Universitat d'Alacant
Universidad de Alicante

Grupo Óptica y Ciencias de la Visión

OCIVIS

Corneal astigmatism compensation by oblique light incidence

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Corneal astigmatism compensation by oblique light incidence

Collaborators

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Justification and Objectives

- Oblique incidence induces two main aberrations: coma and oblique astigmatism.
- Previous works show kappa angle compensates coma due to crystalline tilt [Tabernero et al., JOSA, 2007]
- Angle kappa and foveal off-centred play a double role compensating coma and astigmatism
- Oblique incidence may compensate corneal astigmatism

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Outline

- With-the-rule astigmatic Kooijman eye modelization.
- Eye transmittance calculation for oblique incidence.
- Light patterns analysis at retina.
- Merit function. Best PSF for an oblique light incidence.
- Passive compensation of astigmatism.

Astigmatic Kooijman eye

Surface	Anterior cornea	Posterior cornea	Anterior lens	Posterior lens
Radius (mm)	R_y=7.8 R_x=7.9	6.5	10.2	-6.0
Conic constant *Q*	-0.25	-0.25	-3.06	-1.0
Thickness (mm)	0.55	3.05	4.0	16.6
Refractive index	1.3771	1.3374	1.42	1.336

Surface equation

$$z(x,y) = \frac{R_y}{(1+Q)}\left[1 - \sqrt{1 - \frac{(1+Q)}{R_y}\left(\frac{x^2}{R_x} + \frac{y^2}{R_y}\right)}\right]$$

