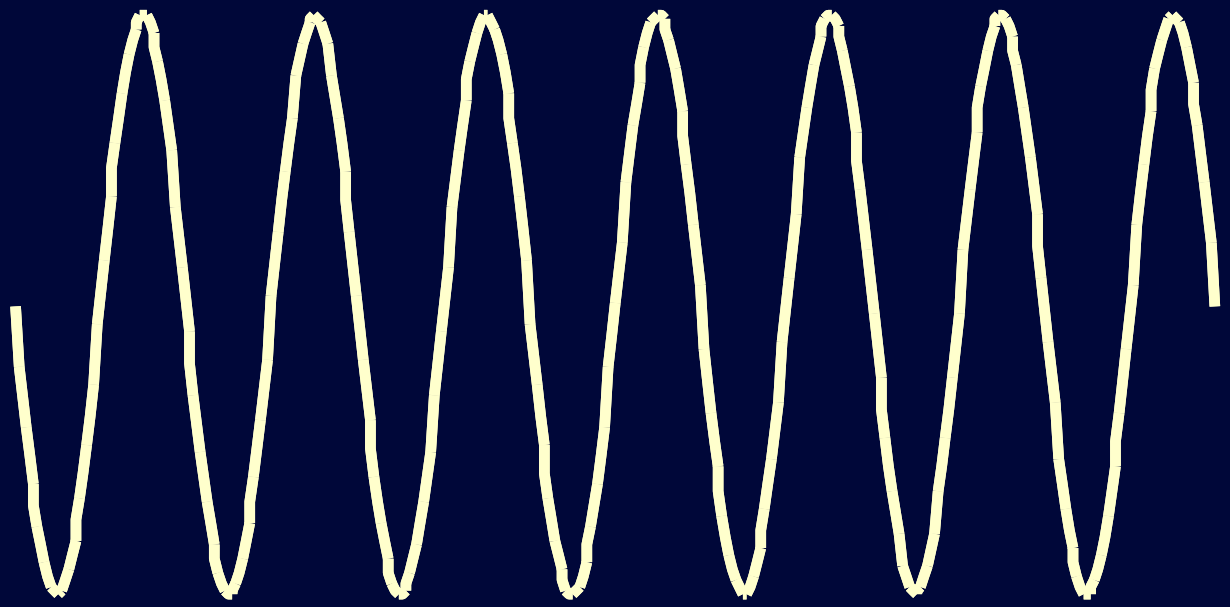
Velocidade: c

Freqüência: f Período: $\tau = 1/f$



Comprimento de onda: λ

$$\lambda = c\,\tau$$



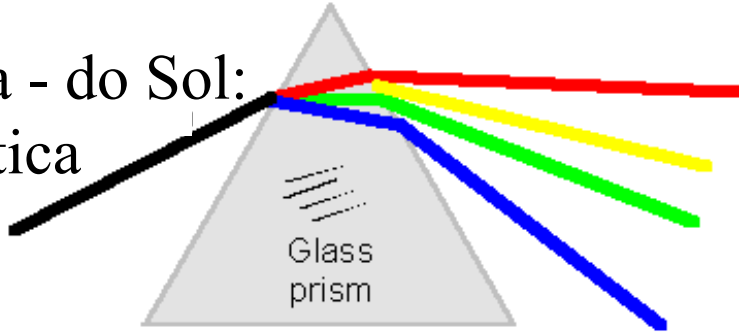
Espectro no dicionário: (do latim Spectrum)

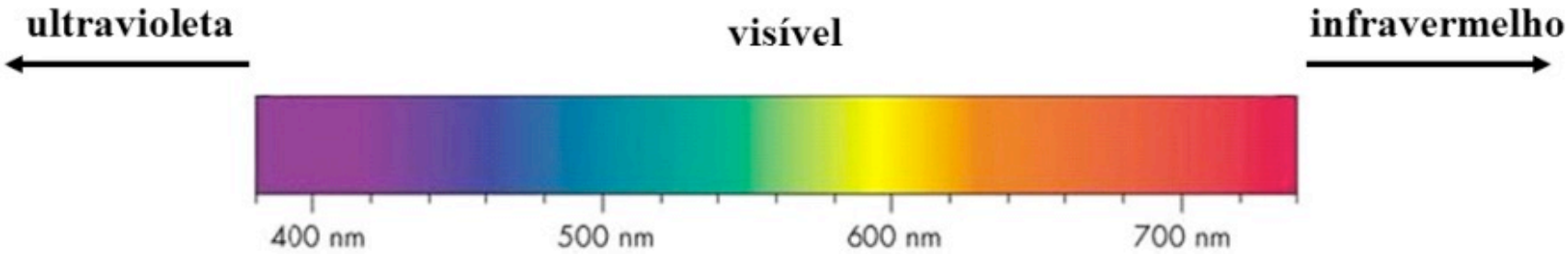
Fantasma, aparição ilusória
Presença ameaçadora - “espectro da fome”.

na física: decomposição da luz
na biologia: resposta de microorganismos à diferentes drogas
genericamente: decompor o todo em suas partes

Espectro Eletromagnético

Luz branca - do Sol: Policromática





Inseto enxerga mais no ultravioleta

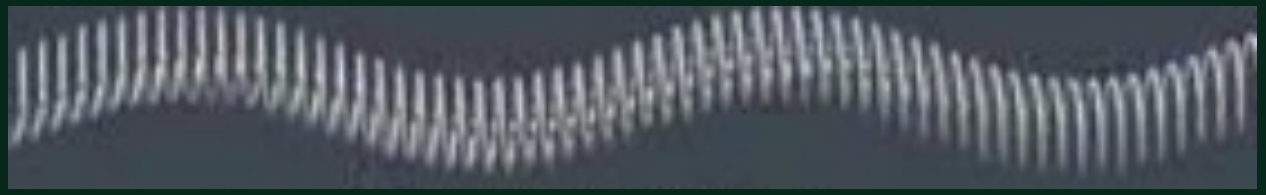
Visão humana

Visão inseto

Ultra violeta não atinge a retina – olhos menores vêm UV
Infravermelho não é detectado

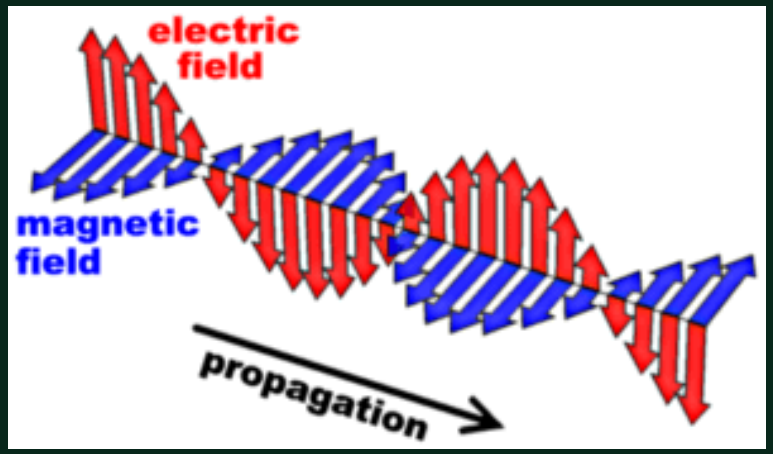
Ondas podem ser:

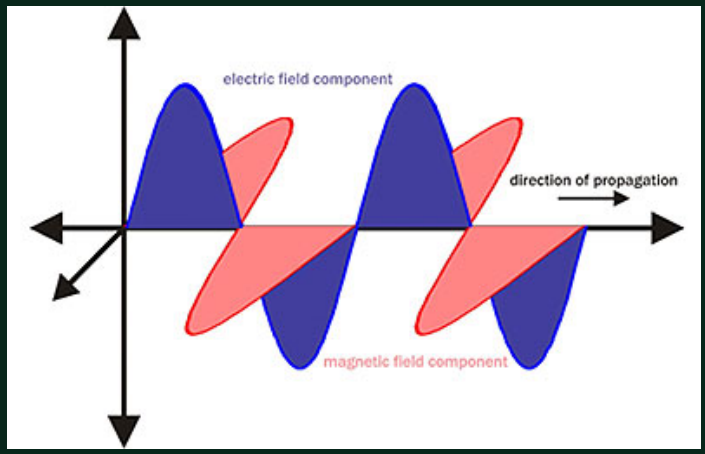
Transversais [POLARIZAÇÃO]



Longitudinais

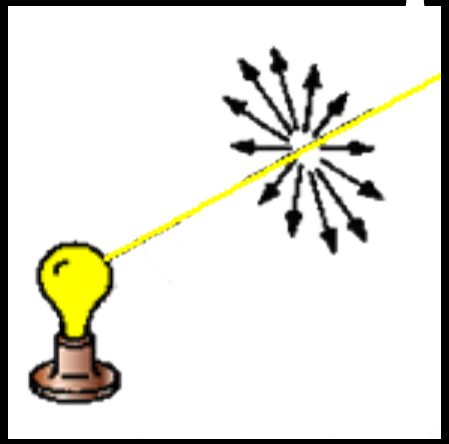
Ondas ópticas são TRANSVERSAIS: $\Psi = \vec{E}\cos\left[k\,x - \omega t\right]$



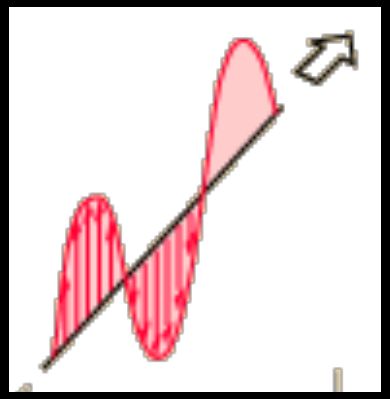


Estados de polarização:

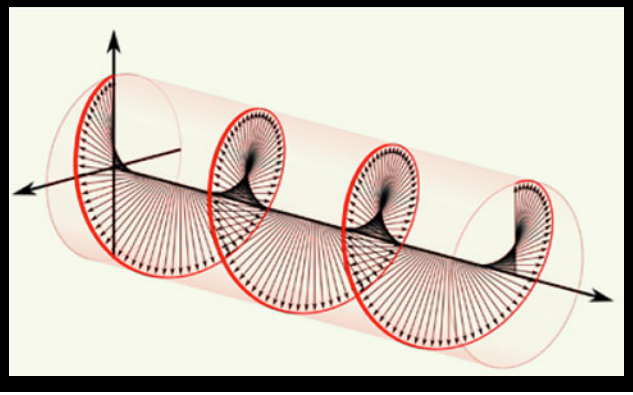
Despolarizado:



Linearmente polarizado:

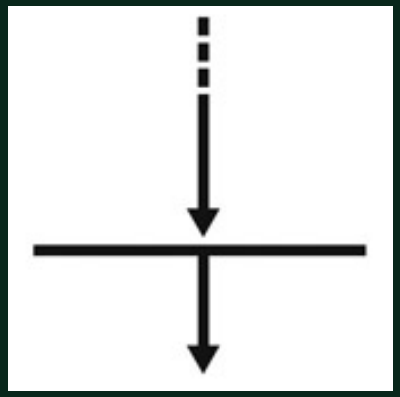


Circularmente polarizado:

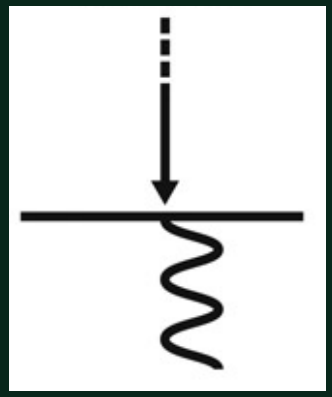


Ondas podem ser:

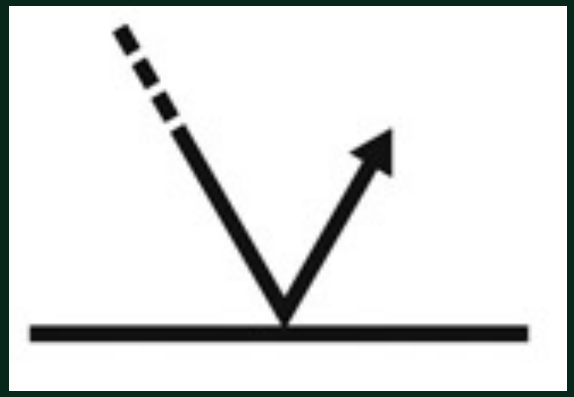
transmitidas



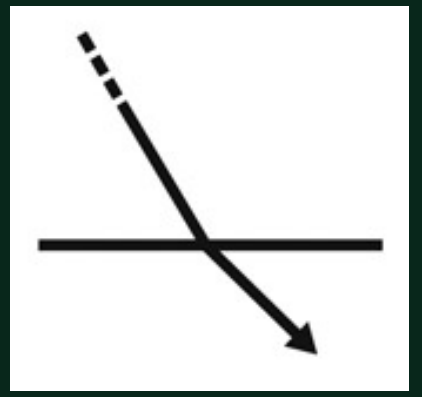
absorvidas



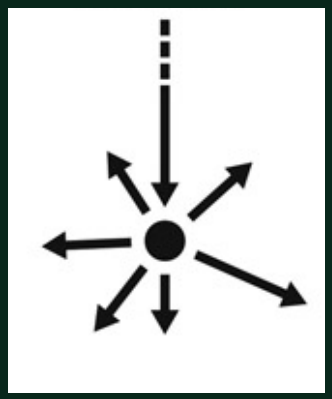
refletidas



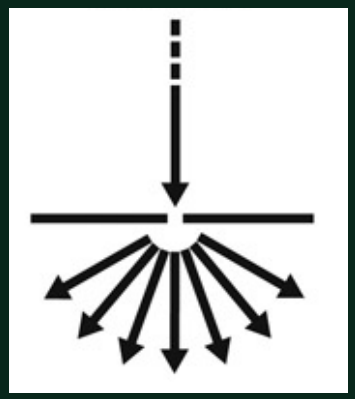
refratadas



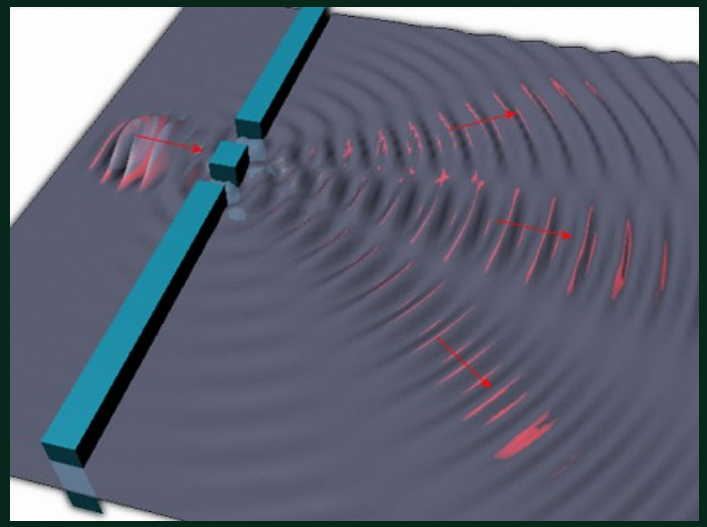
espalhadas



difratadas

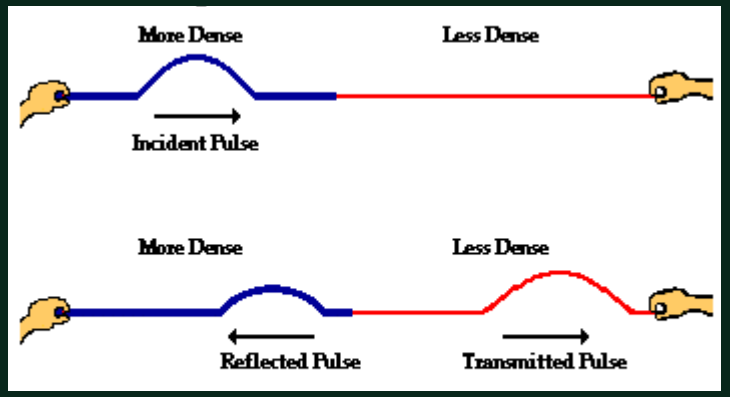


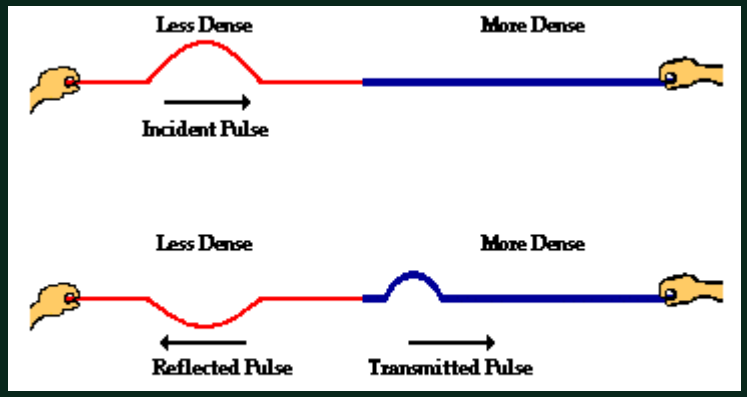
Duas ondas sofrem interferência



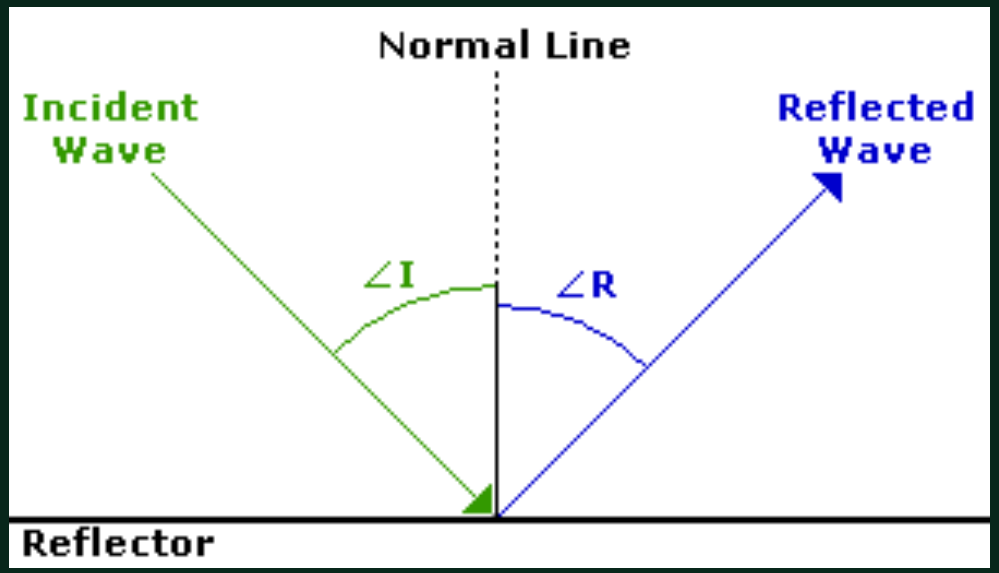
Reflexões

Reflexão ocorre sempre que dois meios são diferentes impedância – índice de refração



