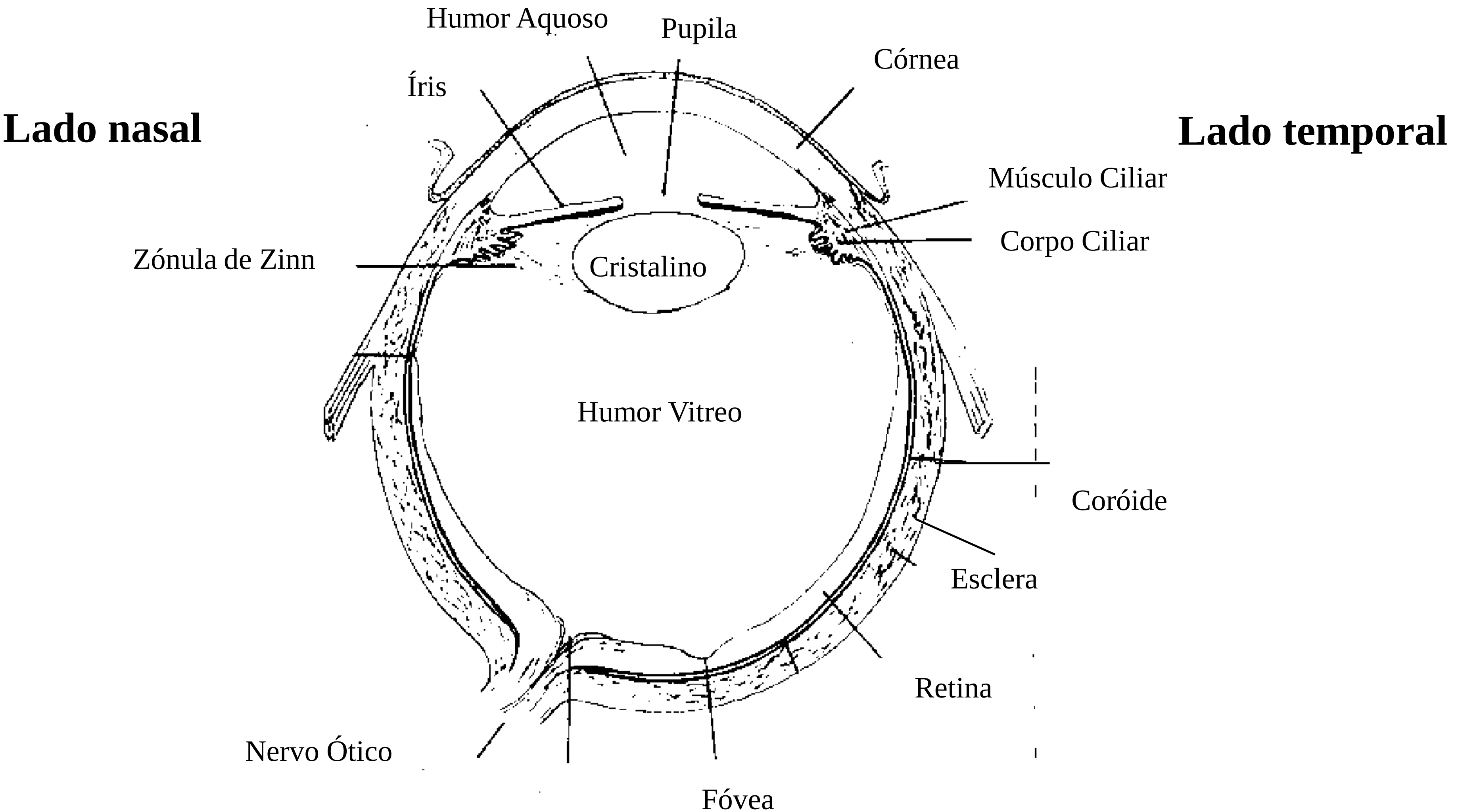
Ótica da Visão

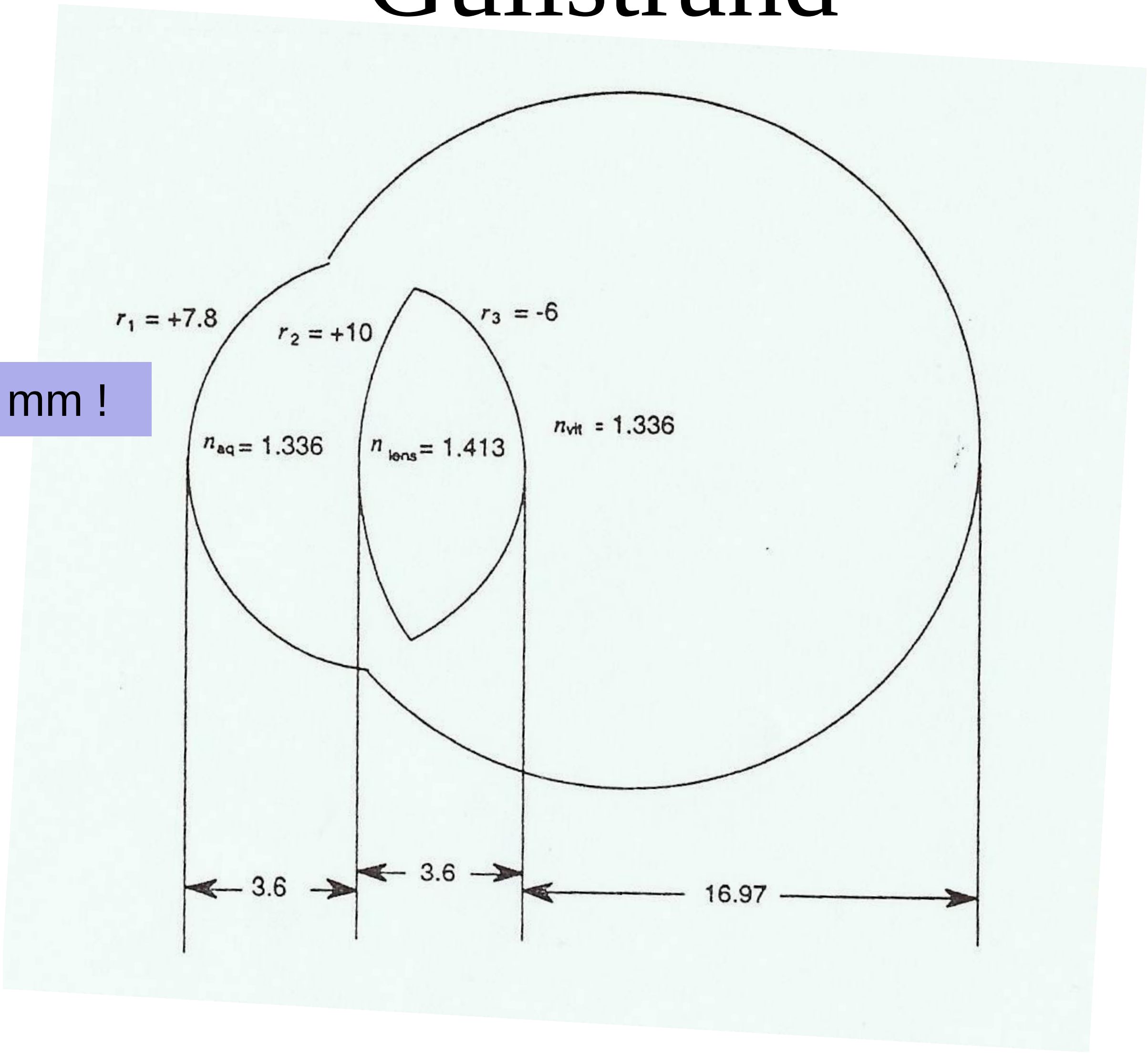
Sérgio Nascimento

Deppartamento de Física da Universidade do Minho

Modelos Óticos do Olho Humano



Modelo Simplificado de Gullstrand



Distâncias em mm !

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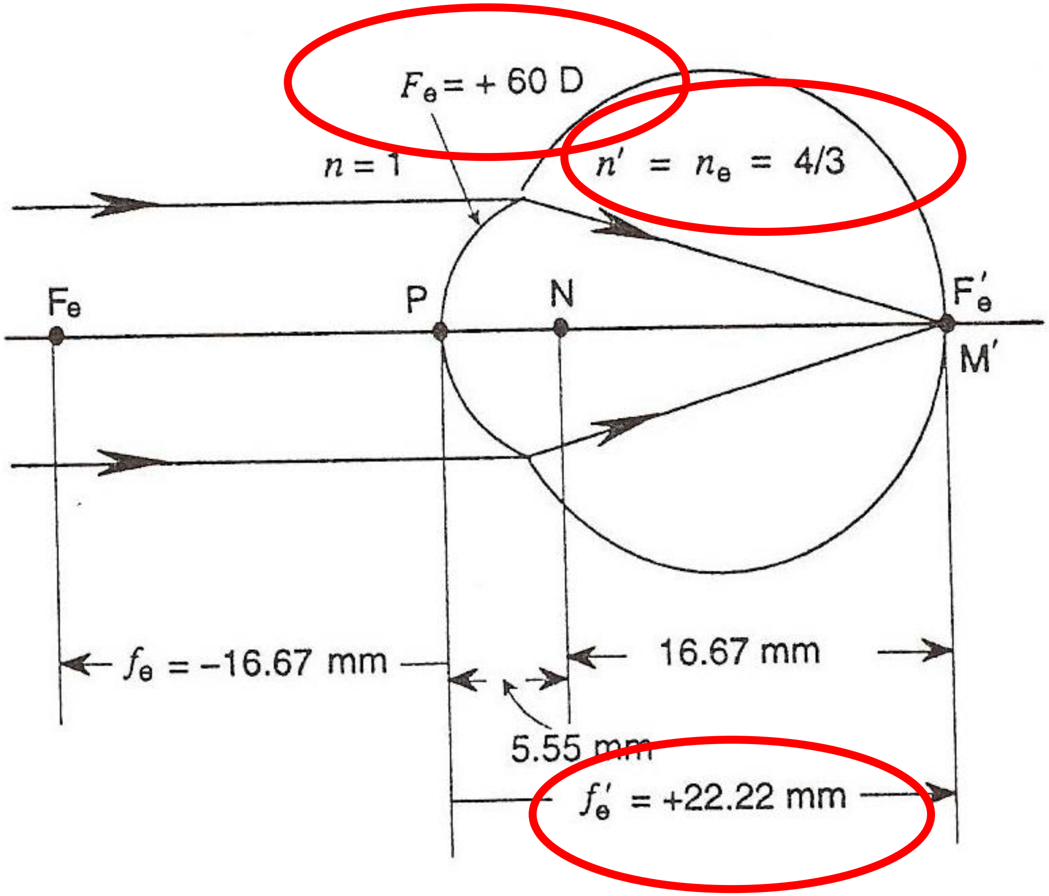
O Modelo *Standard* Reduzido



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Potência da superfície reduzida:

$$P_{olho} = +60 \text{ D}$$

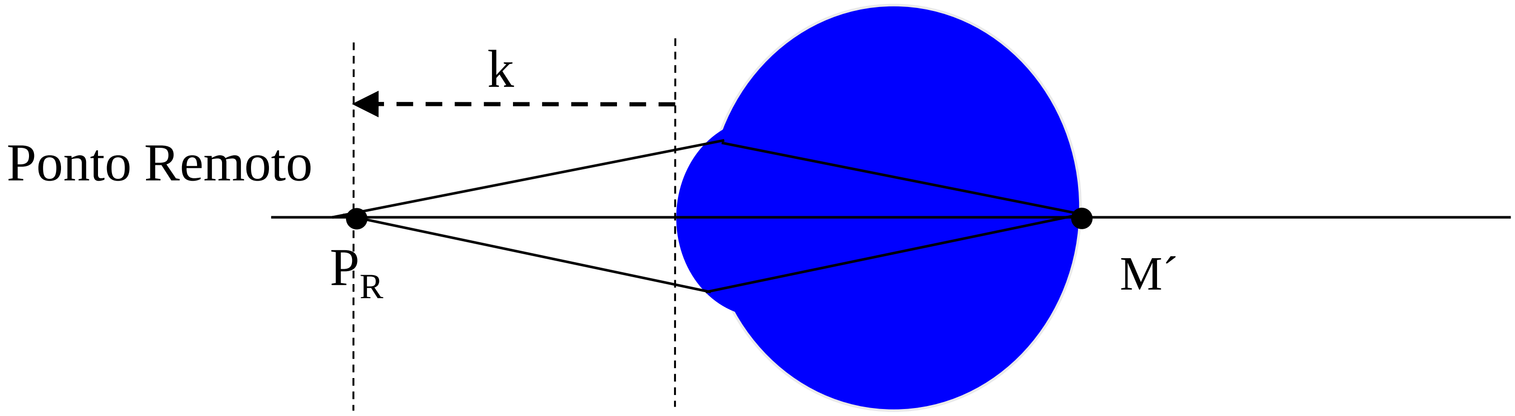
Comprimento axial do olho:

k’ = +22,22 mm

Índice de refração do olho:

$$n' = n_{olho} = 4/3$$

Ametropias esféricas e sua compensação

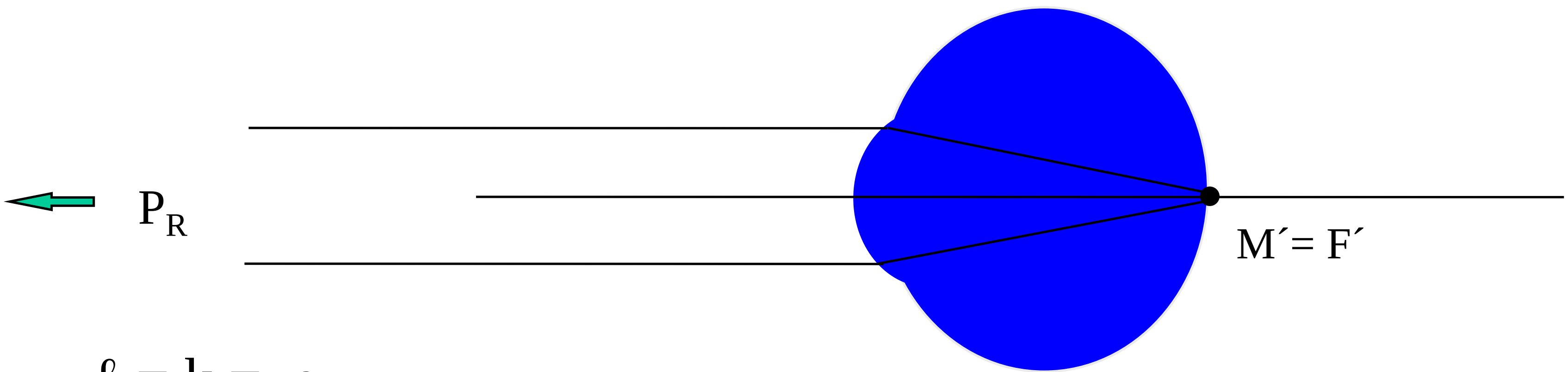


P_R = Ponto remoto **M' = Mácula**

(o ponto remoto é o conjugado da mácula

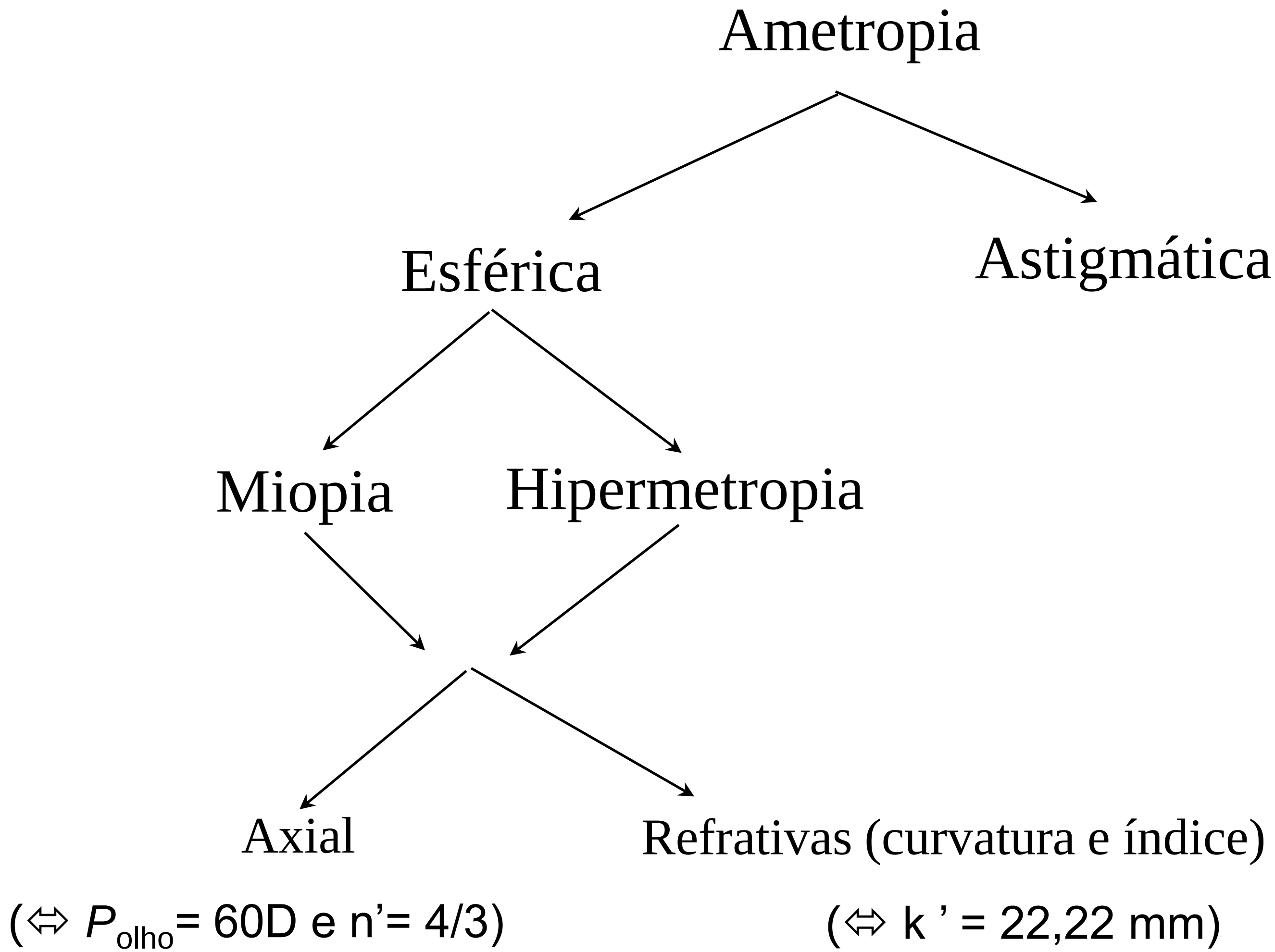
quando o olho não está acomodado)

