Basic Optics Course, Maastricht 2017

Optics of the crystalline lens and accommodative response

Rafael Navarro*

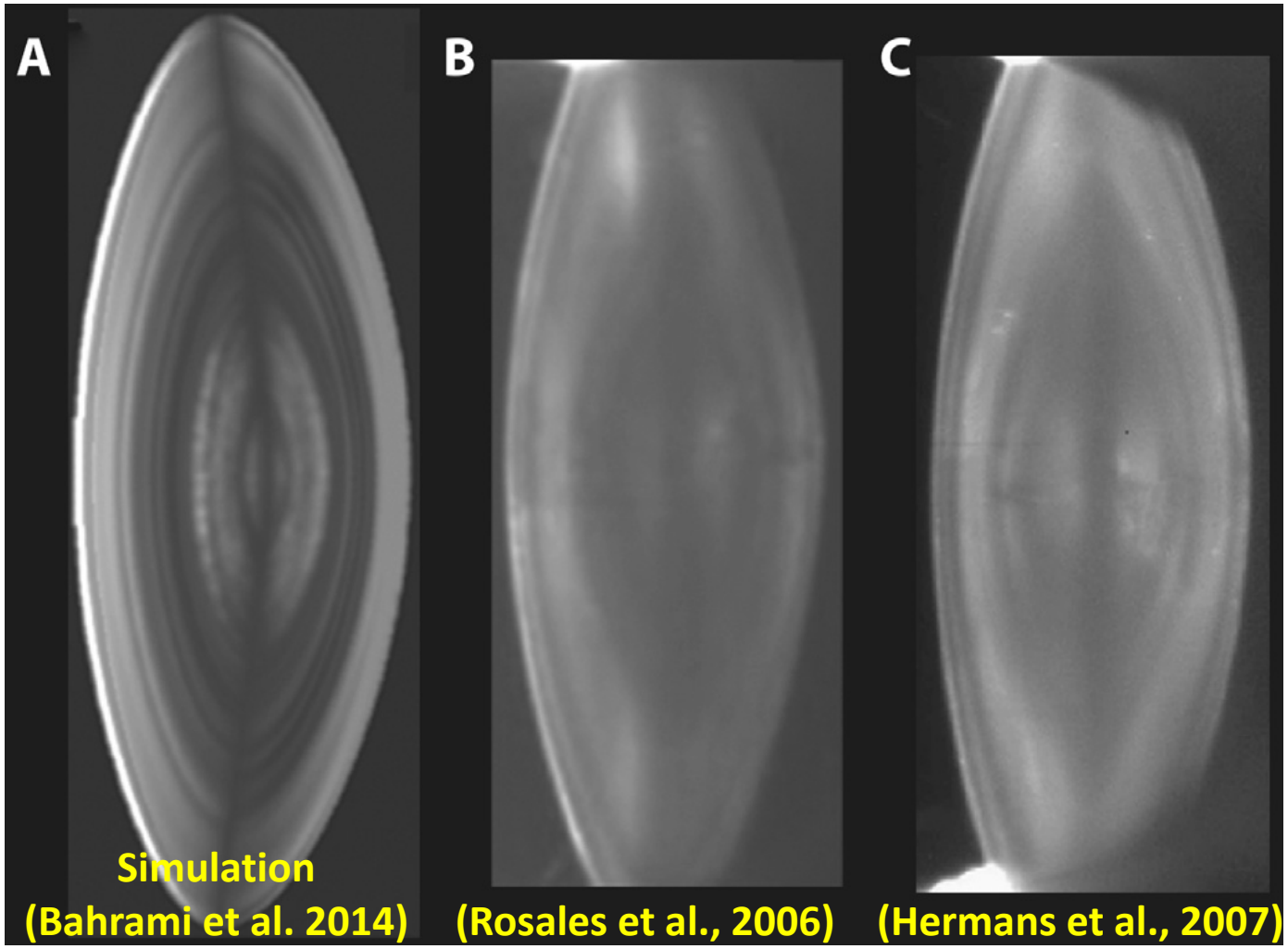
CSIC
Consejo Superior de Investigaciones Científicas

Universidad Zaragoza
1542

*No financial interest

1. Optics of the lens

Biconvex lens with **complex** inner structure



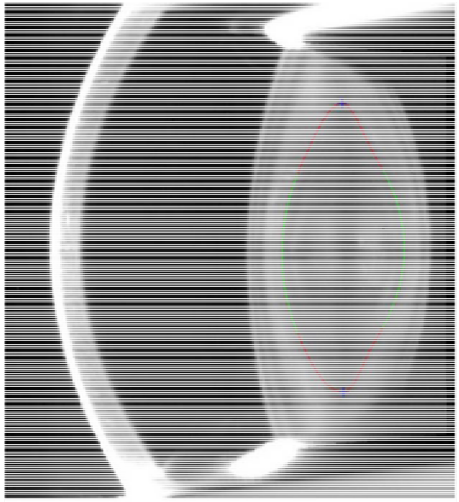
Optics of the crystalline lens: Power

1.- The primary function of the ocular lens is to **refract** light after it passes through the cornea to focus on the retina

Dioptric power (average):

P_{cornea} = 42.5 D

[68%]



(Hermans et al. 2007)

P_{lens} = 24.96 D

(Jongenelen et al. IOVS, 2014)

[40%]

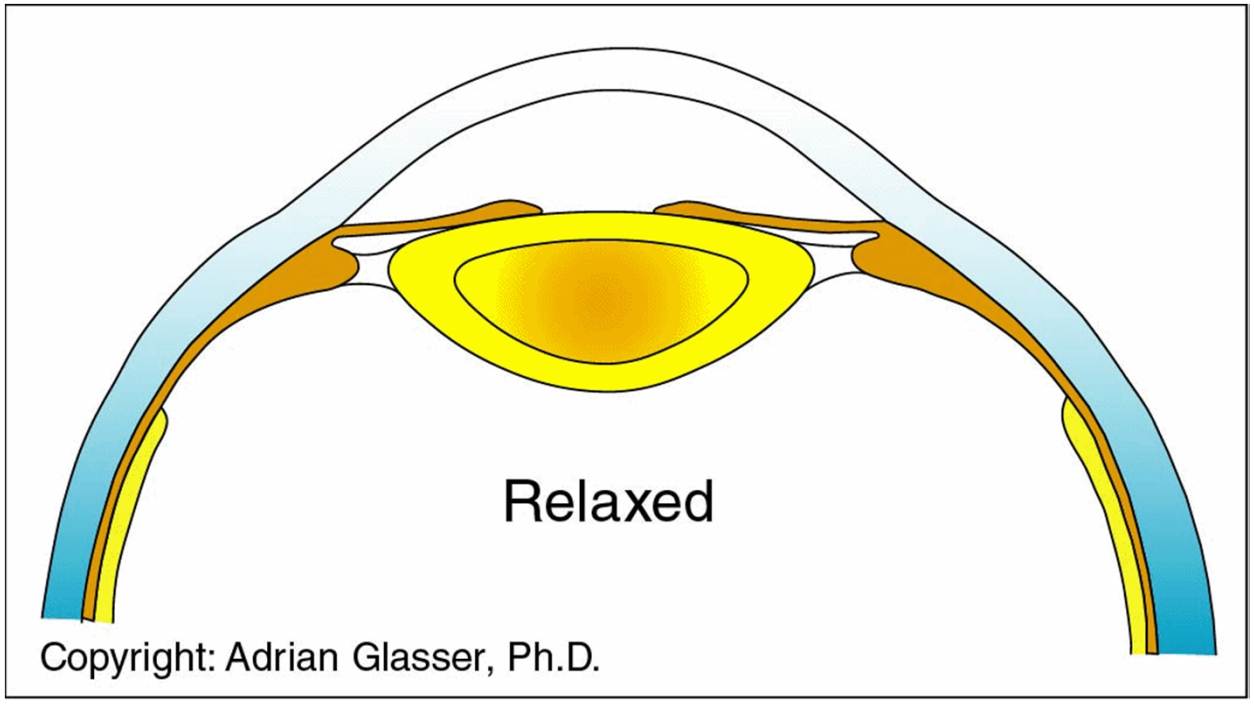
$$P_{eye} = P_{co} + P_{le} - \frac{d}{n} P_{co} P_{le} \simeq 62.6 \text{ D}$$

P_{eye} = 62.6 D

Optics of the crystalline lens: Accommodation

2.- A secondary function the lens in some species is to **accommodate** to increase the refracting power of the eye

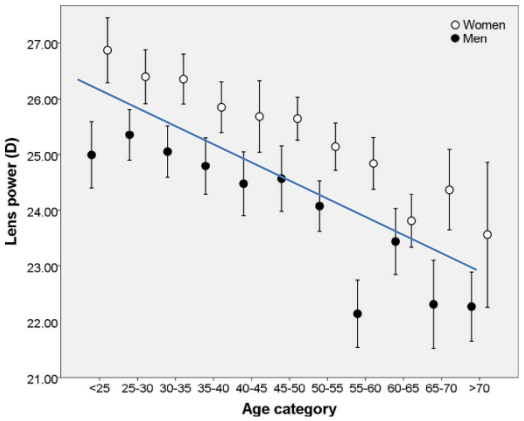
to focus near objets



Courtesy of A. Glasser

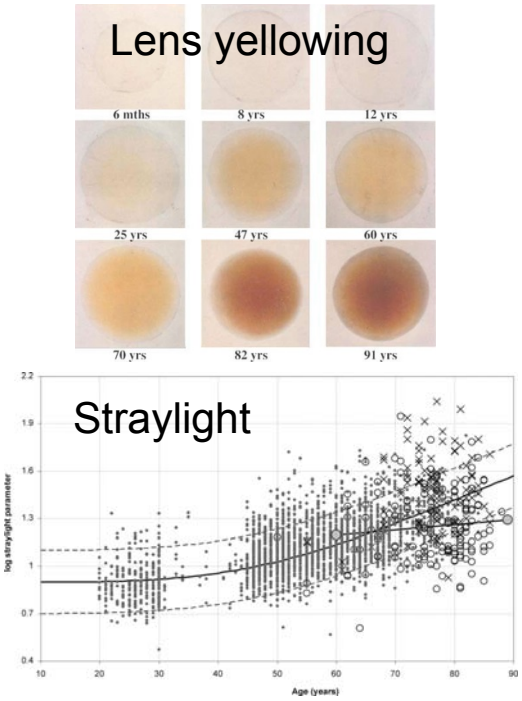
Optics of the crystalline lens: Age-related changes

Loss of power



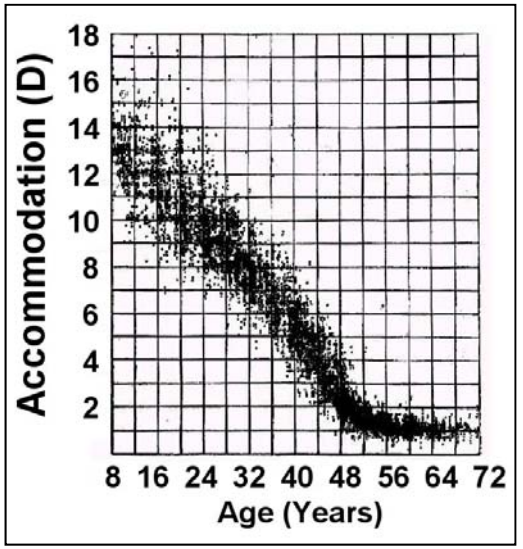
(Jongenelen et al., 2014)