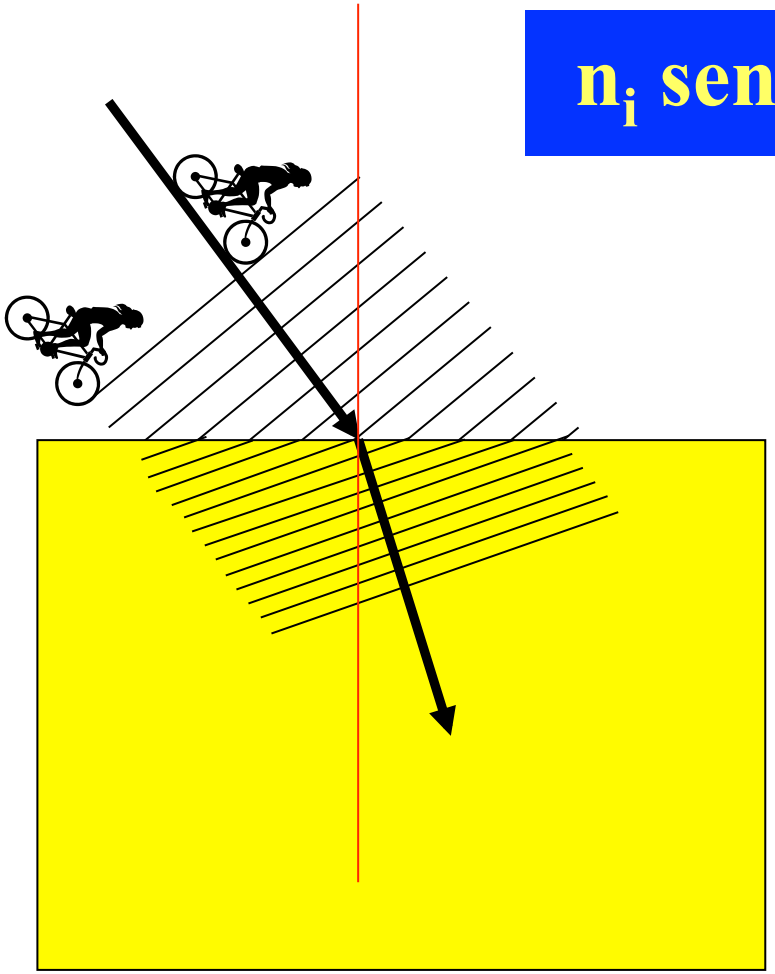


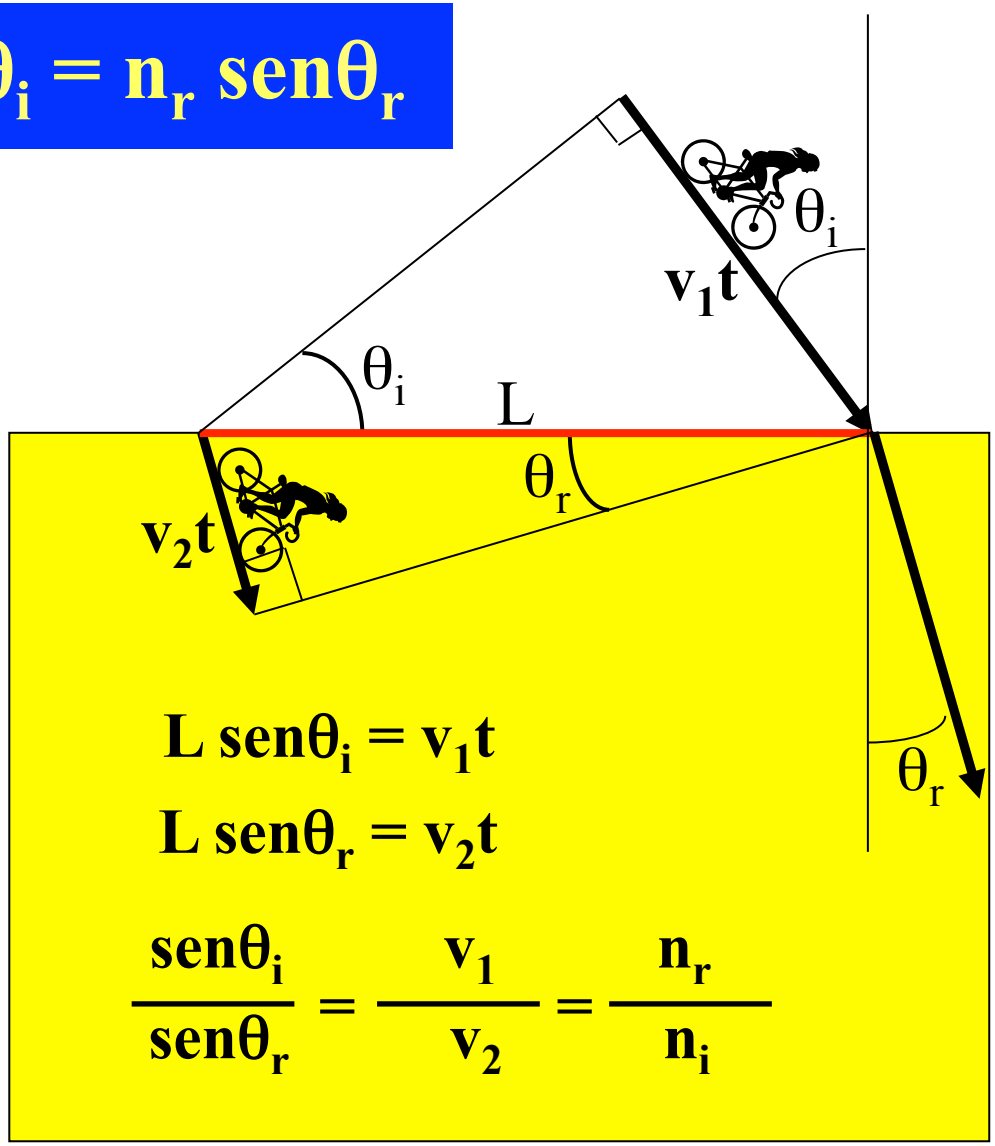
Ângulo de incidência igual ao de reflexão



Refração: Snell (1580-1626) is still alive

$$n_i \operatorname{sen}\theta_i = n_r \operatorname{sen}\theta_r$$





$$L \operatorname{sen}\theta_i = v_1 t$$

$$L \operatorname{sen}\theta_r = v_2 t$$

$$\frac{\operatorname{sen}\theta_i}{\operatorname{sen}\theta_r} = \frac{v_1}{v_2} = \frac{n_r}{n_i}$$

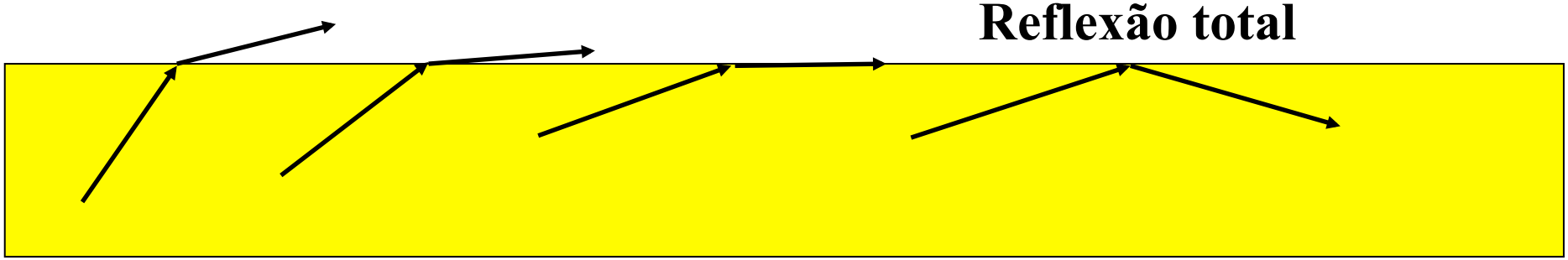
$$k_{vac} = \frac{2\pi}{\lambda} \qquad k_{meio} = \frac{2\pi n}{\lambda}$$

Reflexão interna total

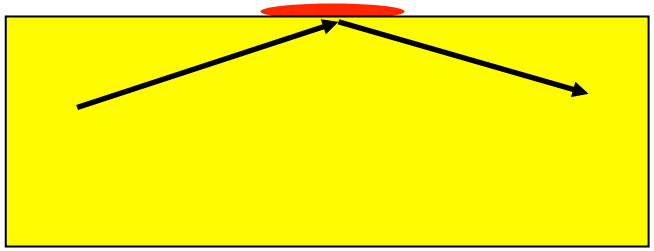
$n_i \, \text{sen}\theta_i = n_r \, \text{sen}\theta_r$

Se $n_i > n_r$ então: $\text{sen}\,\theta_{crit} = [n_r/n_i]$

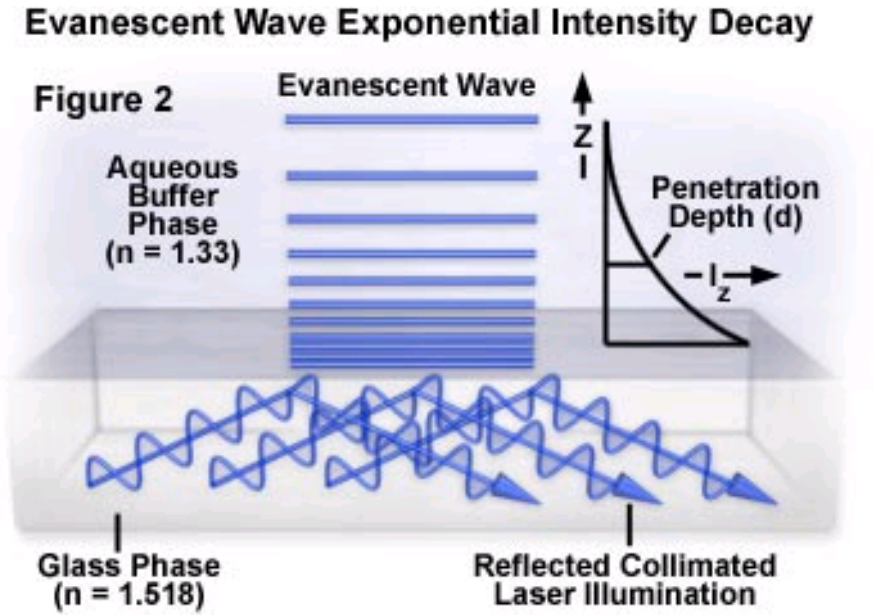
Reflexão total



Campo Evanescente

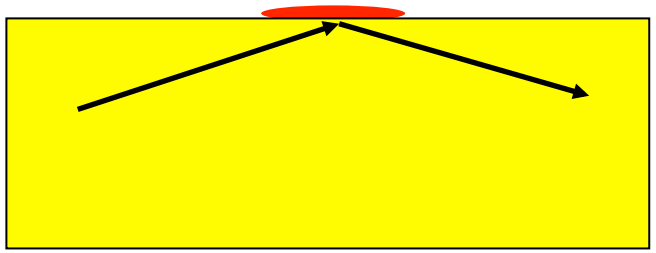


$$E_z = E_o \, e^{-\frac{z}{\delta}}$$



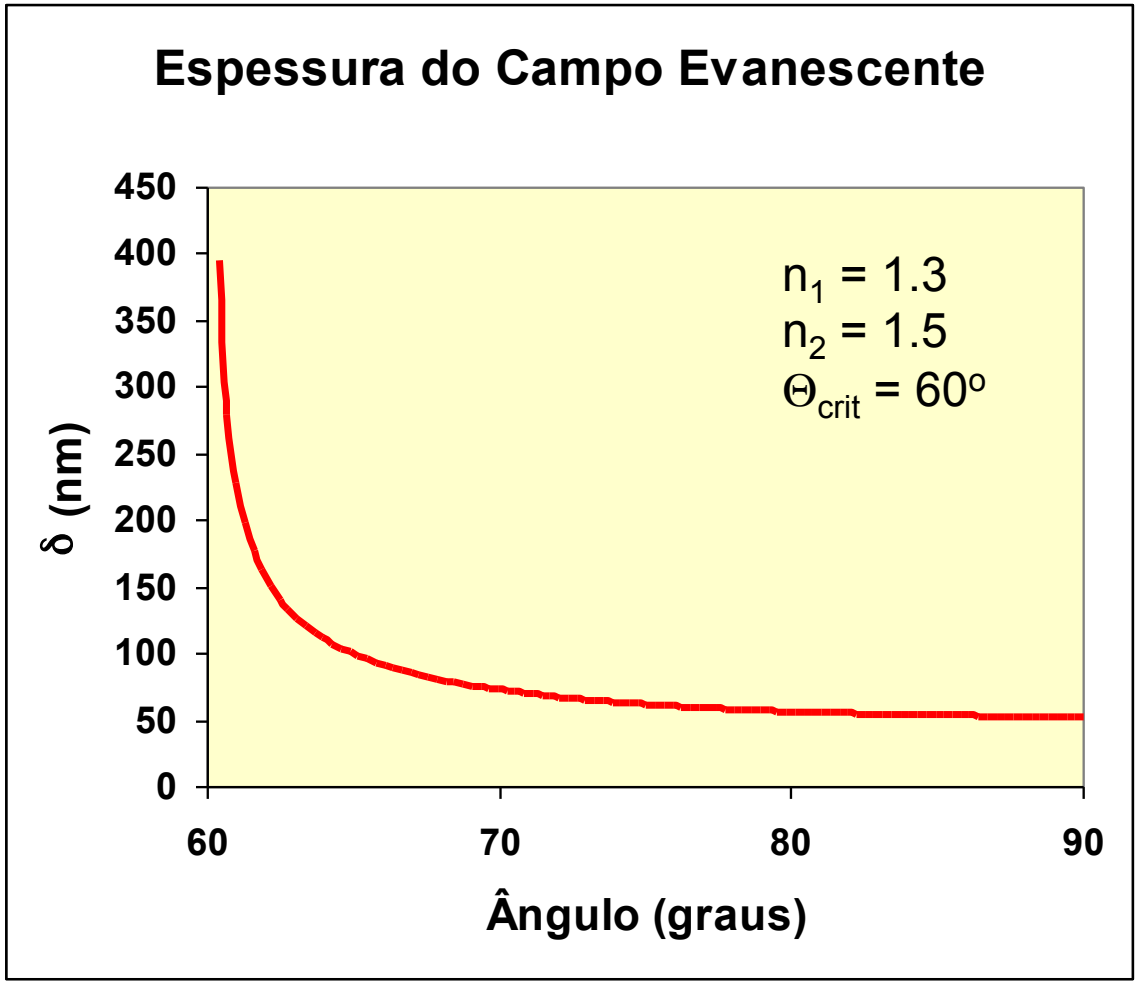
Campo Evanescente
TIRF – Total Internal Reflection Fluorescence

Campo Evanescente



$$E_z = E_o \; e^{-\frac{z}{\delta}}$$

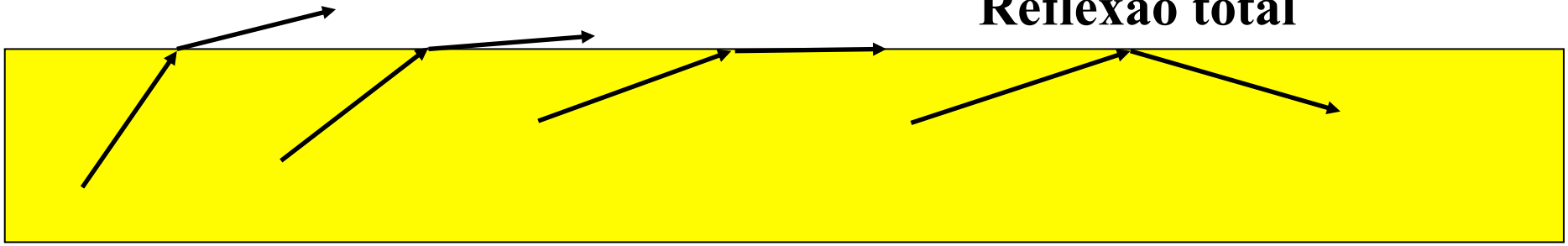
$$\delta = \frac{\lambda_{inc}}{4\pi} \frac{1}{\sqrt{n_1^2 sen^2\theta_1 - n_2^2}}$$