Emetropia / Olho Emétrope

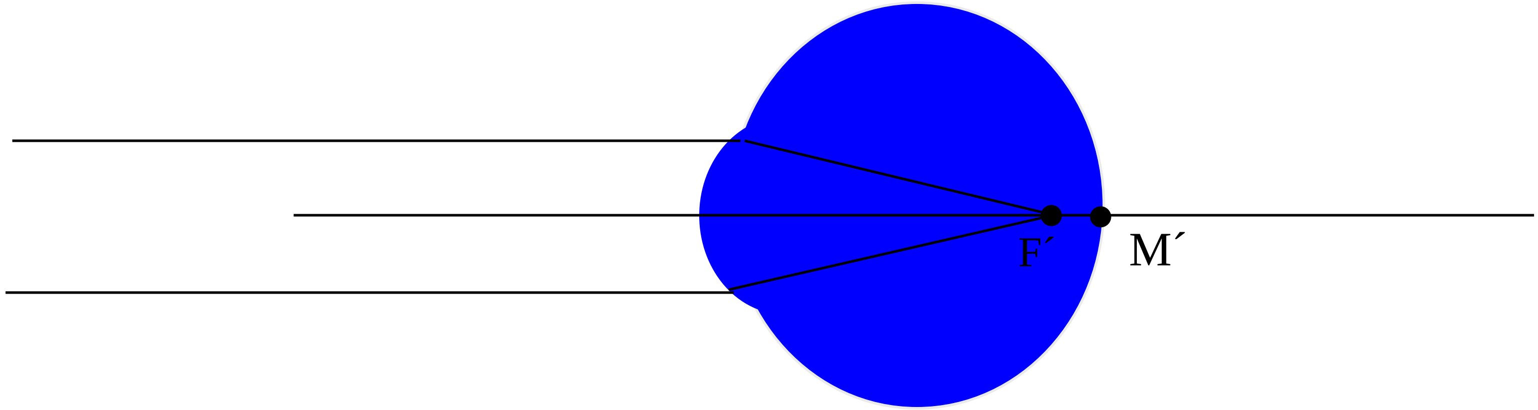


$\ell = k = \infty$

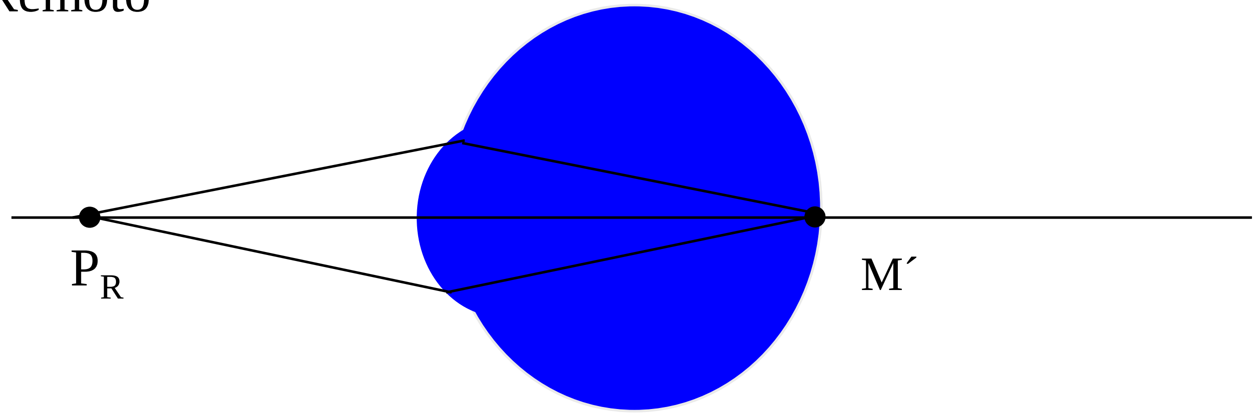
Tipos de Ametropias



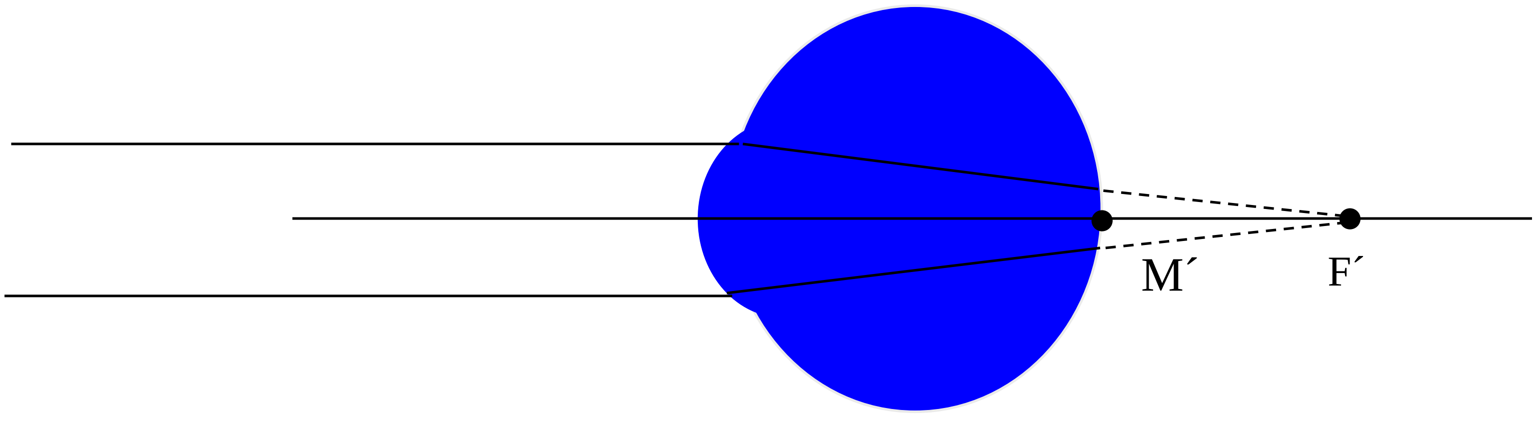
Miopia

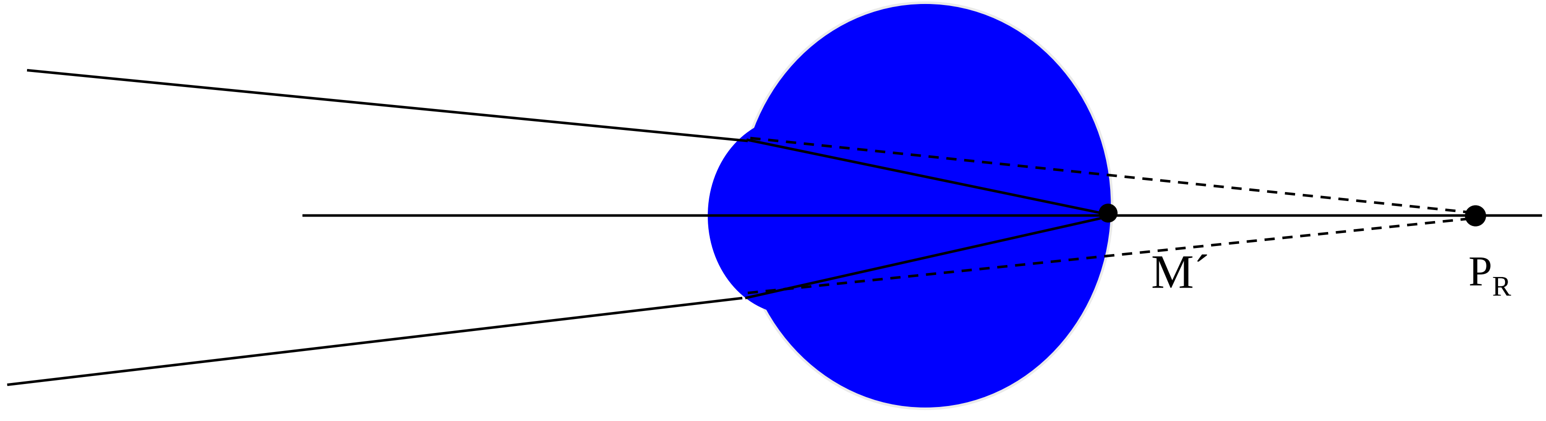


Ponto Remoto

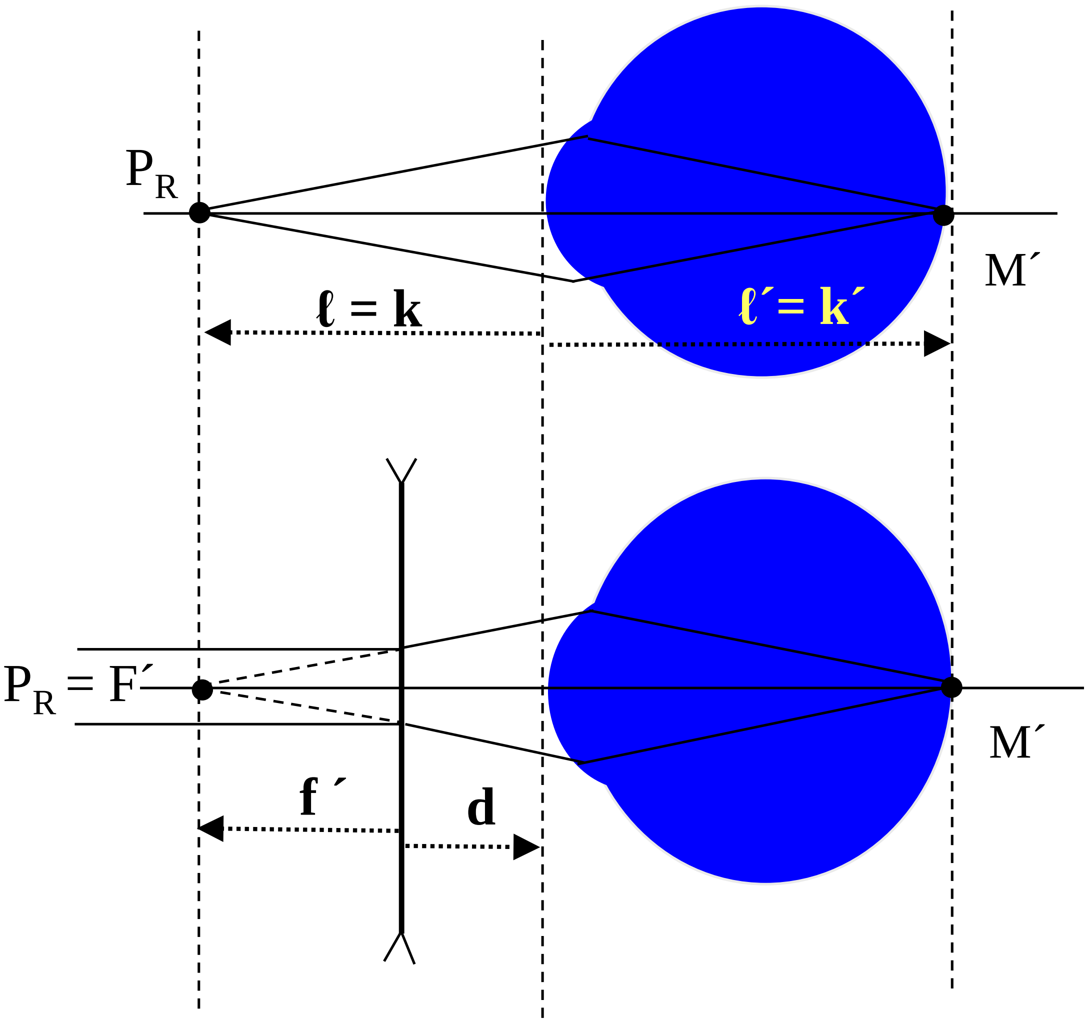


Hipermetropia





Compensação da miopia



Com compensação:

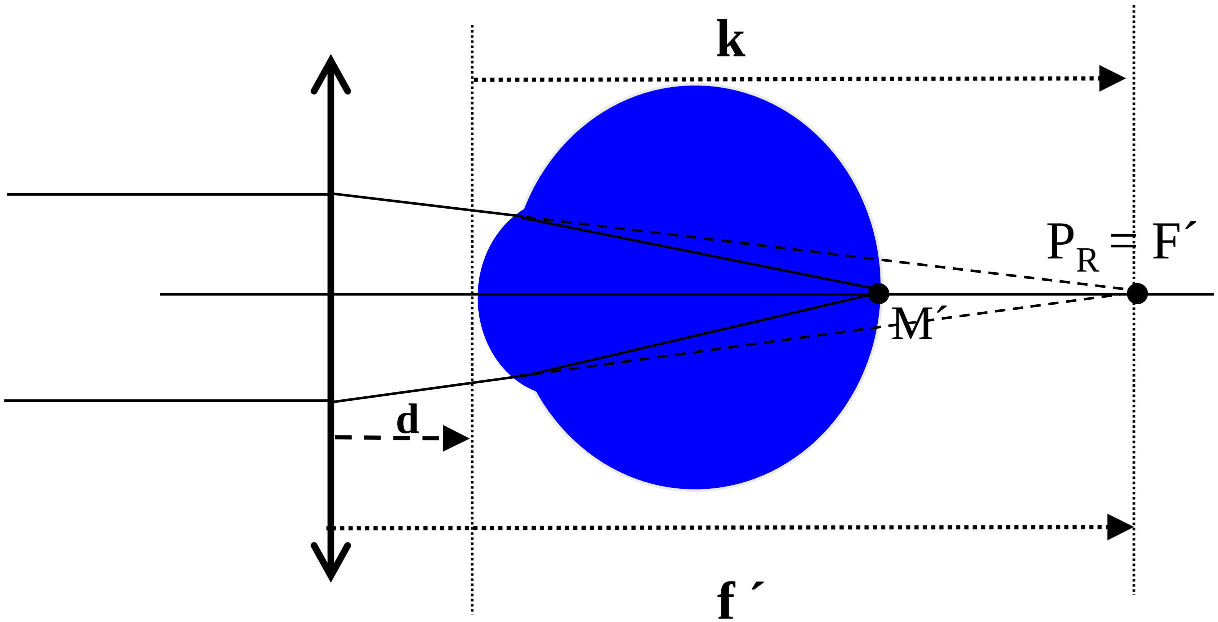
$$f' - d = k$$

$$P_{oc} = \frac{1}{f'} = \frac{K}{1 + dK}$$

Lente espessa :

$$P'_{\mathrm{v}} = \frac{K}{1 + dK}$$

Compensação da hipermetropia



Com compensação:

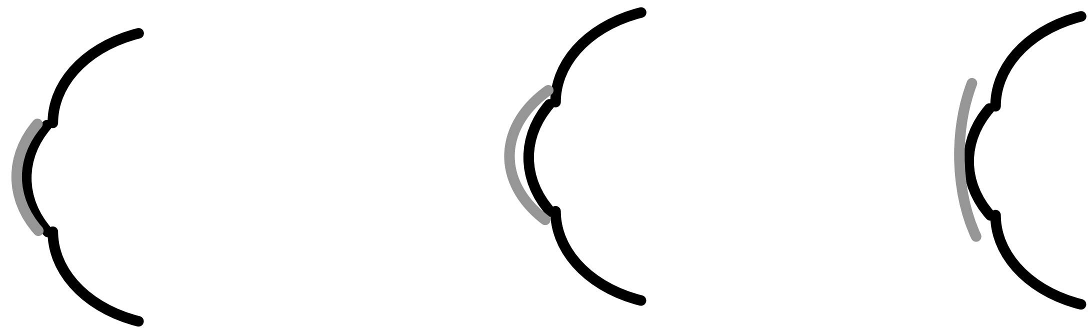
$$f' - d = k$$

$$P_{oc} = \frac{1}{f'} = \frac{K}{1 + dK}$$

Lente espessa:

$$P'_{v} = \frac{K}{1 + dK}$$

Compensação com lentes de contacto



$$P_X = \frac{P_{oculos}}{1 - d \times P_{oculos}}$$

a potência de vértice posterior de <u>lente de contacto + lente da lágrima</u> = $\boldsymbol{P_X = K}$

Avaliação da qualidade da visão

- **Testes objetivos:** determinam por processos físicos as propriedades refrativas do olho (retinoscopia, fotorefração, …)
- **Testes subjetivos:** determinam com testes psicofísicos a qualidade da visão (medida da acuidade visual, testes cromáticos, …)

O que é o ângulo visual?

Os pontos nodais de um sistema ótico são pontos para os quais a luz que por eles passa emerge do sistema sem se desviar da sua direcção.

É o ângulo que a imagem subtende relativamente ao 2º ponto nodal.
E é o ângulo que o objecto subtende relativamente ao 1º ponto nodal.

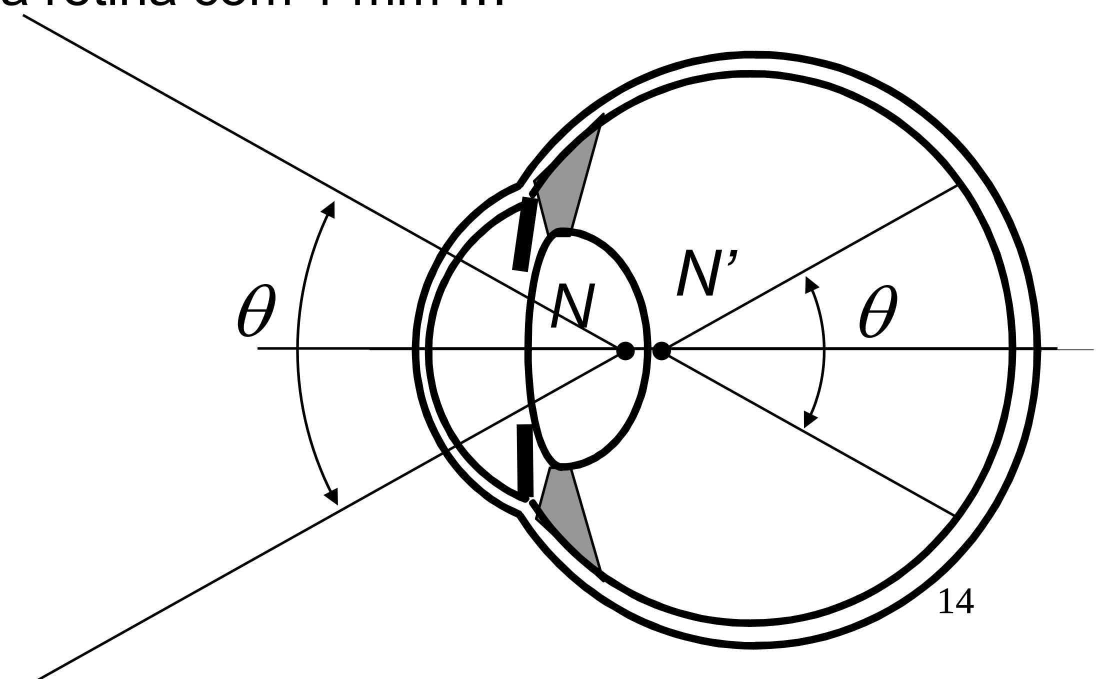
O 2º ponto nodal do olho está a cerca de 16,5 mm da retina.

Considerando uma imagem na retina com 1 mm …

$$\tan\theta/2 = \frac{0.5}{16.5} \Rightarrow \theta/2 = 1.73^{o}$$

$$\text{visual angle} = \theta = 3.47^{o}$$

$$1^{o} = 288\mu m$$



Adaptado de
http://vision.berkeley.edu/roordalab/

UNITS

- *Radiometric units* represent a physical measurement (e.g., radiance is measured in watts sr^{-1} m^{-2}).
- *Colorimetric units* adjust radiometric units for visual wavelength sensitivity (e.g., luminance is measured in cd/m^2). Scotopic luminance units are proportional to the number of rod absorptions; photopic luminance units are proportional to a weighted sum of the L- and M-cone absorptions.
- *Typical ambient luminance levels* (cd/m^2): starlight, 10^{-3}; moonlight, 10^{-1}; indoor lighting, 10^2; sunlight, 10^5; maximum intensity of common CRT monitors, 10^2.
- One *Troland* (Td) of retinal illumination is produced when an eye with a pupil size of 1 mm^2 looks at a surface whose luminance is 1 cd/m^2.
- *Lens focal length*: f (meters); lens power = $1/f$ (diopters).
- *Conversion of linear units* (x) *to decibels* (y): $y = 20 \log_{10}(x)$; a change of 0.3 $\log_{10}$ units is a factor of 2, or 6 dB.

IMAGE FORMATION

- *The eyes* are 6 cm apart and halfway down the head.
- *Visual angle of common objects* (degrees): the sun or moon = 0.5; (at arm's length) thumbnail = 1.5, thumb joint = 2.0, fist = 8–10.
- *Visual field* (measured from central fixation): monocular, 160 deg (w) × 175 deg (h); binocular, 200 deg (w) × 135 deg (h). Region of *binocular overlap*: 120 deg (w) × 135 deg (h).
- Range of *pupil diameters*: 1–8 mm.
- *Refractive indices*: air 1.000; glass 1.520; water 1.333; cornea 1.376.
- *Optical power* (diopters): cornea, 43; lens (relaxed), 20; whole eye, 60.
- Change in power due to *accommodation*: 8 diopters.
- *Axial chromatic aberration* over the visible spectrum: 2 diopters.