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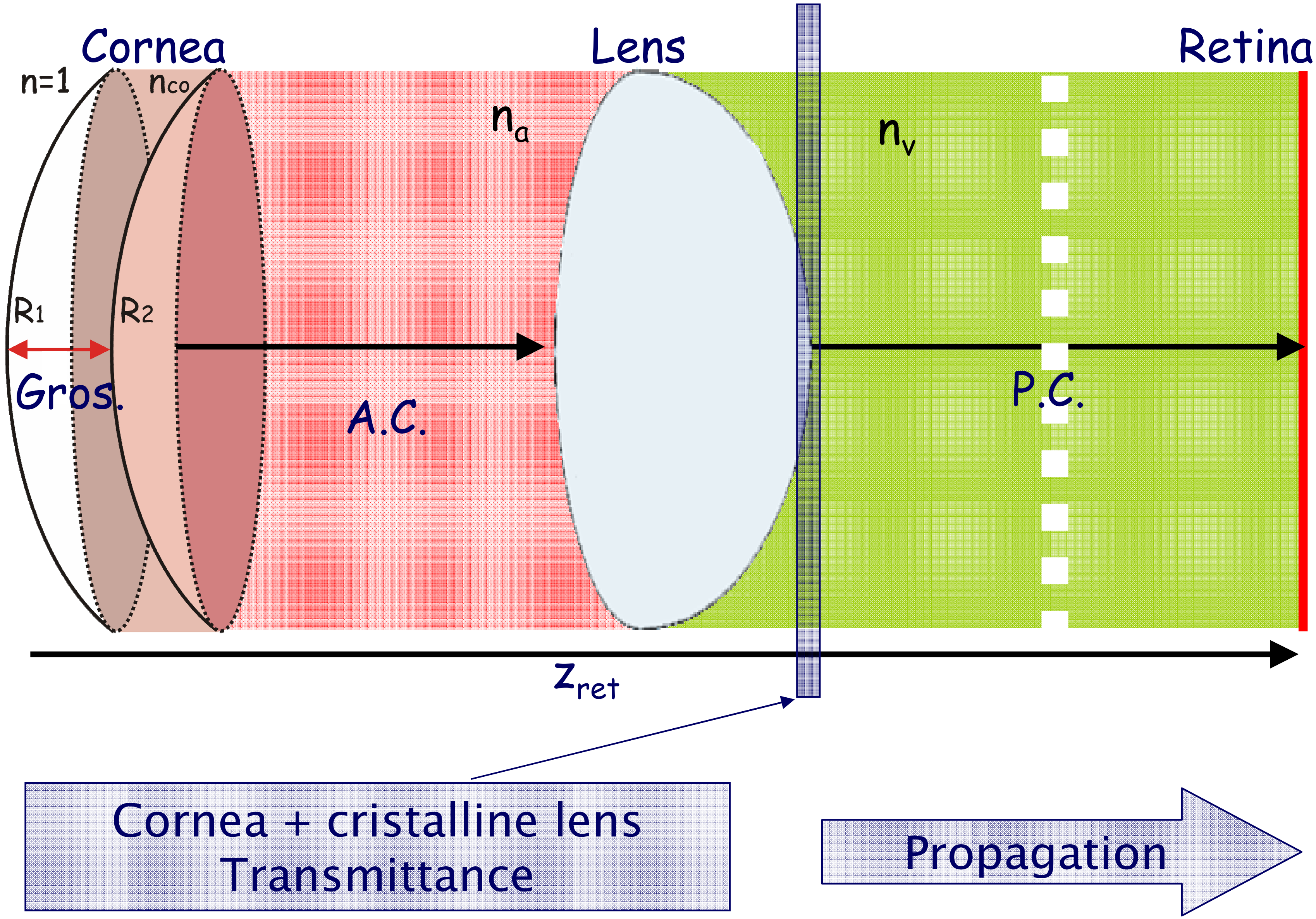
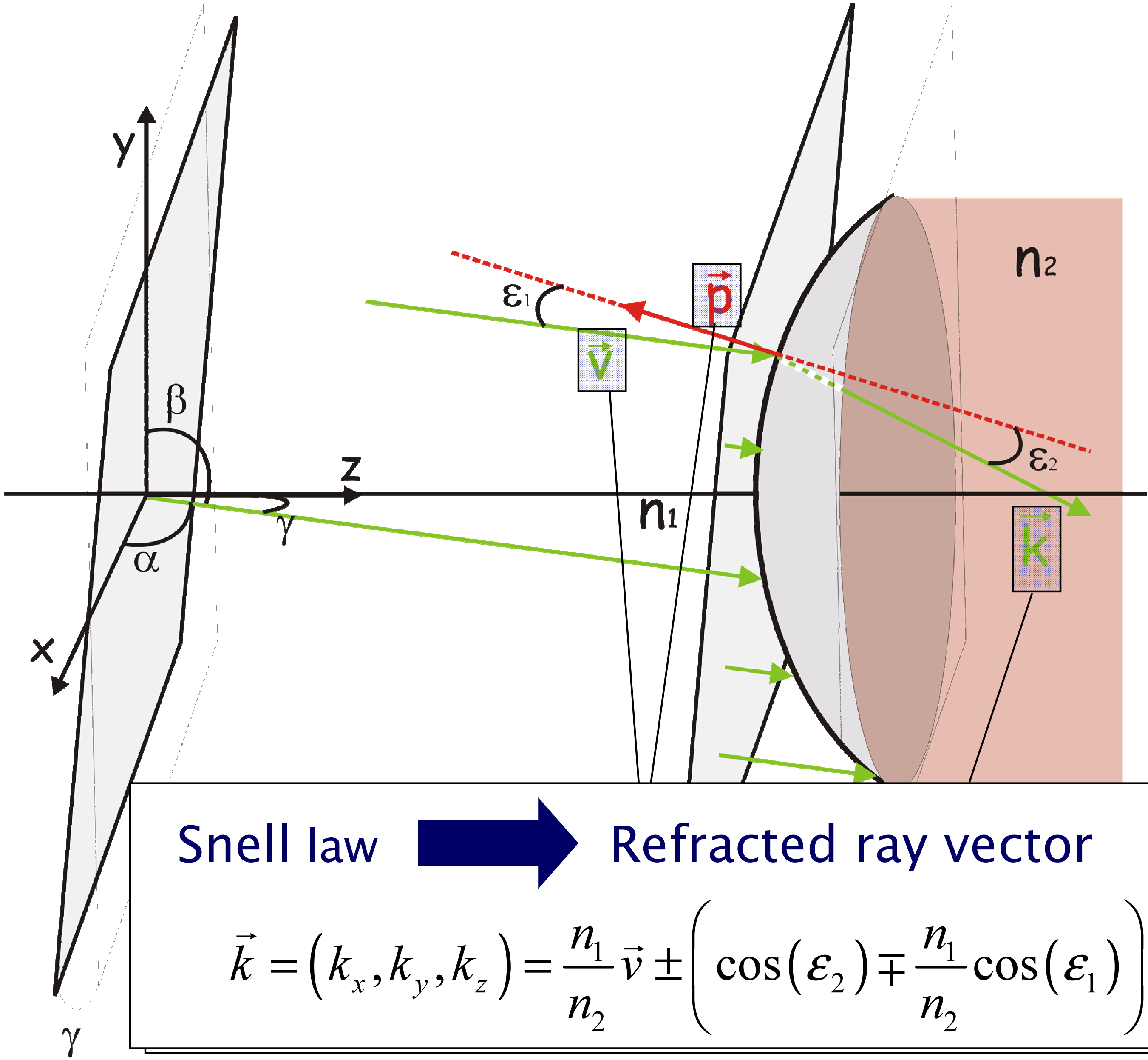
Eye transmittance