Loss of Optical Quality



(Van den Berg et al. 2007)

Loss of Accommodation



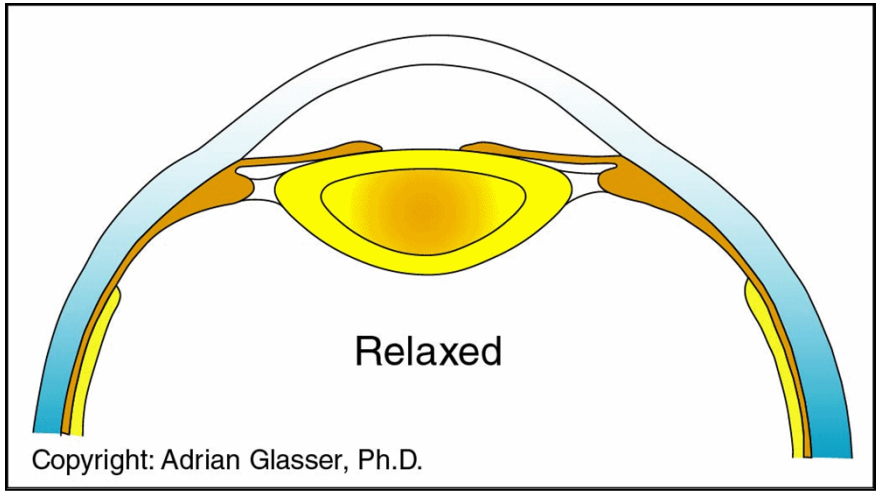
(Duane, 1912)

The optical properties of the lens change dramatically with increasing age

Temporal changes

Short-term (fast) changes

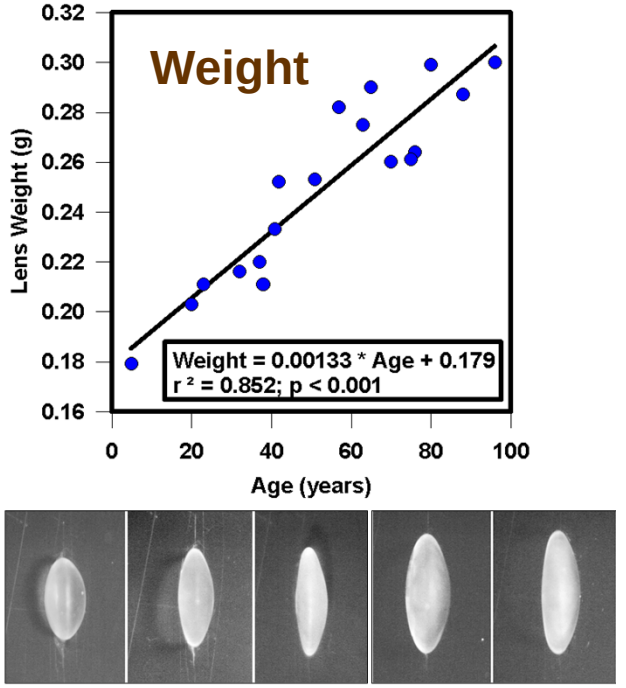
Active focus of objects



Courtesy of A. Glasser

Long-term (slow) changes

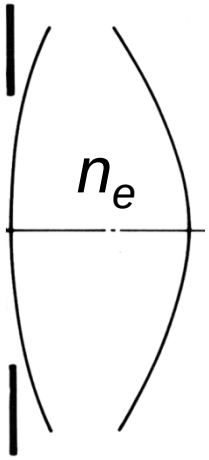
Continuous growth



(Glasser & Campbell, 1999)

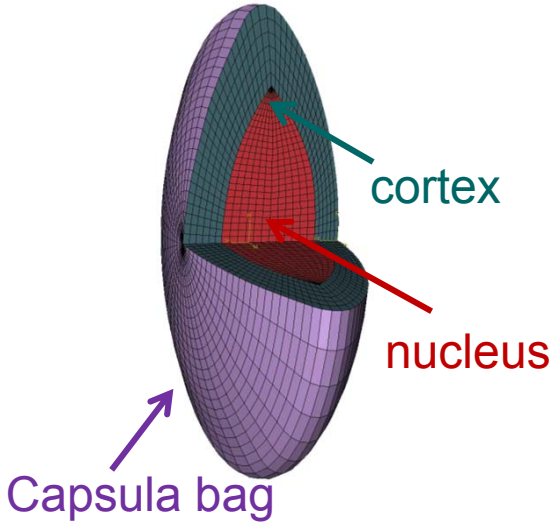
Optical models of the human lens

Homogeneous lens

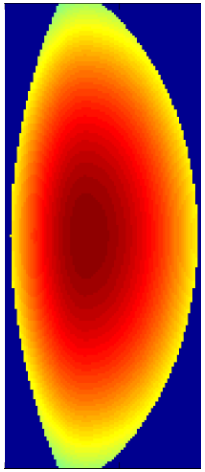


Effective refractive index

4-surfaces



GRIN



$$n_P(Z,\omega) = n_o + \delta_n\left(r^2\right)^p$$

Realism & complexity

Conicoid surfaces: Hyperbolas Q < -1
Apical radii: +10.2 mm (anterior) -6 mm (posterior)

Convex surface Concave surface

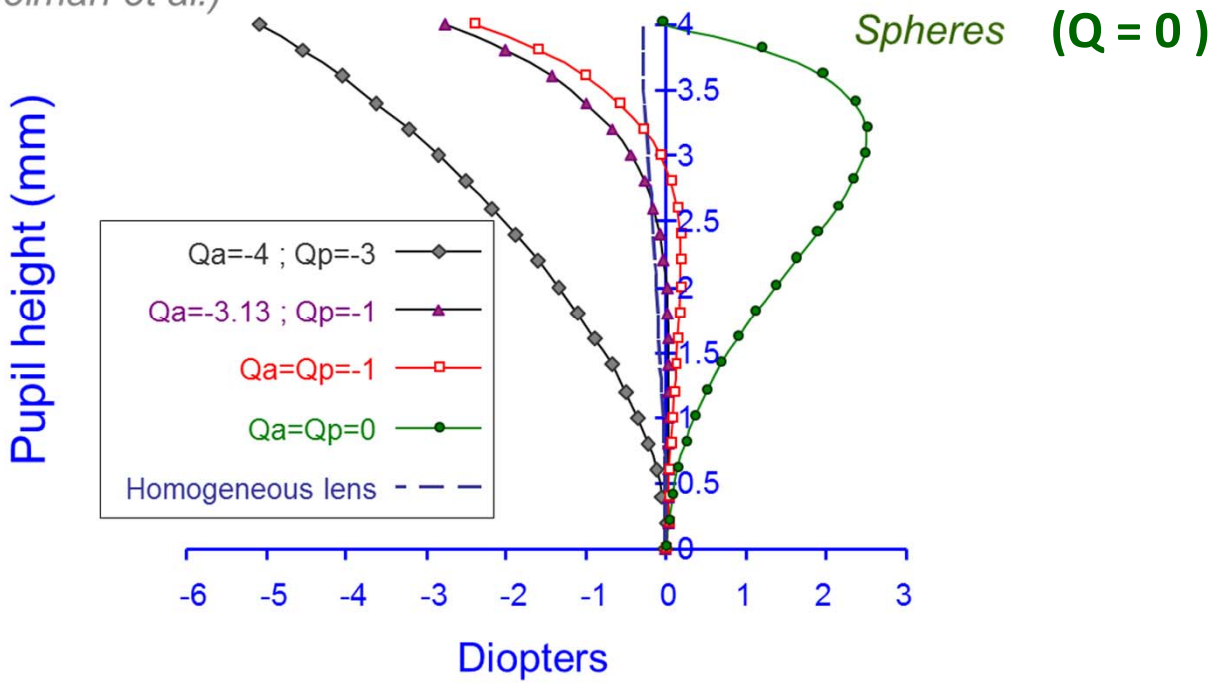
Impact of conic constants (Q)