RETINA

- *Retinal area*: 5 cm × 5 cm; *retinal thickness*: 0.4 mm.
- One degree of *visual angle on the retina*: 0.3 mm.
- *Number of cones* in each retina: 5×10^6; *number of rods* in each retina: 10^8.
- *Diameter of the fovea*: 1.5 mm (5.2 deg); rod-free fovea, 0.5 mm (1.7 deg); foveola (rod-free, capillary-free fovea), 0.3 mm (1 deg).
- *Size of the optic nerve head*: 1.5 mm × 2.1 mm (5 deg [w] × 7 deg [h]).
- *Peak cone density*: $1.6 \times 10^5/mm^2$.
- *Cone size*: foveal, 1–4 μ (diameter) × 50–80 μ (length); extrafoveal, 4–10 μ (diameter) × 40 μ (length).
- *Rod size* near fovea: 1 μ (diameter) × 60 μ (length).
- *Cone spacing* (foveal): S-cones, 10 arc min; L- and M-cones: 0.5 arc min.
- *(L + M) cone:S-cone ratio*: 100:1.
- Number of *optic nerve fibers* from each retina: 1.5×10^6.
- *Receptor:ganglion cell ratio*: foveal, 1:3; whole retina, 125:1.

Useful Quantities in Vision Science

CORTEX

- Total *cortical area*: 1.3×10^5 mm^2; *cortical thickness*: 1.7 mm.
- *Cortical neurons*: total number, 10^{10}; average density, $10^5/mm^3$.
- *Synapses*: average density, $5 \times 10^8/mm^3$; per neuron, 4×10^3.
- *Axons*: 3 km/mm^3.
- Number of *corpus callosum fibers*: 5×10^8.
- Number of *macaque visual areas*: 30.
- *Size of area V1* (each hemisphere): 3 cm × 8 cm. Half of area V1 represents the central 10 deg (2%) of the visual field.
- Width of *ocular dominance columns*: human, 0.5–1.0 mm; macaque, 0.3 mm.

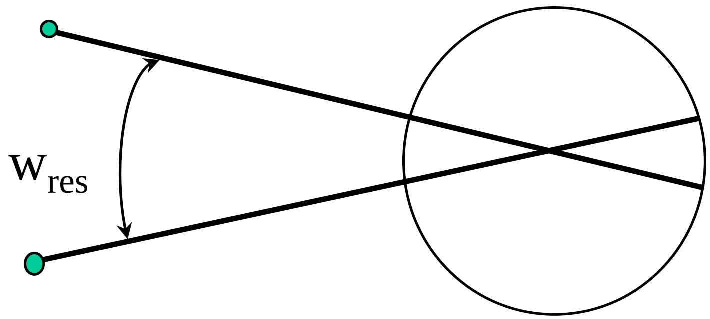
SENSITIVITY

- *Minimum number of absorptions*: detectable electrical excitation of a rod, 1; scotopic detection, 1–5; photopic detection,10–15.
- Following exposure to a sunny day, *dark adaptation* to a moonless night requires: photopic, 10 minutes; scotopic, 40 minutes; change in visual sensitivity, 6 $\log_{10}$ units.
- *Highest detectable spatial frequency*: at high ambient light levels, 50–60 cpd; at low ambient light levels, 20–30 cpd.
- *Contrast threshold* ($\Delta L/L$) for a static edge at photopic luminances: 1%.
- *Highest detectable temporal frequency*: high ambient light, large field, 80 Hz; low ambient light, large field, 40 Hz.
- Typical *localization threshold*: 6 arc sec (0.5 μ on the retina).
- *Minimum temporal separation* needed to discriminate two small, brief light pulses from a single equal-energy pulse: 15–20 ms.
- *Stereoscopic depth discrimination thresholds*: step threshold, 3 arc sec; point threshold, 30 arc sec.

COLOR

- *Visible spectrum*: 370–730 nm.
- *Peak wavelength sensitivity*: scotopic, 507 nm; photopic, 555 nm.
- *Spectral equilibrium hues*: blue, 475 nm; green, 500 nm; yellow, 575 nm (no spectral equilibrium red).
- Number of basic *English color names*: 11.
- *Incidence of color deficiencies*: anomalous trichromacy, 10^{-2} (male), 10^{-4} (female); protanopia and deuteranopia, 10^{-2} (male), 10^{-4} (female); tritanopia, 10^{-4}; rod monochromacy, 10^{-4}; cone monochromacy, 10^{-5}.

Resolução e Acuidade Visual



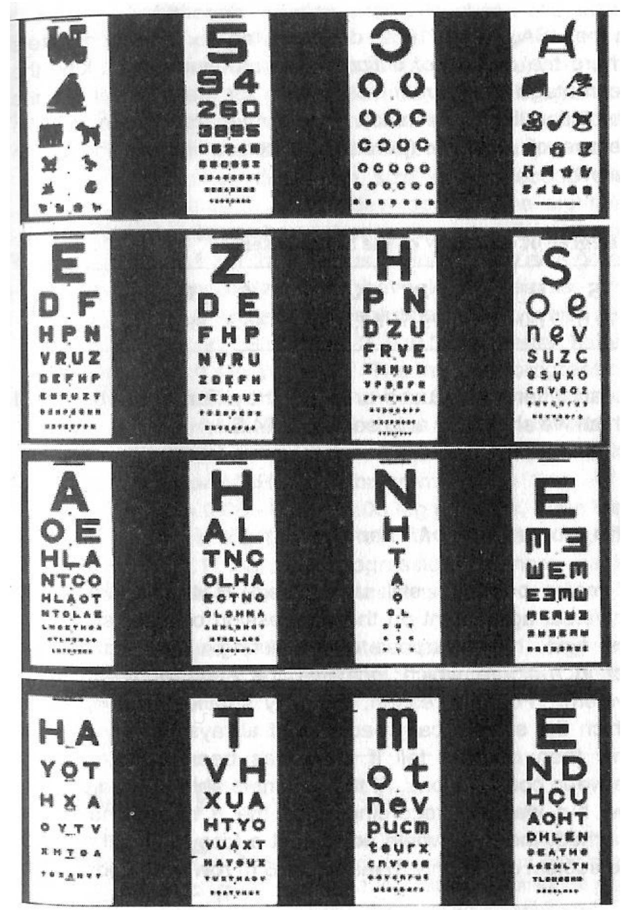
w_{res} = ângulo mínimo de resolução (arcmin)

Acuidade Visual = AV = 1/ w_{res}

Se w_{res} = 1'   AV = 1.0

Se w_{res} = 2'   AV = 0.5

Quadros Modernos



Logaritmico: 0.1 unidades log por linha

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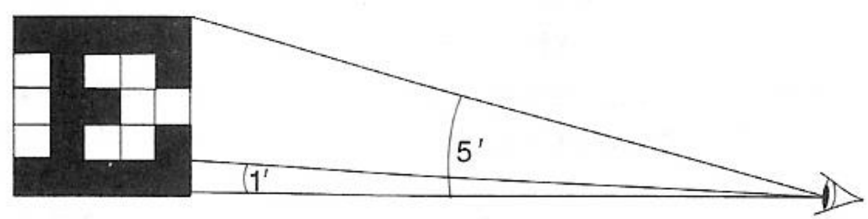
Quadros e notação de Snellen



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Quadros e notação de Snellen

- Acuidade Visual = AV = w_s / w = d / d_s

  w_s = Ângulo mínimo de resolução de um observador *standard* = 1´

  d_s = distância de observação a que as letras da melhor linha fazem 5´

  d = distância de teste: fixa e habitualmente = 6 m (USA = 20 feet)

- Tamanhos das letras tais que subtendem 5´ a 6, 9, 12, 15, 21, 30, 60 m
- Exemplos: 6/6 corresponde a 1.0 AV decimal; 6/12 = 0.5 AV decimal

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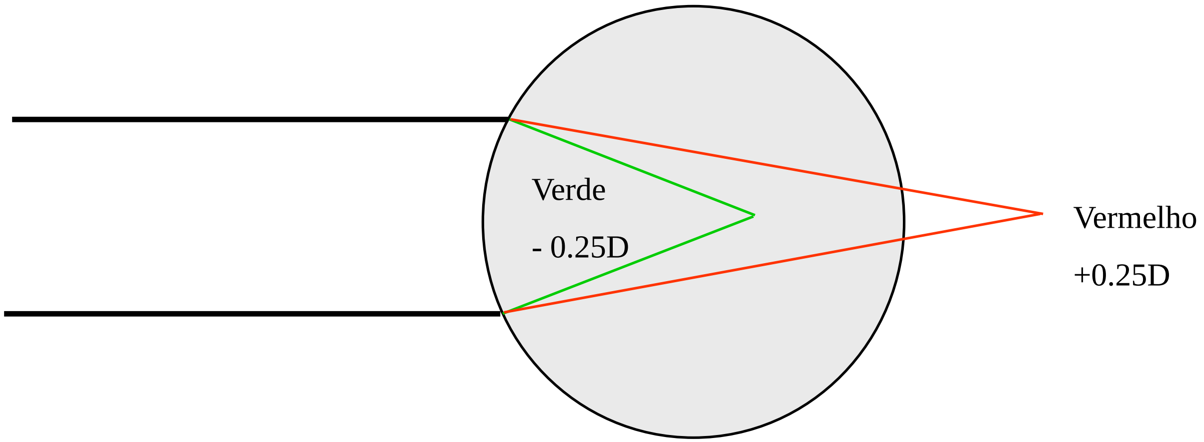
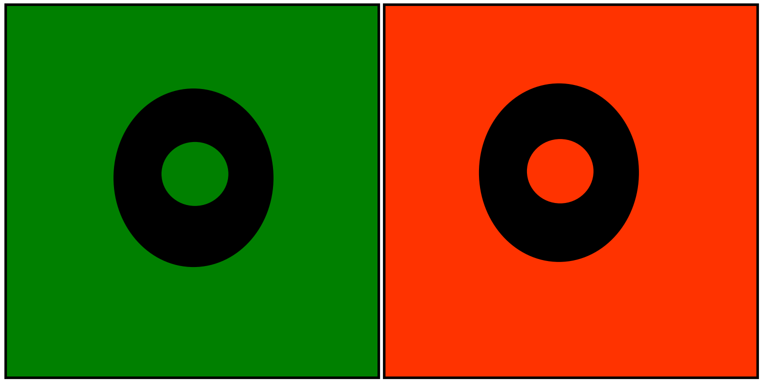
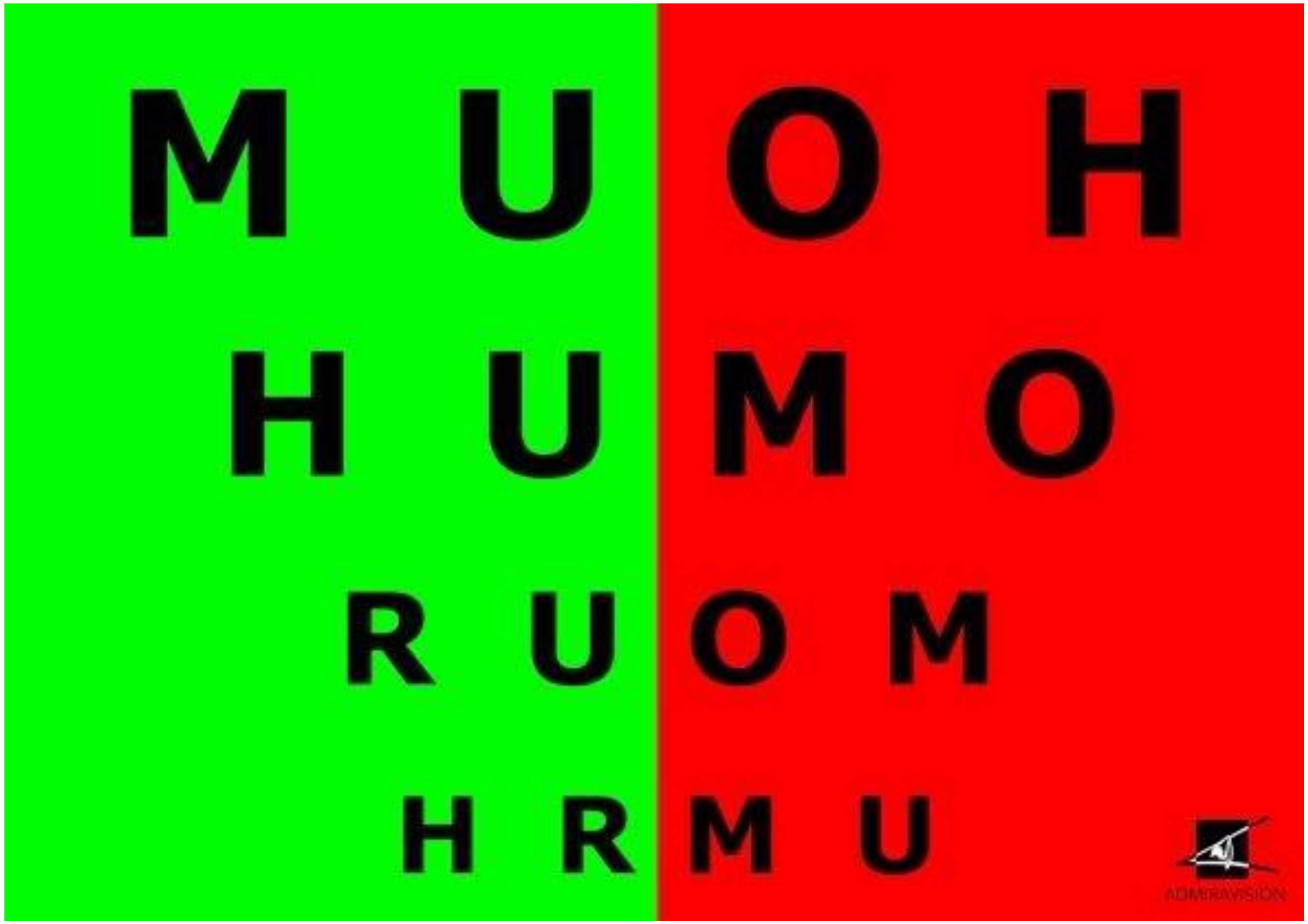
Teste dicromático





Fundo verde | Fundo vermelho


M U O H
H U M O
R U O M
H R M U

Teste dicromático
Aberração cromática do olho

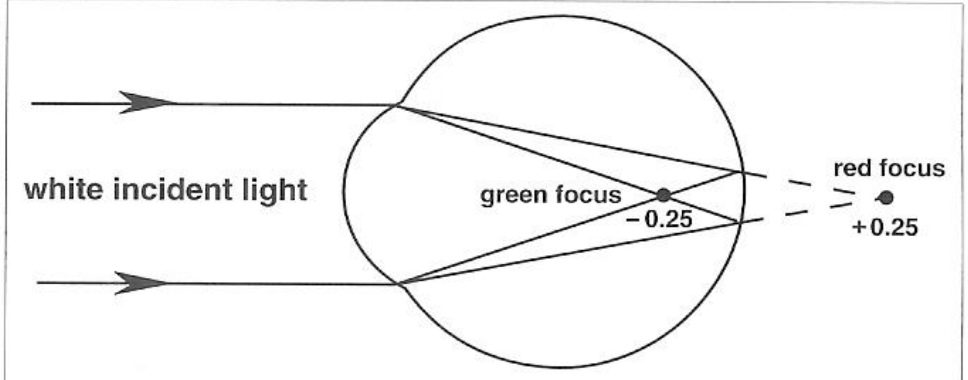


Fig. 3.42 In the eye, focused for distance, green and red light of wavelengths 530 nm and 620 nm focus in front of and behind the retina, respectively. The power of the eye differs by about 0.5 D for these colours and when equally blurred the two foci are 0.25 D from the retina. Note the equal size of the blur discs on the retina.

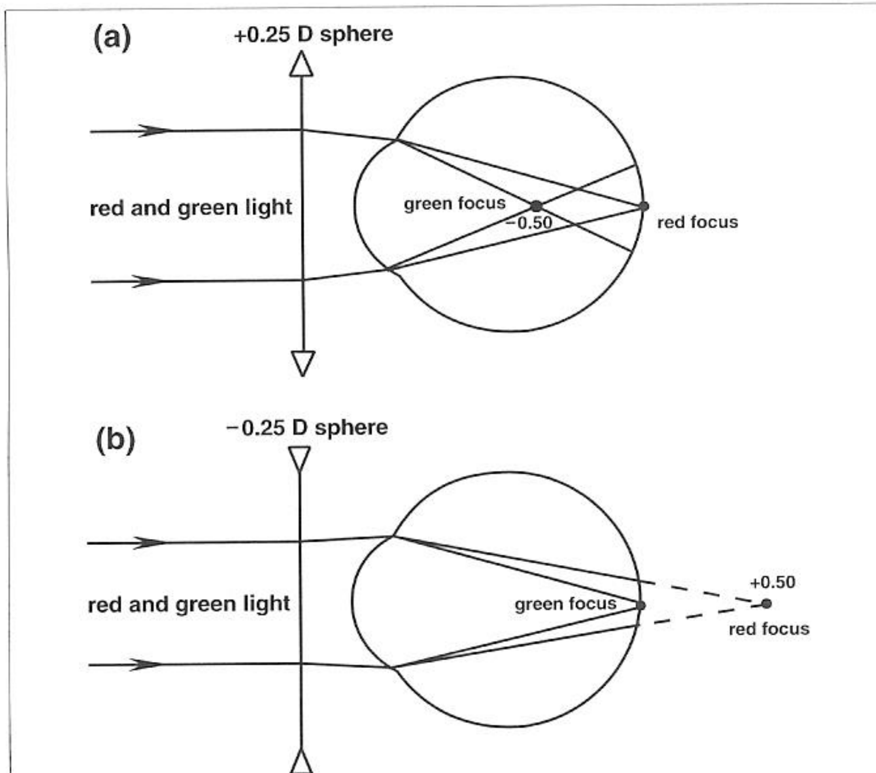
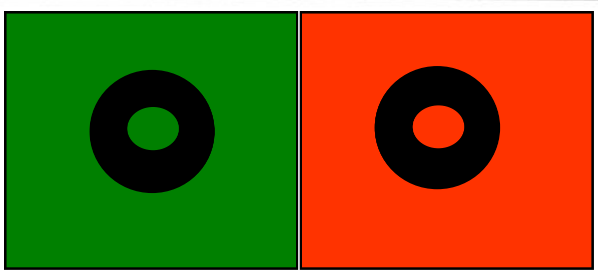


Fig. 3.45(a) Adding +0.25 D sphere to the situation in figure 3.42 brings the red focus onto the retina. The patient sees the targets on the red as clearer than those on the green.
(b) Adding −0.25 D sphere to the situation in figure 3.42 puts the green focus on the retina.