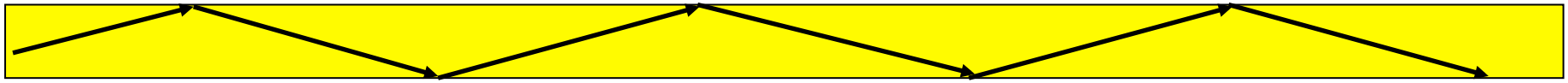
Reflexão interna total e a fibra óptica

$$\text{sen}\theta_{rit} = n_r / n_i$$

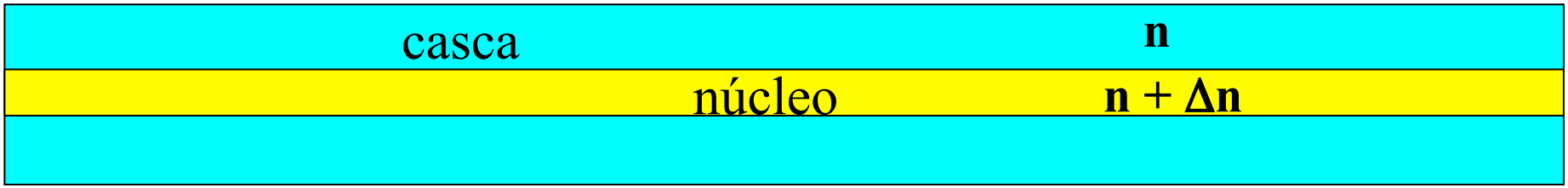
Reflexão total



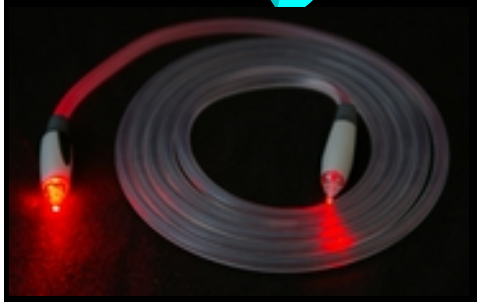
Fibra óptica

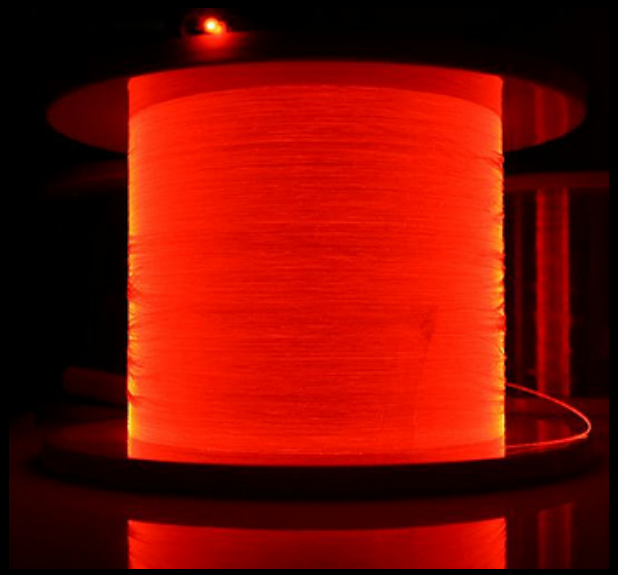


$$\text{sen}\theta = n /(n + \Delta n)$$



Mangueira de luz: fibras ópticas

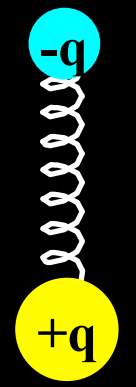


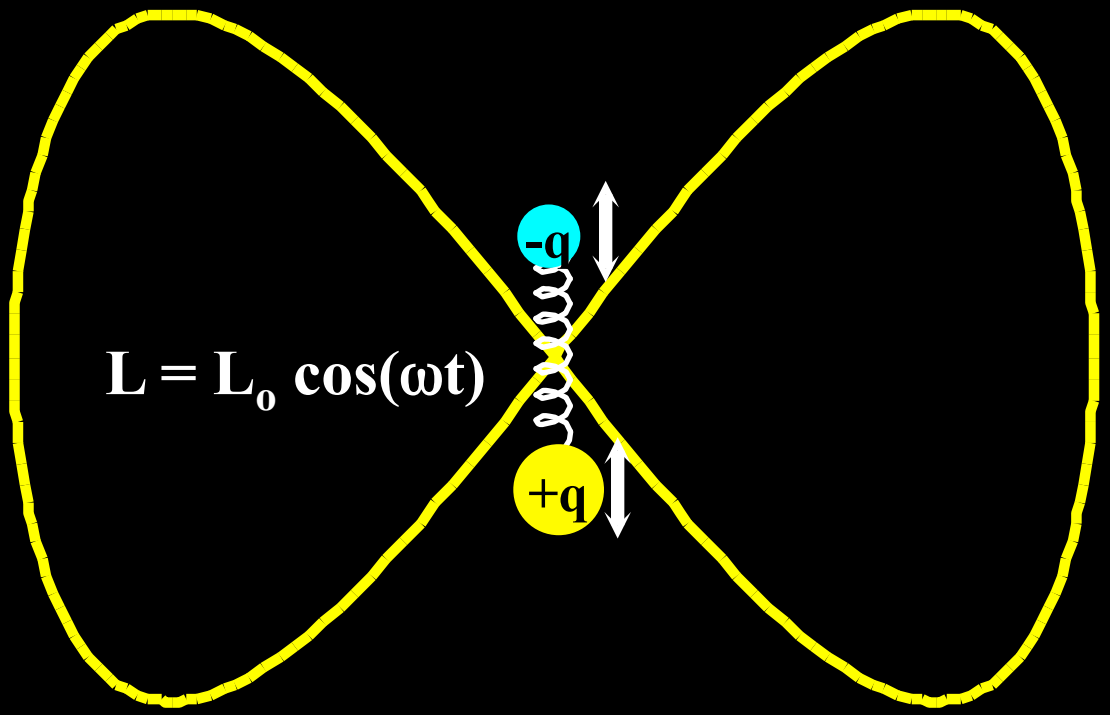


Moda FIBRA - LASER

Geração de radiação: Dipolo oscilante

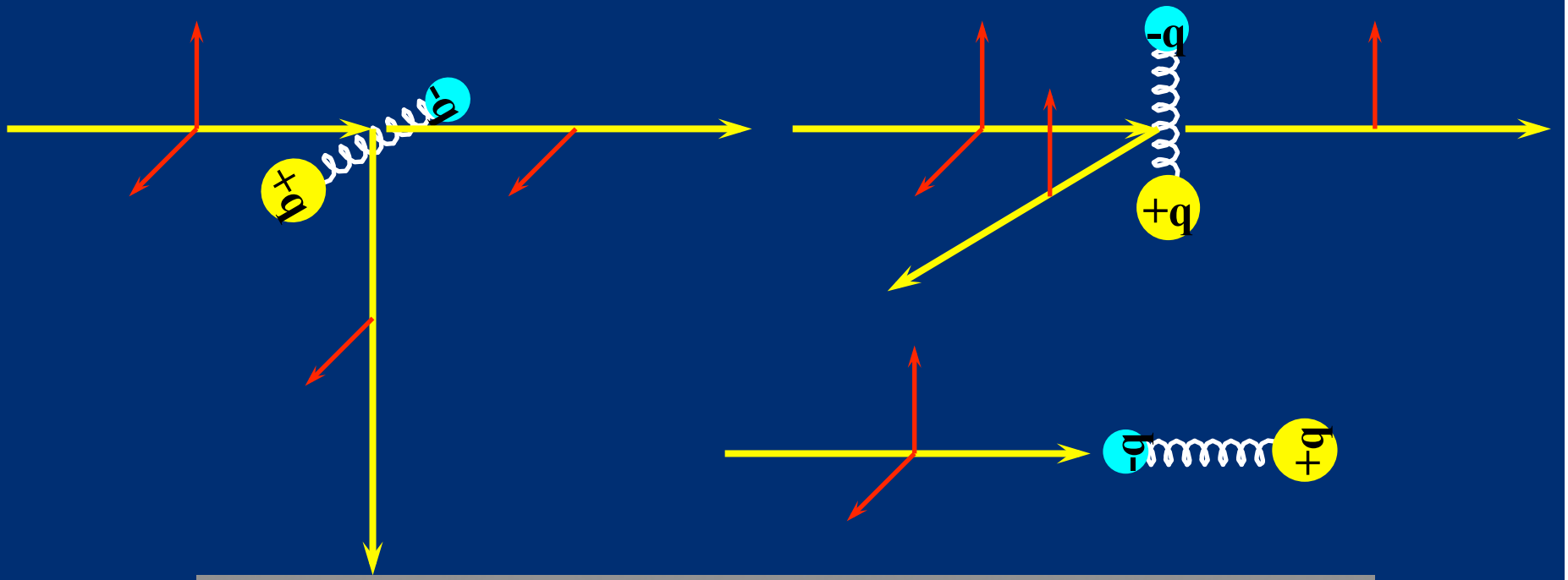
momento de dipolo: p = q L



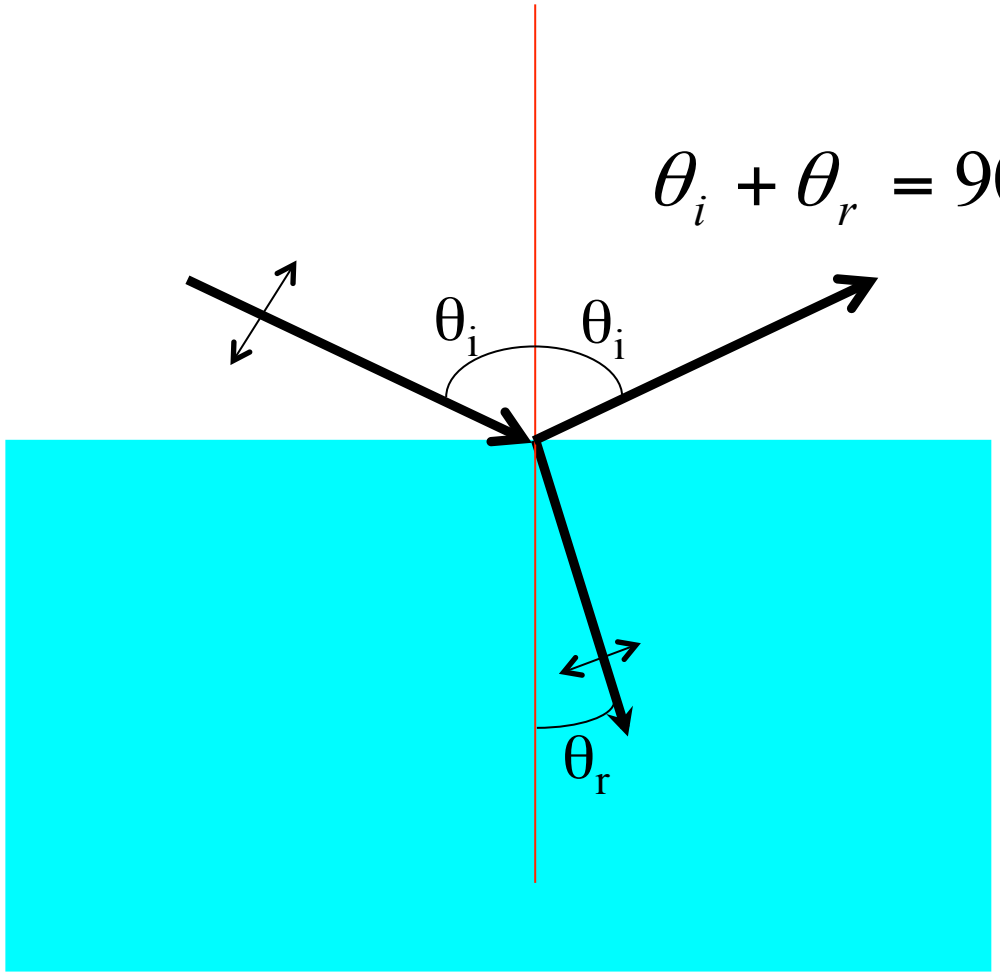


Padrão de Radiação

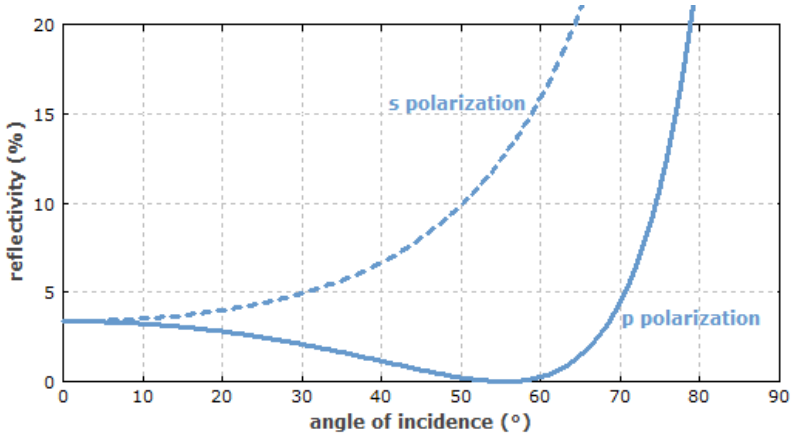
Polarização do céu



Ângulo de Brewster



$$\theta_i + \theta_r = 90^o$$

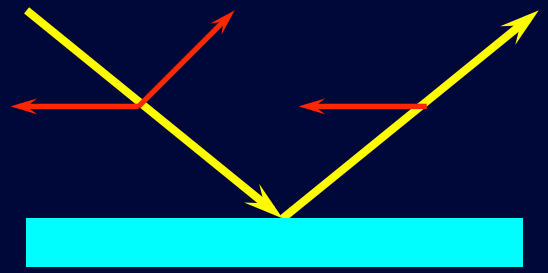


$$n_i \sin\theta_i = n_r \sin\theta_r = n_r \sin[90 - \theta_i]$$

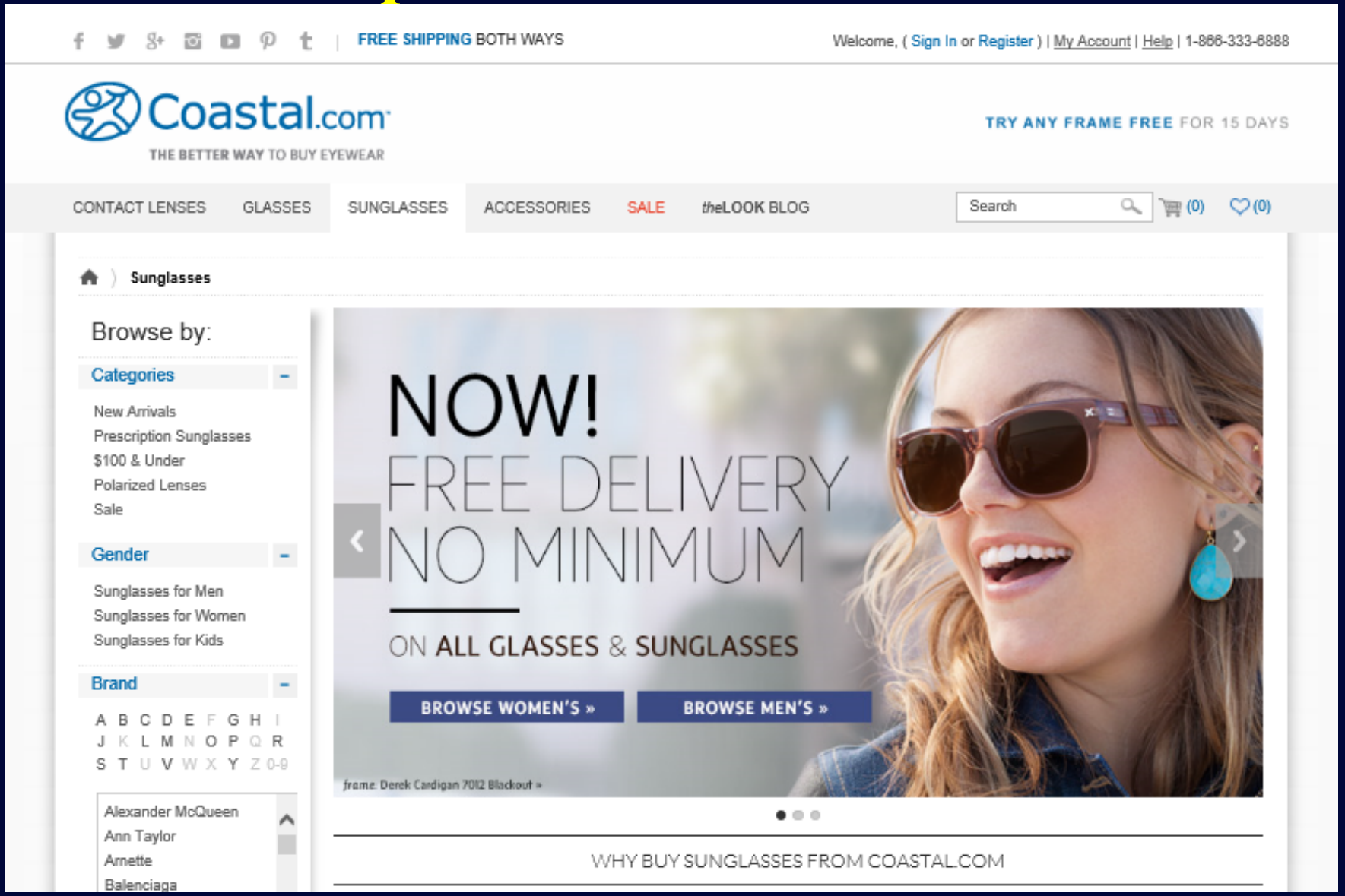
$$n_i \sin\theta_i = n_r \cos\theta_i$$

$$\tan\theta_{Brewster} = \frac{n_r}{n_i}$$

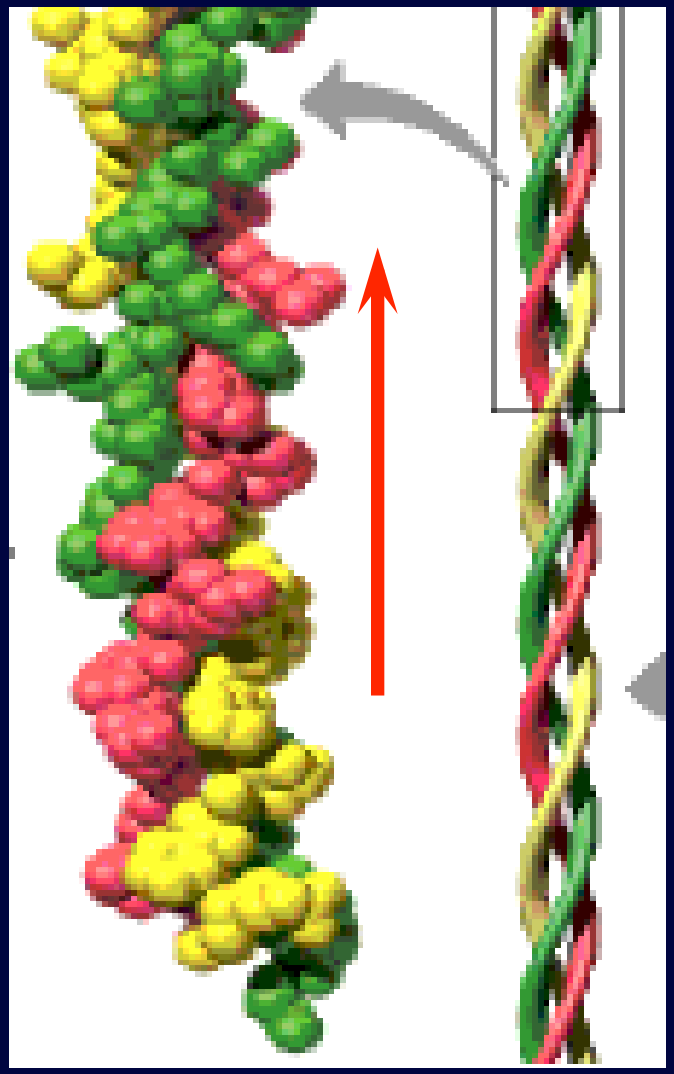
Óculos polarizado: evita reflexão direta



Óculos polarizados
http://www.coastal.com/



Polarização faz diferença: SHG
Fibrilas de colágeno



Porque ondas interferem?