Longitudinal Spherical Aberration

(Q < -1) *Hyperbolas (Dubbelman et al.)*

Parabolas **(Q = -1)**

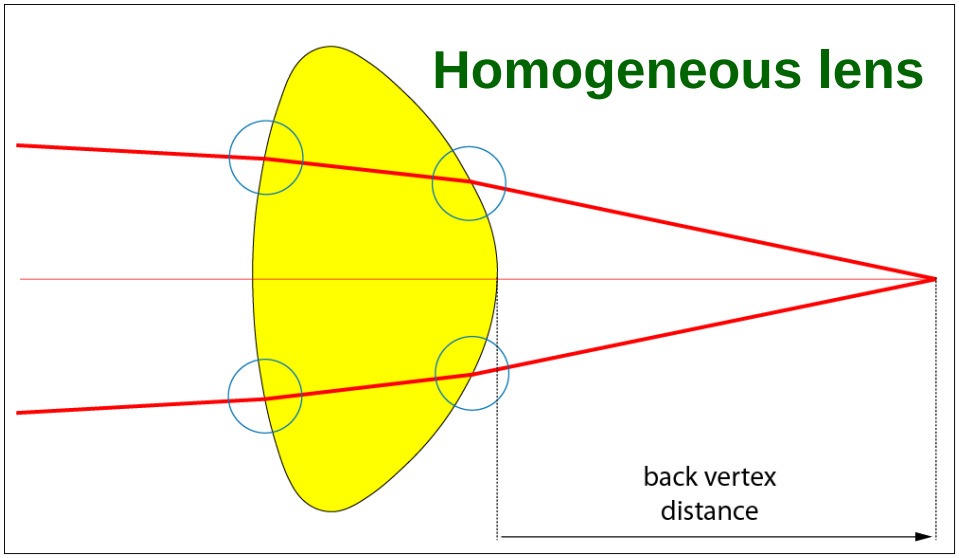
Spheres **(Q = 0)**

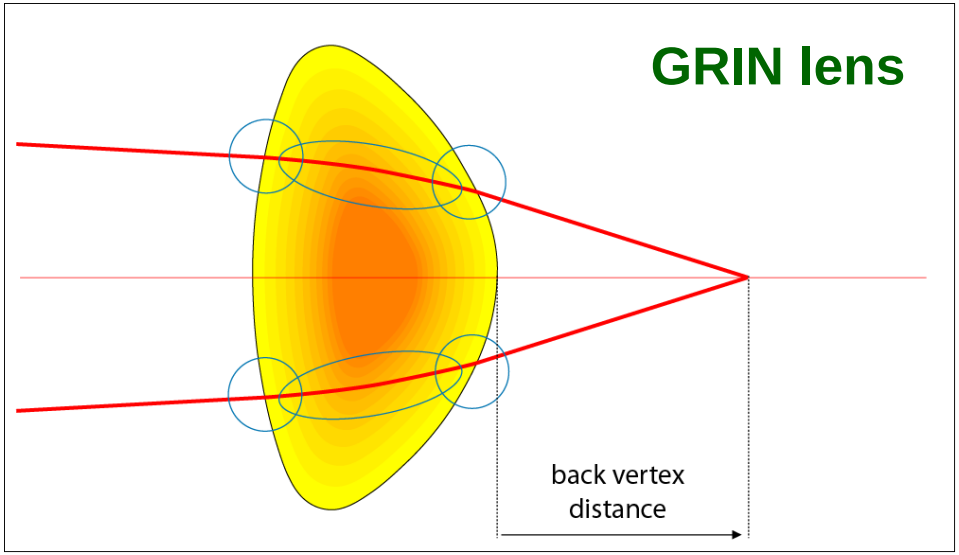


Hyperbolic surfaces ➡ <u>Negative</u> Spherical aberration

Partial compensation of positive SA of the cornea

GRIN increases lens power

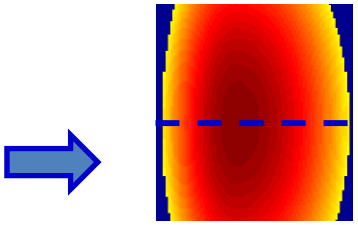


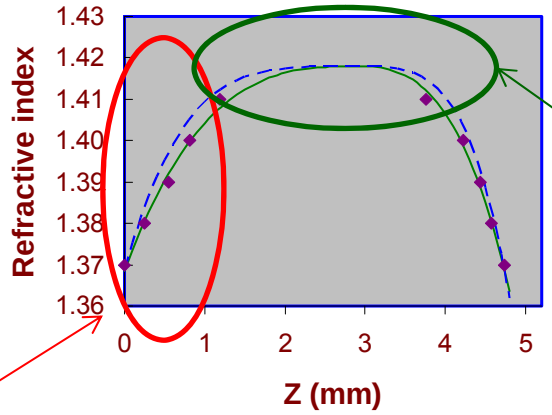


Shorter focal:
Higher power

GRIN: inhomogeneous distribution of refractive index

Axial distribution of refractive index





Gradient ~ cortex

Homogeneous ~ nucleus

(Jones et al 2005)

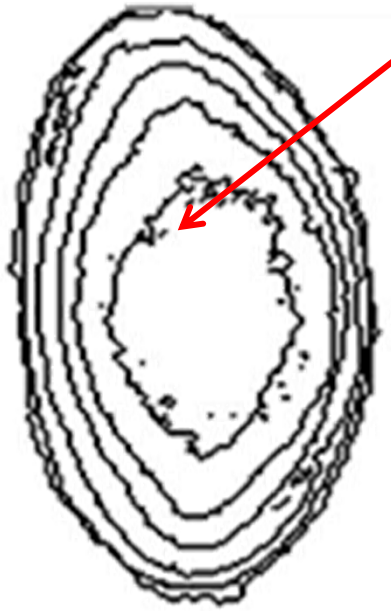
Effective n_e > central n_0 > mean n_m > surface n_s

Effective index greater than physiological values

Internal geometry & optical performance

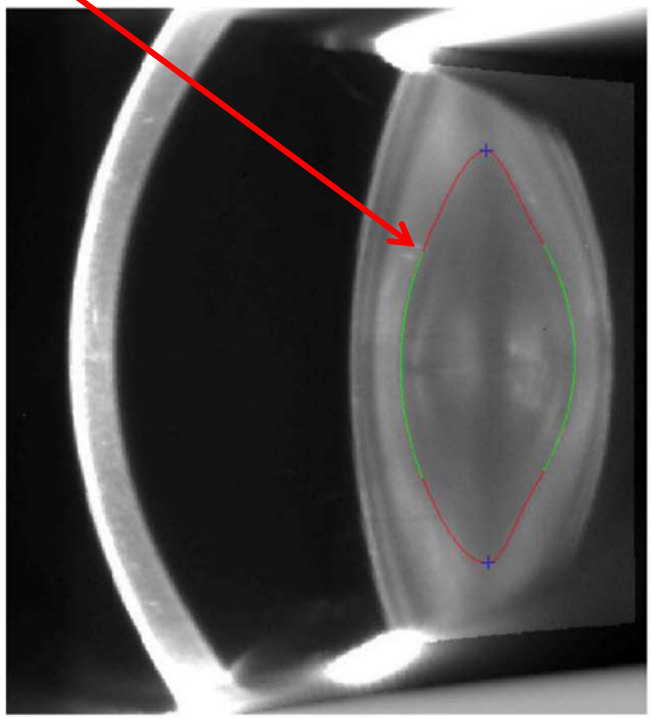
Curvature gradient

In vitro



(Jones et al. 2005)

In vivo

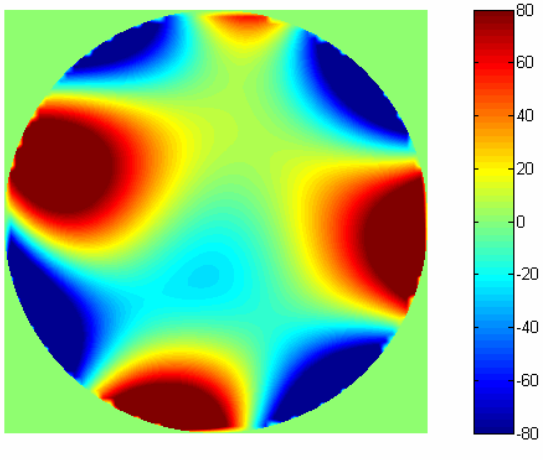


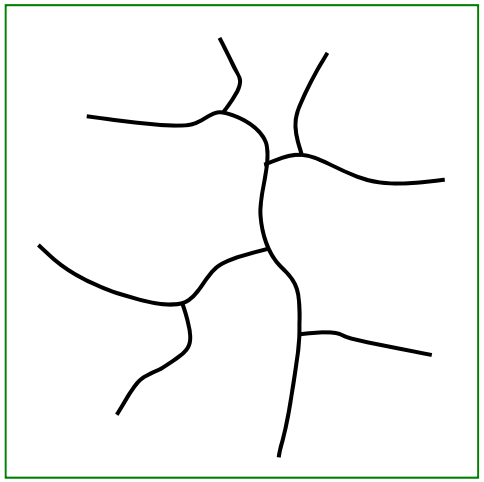
(Hermans et al. 2007)

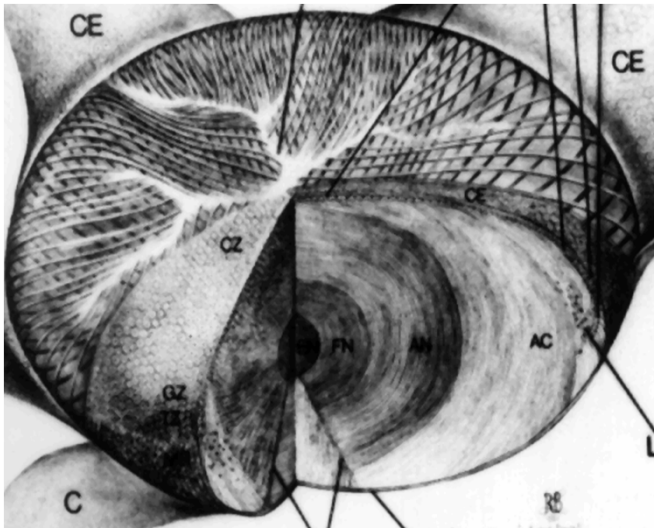
Higher curvature gradient ⇨ Higher Lens Power (+ 3-5 D)