Fundo verde Fundo vermelho

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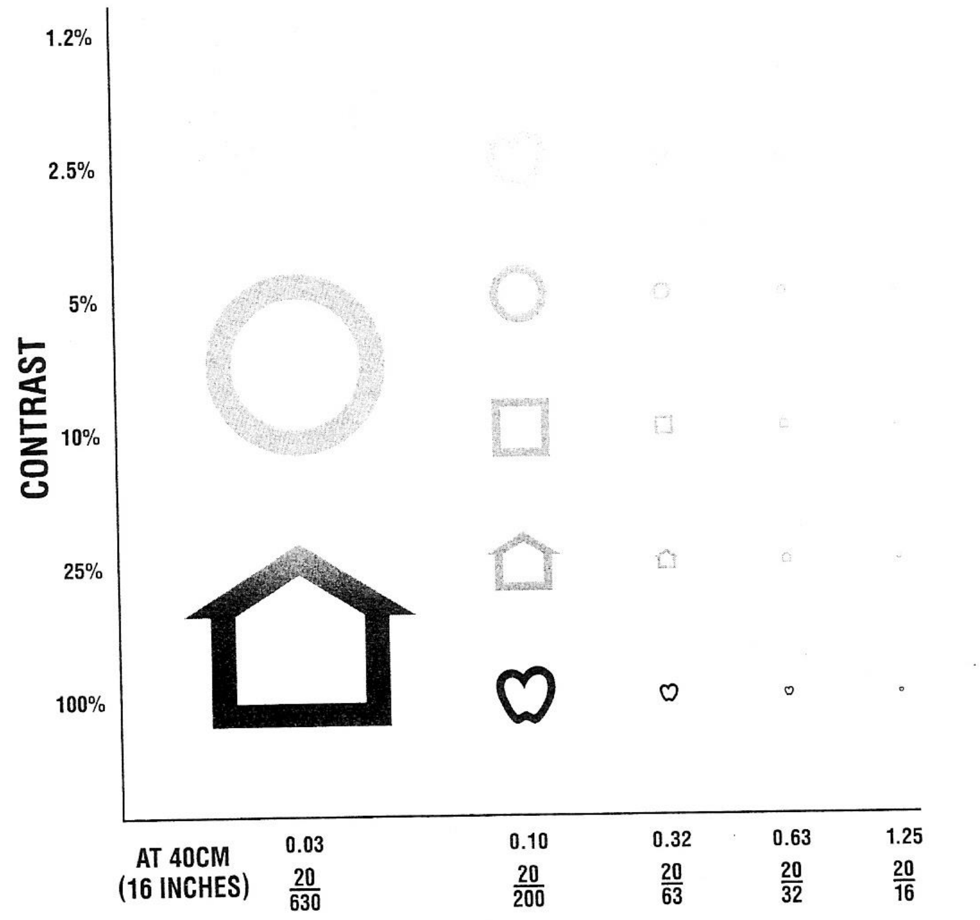
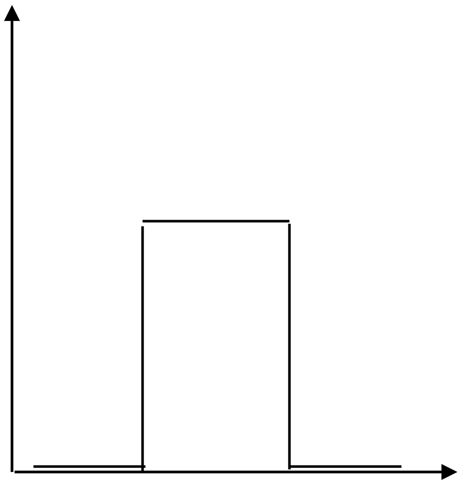
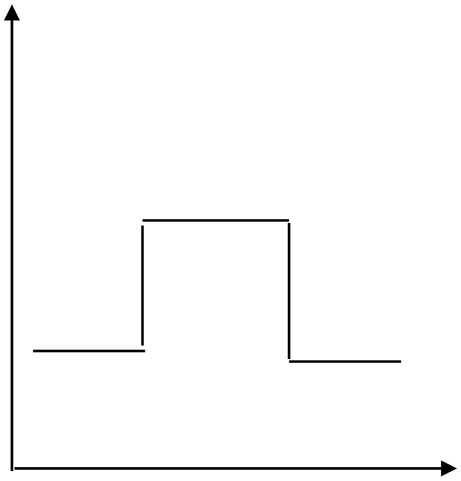
Sensibilidade ao contraste



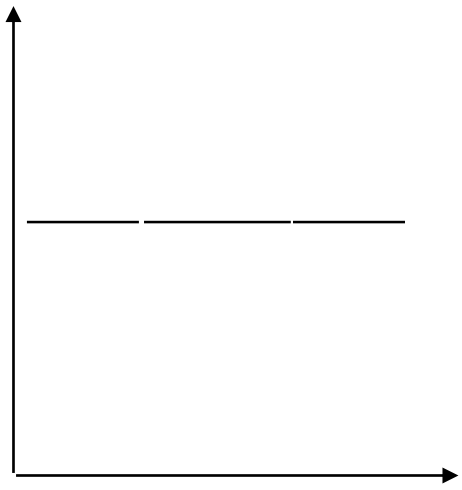
Definição de contraste para letras



C=1



C=0.5

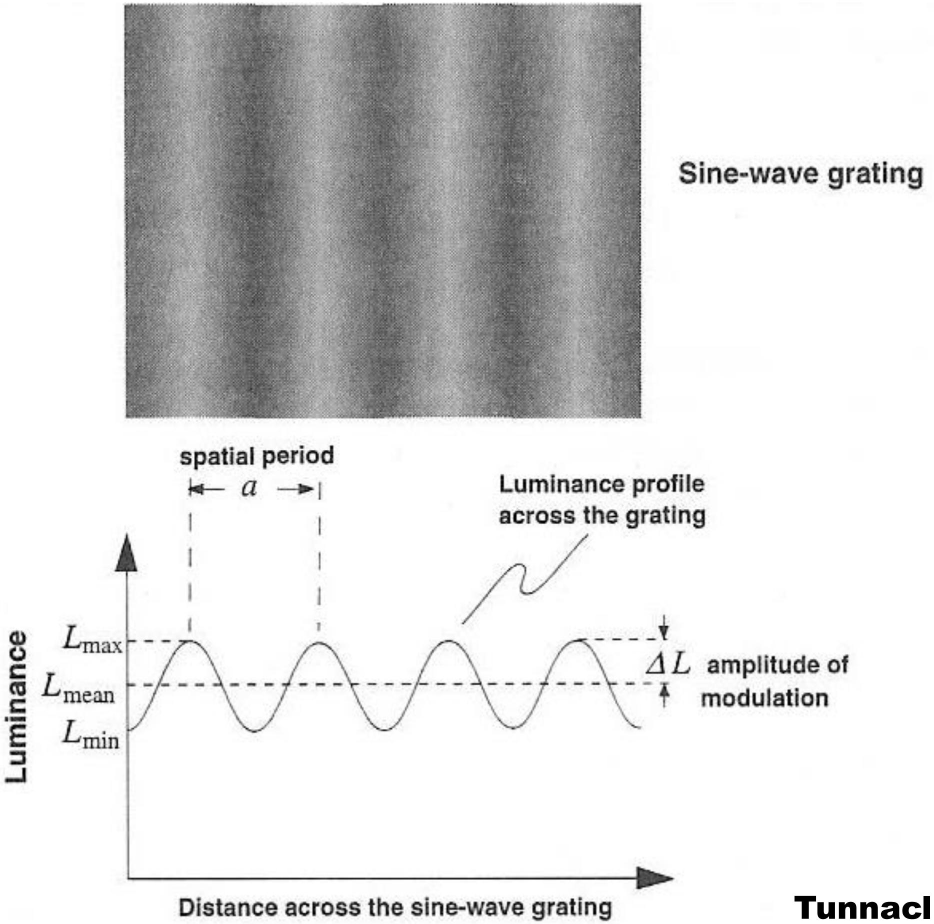


C=0

$$C = \frac{L_{max} - L_{min}}{L_{max}}$$

Teste da sensibilidade ao contraste com padrões sinusoidais

$$C = \frac{L_{max} - L_{min}}{L_{max} + L_{min}}$$



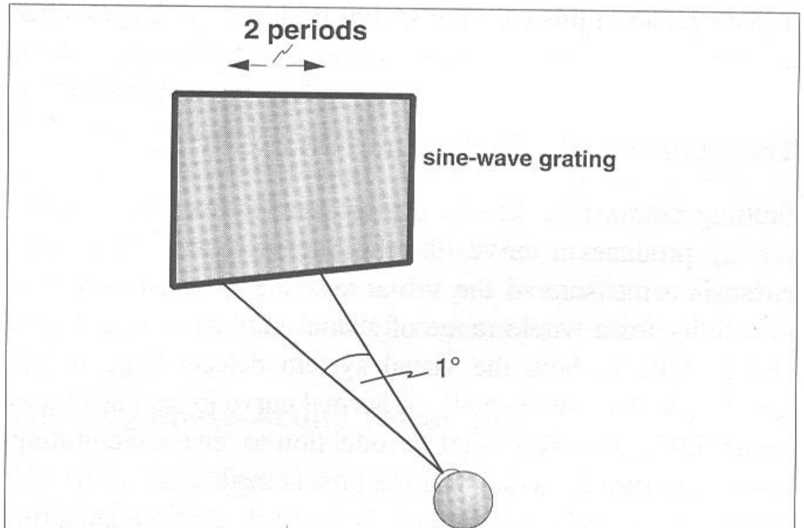


Fig. 7.94 Illustration of 2 spatial periods subtending 1° at the eye. The spatial frequency of the sine-wave grating is therefore 2 cycles per degree.

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Contraste para padrões sinusoidais

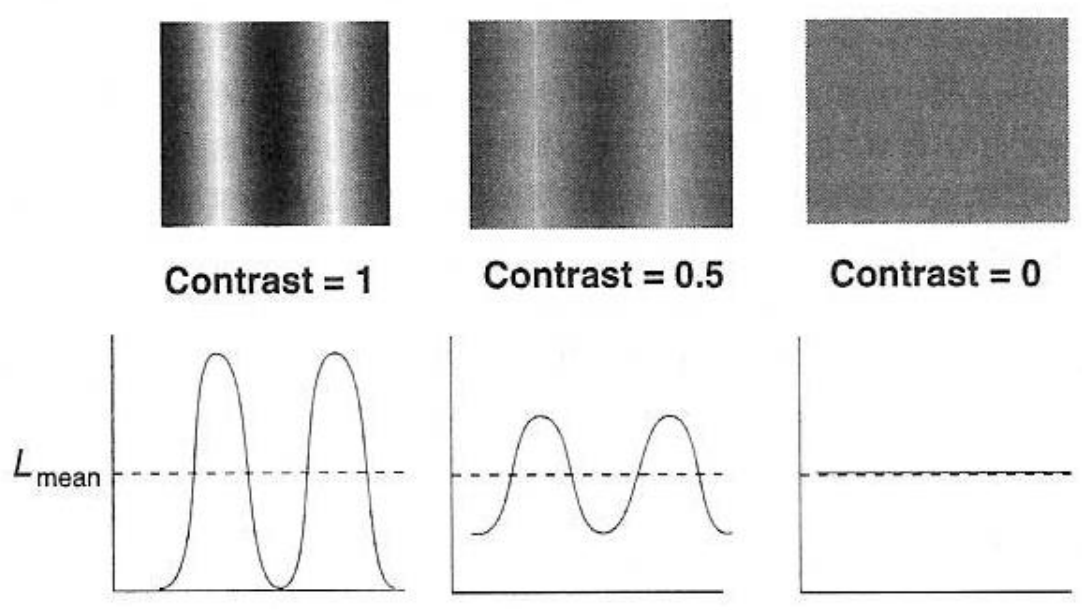

Fig. 8.48 Sine-wave gratings with the same mean luminance and contrasts of 1, 0.5 and 0. Note that zero contrast means no detail is present.

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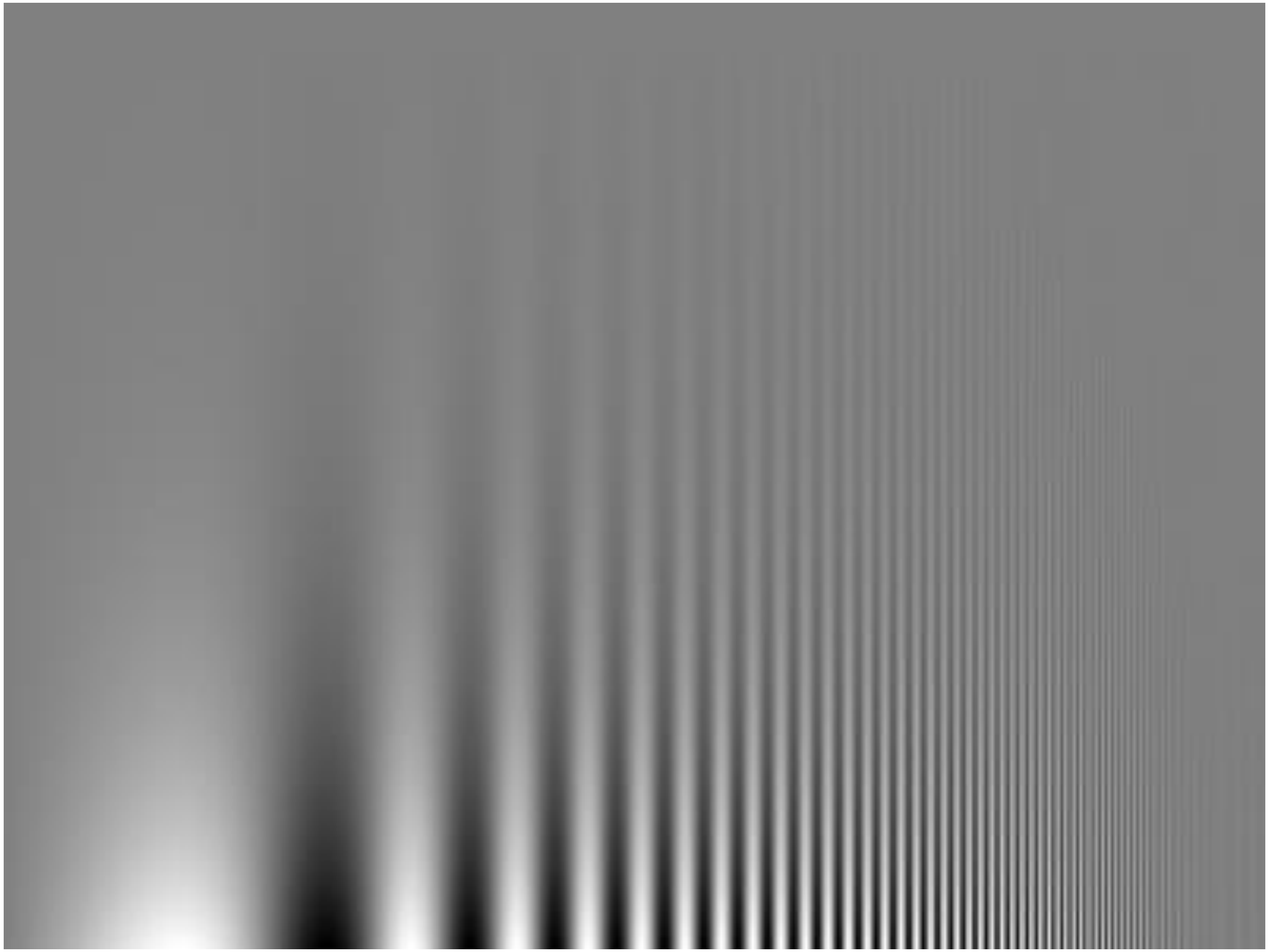
Sensibilidade ao contraste



Curva de sensibilidade ao contraste normal

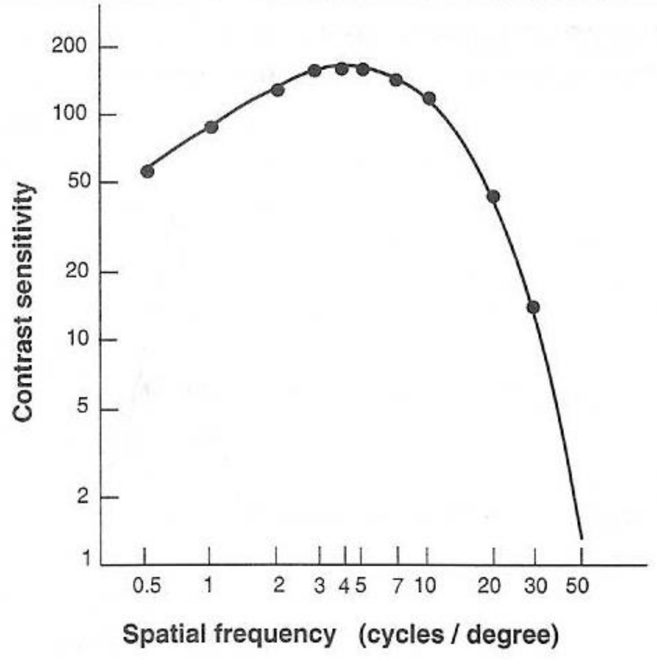


Fig. 8.55 A plot of the sine-wave contrast sensitivity against spatial frequency: the *contrast sensitivity function.*
For each sine-wave grating, the minimum detectable contrast is determined, the reciprocal of this threshold contrast being the contrast sensitivity for that frequency.

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Porquê determinar a curva de sensibilidade ao contraste?

- Glaucoma
- Diabetes
- Doença de Parkinson
- Esclerose múltipla
- Cataratas
- . . .

Apresentam acuidade normal mas

curva de sensibilidade ao contraste alterada

Curvas de sensibilidade ao contraste anormais

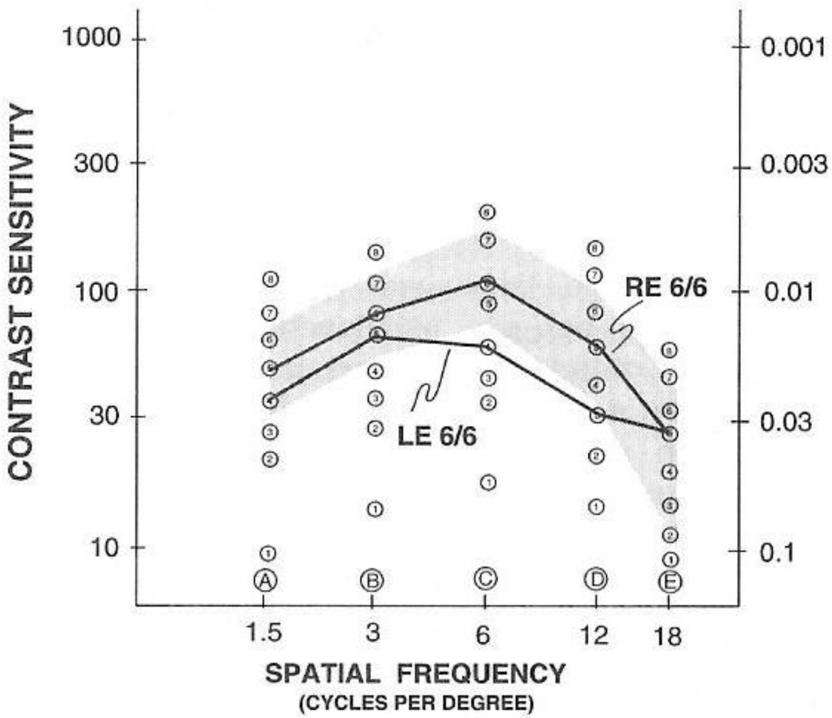

Fig. 8.68 A case with multiple sclerosis affecting the optic nerve in the left eye. The visual acuity is normal but there is a medium frequency contrast sensitivity deficit.

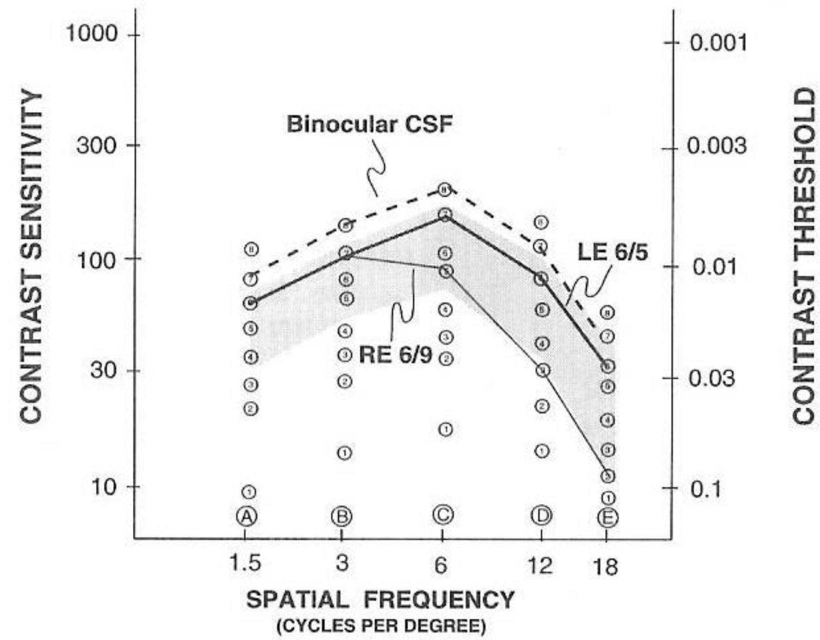

Fig. 8.67 The CSF in a subject's normal left eye and an anisometropic amblyopic right eye. Note how the low spatial frequency response is unaffected in the amblyopic eye; this was discussed earlier when referring to the modulation transfer function and defocus blur; the large contrast detectors did not suffer contrast deprivation during the critical period. Further note that the binocular CSF is higher at all the spatial frequencies tested here.