Intensidade proporcional a E^2

$$\Psi = \vec{E}\cos\left[k\,x - \omega t\right] \qquad I \propto \left|\vec{E}\right|^2$$

Duas ondas – qual operação vem primeiro?

Soma e eleva ao quadrado $$I_{total} \propto \left|\vec{E}_1 + \vec{E}_2\right|^2$$

Eleva ao quadrado e soma $$I_{total} \propto \left|\vec{E}_1\right|^2 + \left|\vec{E}_2\right|^2$$

$$\left|E_1\cos(\theta_1) + E_2\cos(\theta_2)\right|^2 = E_1^2\cos^2(\theta_1) + 2E_1E_2\cos(\theta_1)\cos(\theta_2) + E_2^2\cos^2(\theta_2)$$

O termo $2E_1E_2\cos(\theta_1)\cos(\theta_2)$ **gera a interferência!**

A trigonometria e a interferência

$$\cos(a+b) = \cos a \cos b - \sin a \sin b$$

$$\cos(a-b) = \cos a \cos b + \sin a \sin b$$

$$\cos a \cos b = \frac{1}{2}\cos(a+b) + \frac{1}{2}\cos(a-b)$$

Invertendo

$$a + b = \theta_2$$
$$a - b = \theta_1$$

$$a = \left(\frac{\theta_2 + \theta_1}{2}\right) \quad b = \left(\frac{\theta_2 - \theta_1}{2}\right)$$

$$\cos(\theta_2) + \cos(\theta_1) = 2\cos\left(\frac{\theta_2 + \theta_1}{2}\right)\cos\left(\frac{\theta_2 - \theta_1}{2}\right)$$

Interferência

$$\cos(\theta_2)+\cos(\theta_1)=2\cos\left(\frac{\theta_2+\theta_1}{2}\right)\cos\left(\frac{\theta_2-\theta_1}{2}\right)$$

$$y_1 = y_o\cos(kx_1-\omega t)$$

$$y_2 = y_o\cos(kx_2-\omega t)$$

$$y_1+y_2=2\cos\left[\frac{k}{2}(x_2+x_1)-\omega t\right]\cos\left[\frac{k}{2}(x_2-x_1)\right]$$

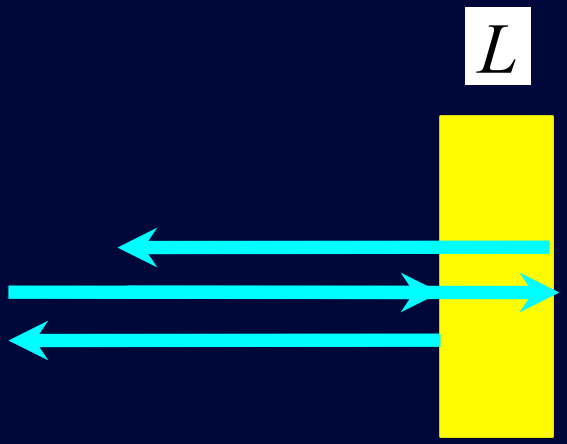
Máximo se: $\cos\left[\frac{k}{2}(x_2-x_1)\right]=\pm 1 \rightarrow \frac{\pi}{\lambda}\delta x = m\pi$ $\quad \delta x = m\lambda$

Mínimo se: $\cos\left[\frac{k}{2}(x_2-x_1)\right]=0$ $\quad \delta x=\left(m+\frac{1}{2}\right)\lambda$

Espelhos dielétricos: Filtros dicróicos

Máximo se: $\delta x = m\lambda$

Mínimo se: $\delta x = \left(m + \frac{1}{2}\right)\lambda$

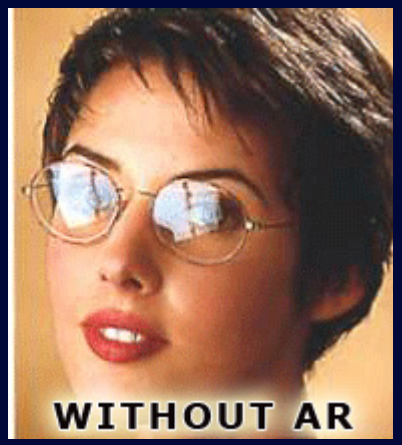


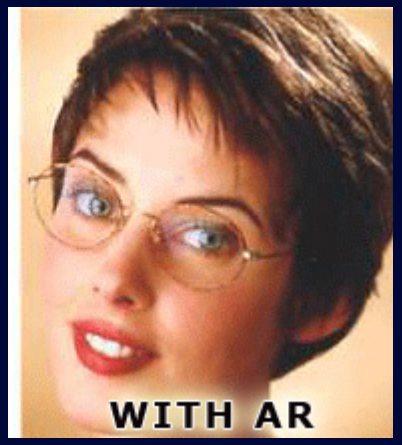
Anti-reflection

$\lambda = 4L$

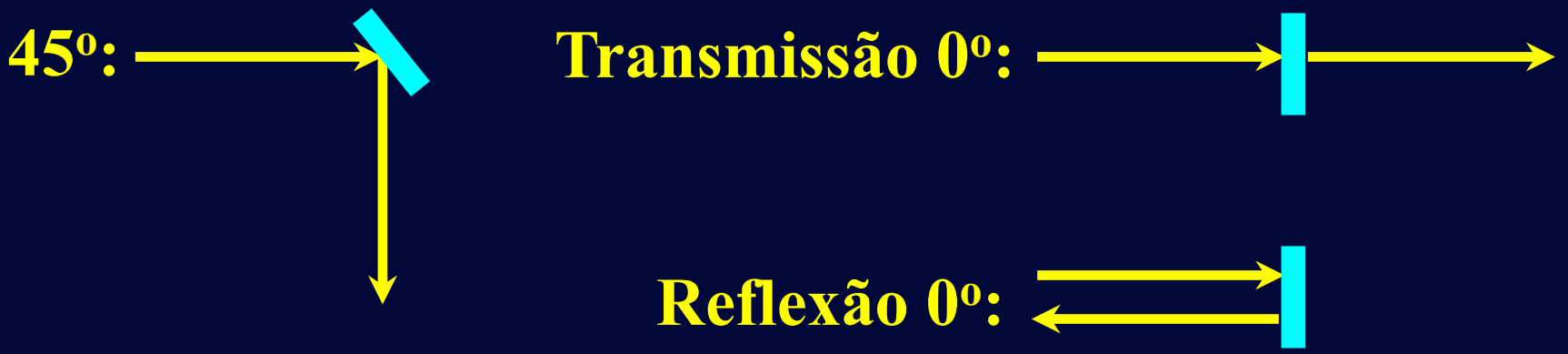
Espelho perfeito

$\lambda = 2L$

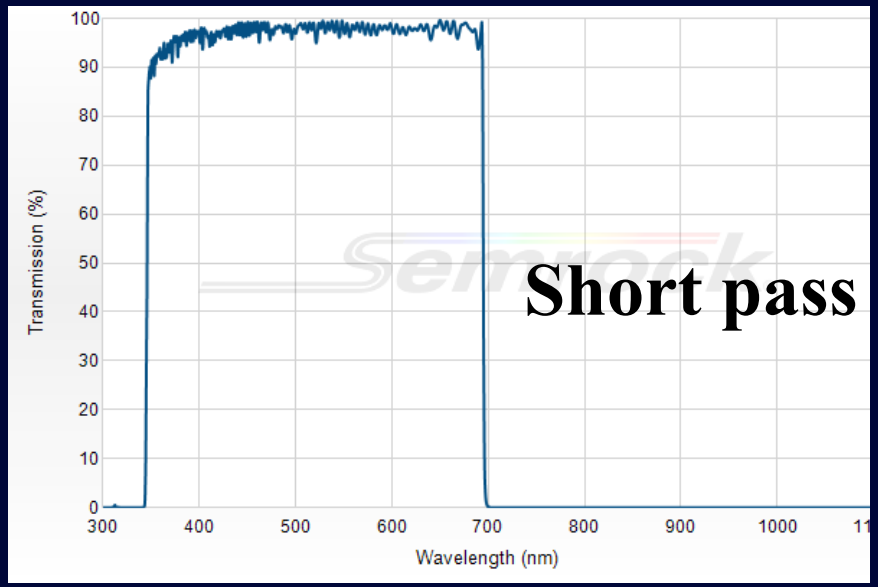




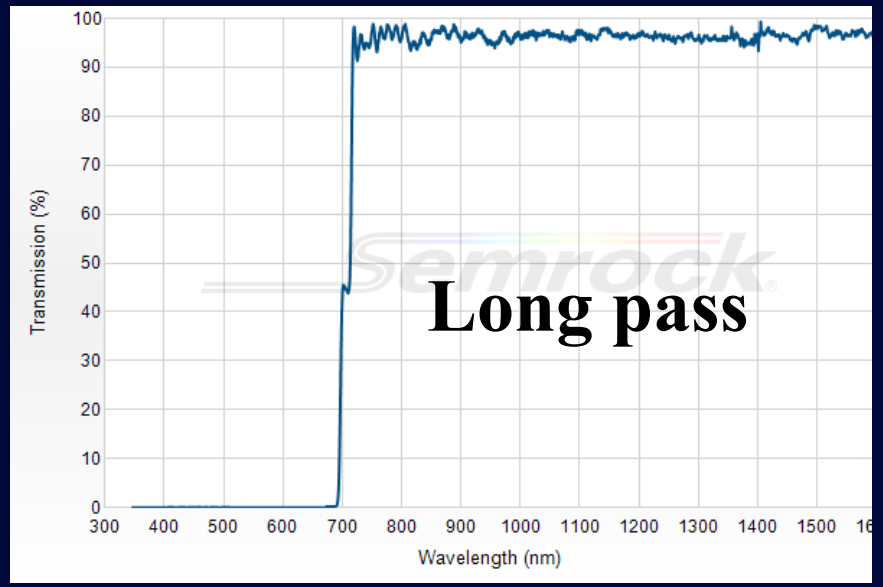
Geometria dos filtros dicróicos:



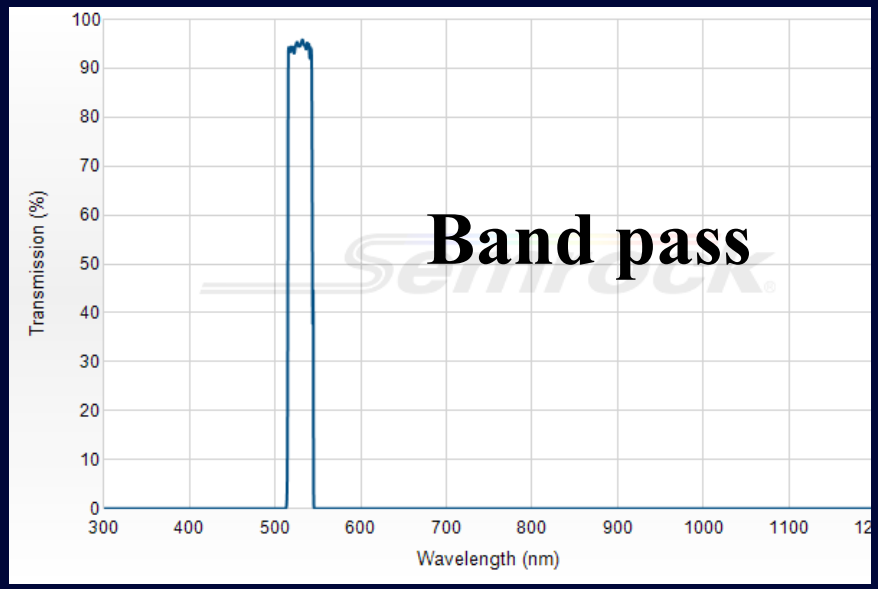
Tipos de filtros dicróicos:



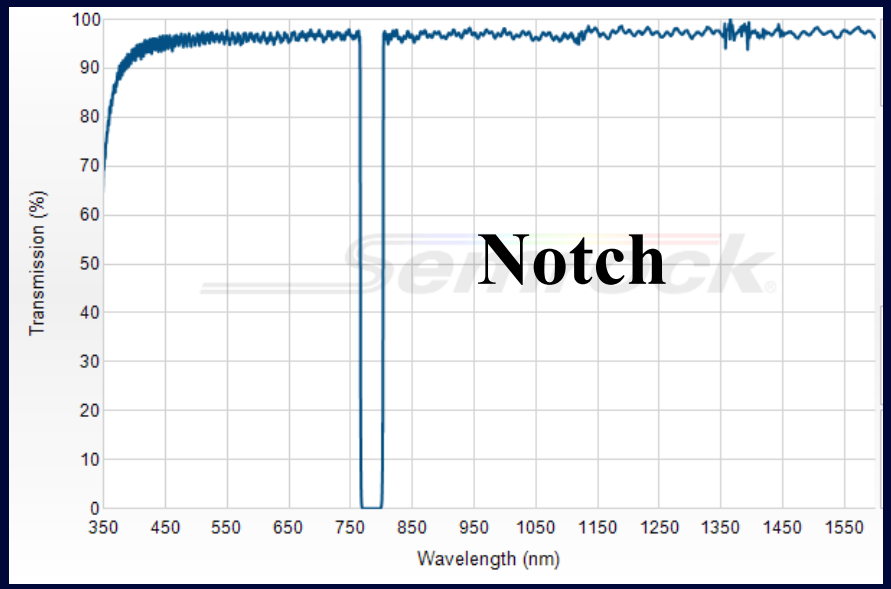
Short pass



Long pass

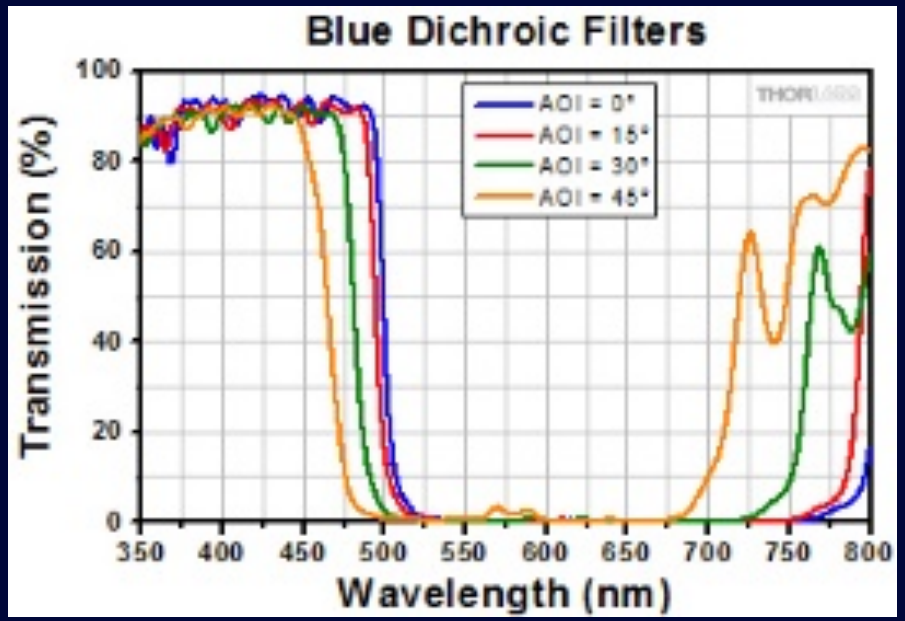


Band pass

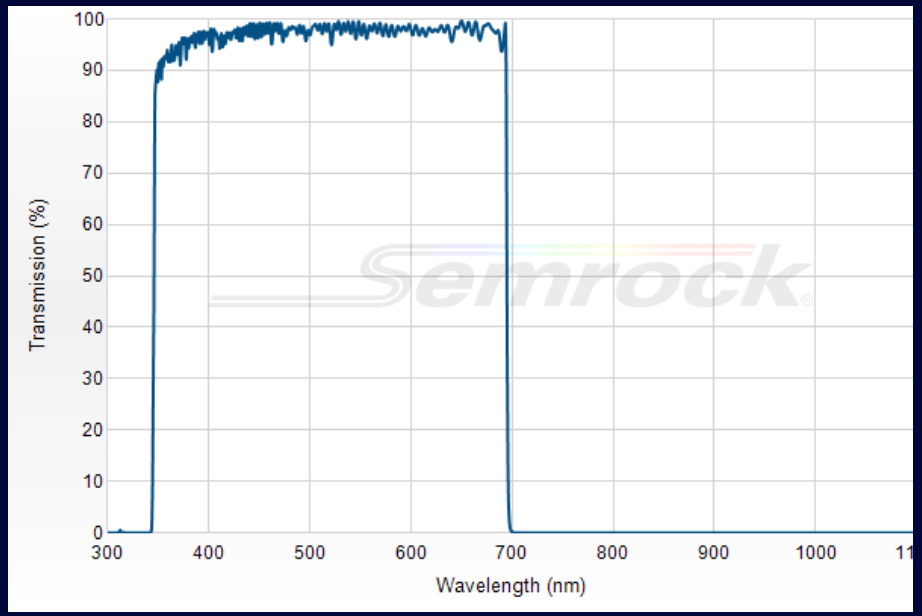


Notch

Dicróicos:



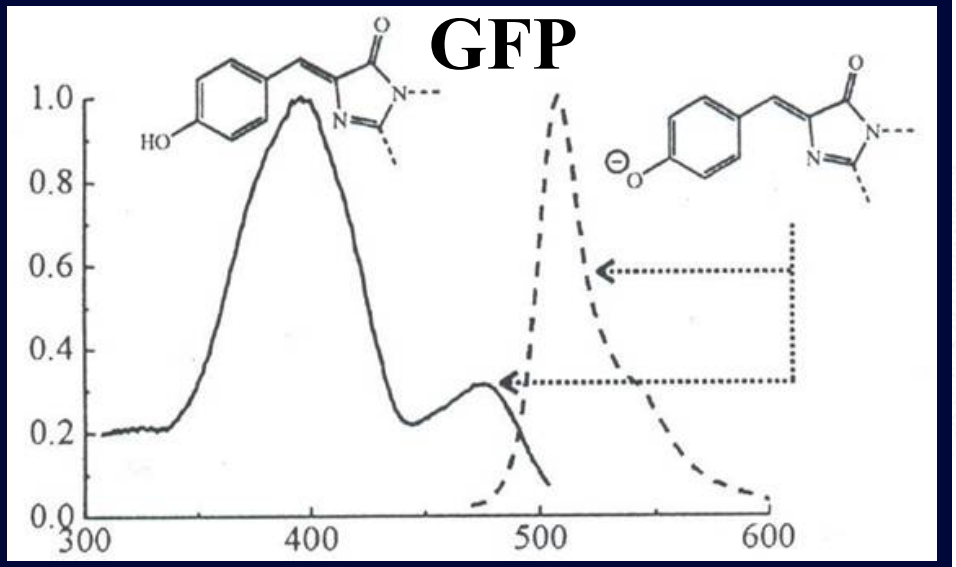
30 USD



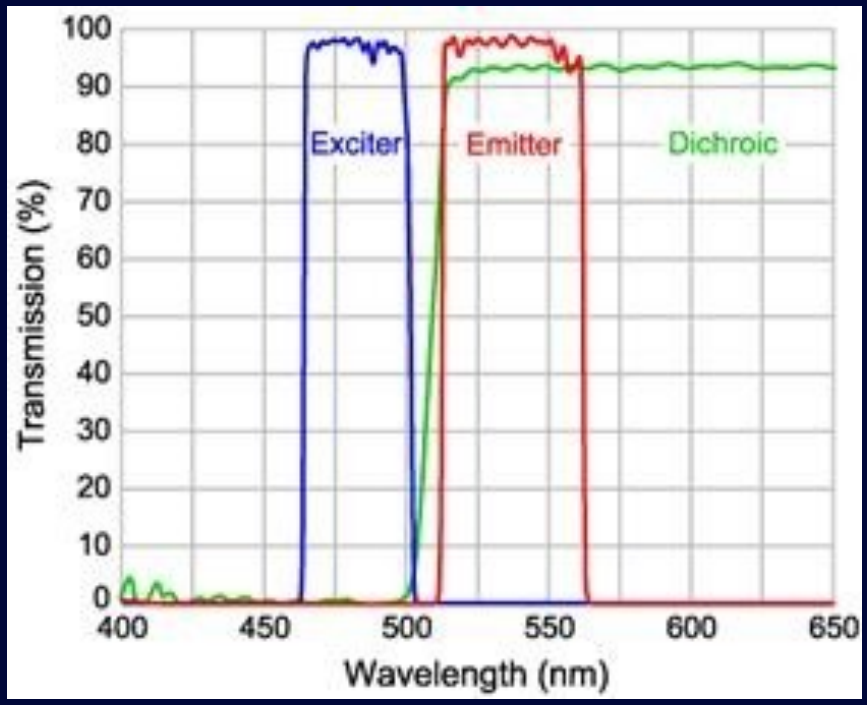
300 USD

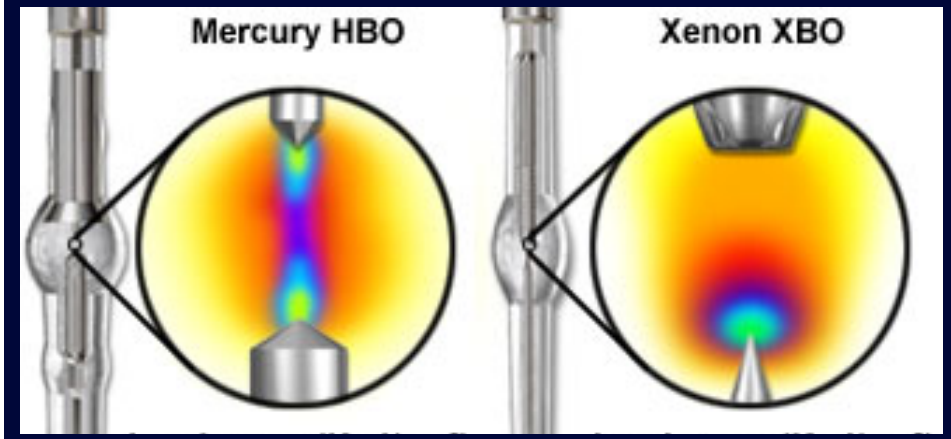
Cubos de filtros para fluorescência

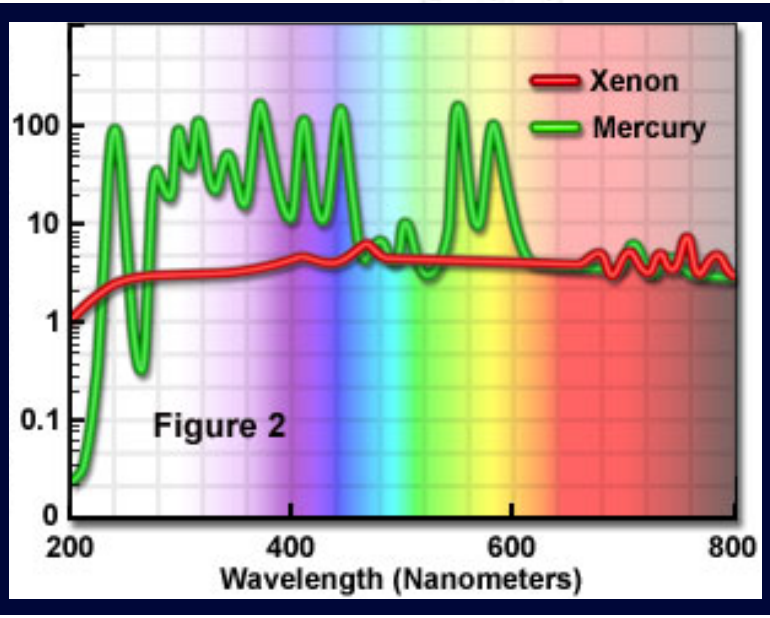
Cubos de filtros para fluorescência



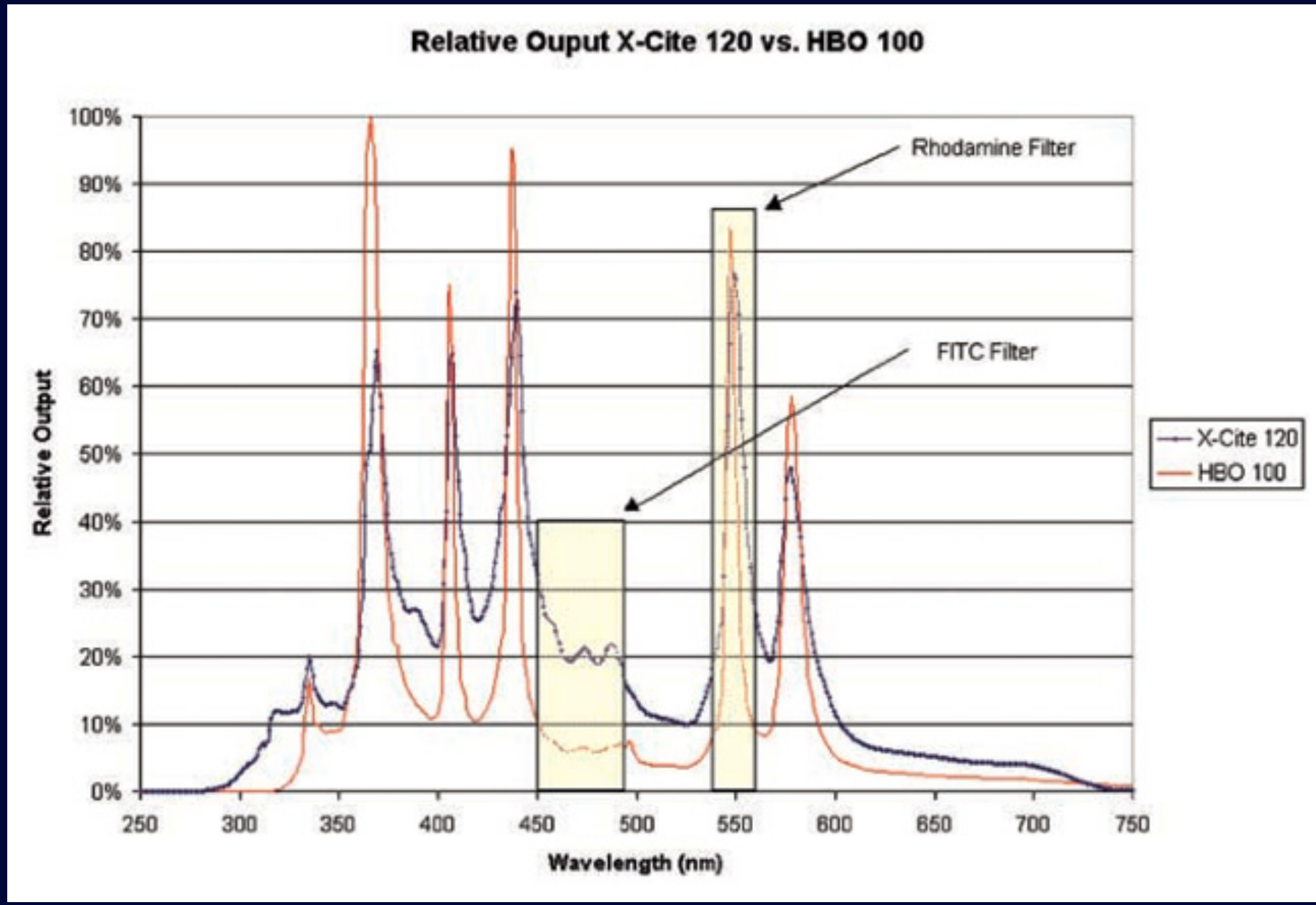
Banda de excitação **Banda de emissão**



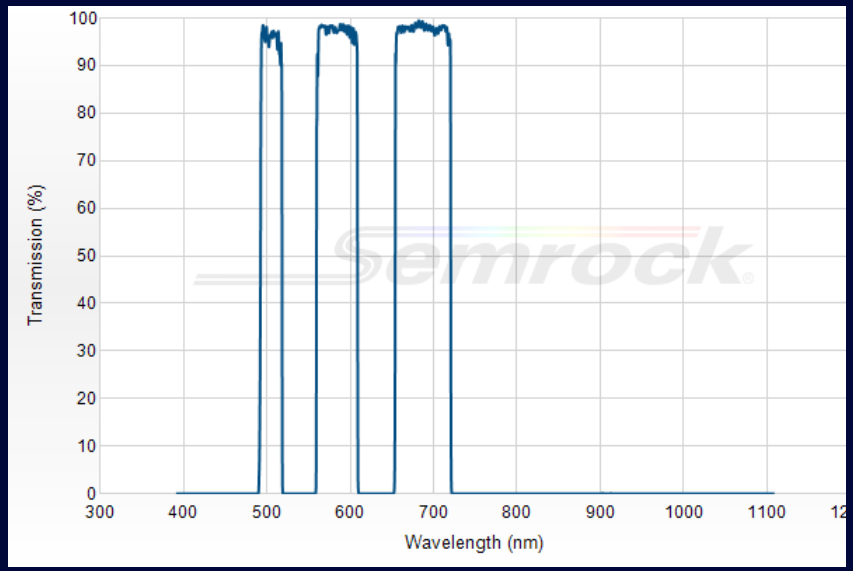




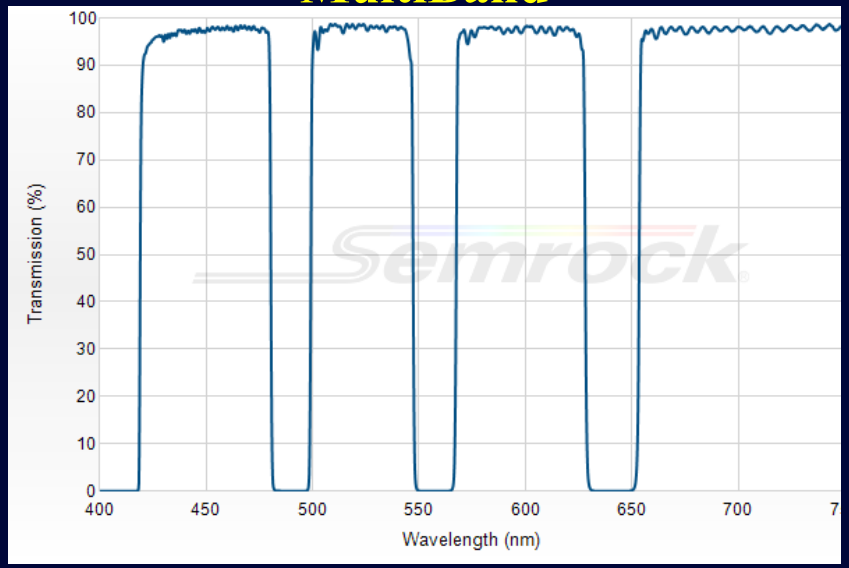
X-Cite – Mercury Lamp



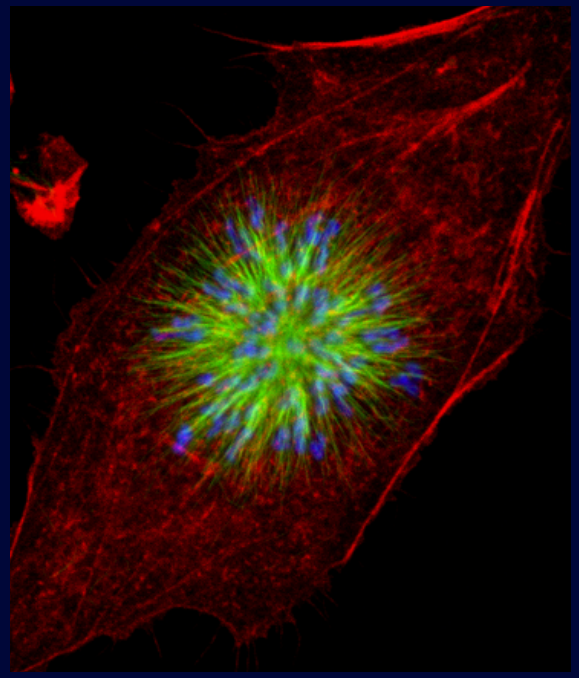
Filtros para marcação multicores

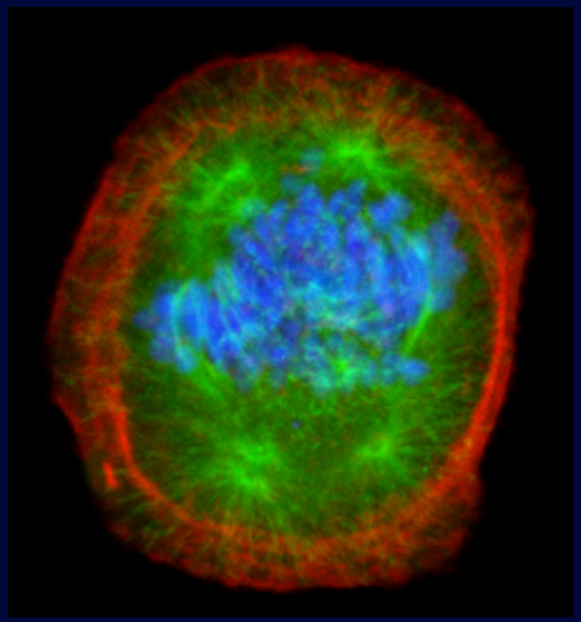


MultiBand



MultiNotch



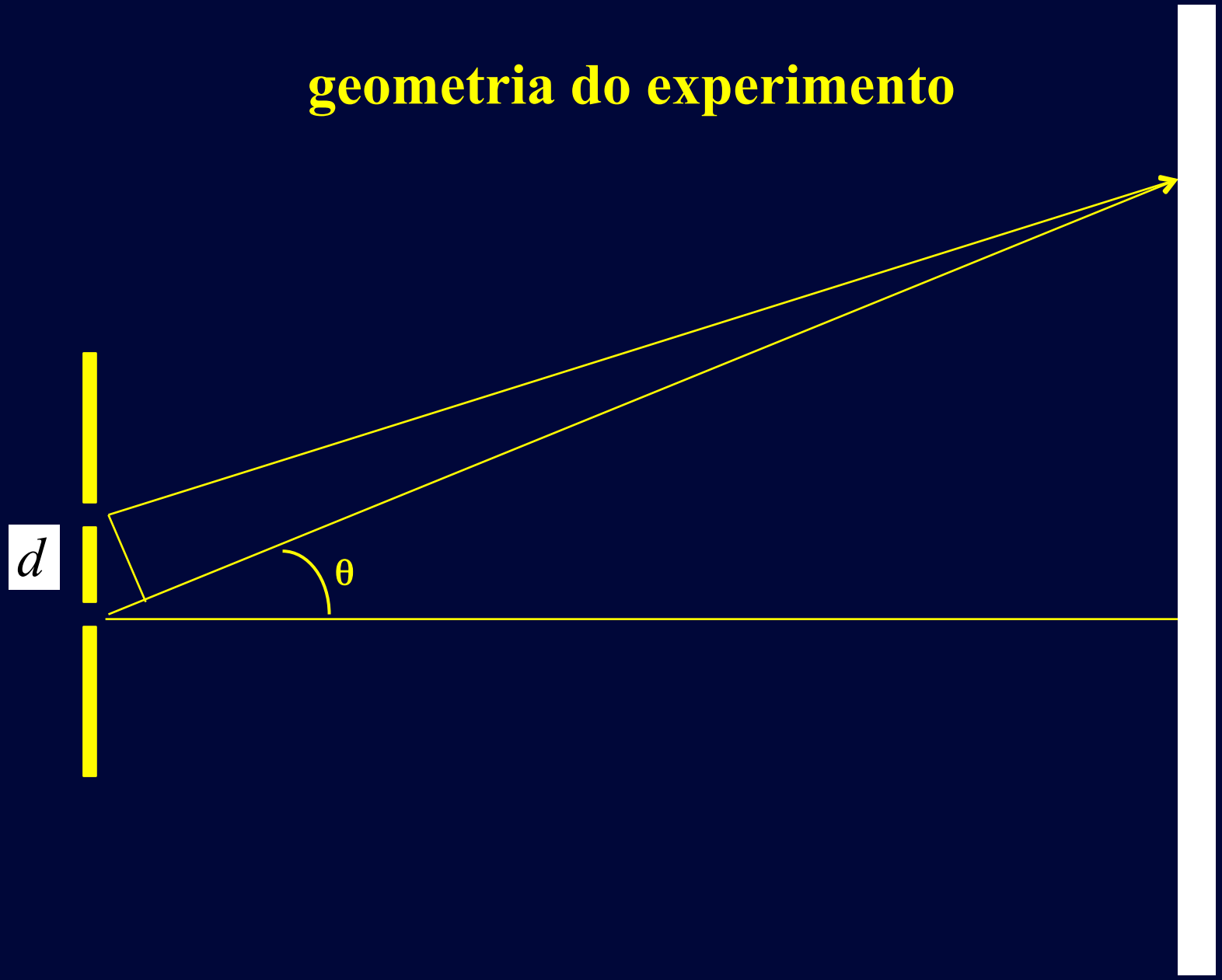


Bovine endothelial

Optical Resolution

Interferência fenda dupla

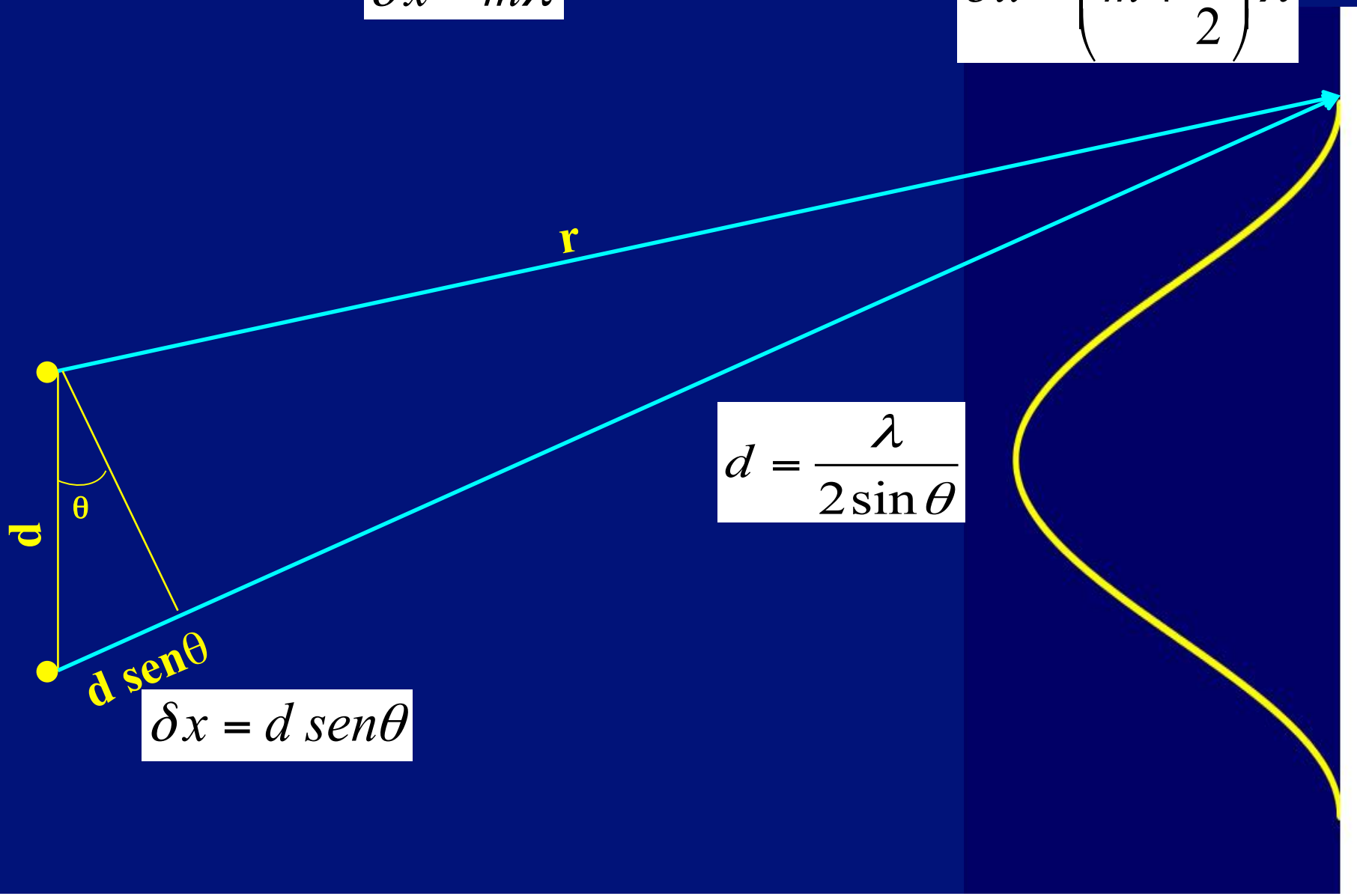
geometria do experimento



Interferência fenda dupla

Máximo se: $\delta x = m\lambda$