HOA of the Lens and suture lines

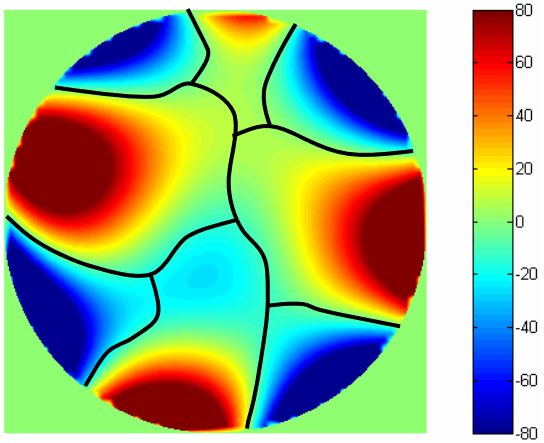
Custom eye model lens

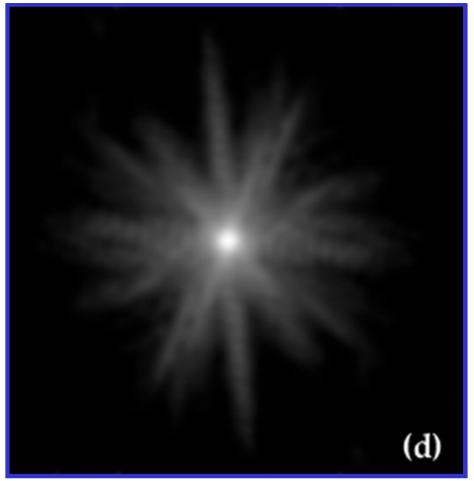






Tetrafoil

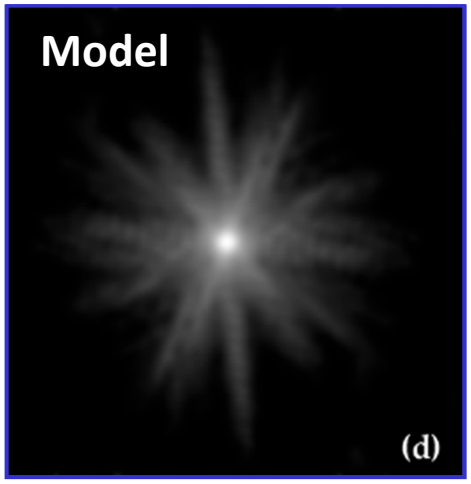


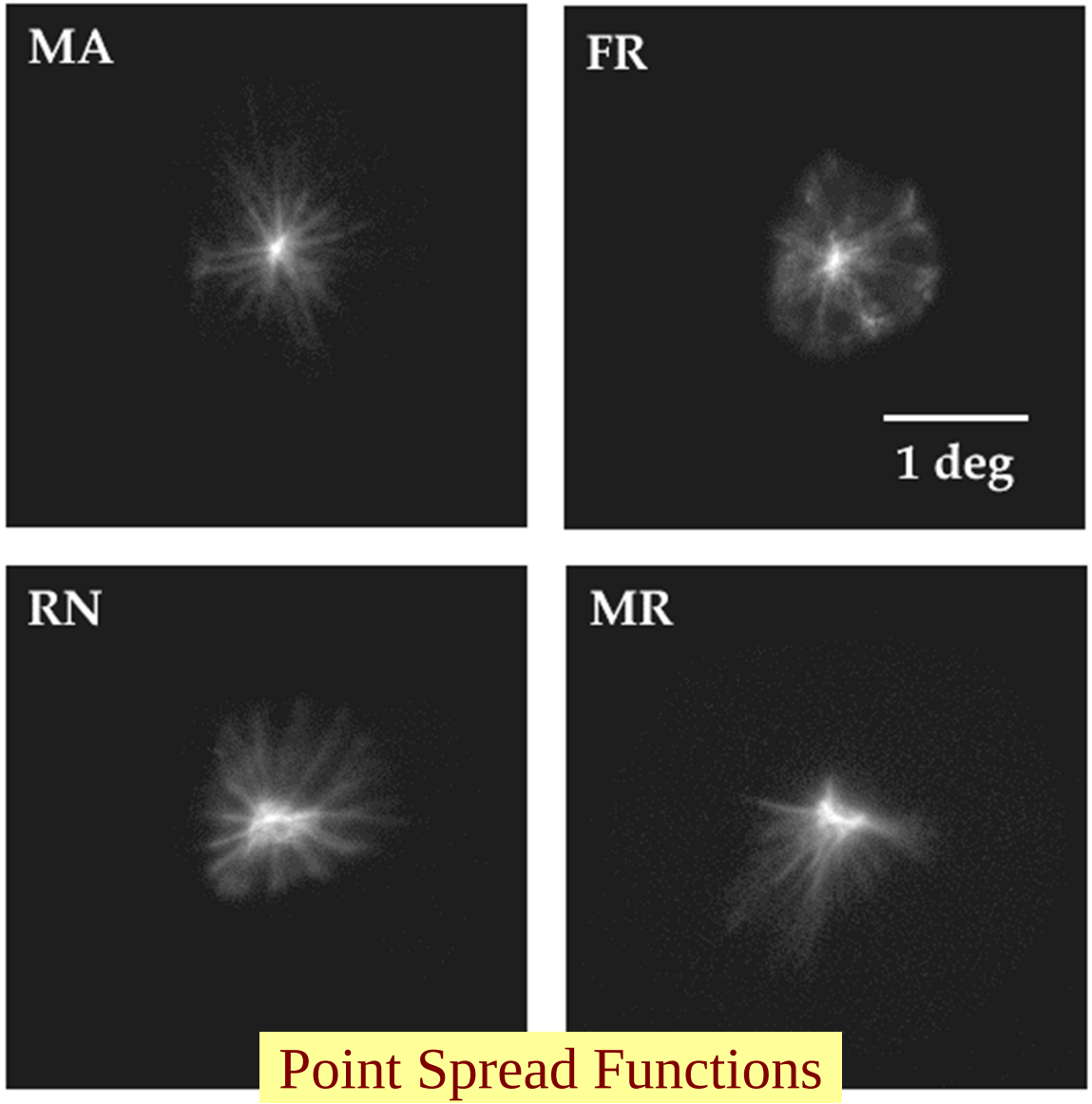


Diffraction Pattern

Retinal Star Images

(Navarro &Losada, 1997)

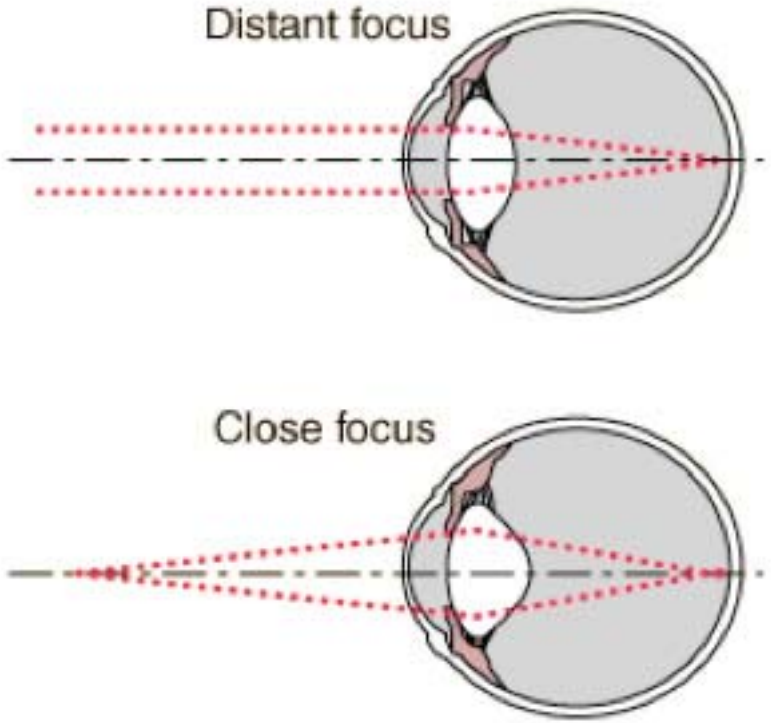




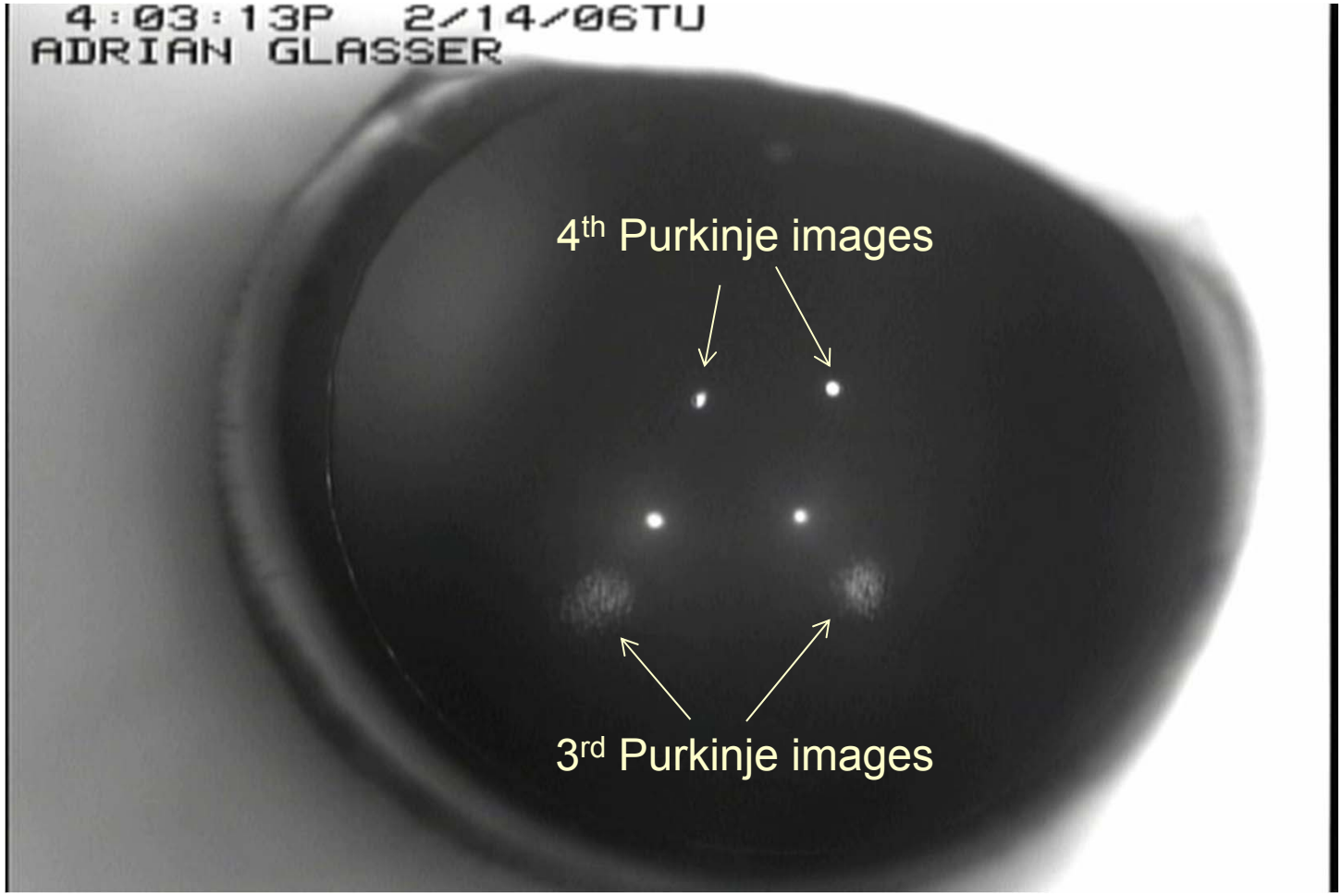
Point Spread Functions

Accommodation is the process by which the eye changes optical power to maintain a clear image on an object as its distance varies.

Hermann von Helmholtz



Accommodative Changes in Lens Surface Curvatures



(Rosales et al, 2008)

Courtesy of A. Glasser

Accommodation: Lens Power increment

$$A_{eye} = \left(1 - \frac{e}{n} P_C\right) A_{Lens} \quad \Rightarrow \quad A_{Lens} = 1.24 A_{Eye}$$

10 D accommodation ⇒ 12.4 D Lens power addition

Lens Power 24.9 D → **37.4 D** @ 10 D accomm. (**50% increase**)

Accommodation: Lens Power increment

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10 D accommodation ⇒ 12.4 D Lens power addition

Lens Power 24.9 D → **37.4 D** @ 10 D accomm. **(50% increase)**

How?

- Increase external curvatures. Power ↑↑↑
- Decrease anterior chamber depth. Power ↑
- Increase lens's effective refractive index. Power ↑

(Changes of internal structure)

Gullstrand's intracapsular mechanism of accommodation???