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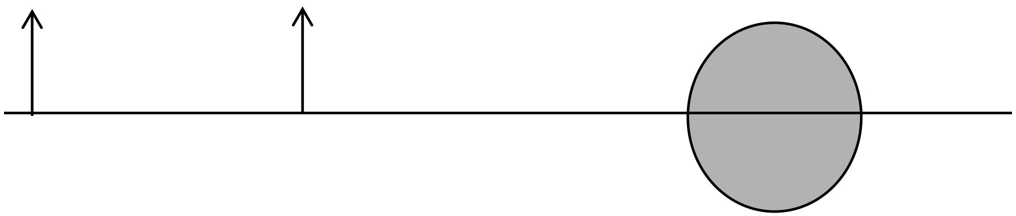
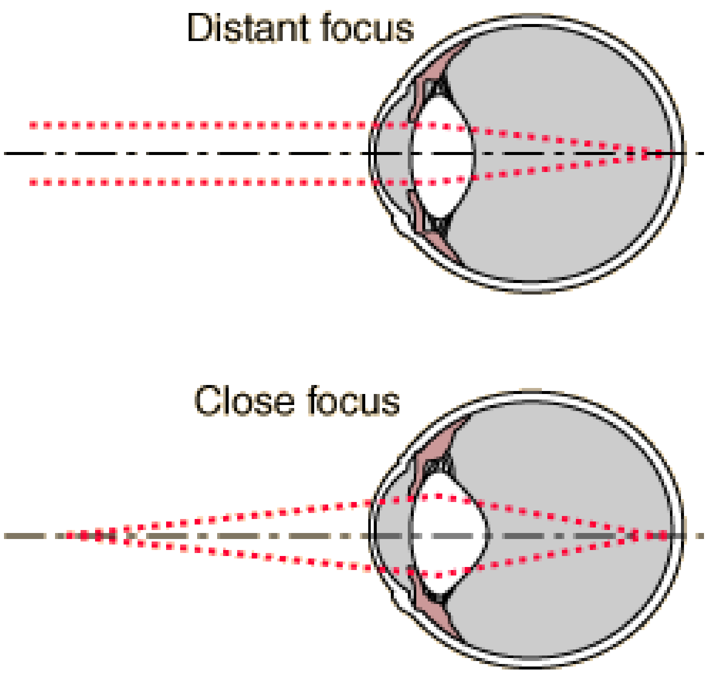
Acomodação

Acomodação: mecanismo de ajuste da potência do olho de forma a poder focar objectos a diferentes distâncias da córnea





• Como funciona a acomodação nos humanos?

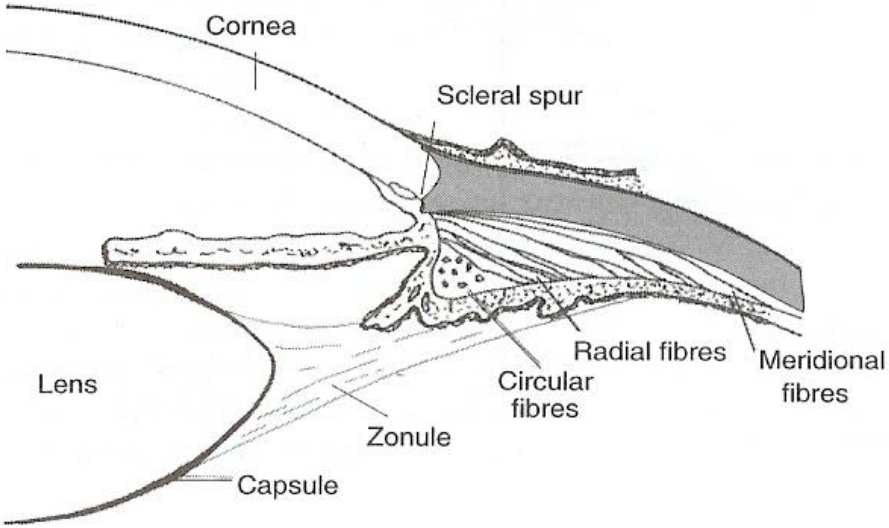
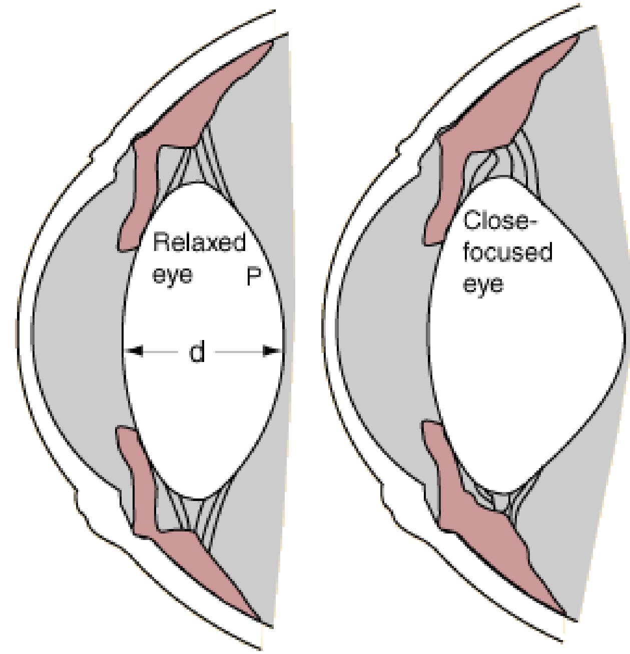


Fig. 4.1 The anatomical features required in the discussion of the mechanism of accommodation. The various fibres are ciliary muscle fibres and the Zonule (of Zinn) is the suspensory ligament of the crystalline lens. The capsule is an elastic membrane surrounding the lens and is crucial to the mechanism.



Tradução:

- ciliary muscle (Circular fibres, radial fibres, Meridional fibres) -- **músculo ciliar**
- Zonule of Zinn -- **Zónula de Zinn**

Atenção! Este é um modelo simplificado pois não estão ainda esclarecidos os mecanismos exatos do processo de acomodação.

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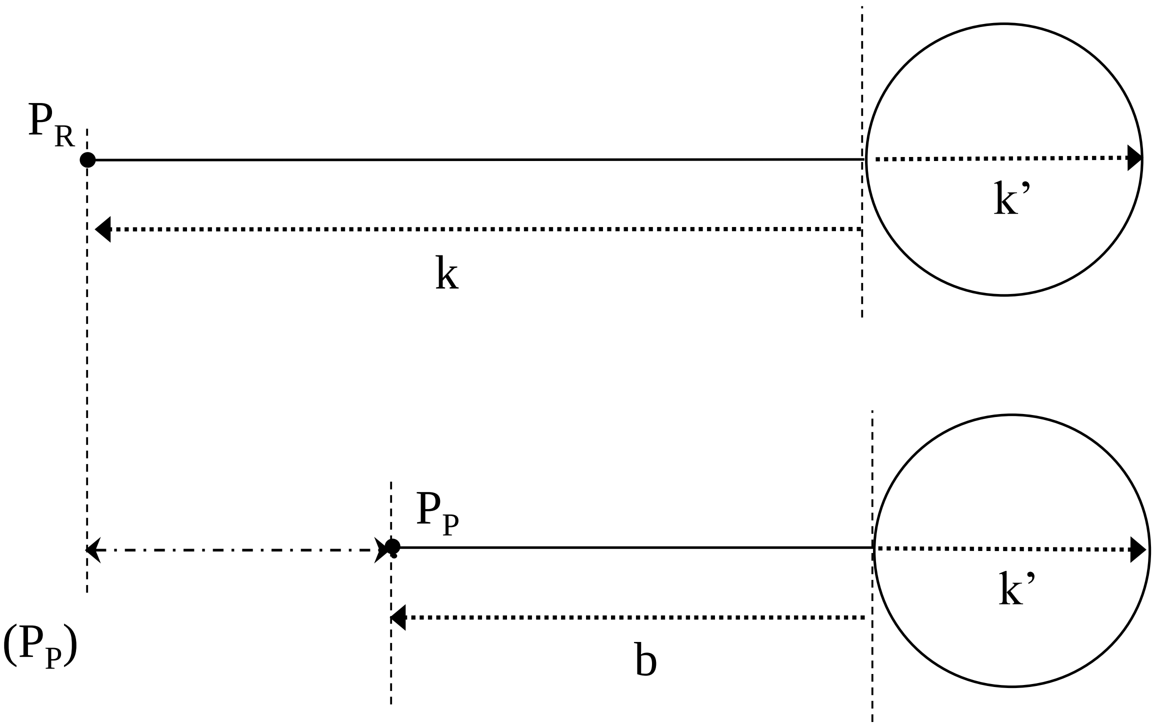
Intervalo e amplitude de acomodação



b ≡ posição do **Ponto Próximo** (P_P)

Intervalo de acomodação = $[P_R, P_P] = |k - b|$ (se $k < 0$)

Amplitude de Acomodação:

$$A_{acomod} = P_{max\_olho} - P_{min\_olho} = (\overline{K}' - \overline{B}) - (\overline{K}' - \overline{K}) = \overline{K} - \overline{B}$$

$$A_{acomod} = \overline{K} - \overline{B}$$

Medida da acomodação

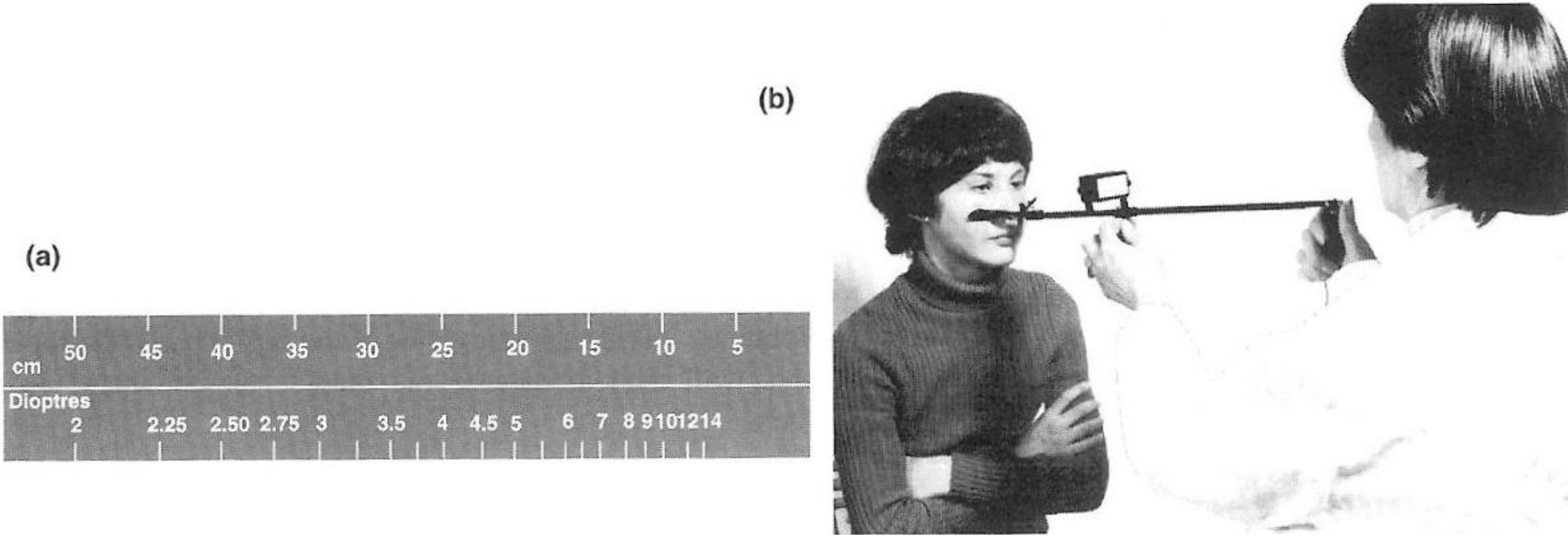


Fig. 4.14 (a) A dioptric scale typically found on a near point rule for measuring the amplitude of accommodation.
(b) Measurement of the amplitude of accommodation with the RAF binocular gauge or near point rule.

Photo: Clement Clarke International Ltd.

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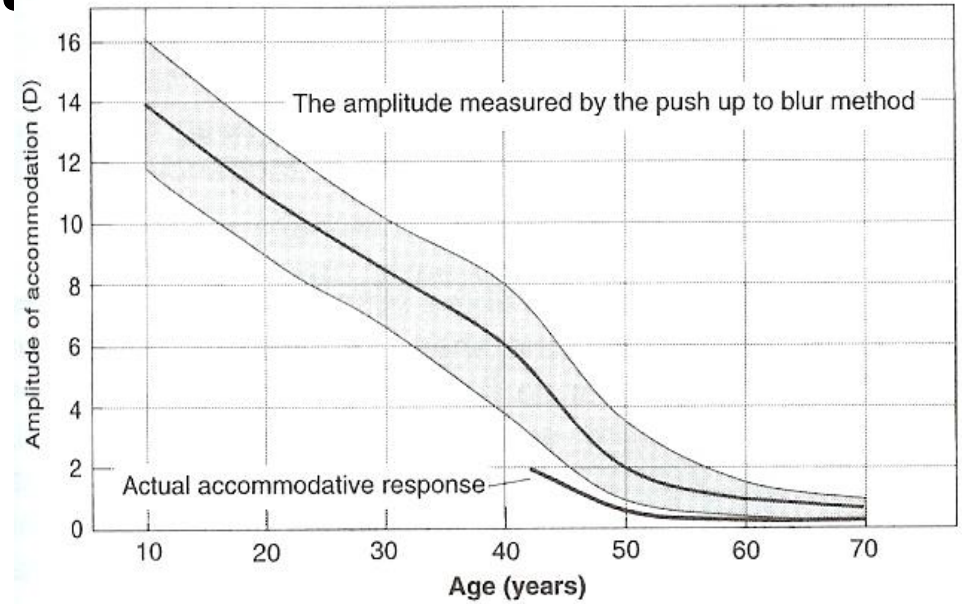
Variação da amplitude de acomodação com a idade

Age (years)	Amplitude of accommodation
10	14
20	10
30	8
40	5
45	3
50	2
60	1
70	<1



Porquê esta variação?

Tunnacliffe
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Perda de elasticidade do cristalino e aumento do seu tamanho.

Mas atenção! as mudanças associadas ao envelhecimento são complexas...

Outros efeitos do envelhecimento associados com o cristalino

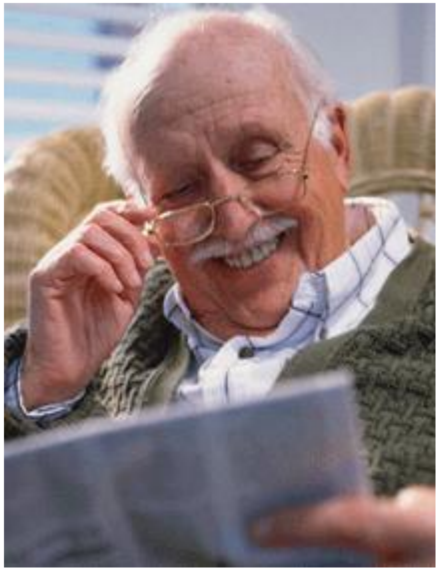
- Aumento da hipermetropia (as lentes ficam mais planas)

Idade:	*50*	*60*	*70*
Hipermetropia adquirida:	*0.5D*	*1.00D*	*1.5D*

- Miopia de índice (n do cristalino aumenta para pessoas com mais de 60 anos)
- Astigmatismo

Presbiopia

Diz-se que há **Presbiopia** quando a amplitude de acomodação é igual ou inferior a 3 dioptrias.



Atenção!

A adição para visão ao perto (ou adição de leitura) ***add*** adiciona-se à correção para visão à distância.

Compensação da afaquia com implantes

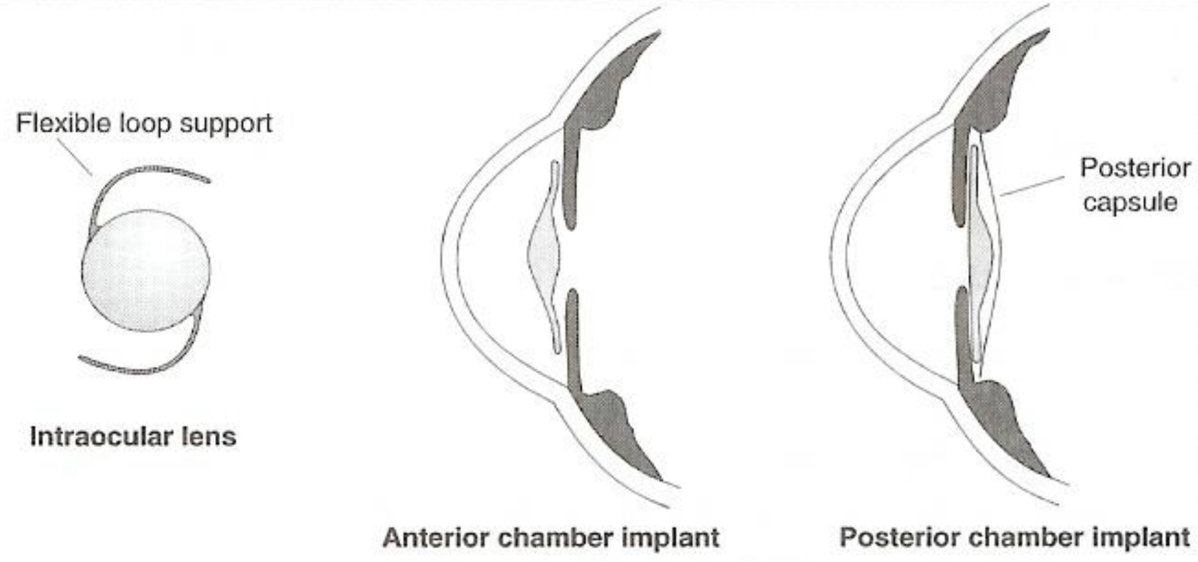


Fig. 4.30 Anterior and posterior chamber intraocular lenses used to replace the crystalline lens which has been surgically removed because of the presence of cataract.