Mínimo se: $\delta x = \left(m + \frac{1}{2}\right)\lambda$

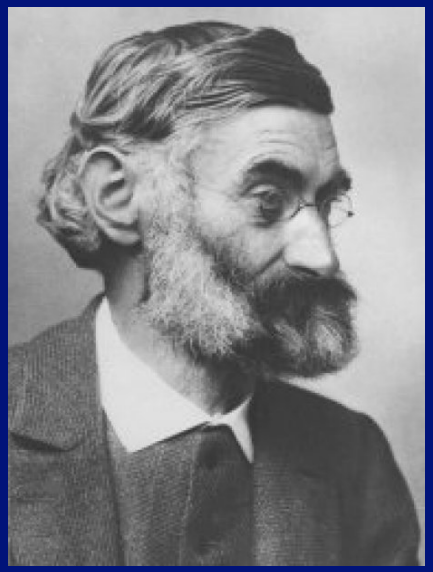


$$d = \frac{\lambda}{2\sin\theta}$$

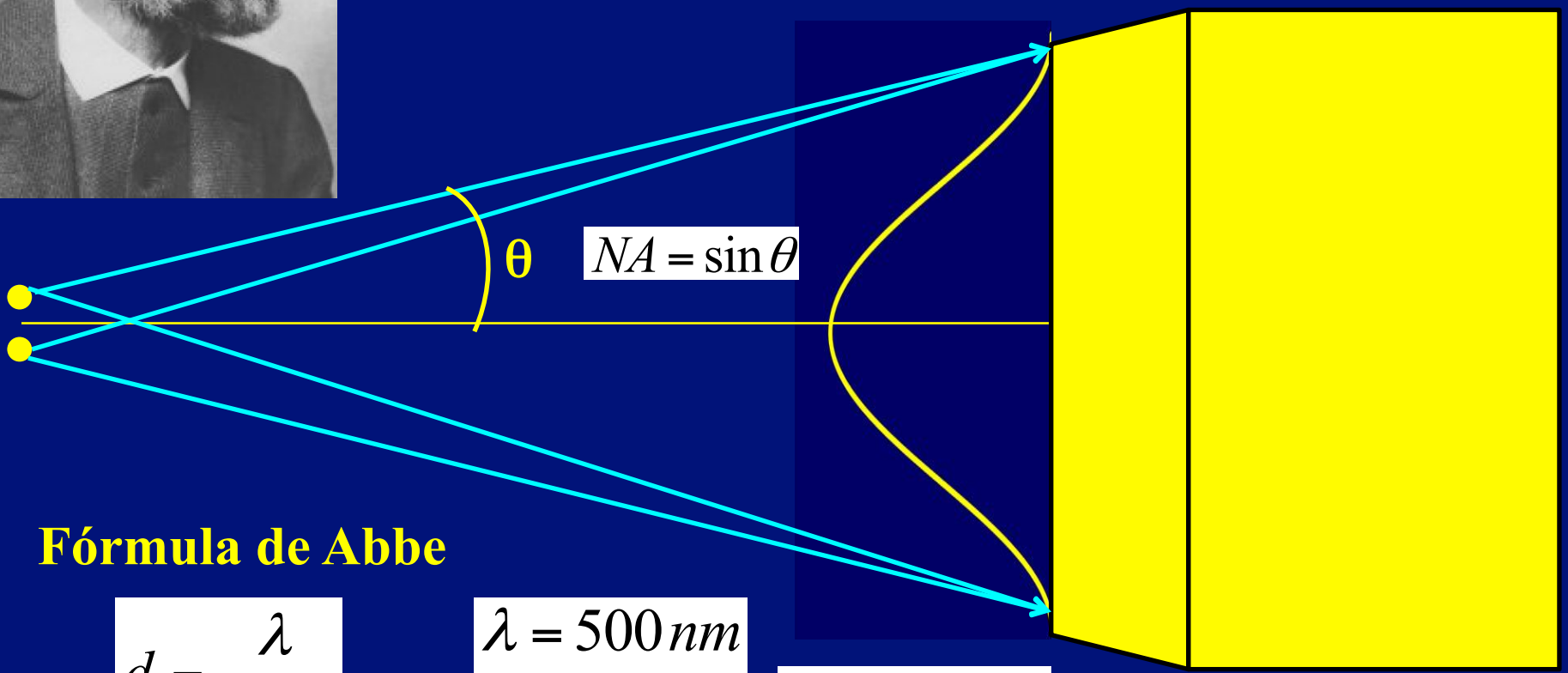
$$\delta x = d\,sen\theta$$

Qual o limite de RESOLUÇÃO? DIFRAÇÃO

1878 – Ernest Abbe 1840-15 e a fórmula da resolução espacial



$$d = \frac{\lambda}{2\sin\theta}$$



Fórmula de Abbe

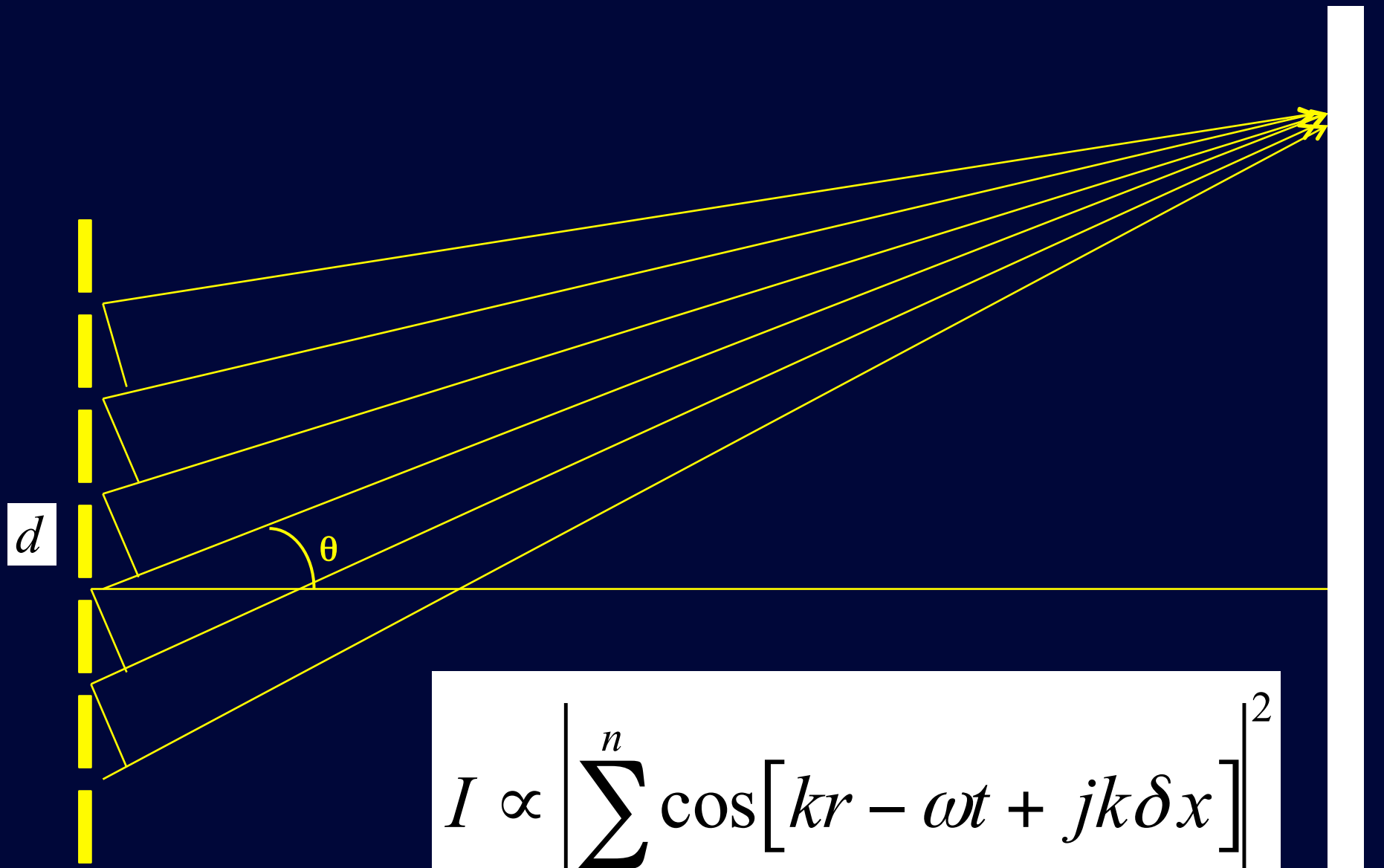
$$d = \frac{\lambda}{2NA}$$

$\lambda = 500\,nm$

$NA = 1$

$d = 250\,nm$

Multiplas fendas



$$I \propto \left| \sum_{j=0}^{n} \cos\left[kr - \omega t + jk\delta x \right] \right|^2$$

Multiplas fendas

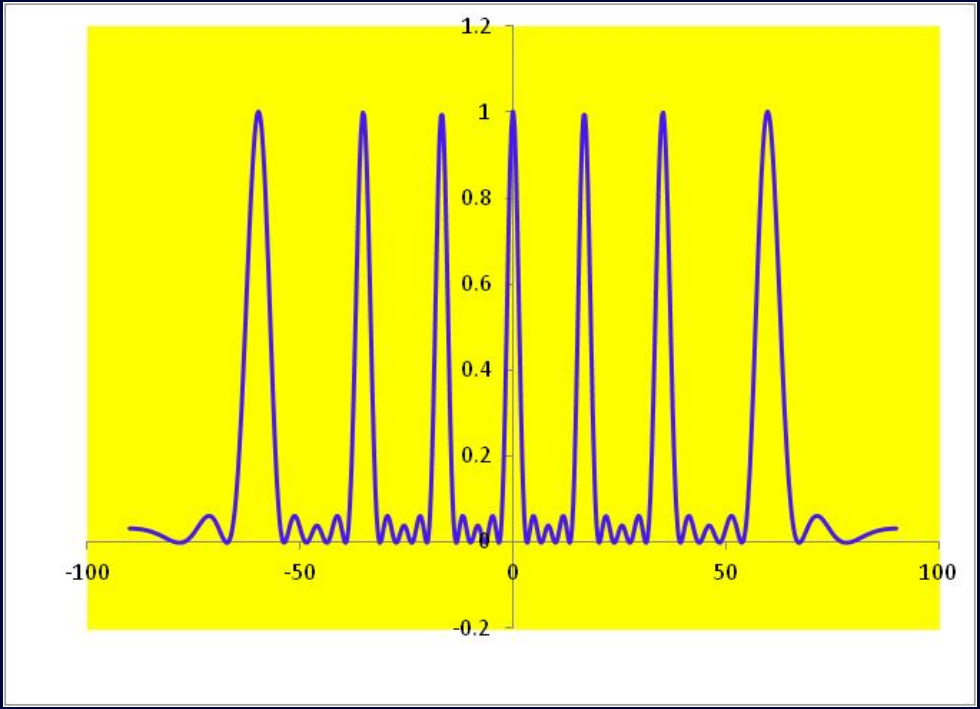
$$\sin\theta = \frac{\lambda}{Nd}$$

$= 0$

$$I \propto \frac{\sin^2\left(N\frac{\pi d \sin\theta}{\lambda}\right)}{\sin^2\left(\frac{\pi d \sin\theta}{\lambda}\right)}$$