Eye transmittance under oblique incidence



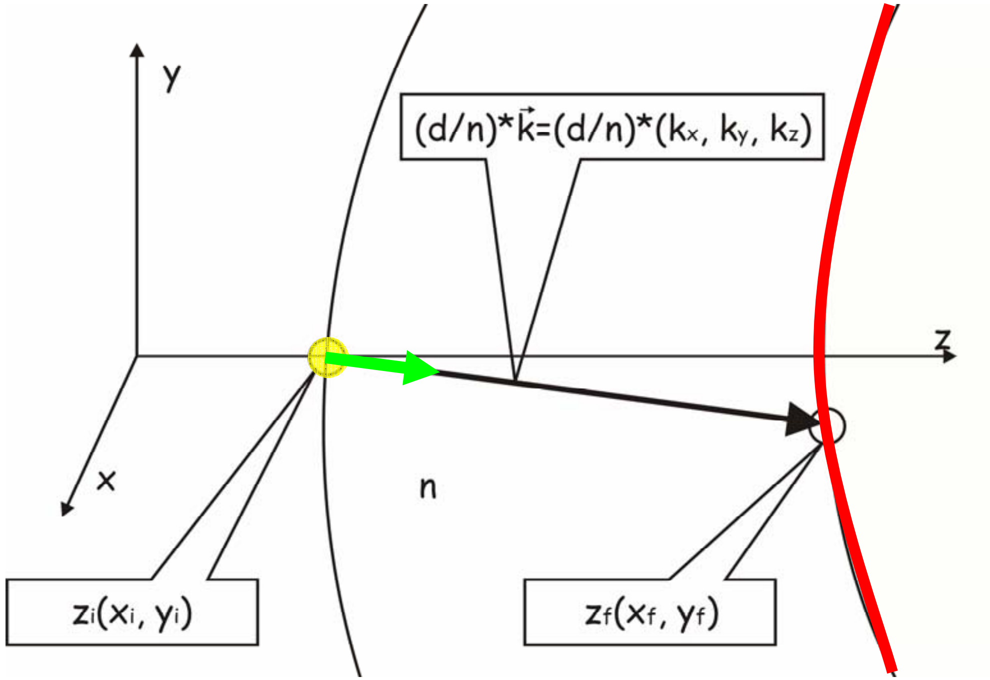
Snell law ➡ Refracted ray vector

$$\vec{k} = \left(k_x, k_y, k_z\right) = \frac{n_1}{n_2}\vec{v} \pm \left(\cos\left(\varepsilon_2\right) \mp \frac{n_1}{n_2}\cos\left(\varepsilon_1\right)\right)\vec{p}$$

Transmittance Calculation

Optical path length *d*, solving:

$$z_i(x_i, y_i) + \left(\frac{d}{n}\right)_i k_{z,i} = z_f\left(x_i + \left(\frac{d}{n}\right)_i k_{x,i}, y_i + \left(\frac{d}{n}\right)_i k_{y,i}\right)$$