Tunnacliffe

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ABERRAÇÕES

€1 million Champalimaud Award recognises novel approaches to imaging the eye

2012 Award shared between research groups responsible for ground-breaking medical imaging advances

Escola de Ciências

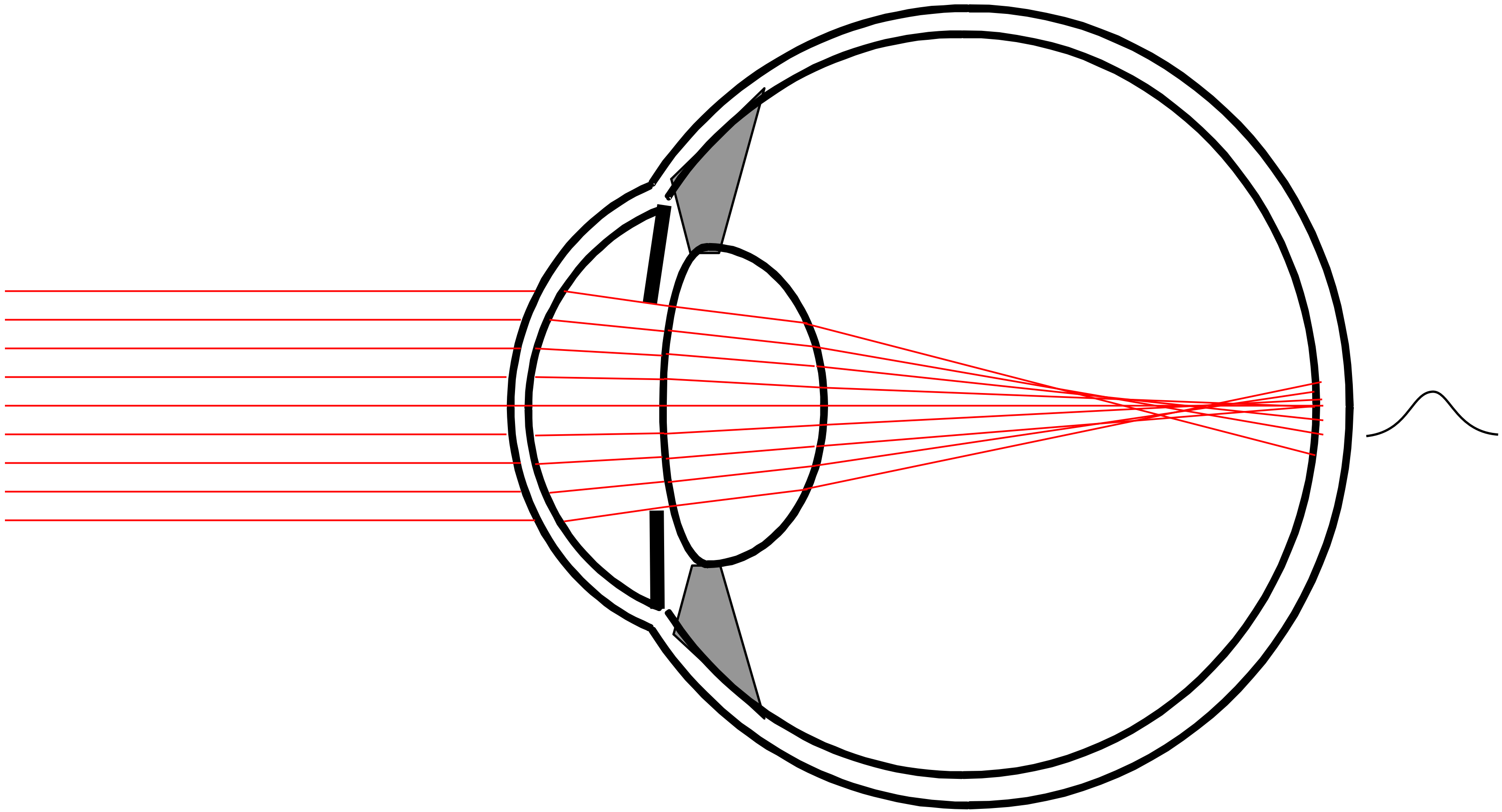
Universidade do Minho

From left: Carmen Puliafito, James Fujimoto, Eric Swanson, Joel Schuman, David Huang and David Williams receive the 2012 Champalimud Vision Award in Lisbon

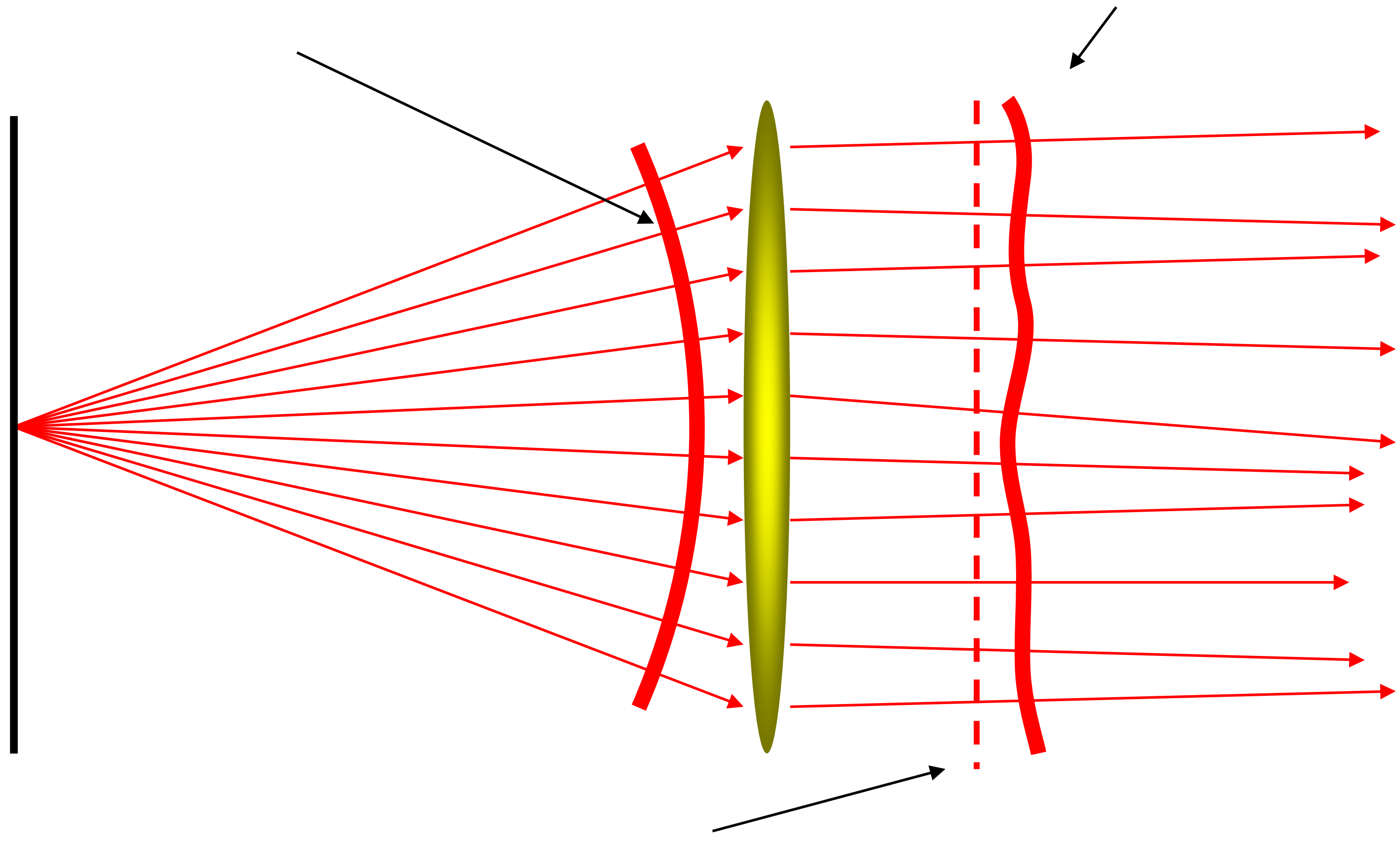
Factores que limitam a qualidade da visão

- retina (foto-receptores, células ganglionares, …)
- neuronais (lesões, patologias, drogas, …)
- ópticos:
  - opacidades
  - difracção
  - aberrações: cromáticas, monocromáticas

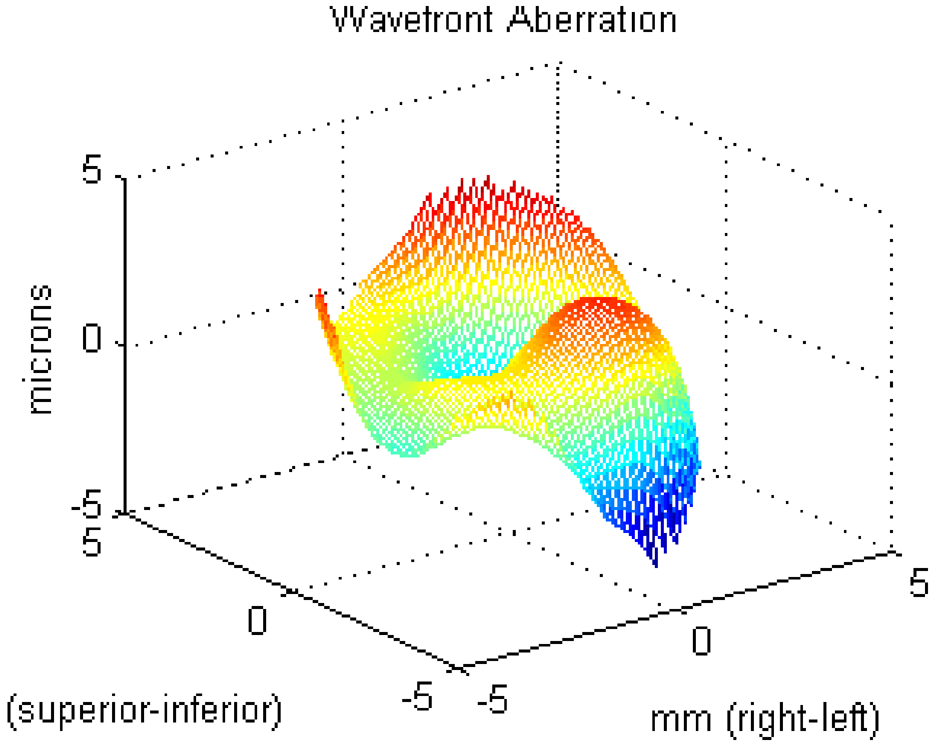
monocromáticas

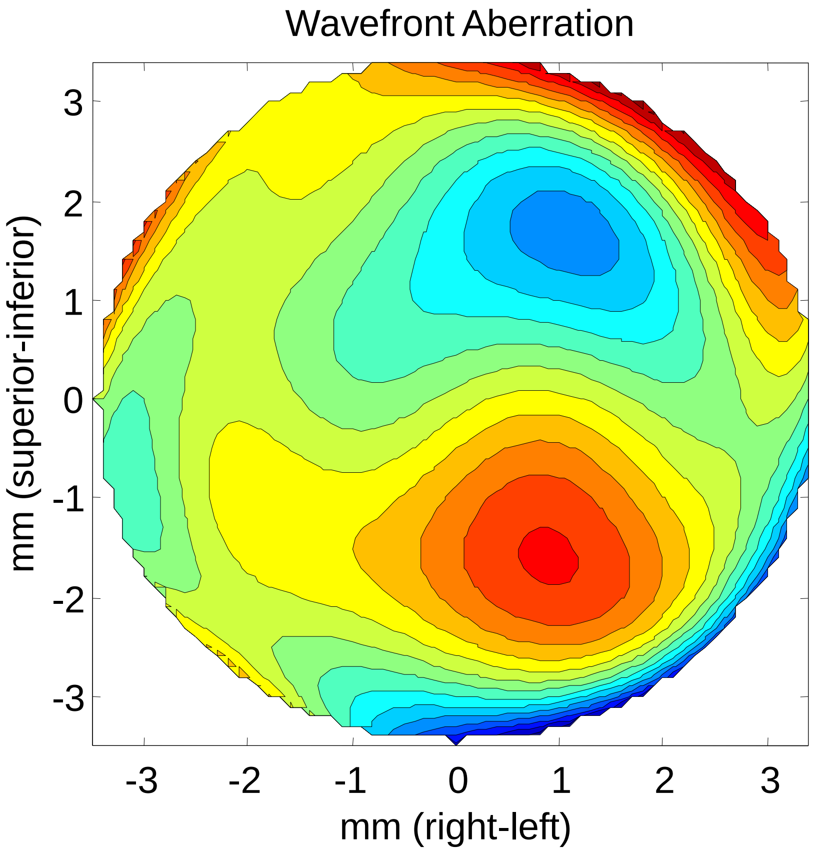


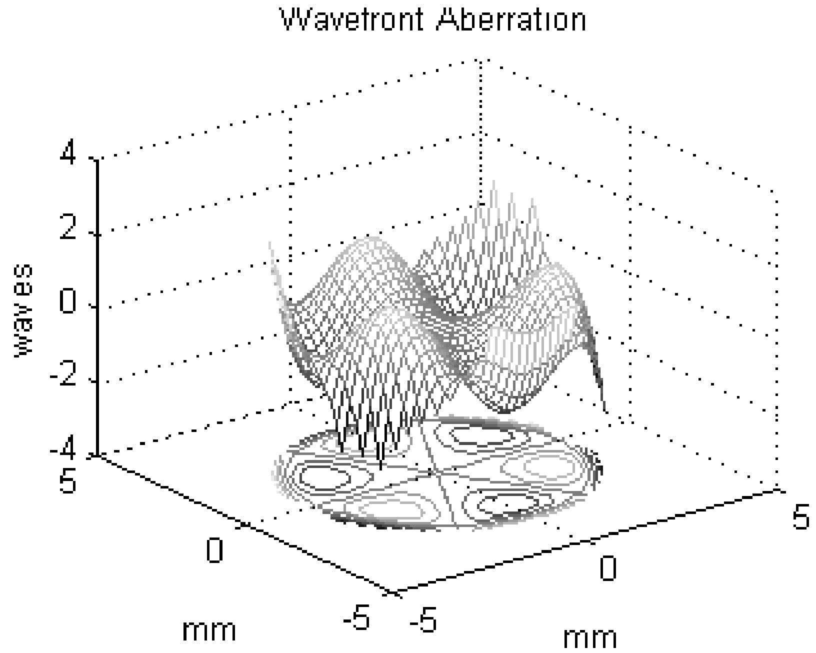
aberrações como distorção da frente de onda

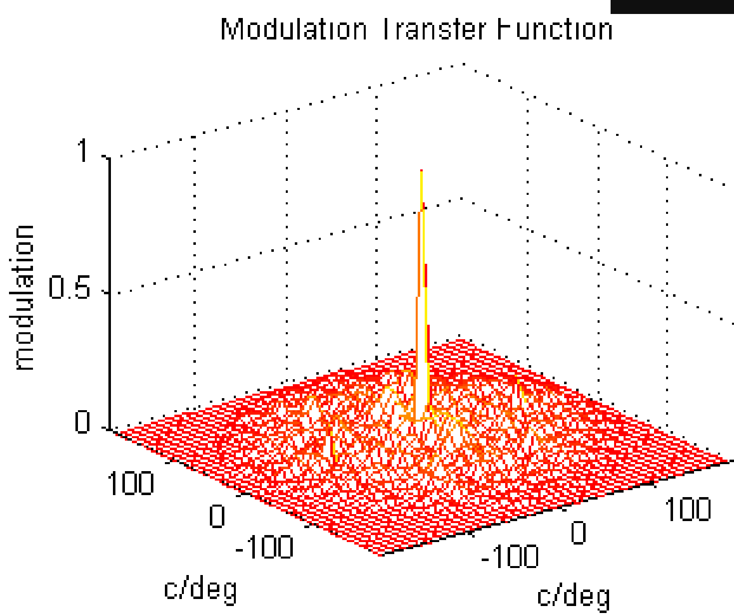


aberrações como distorção da frente de onda

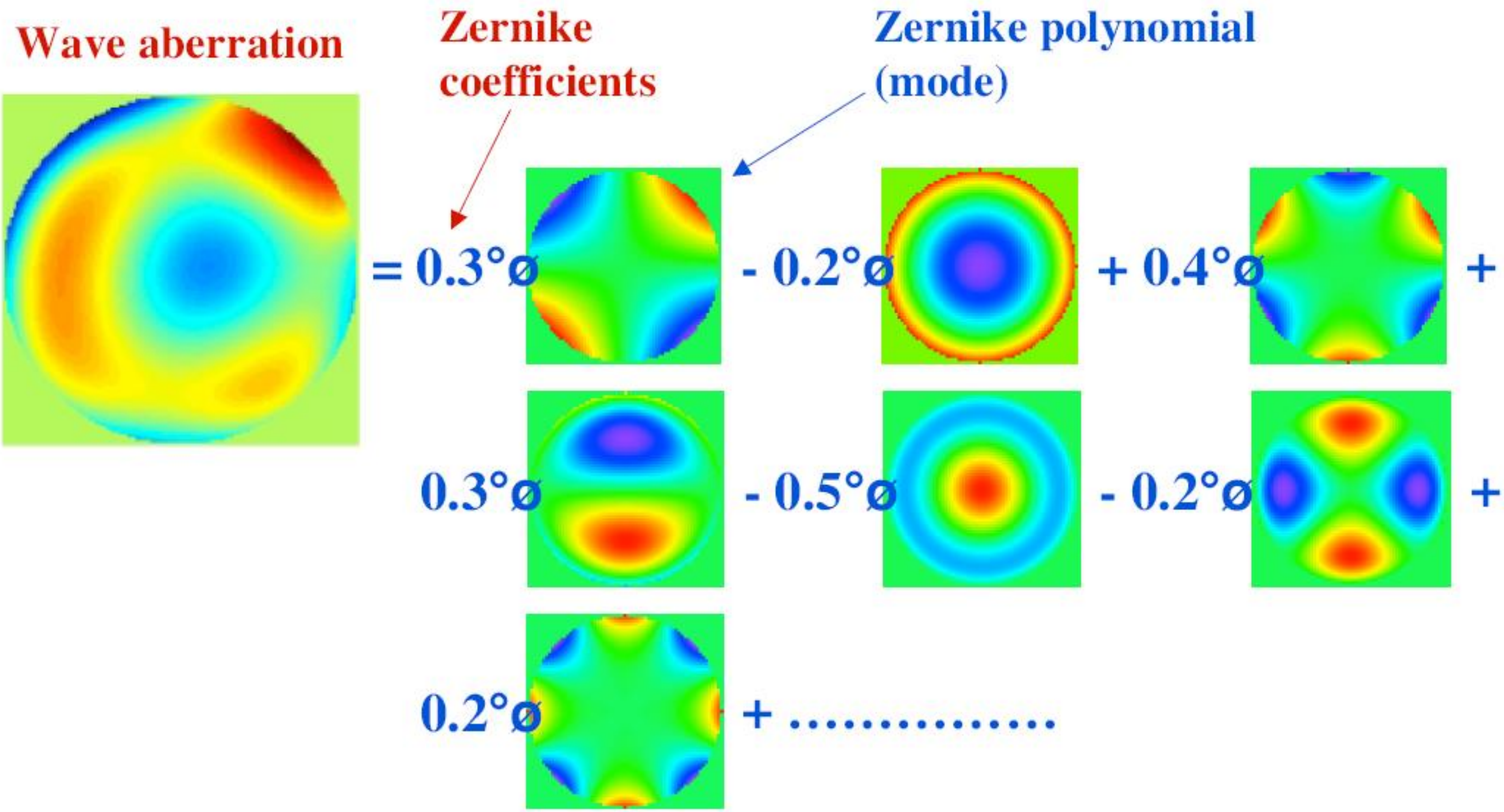




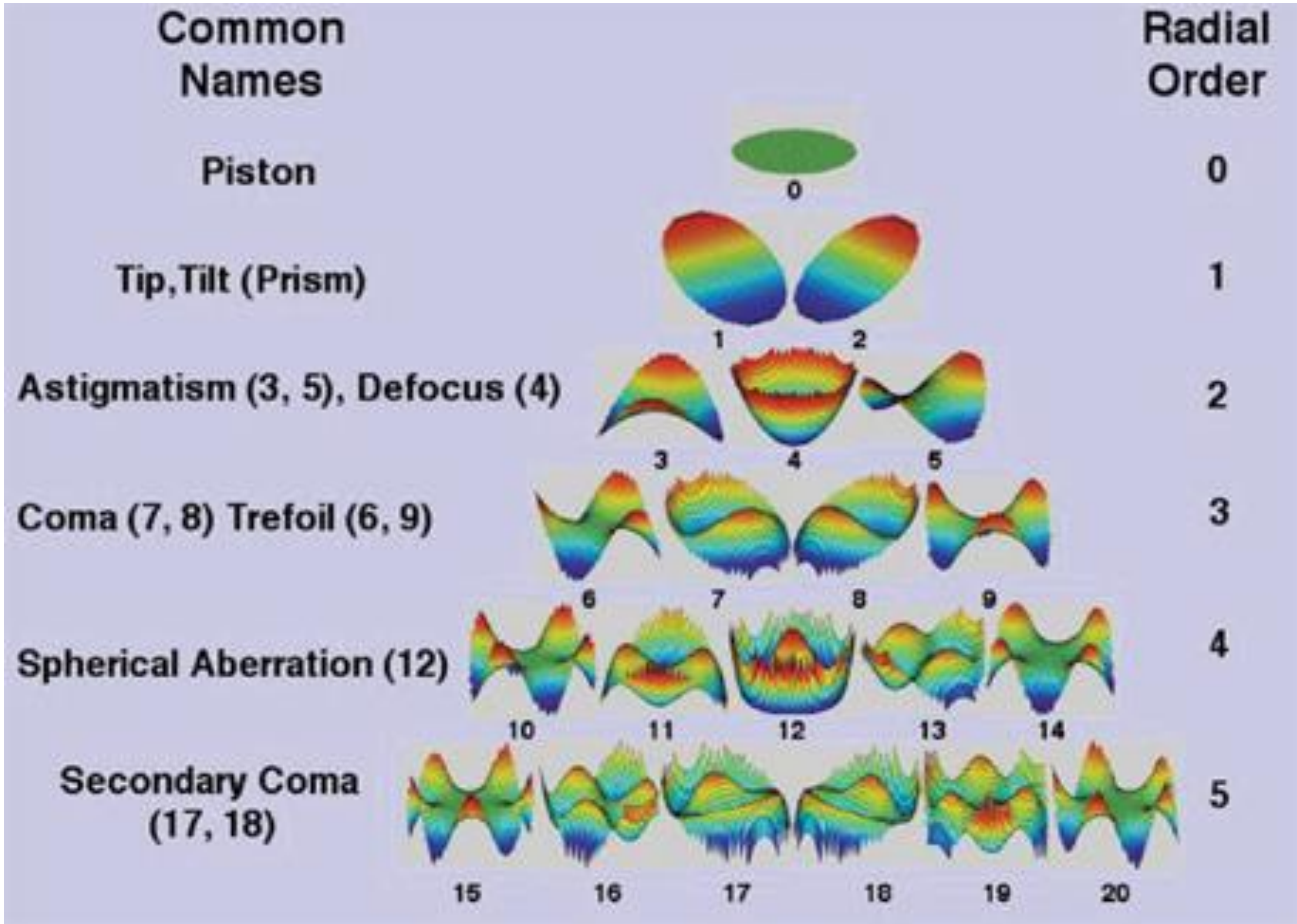

Wavefront Aberration
waves
4
2
0
-2
-4
5
0
-5
mm
-5
0
5
mm


Modulation Transfer Function
modulation
1
0.5
0
100
0
-100
c/deg
-100
0
100
c/deg