$= 0$

$$\sin\theta = m\frac{\lambda}{d}$$



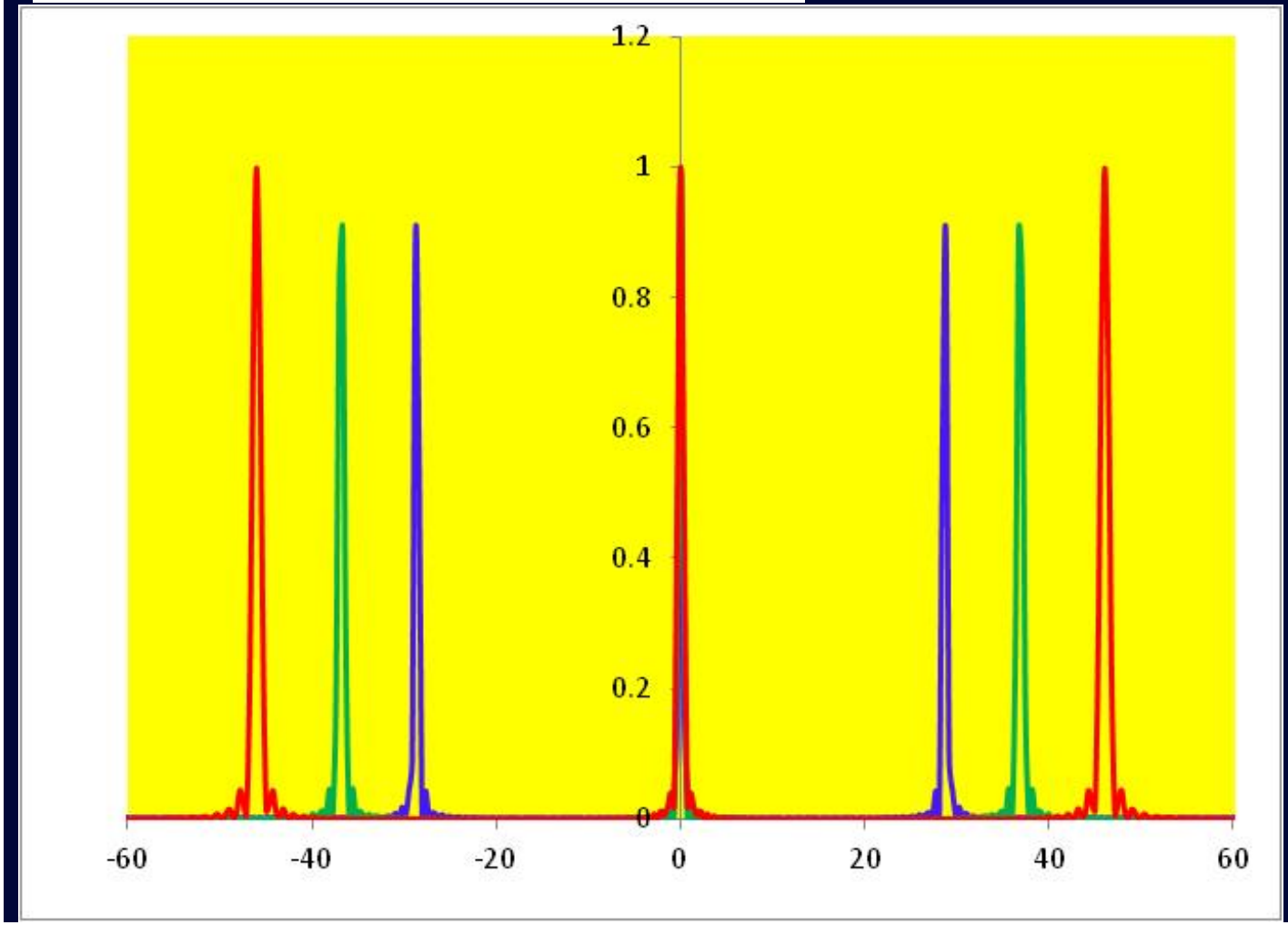
$m = 0 \rightarrow ordem\,0$

$m = \pm 1 \rightarrow ordem\,1$

$m = \pm 2 \rightarrow ordem\,2$

Grade de difração:
separando comprimentos de ondas

$$M = n^o \frac{\text{riscos}}{\text{mm}} \rightarrow d = \frac{1}{M}$$



Valores típicos

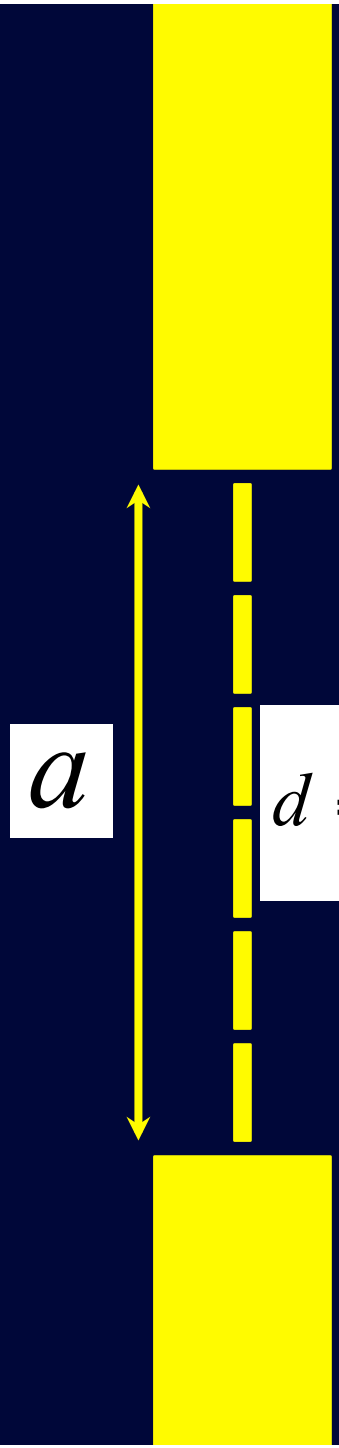
$$M = 300\ {}^{g}/_{mm}$$

$$M = 600\ {}^{g}/_{mm}$$

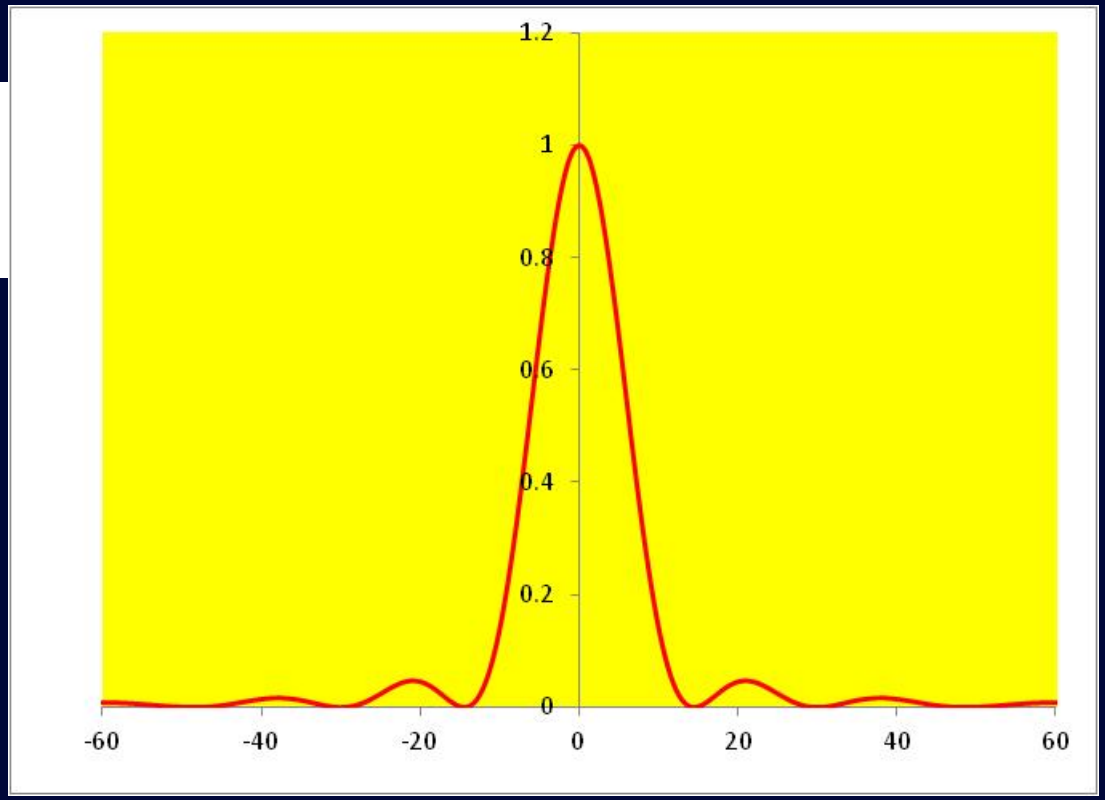
$$M = 1200\ {}^{g}/_{mm}$$

DIFRAÇÃO

$$I \propto \frac{\sin^2\left(\frac{\pi a \sin\theta}{\lambda}\right)}{\sin^2\left(\frac{\pi a \sin\theta}{N\lambda}\right)} \equiv N^2 \frac{\sin^2\left(\frac{\pi a \sin\theta}{\lambda}\right)}{\left(\frac{\pi a \sin\theta}{\lambda}\right)^2}$$



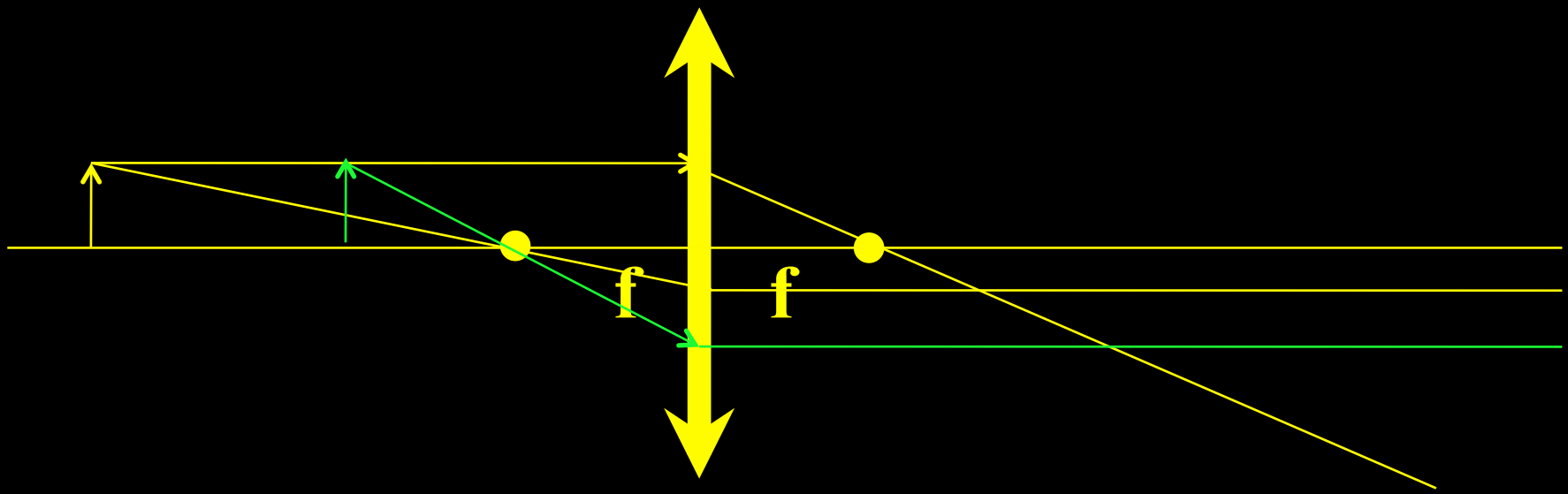
$$d = \frac{a}{N}\left[N \to \infty\right]$$

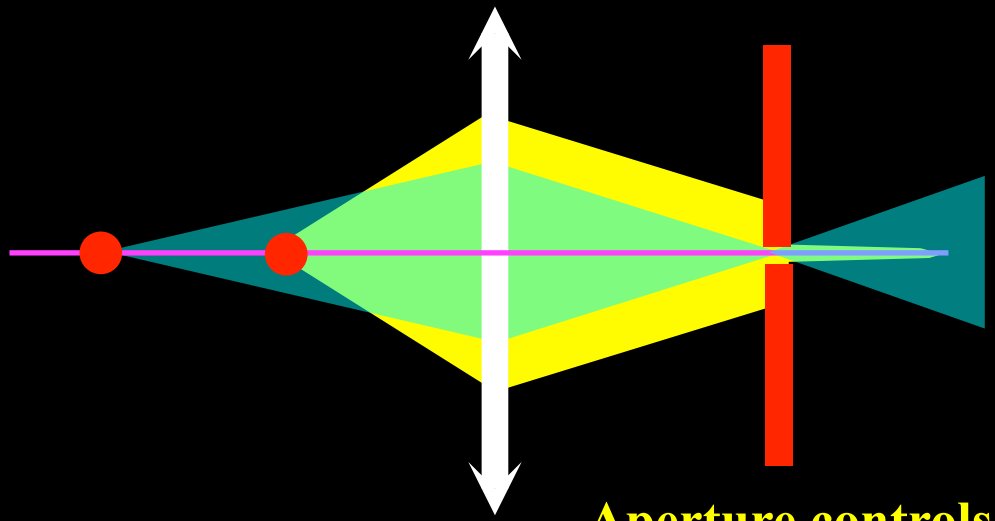


Microscopia Confocal

Entendendo o equipamento

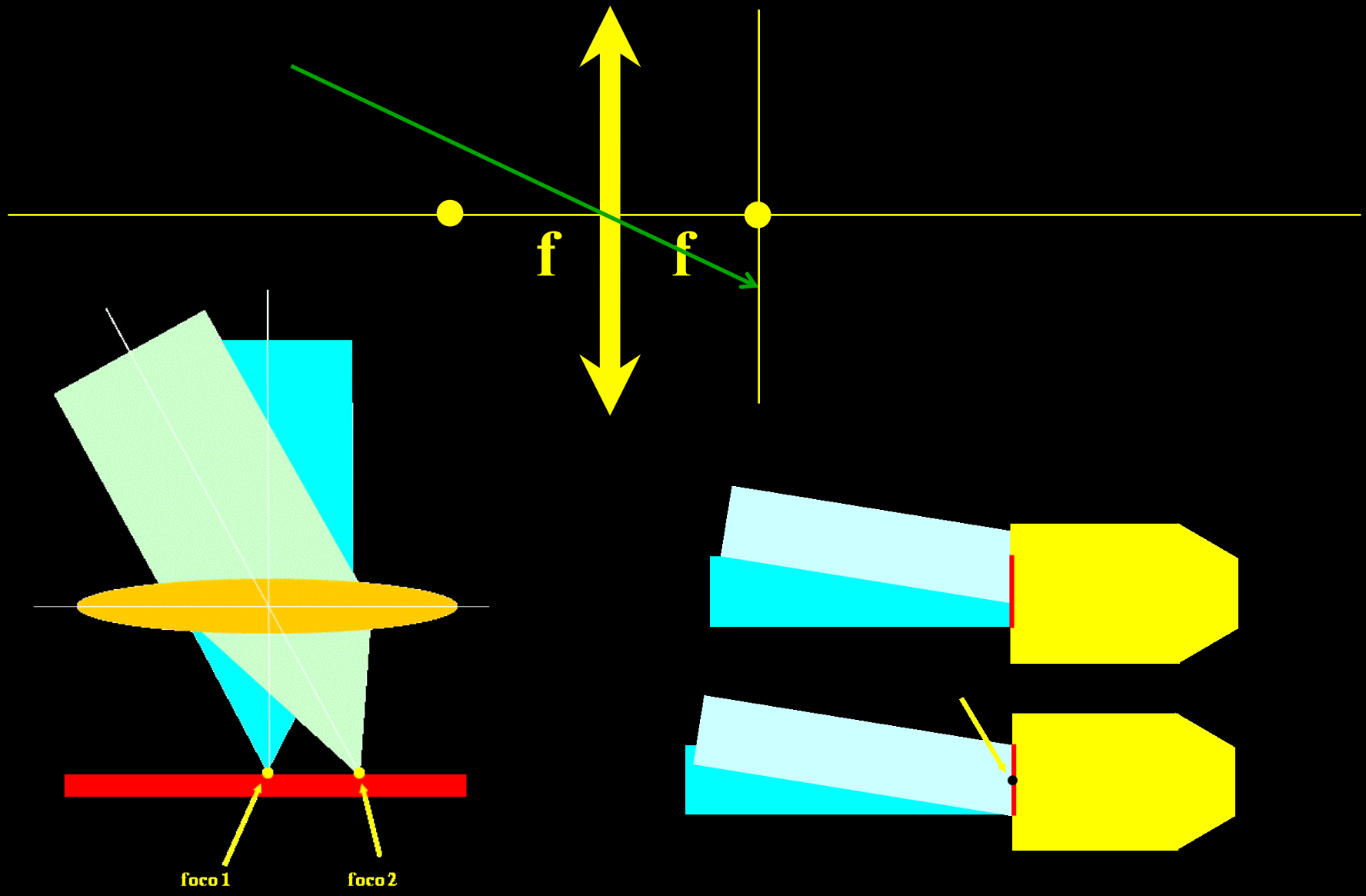
Lentes: raio paralelo passa no foco; passa no foco sai paralelo