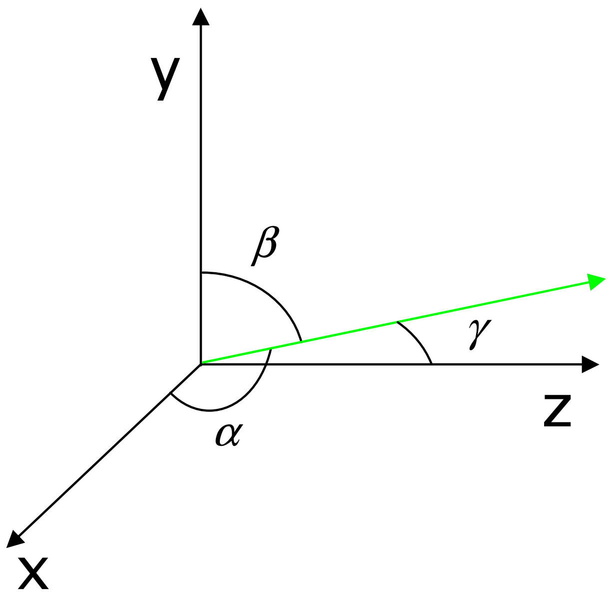
Transmittance

$$t(x,y) = \exp\left(\frac{i2\pi}{\lambda}[d_{tot}(x,y)]\right)$$

Light Patterns Analysis

Fresnel propagation

$$(u_z)_{\mu'} = \exp\left(i\pi \frac{\lambda z}{\Delta x_0^{\,2}}\mu'^2\right) DFT\left[u_0\left(\frac{\mu\Delta x_0}{N}\right)\exp\left(\frac{i\pi\Delta x_0^{\,2}}{\lambda z N^2}\mu^2\right)\right]$$



Merit function

$$J(\alpha,\beta) = \frac{I_{\max}(\alpha,\beta)}{M(\alpha,\beta)\,RMS(\alpha,\beta)}$$

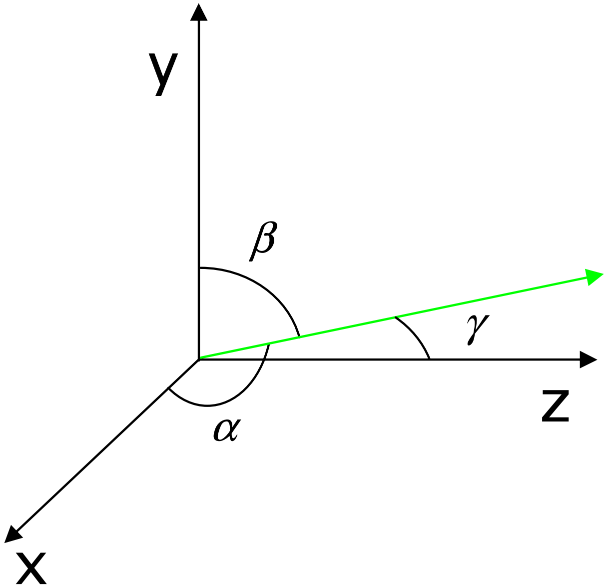
Maximum Intensity

$$I_{\max} = \max\left[I(x,y)\right] = \max\left[\left|u_z(x,y)\right|^2\right]$$

Light Patterns Analysis

Fresnel propagation

$$(u_z)_{\mu'} = \exp\left(i\pi \frac{\lambda z}{\Delta x_0^{\,2}}\mu'^2\right) DFT\left[u_0\left(\frac{\mu \Delta x_0}{N}\right)\exp\left(\frac{i\pi \Delta x_0^{\,2}}{\lambda z N^2}\mu^2\right)\right]$$



Merit function

$$J(\alpha,\beta) = \frac{I_{\max}(\alpha,\beta)}{M(\alpha,\beta)\, RMS(\alpha,\beta)}$$