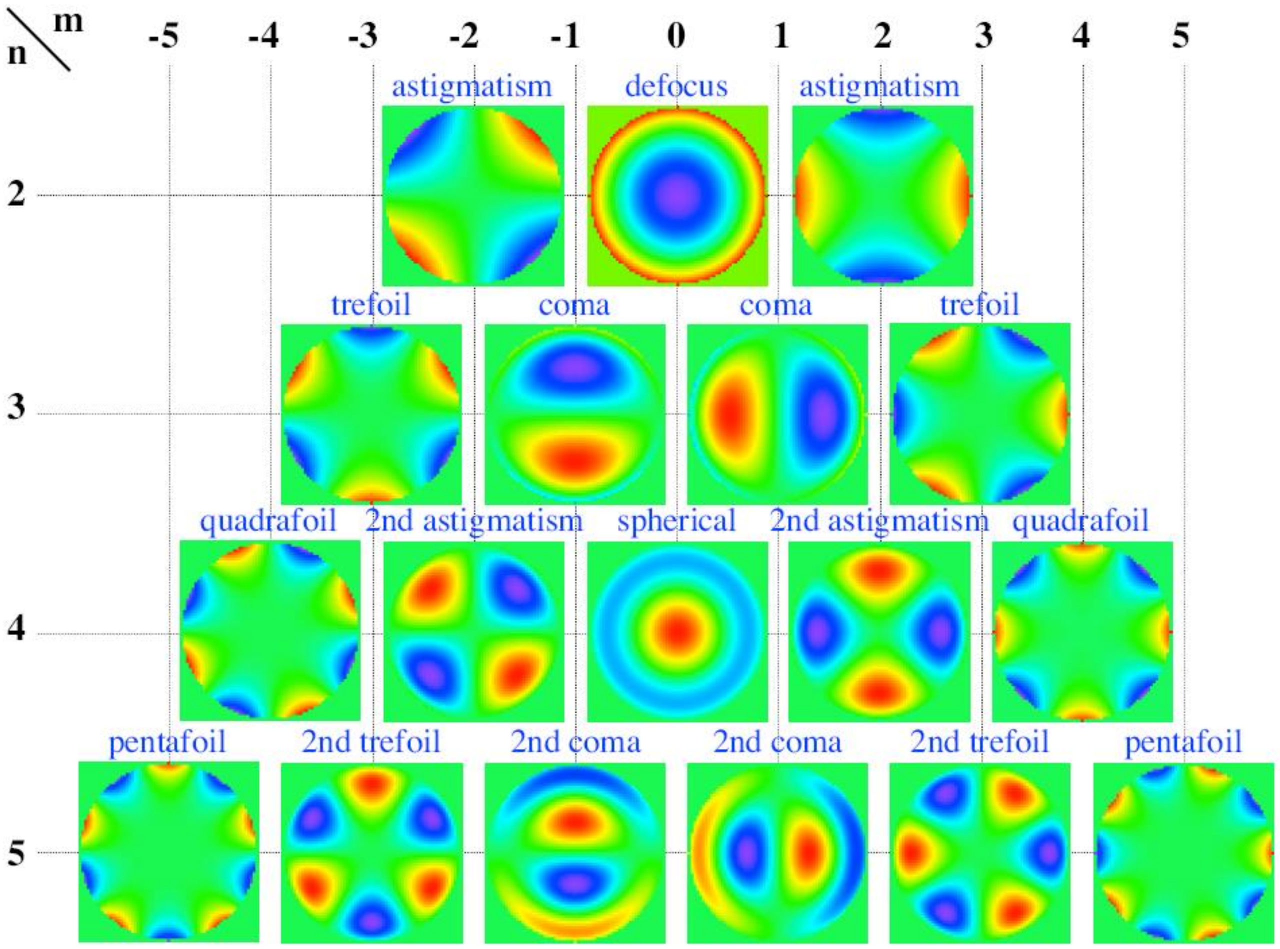
polimómios de Zernike



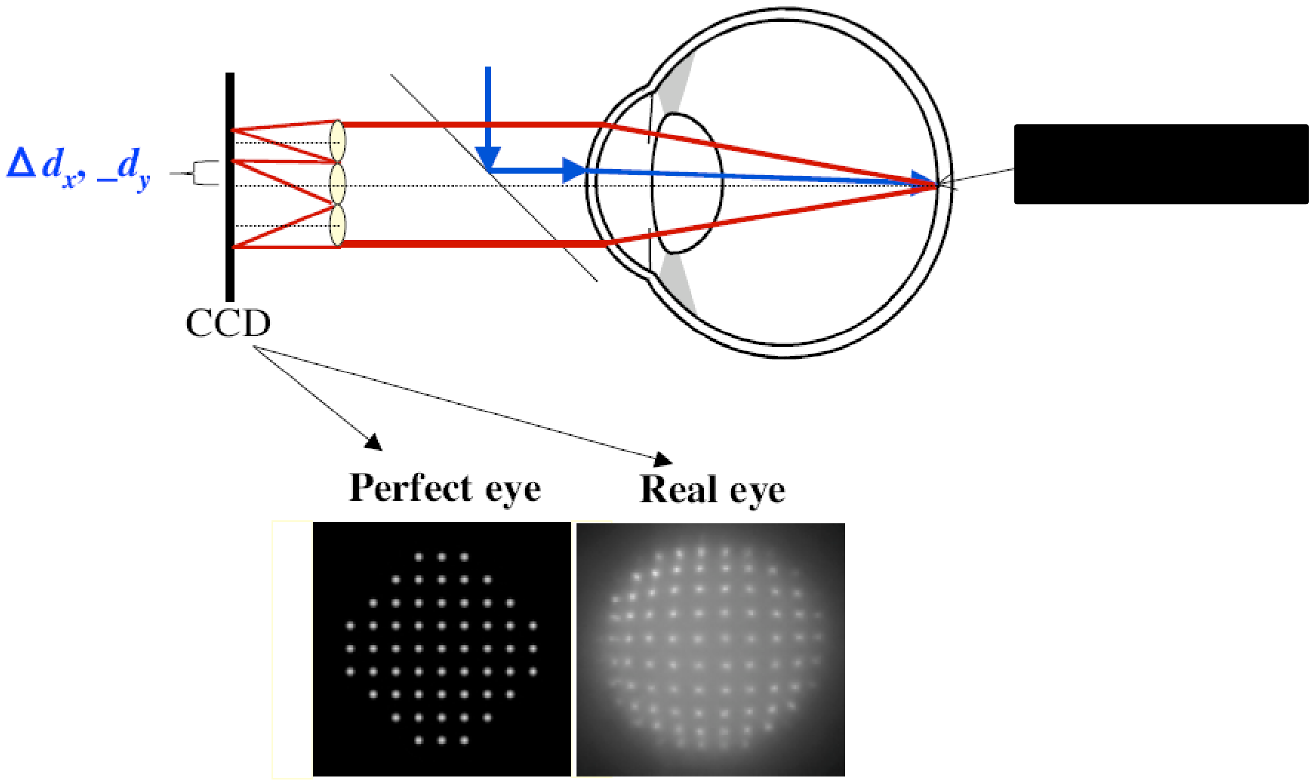
polinómios de Zernike



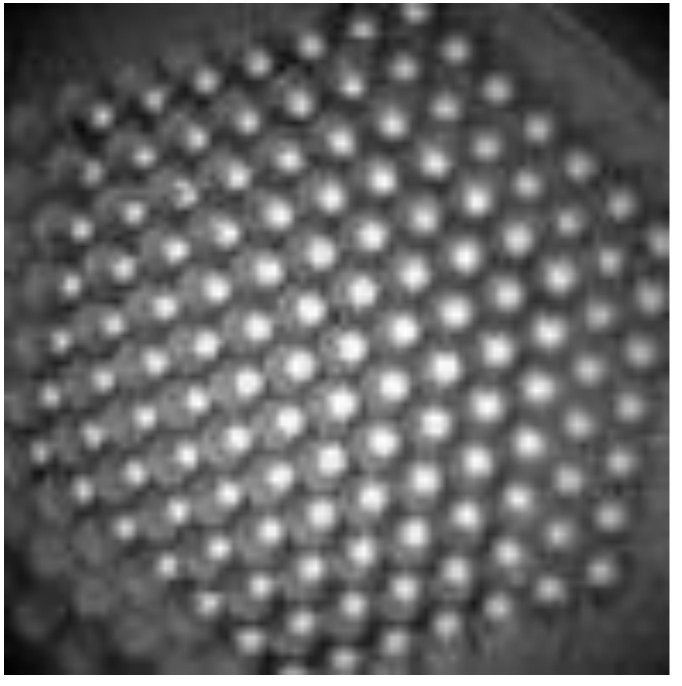
polinómios de Zernike



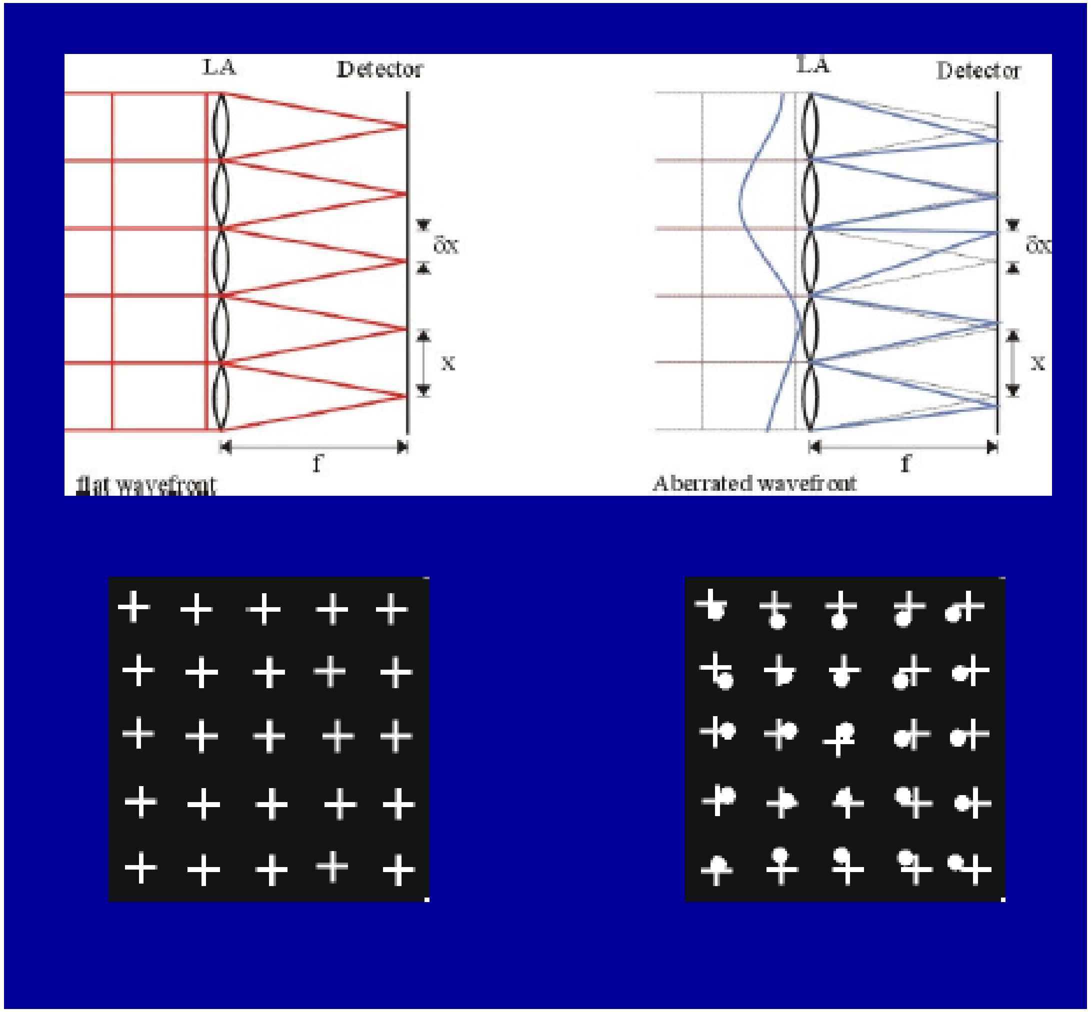
sensor Hartmann-Shack



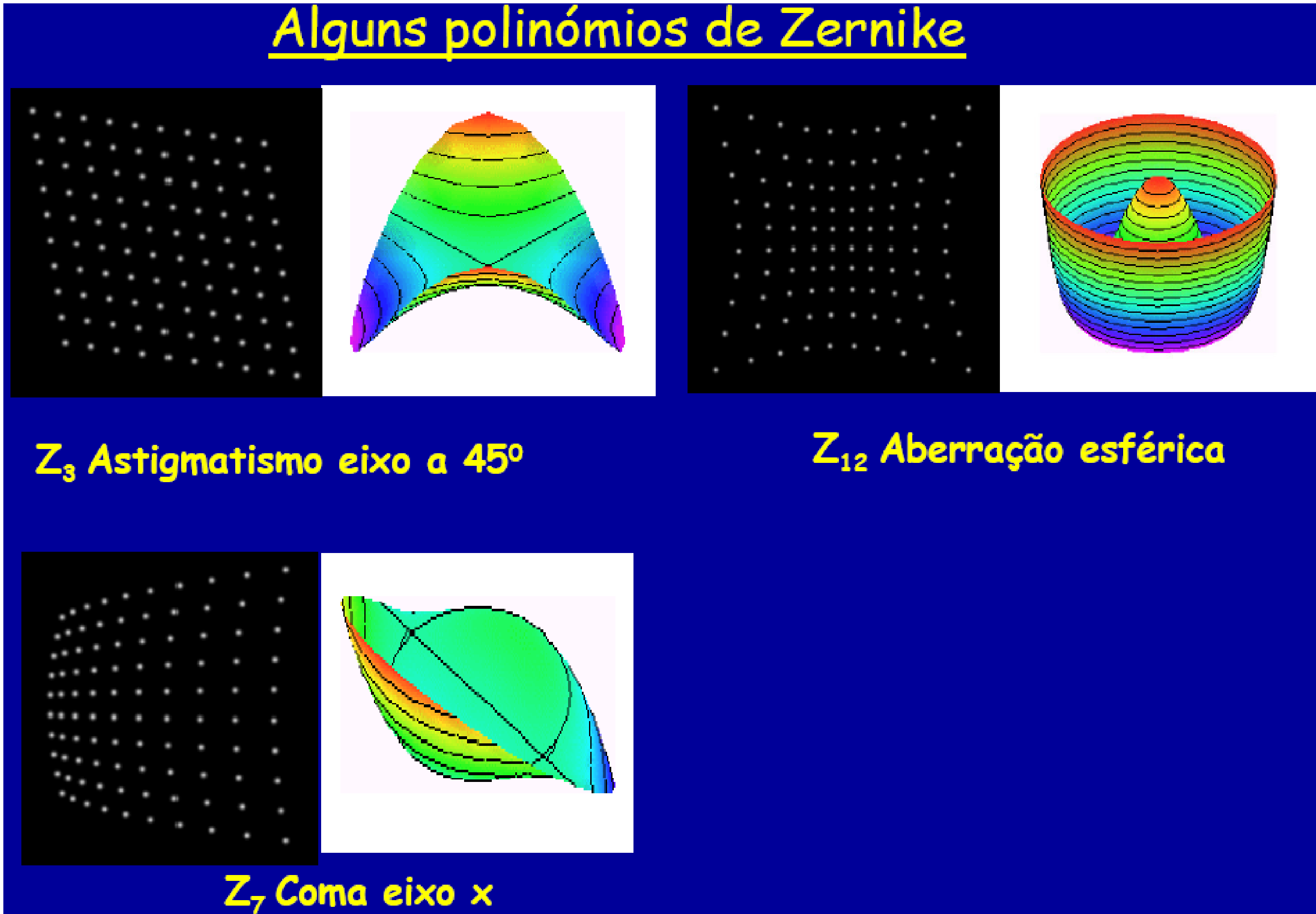
matriz de lentes



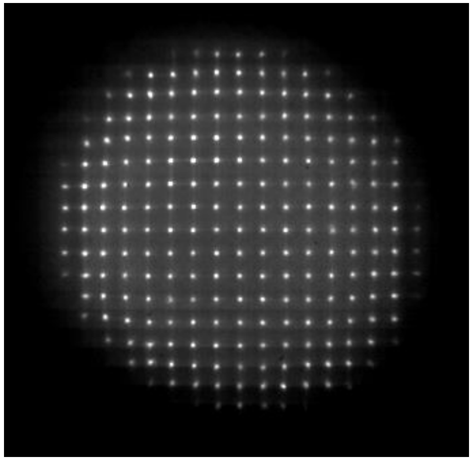
reconstrução da frente de onda

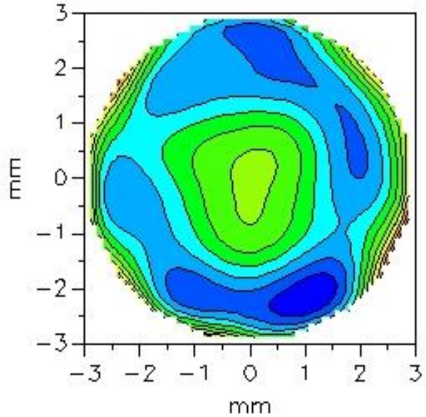


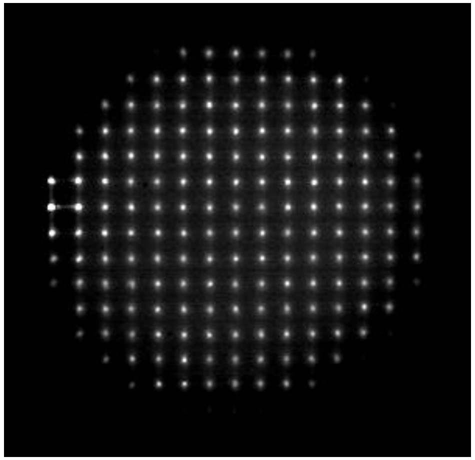
reconstrução da frente de onda

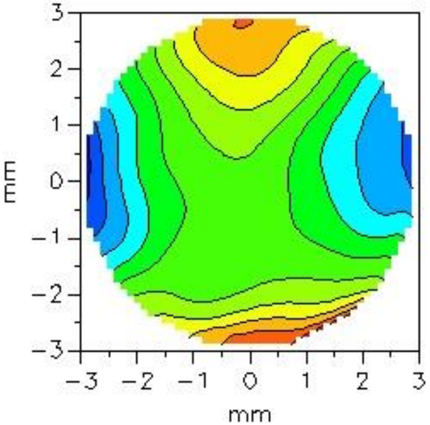