Changes with accommodation

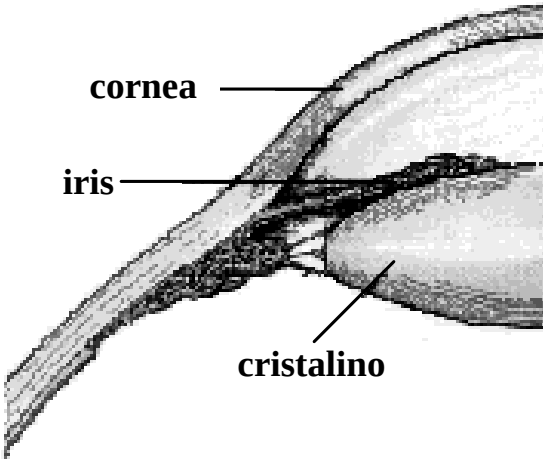
Unaccommodated

- Distance vision
- Ciliary muscle relaxed
- Lens under tension (~0.078 N)
- Lens flatter (less power)

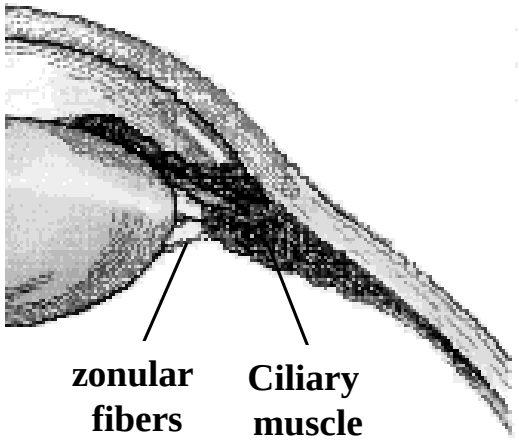
Accommodated

- Close vision
- Ciliary muscle actively contracted
- Zonular tension reduced (~0 N)
- Lens more curved (more power)
- Iris contracts (pupil miosis)

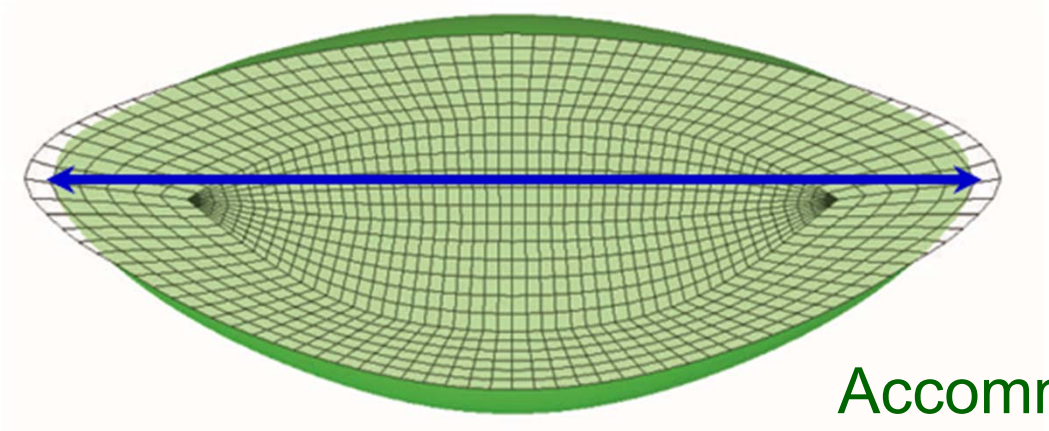
Unaccommodated



Accommodated (8 D)



Lens changes @ 9 D accommodation

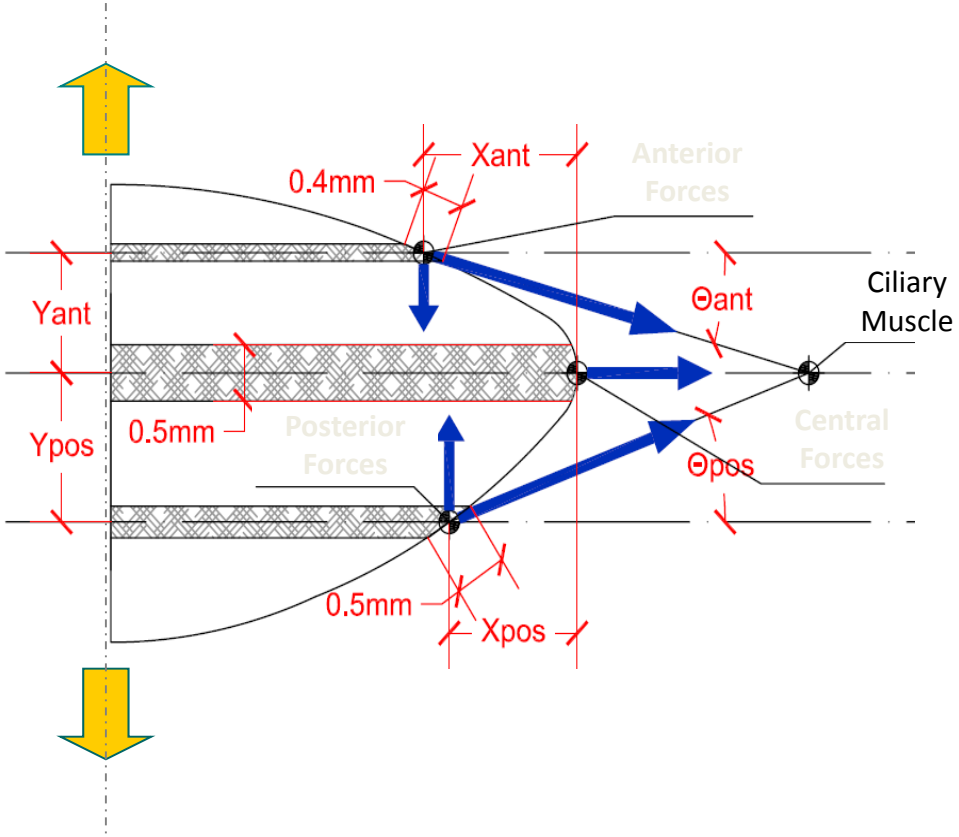


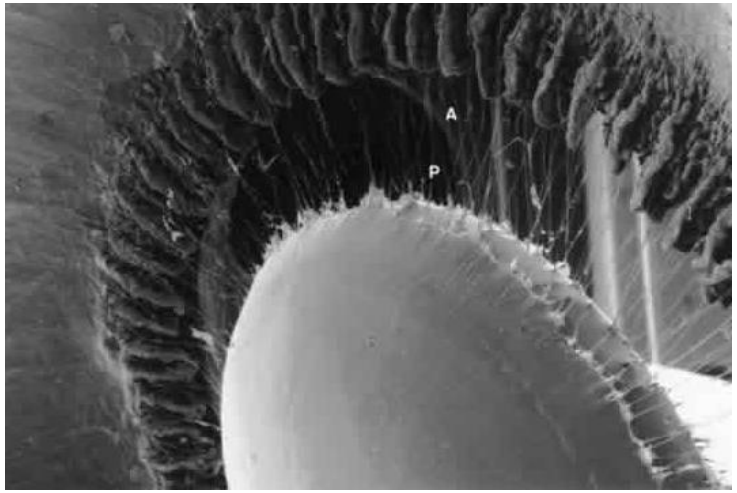
Accommodated

- Equatorial diameter decreases **~0.4 mm** (10 → 9.6 mm)
- Anterior pole moves forward **~0.3 mm** (ACD ↓) power ↑
- Surface curvature increases (Ra: 11 mm → 5.5 mm) power ↑↑↑
- Axial thickness increases (T: 0.36 → 0.58 mm) power ↓ (slight)
- Lens sinks **~0.3 mm** due to gravity (lack of zonular tension). Misalignr
- Equivalent refractive index increases. power ↑

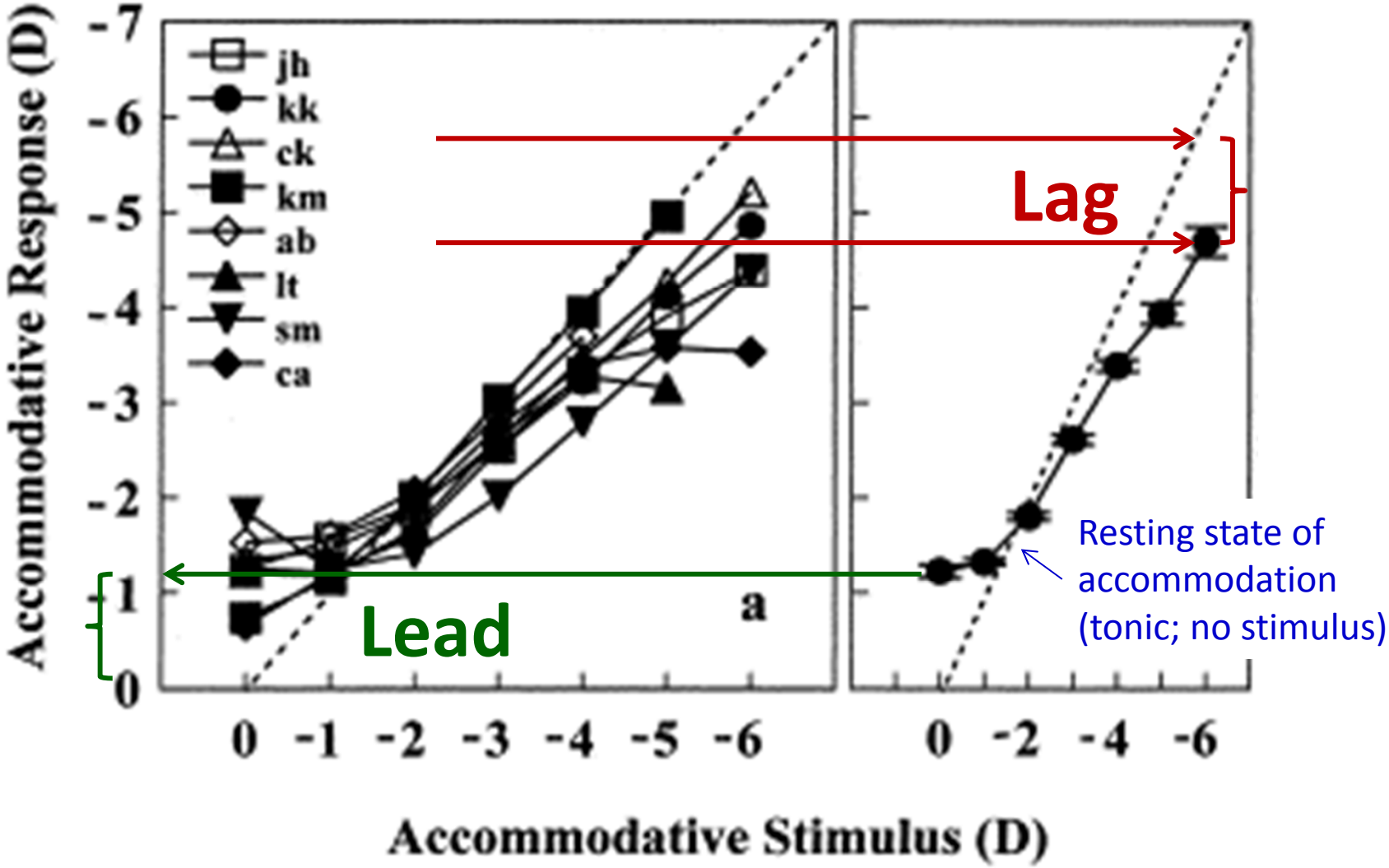
Hyperelastic model of accommodation and presbyopia

(Lanchares, Navarro, Calvo, 2012)