Secondary Momentum

$$M = \sum I(x,y)\,\Re(x,y)^2$$

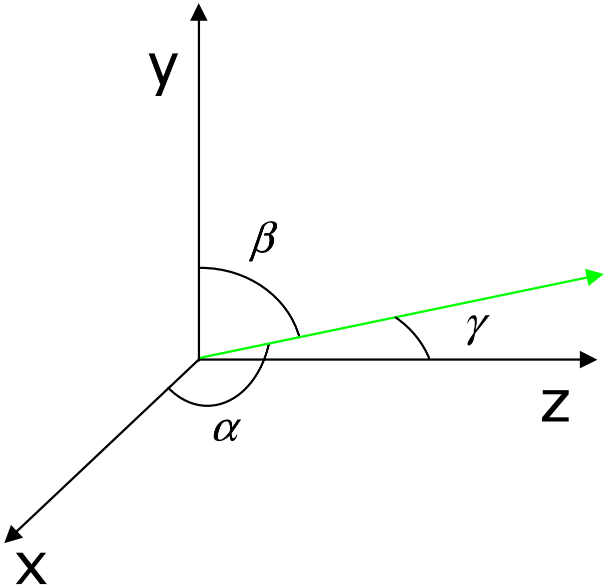
Centroid position

$$\Re(x,y) = \left[\Re_x, \Re_y\right] = \frac{\left[\sum I(x,y)x, \sum I(x,y)y\right]}{\sum I(x,y)}$$

Light Patterns Analysis

Fresnel propagation

$$\left(u_z\right)_{\mu'} = \exp\left(i\pi \frac{\lambda z}{\Delta x_0^{\,2}} \mu'^2\right) DFT\left[u_0\left(\frac{\mu \Delta x_0}{N}\right) \exp\left(\frac{i\pi \Delta x_0^{\,2}}{\lambda z N^2} \mu^2\right)\right]$$



Merit function

$$J(\alpha,\beta) = \frac{I_{\max}(\alpha,\beta)}{M(\alpha,\beta)\, RMS(\alpha,\beta)}$$

Root Mean Square function

$$RMS = \sqrt{\sum c_j (x,y)^2}$$

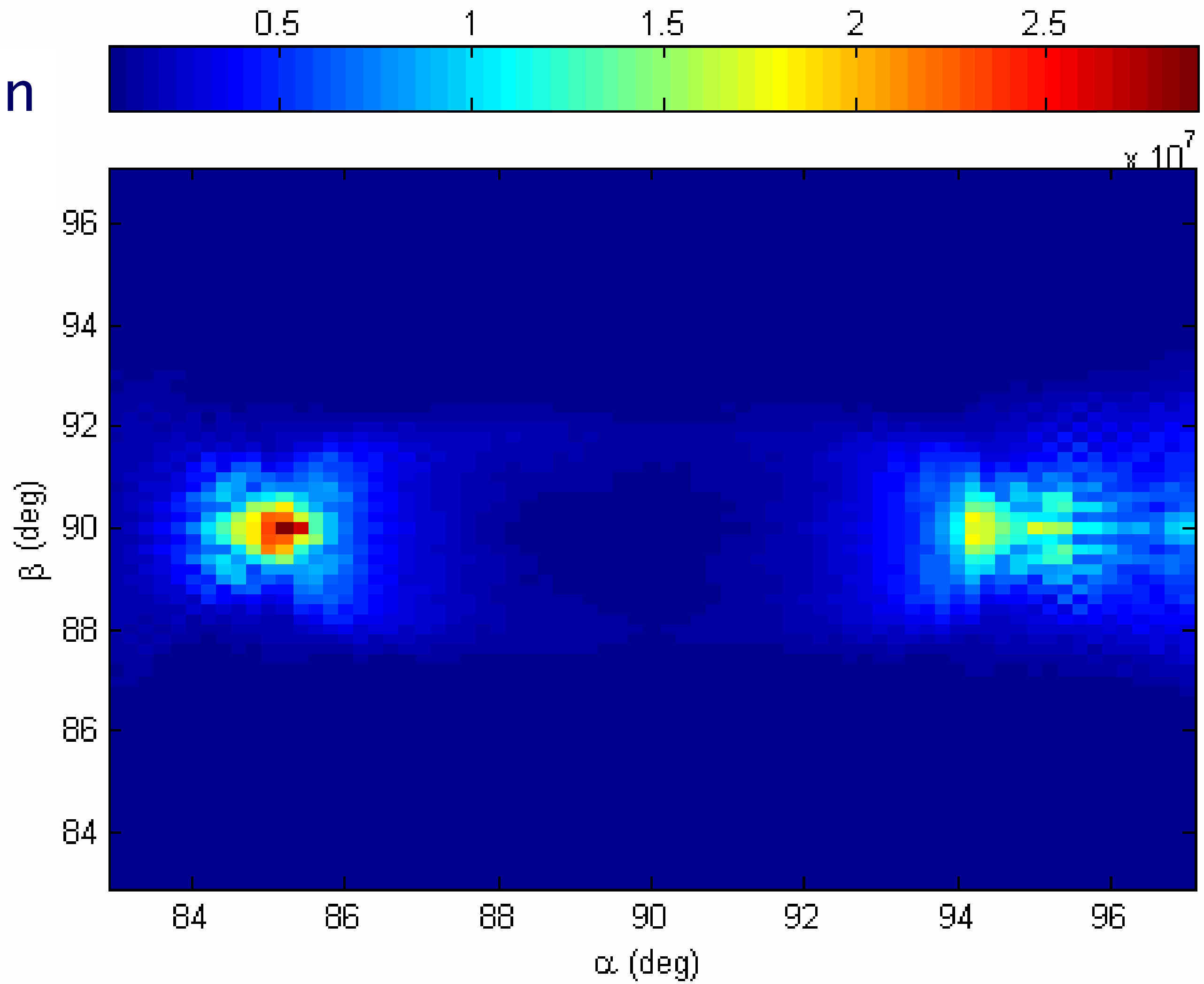
Zernike decomposition of the optical path length