normais

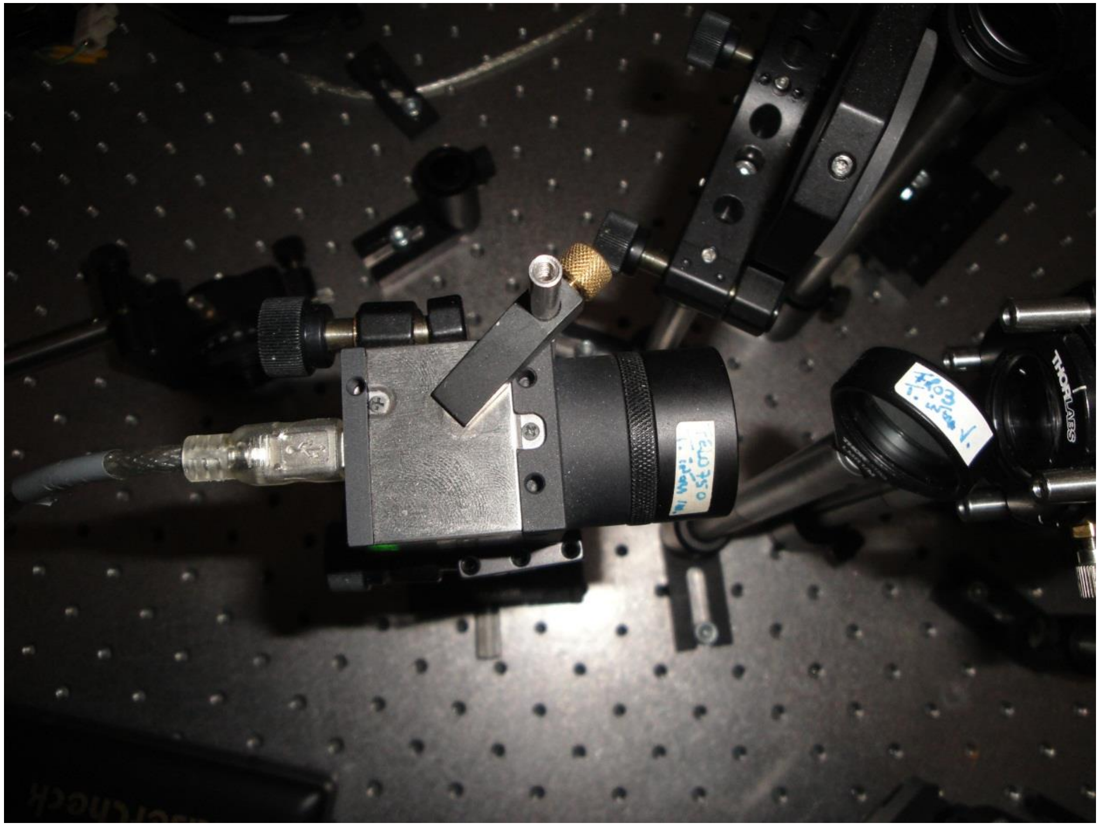


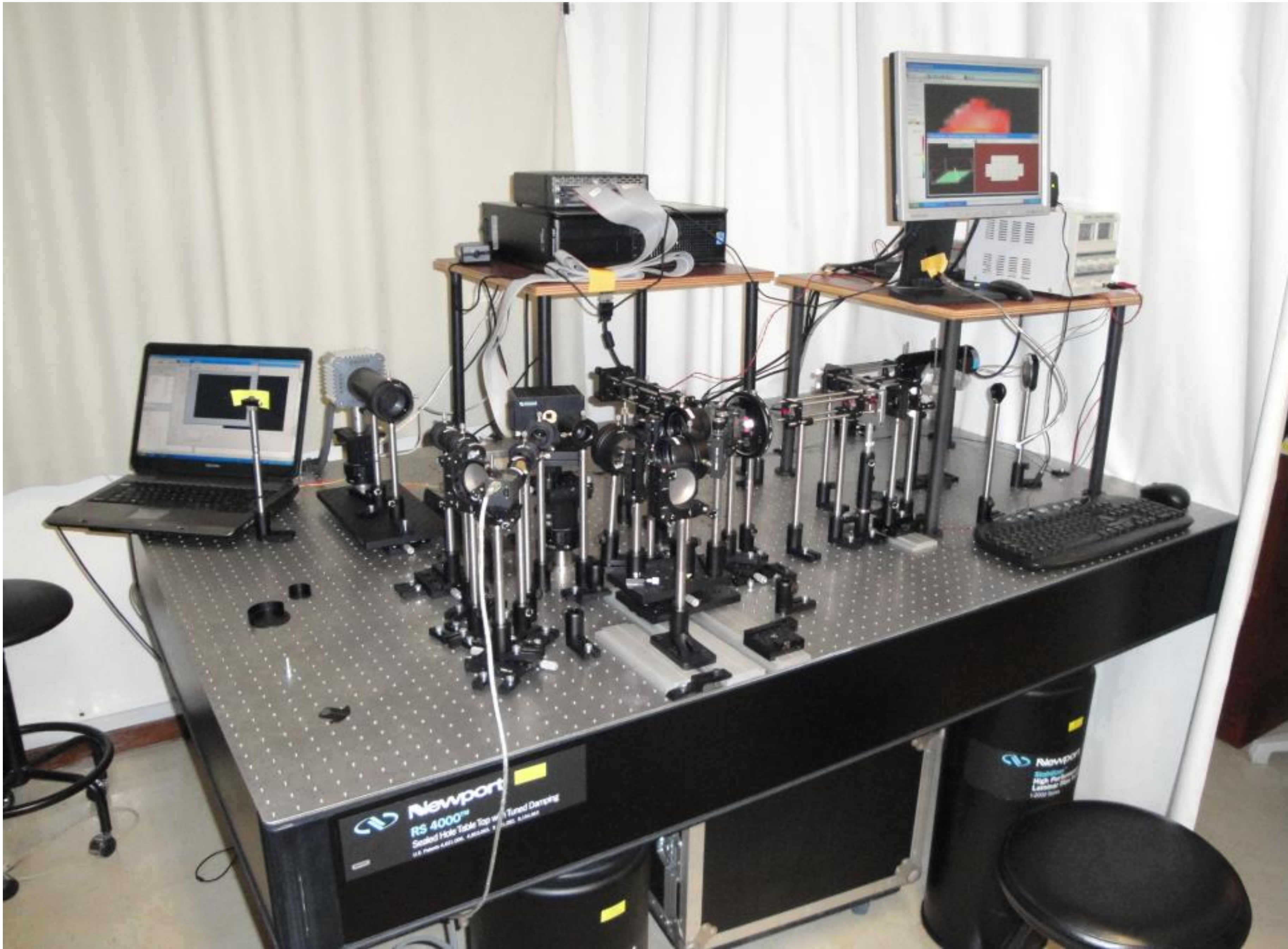




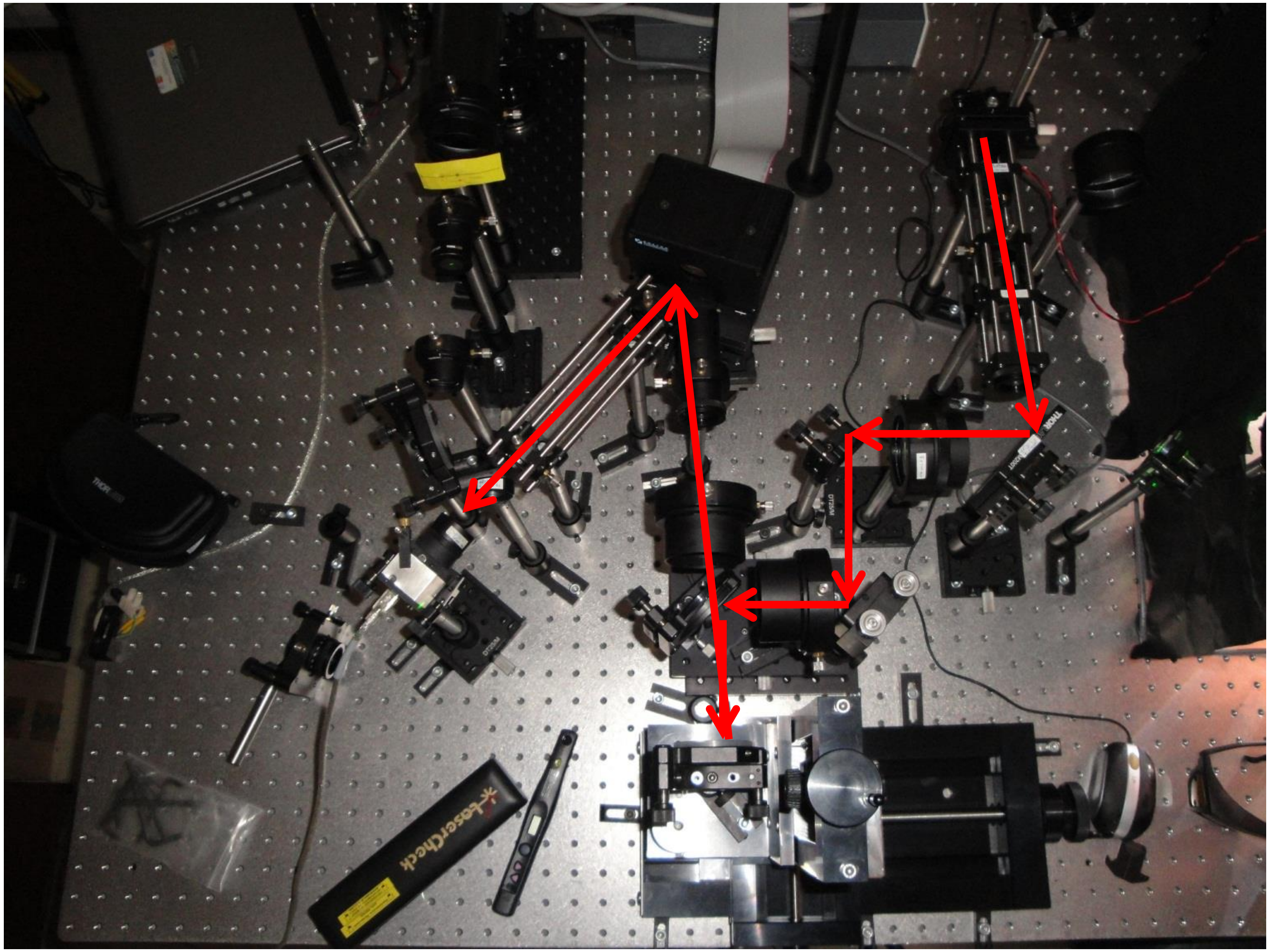


HS sensor na UMinho

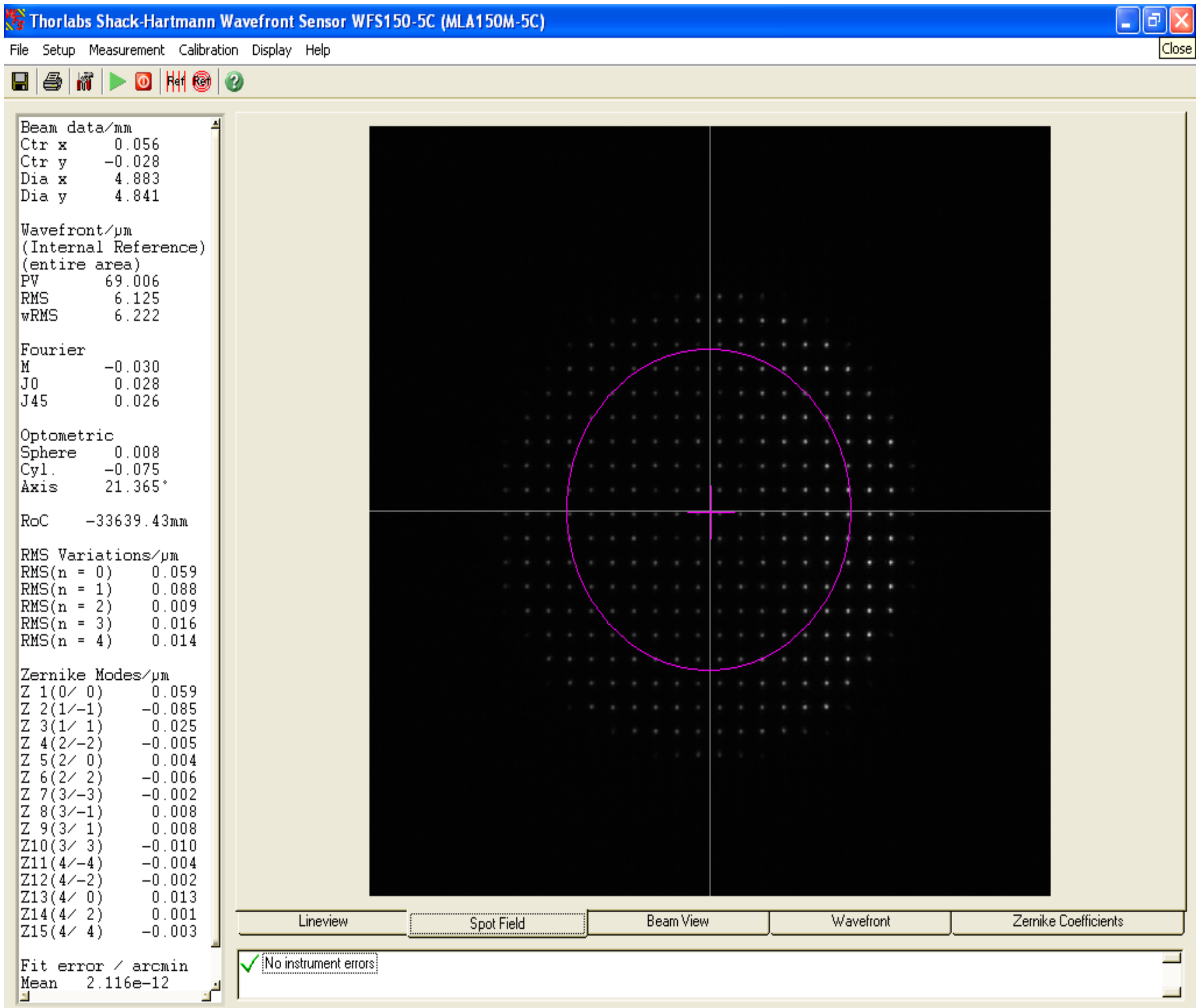



Newport
RS 4000™
Newport

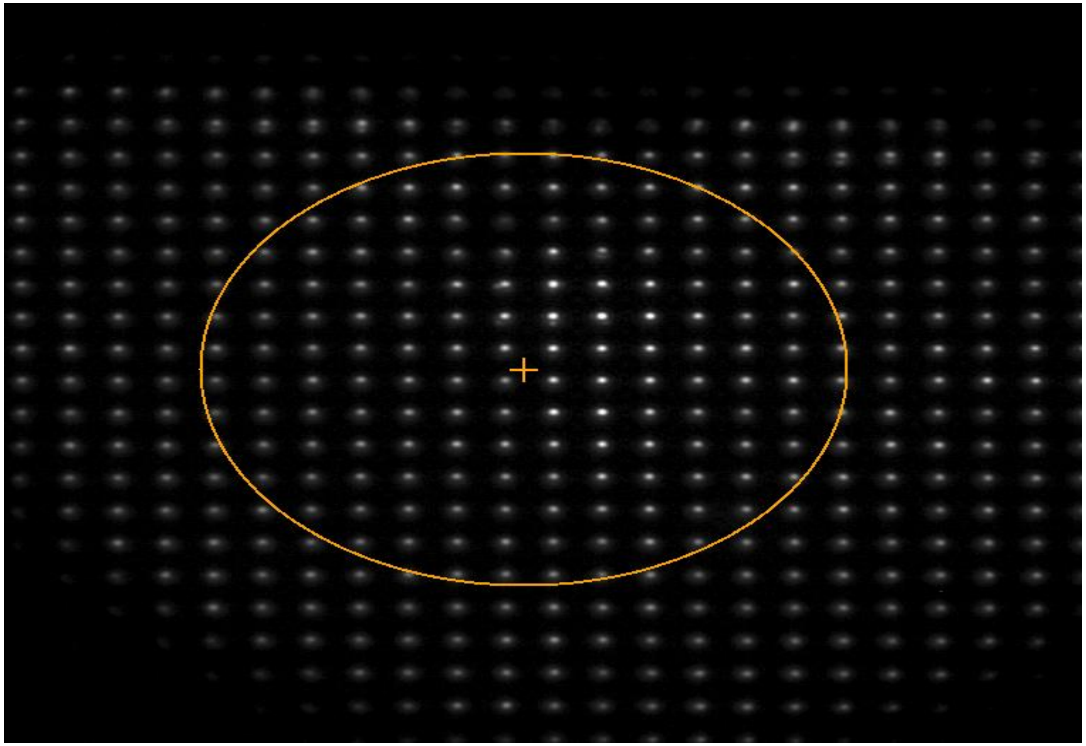
System as a simple aberrometer

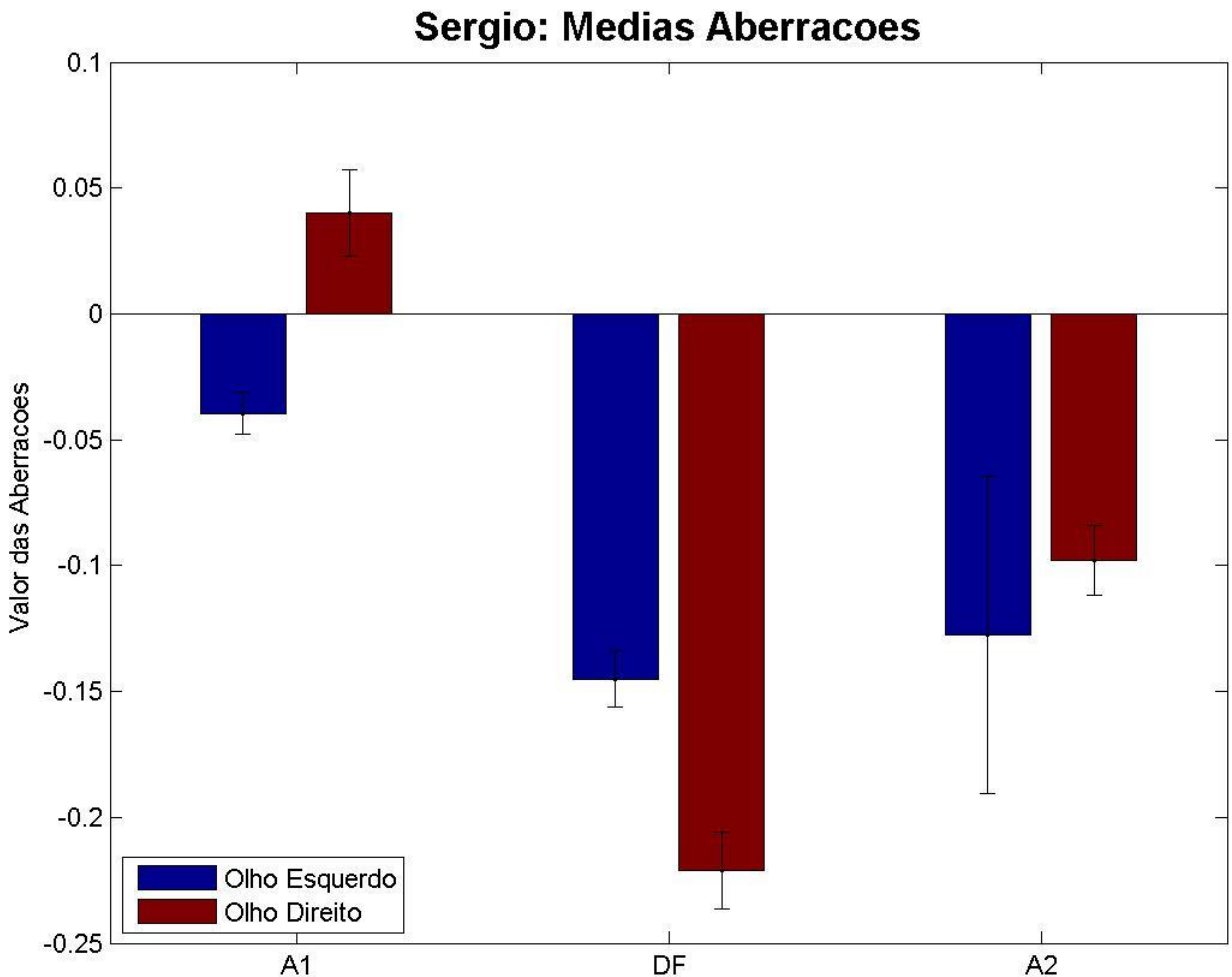


Baseline (sem olho)



Olho Real (HT)





Sergio: Medias Aberracoes
Valor das Aberracoes
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25
A1
DF
A2
Olho Esquerdo
Olho Direito

Olho real (HT)