Accommodative response

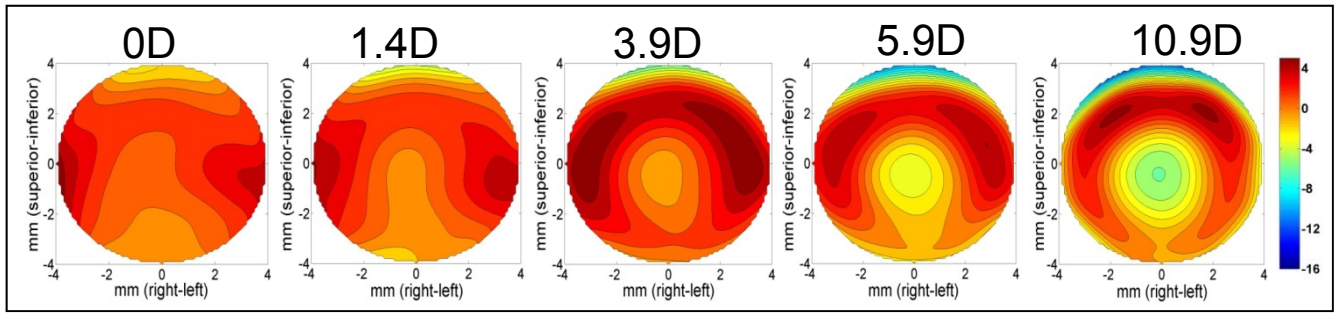


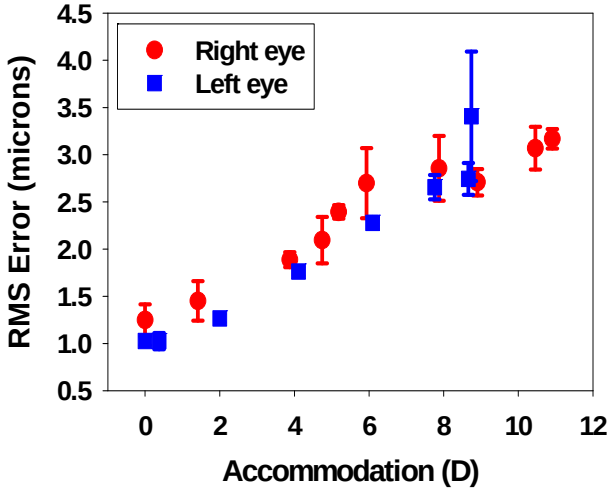
[He et al. Vis. Res. 2000]

Accommodative Changes in Aberrations

Rhesus monkey - 8mm entrance pupil diameter

(defocus term removed)





Strong increase with accommodation

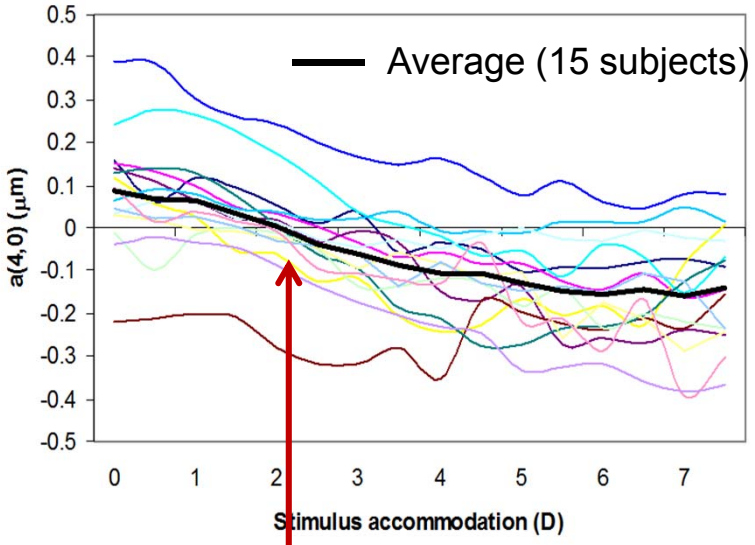
(Vilupuru, et al. 2004)

Accommodative Changes in Aberrations

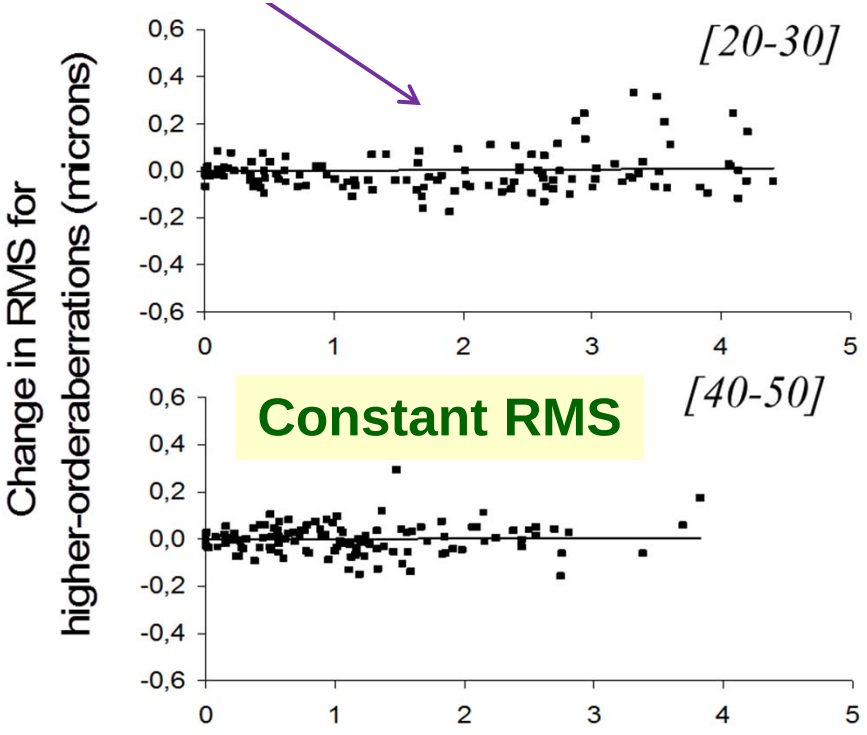
Humans - Natural pupil (myosis)

Higher-order aberrations

Spherical aberration



Sign reversal

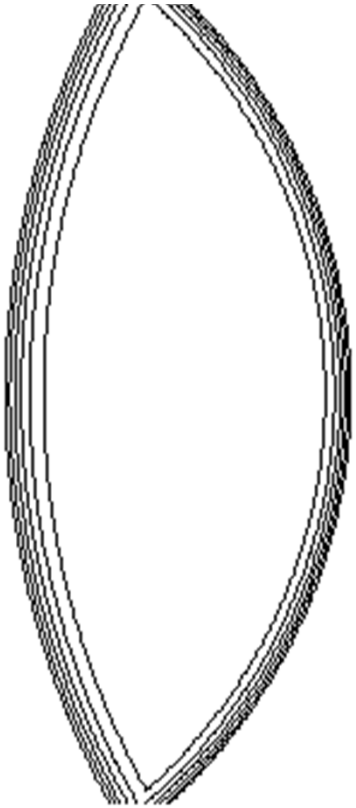


[López-Gil et al. IOVS, 2008]

[Ivanoff, 1953] [He et al. 2000] [Sotiris et al. 2004][Chen et al. 2004]