$$d_{tot}(x,y) = \sum_j c_j Z_j (x,y)$$

Results: Astigmatic Kooijman eye

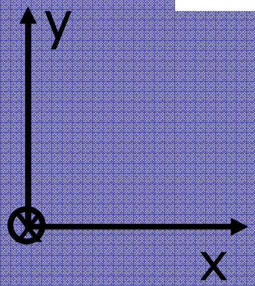
First corneal surface R_x= 7.9 mm R_y= 7.8 mm

Merit function
$J\,(\alpha,\beta)$



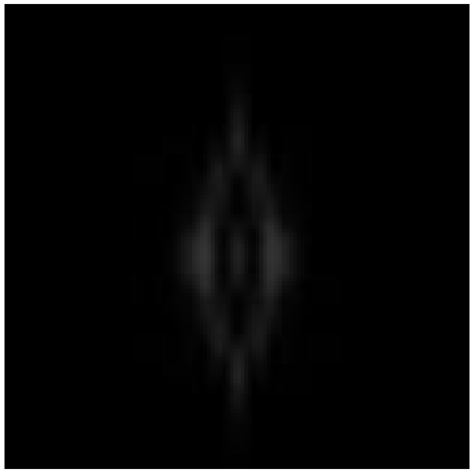
Results: Astigmatic Kooijman eye

R_x= 7.9 mm R_y= 7.8 mm γ from 0º to 7º



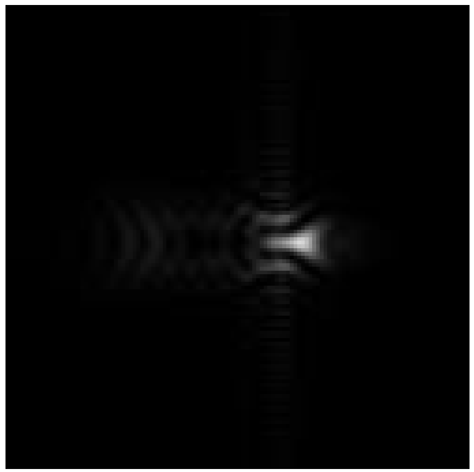
100 µm

(0,0,1)



86 µm

(cos(85.25º),0,cos(4.75º))