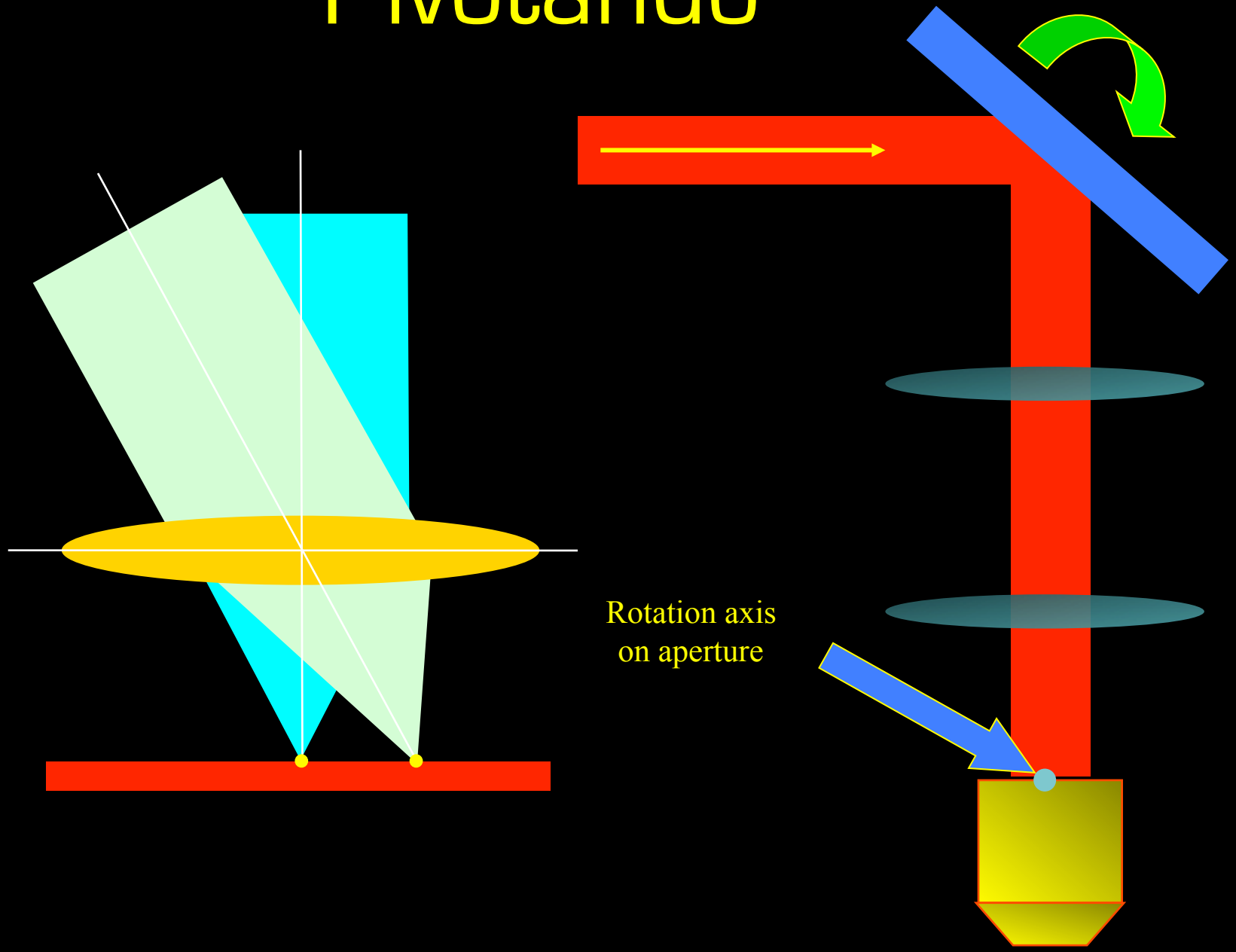


Aperture controls
Vertical resolution

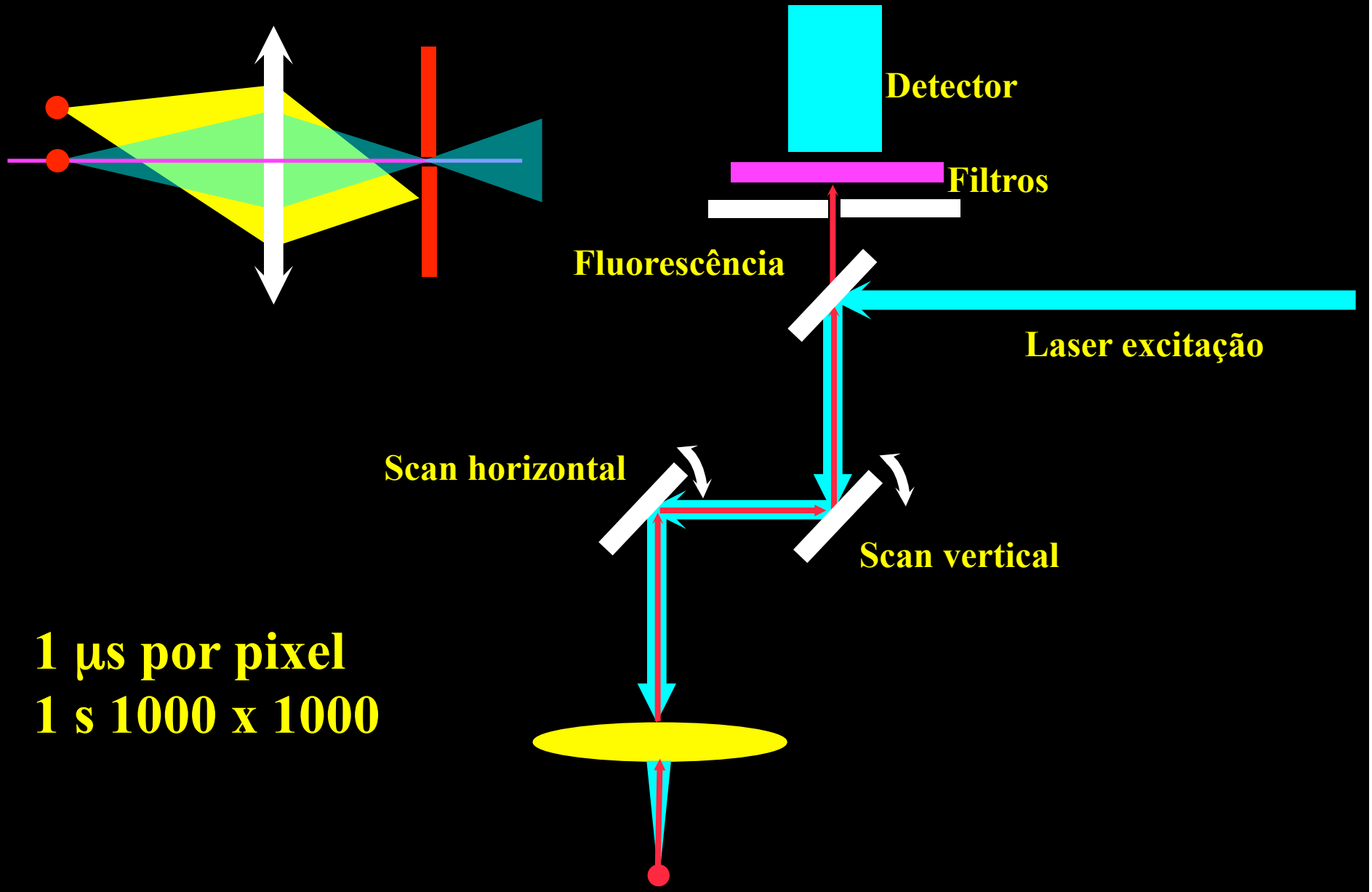
Varredura - raio que passa no centro da lente não é desviado



Pivotando

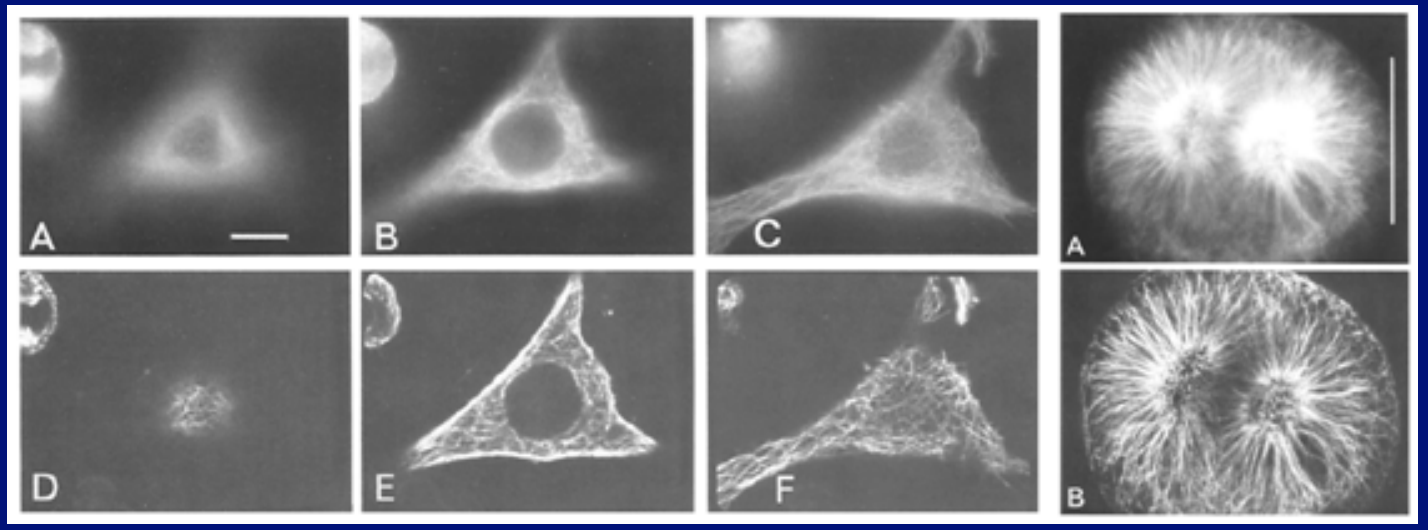


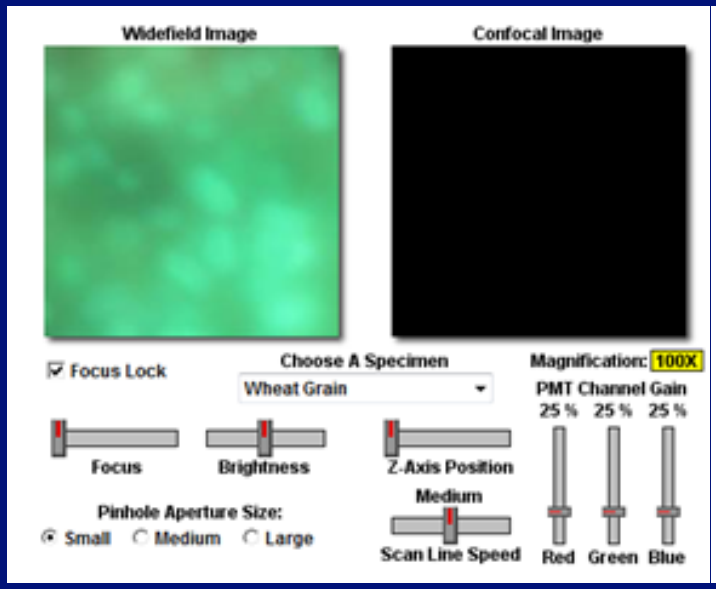
Microscopia confocal: descanning

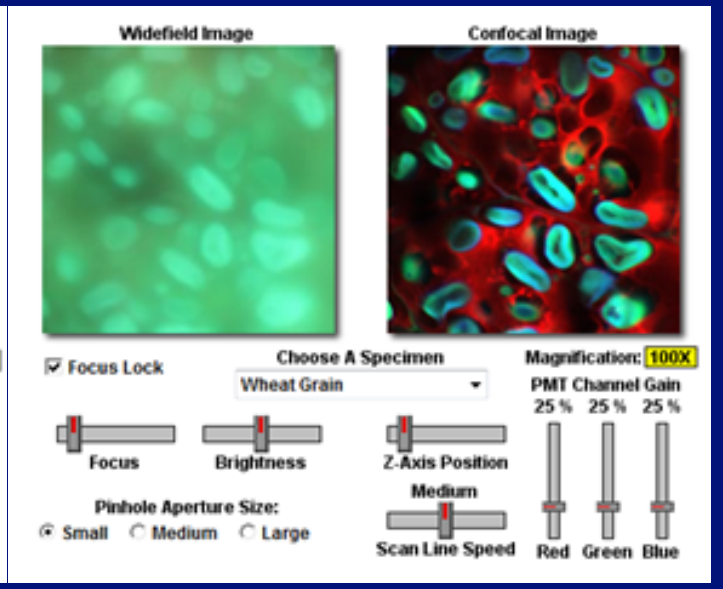


1 µs por pixel
1 s 1000 x 1000

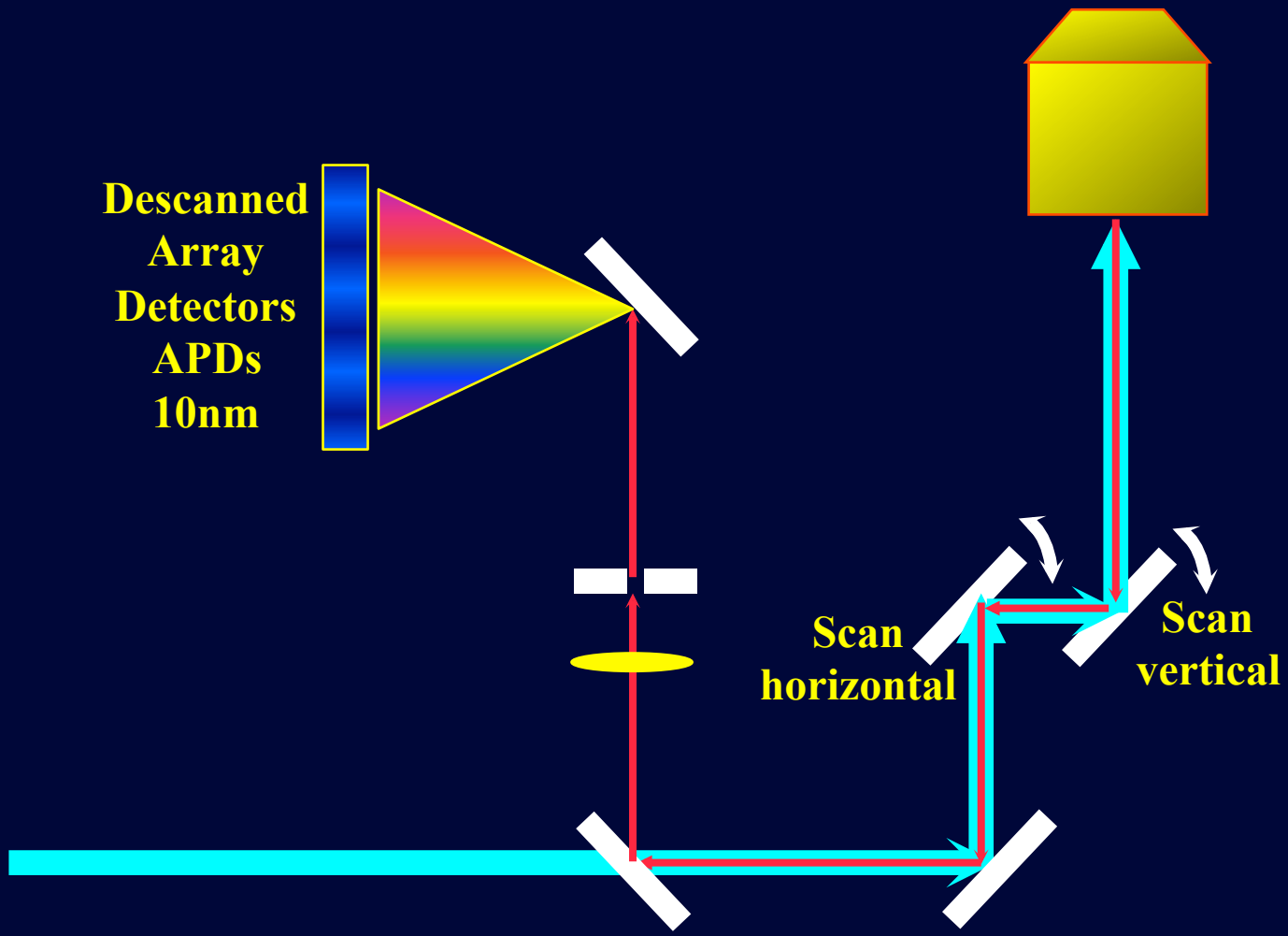
Sectioning capability



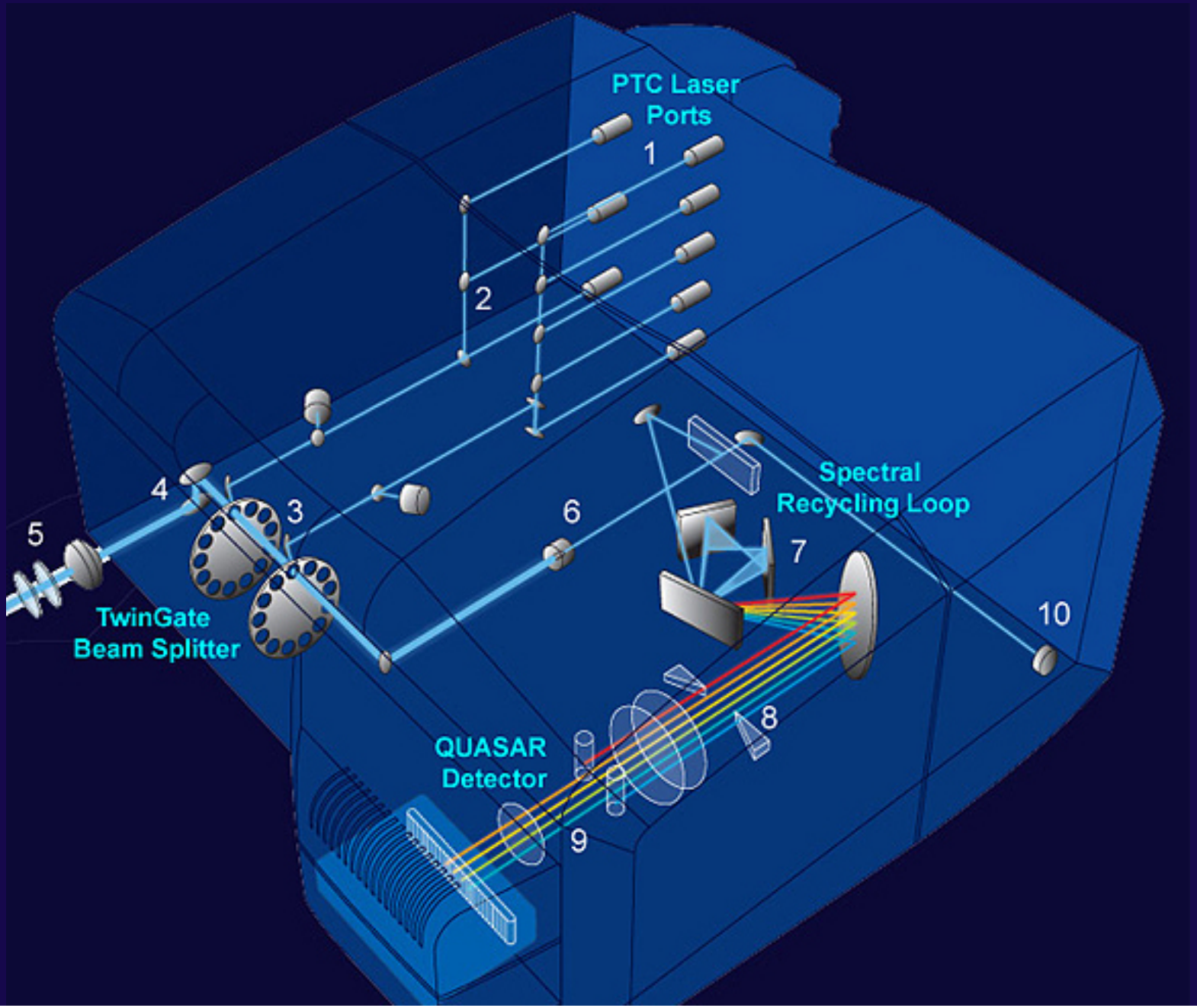




Spectral Confocal microscope



Zeiss LSM 780 Scan Head



Obrigado pela atenção!

Thanks for the attention