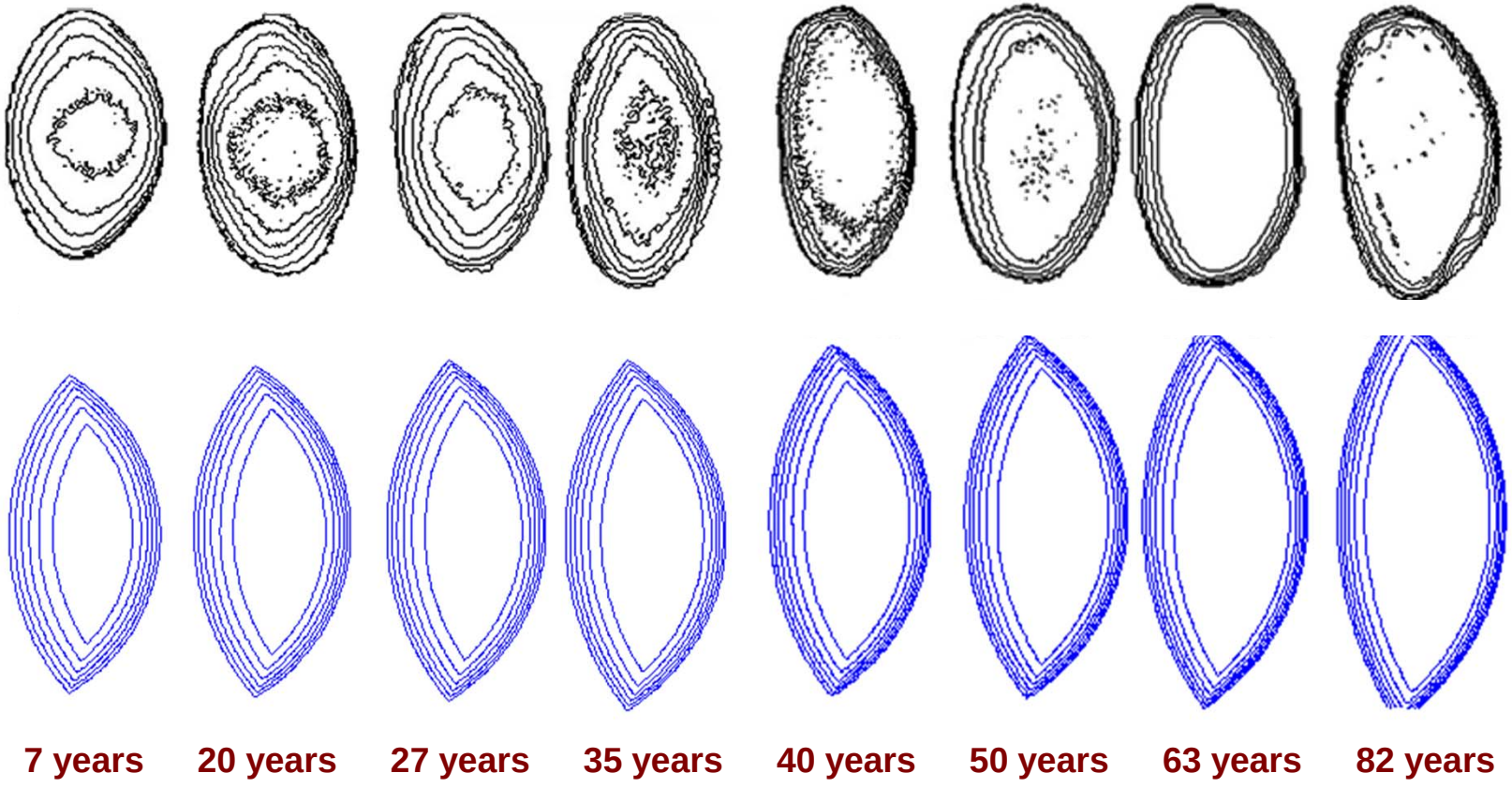
3. Age-related changes

82 years



Ex-vivo samples

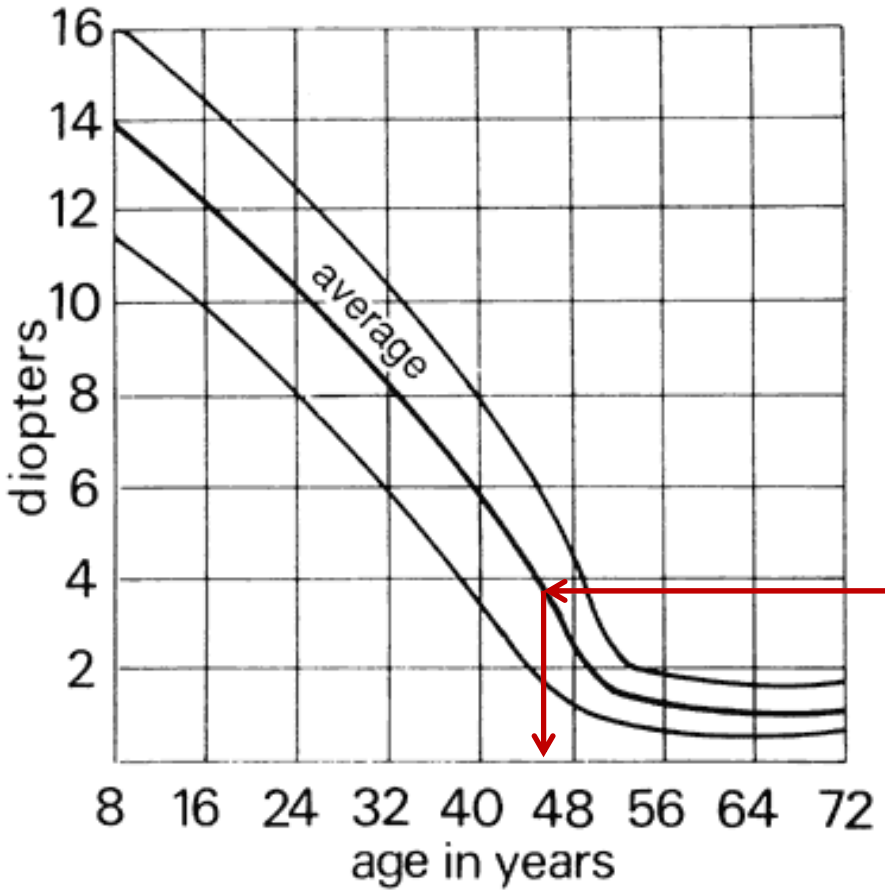
(Jones et al. 2005)



Ageing Model

(Navarro et al. 2007)

Amplitude of accommodation versus age



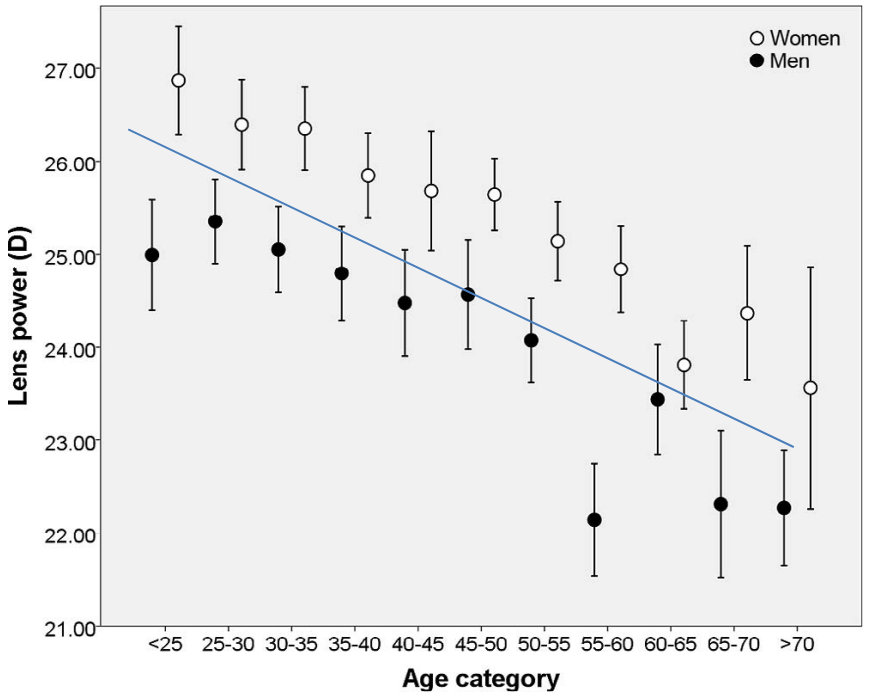
Presbyopia

Linear approximation: **AA = 15 – 0.25 A** (A: years; AA diopters)

Lens power versus age *(in vivo)*

(Jongenelen et al. IOVS, 2014)

Gullstrand project:1069 Caucasians

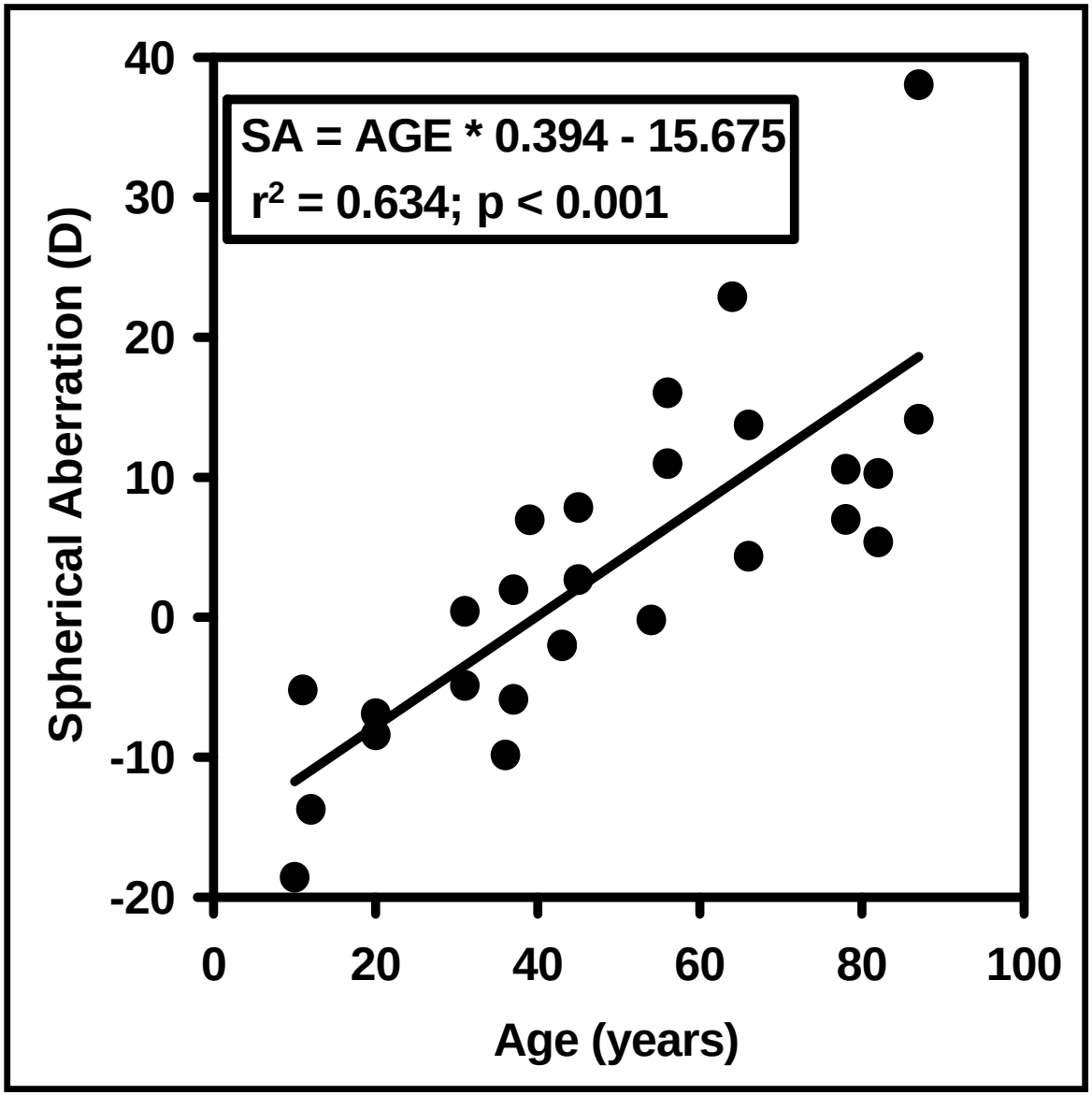


3 D

Brown's **lens paradox:** Lens loses power despite curvatures increase

→ The effective refractive index must **decrease** with age

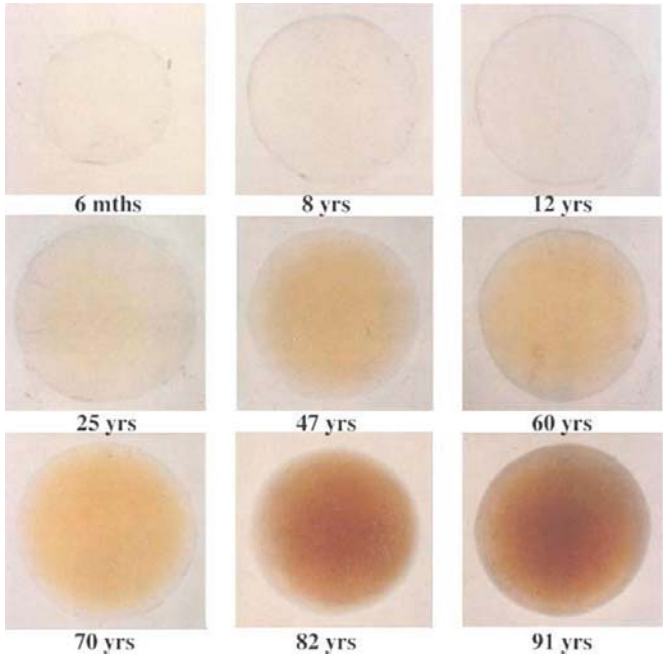
→ Internal structure must change



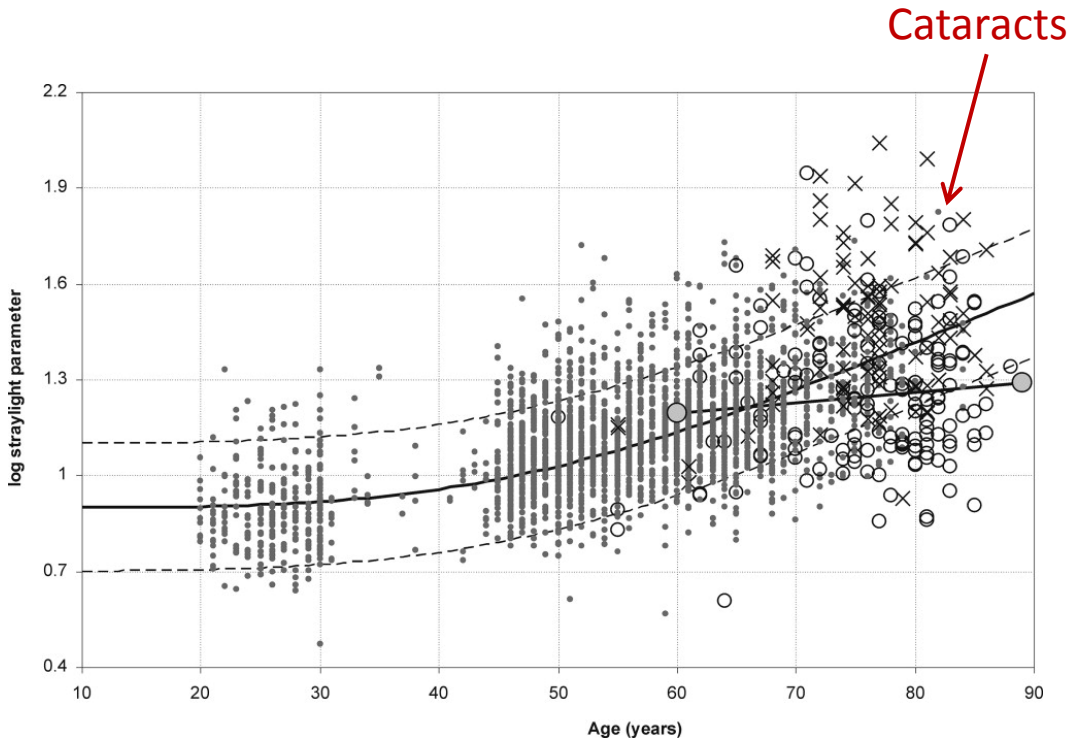
Glasser & Campbell, Vision Resea

Scattering increases with ageing

Lens yellowing



Styraylight versus age



(Van den Berg et al. 2007)

Conclusions

The functions of the primate lens are to refract light passing throug cornea to focus on the retina and to accommodate

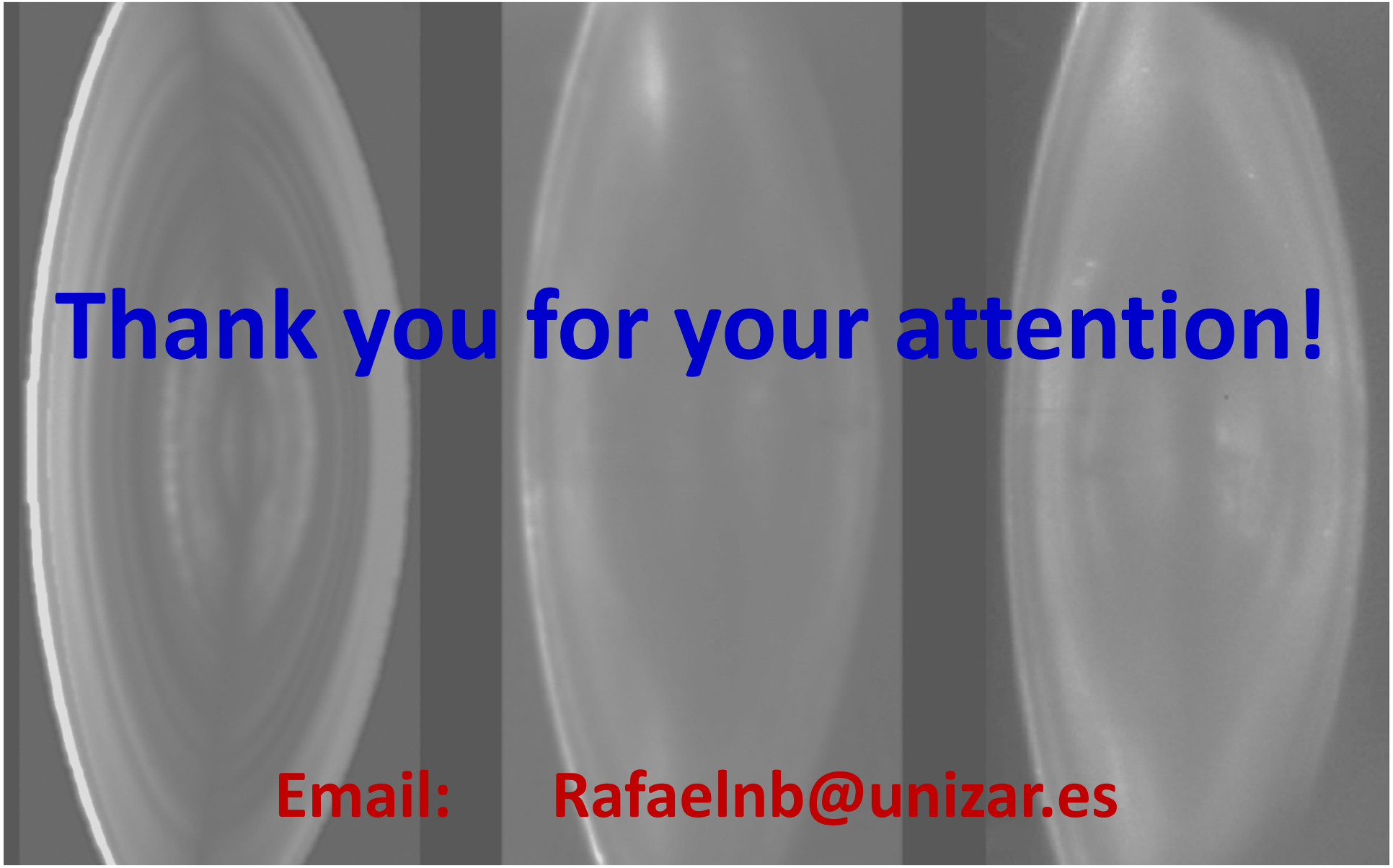
The refractive power of the lens is due to the surface curvatures a lens gradient refractive index

The lens undergoes accommodation by virtue of an increase in the anterior and posterior surface curvatures

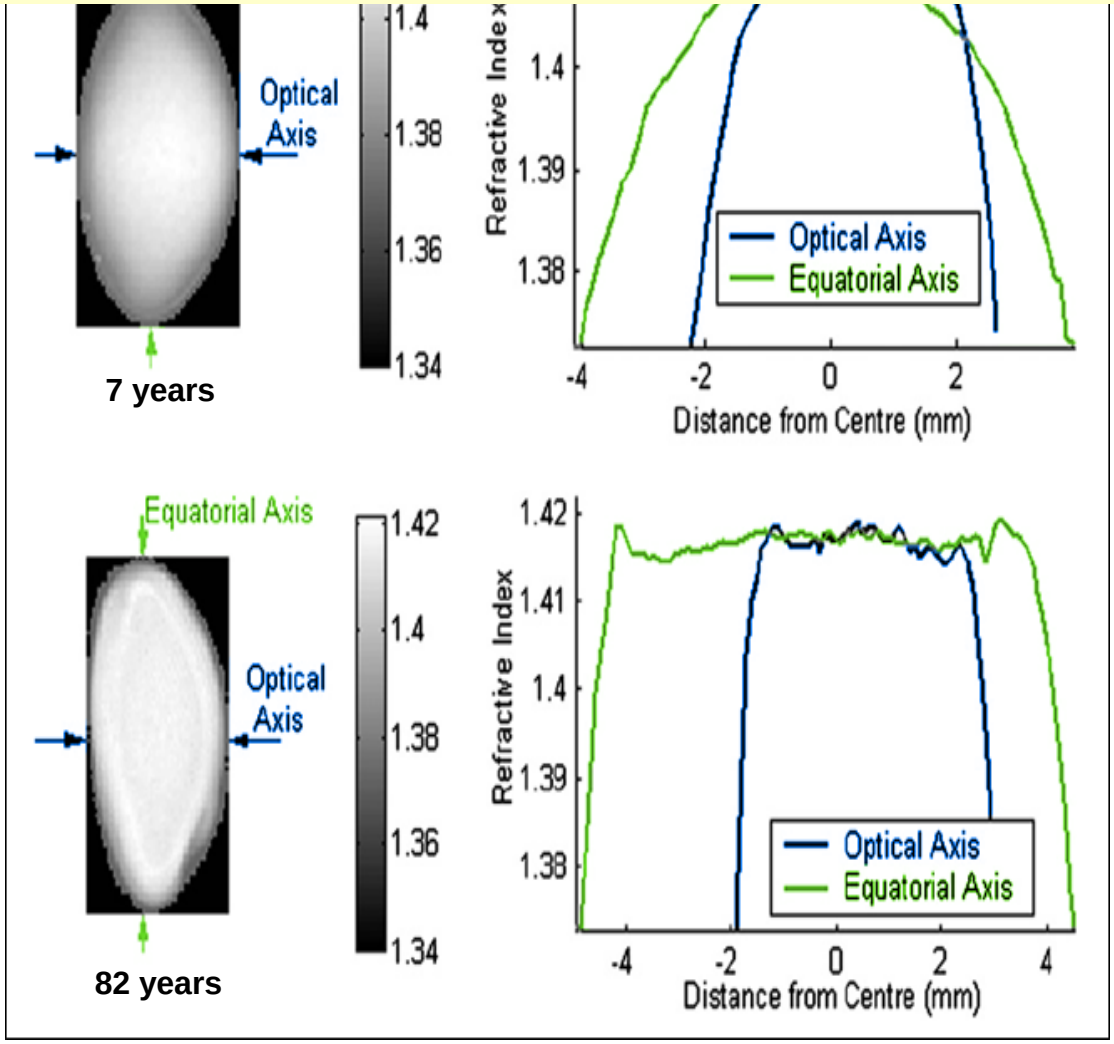
Optical and physical properties of the lens are highly coordinated d accommodation and aging

The lens continues to grow and the optical properties change throu life

The lens gradient refractive index changes with age, becoming fla the nucleus in older lenses


Thank you for your attention!
Email: RafaelNb@unizar.es

Gradient Refractive Index



Jones, Atchison, Meder, and Pope. *Vision Res.* 45 (18):2352-2366, 2005

Main age-related structural changes

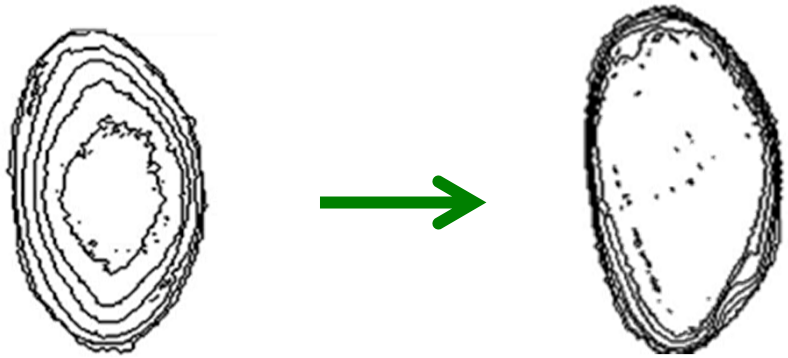
Increase: - Size (nucleus)

- External curvatures

$R_a = 12.7\text{-}0.058Age$ R_a (20 y) = 11.4 mm ⟶ R_a (60 y) = 9.22 mm

$R_p = -5.9\text{-}0.013Age$

$t = 2.93 + 0.0236Age$ (axial thickness) (Dubbelman et al. 2005)



Decrease: - GRIN (more homogeneous)

- Elasticity (stiffer lens)