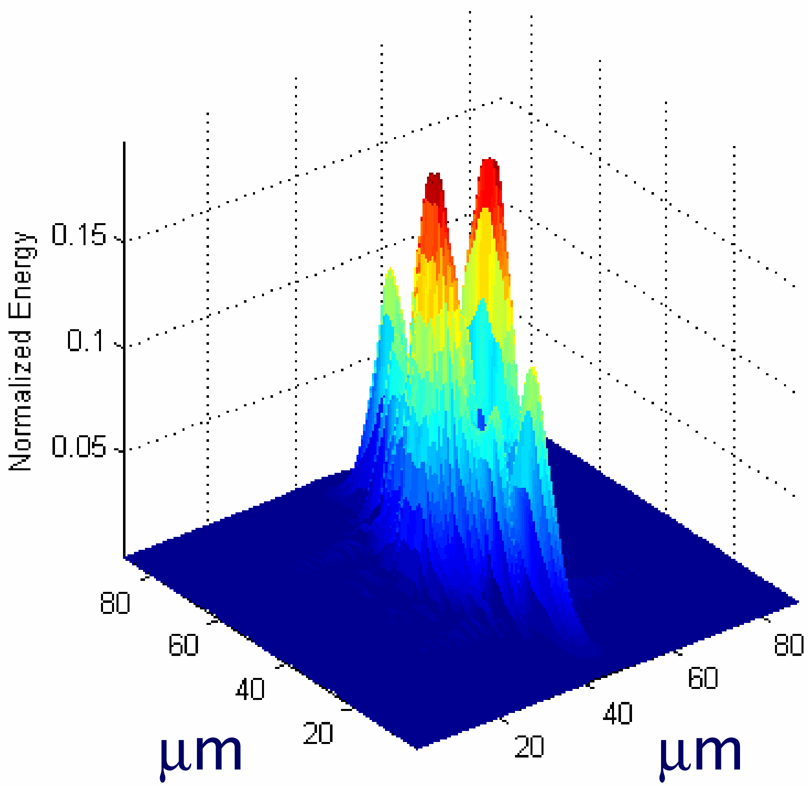


86 µm

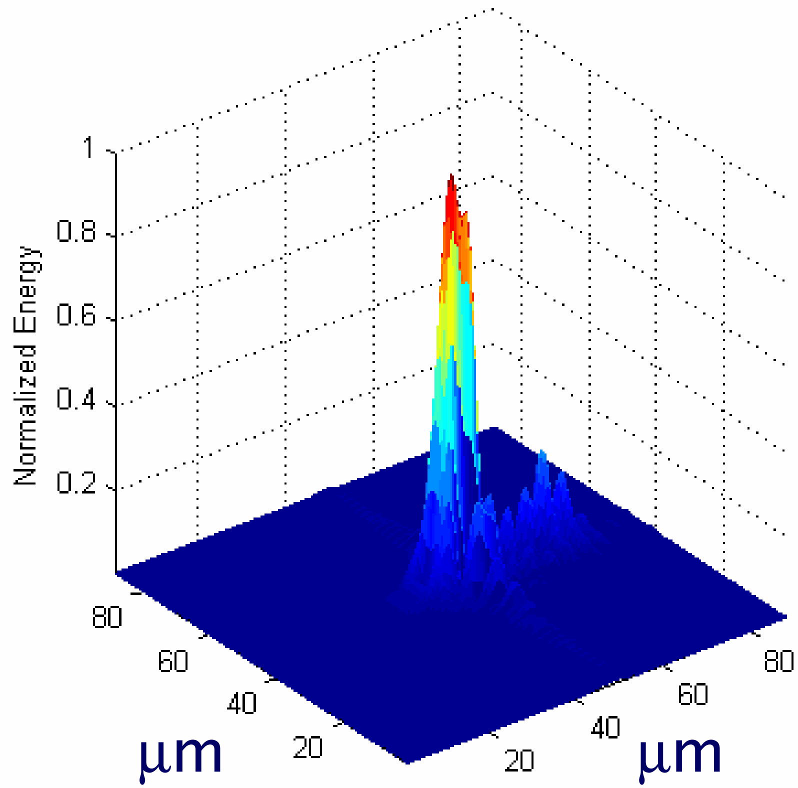
Results: Astigmatic Kooijman eye

Point Spread Function at different incidence angles

(0,0,1)



(cos(85.25º),0,cos(4.75º))



Real astigmatic eye

Corneal heights from Pentacam

Surface	Anterior cornea	Posterior cornea	Anterior lens	Posterior lens
Radius (mm)	R_y=7.82 R_x=7.92	R_y=6.11 R_x=6.31	10.2	-6.0
Conic constant *Q*			-3.06	-1.0
Thickness (mm)	.524	2.44	4.0	17.3
Refractive index	1.3771	1.3374	1.42	1.336

Surface equation

$$z(x,y)=\frac{R_y}{(1+Q)}\left[1-\sqrt{1-\frac{(1+Q)}{R_y}\left(\frac{x^2}{R_x}+\frac{y^2}{R_y}\right)}\right]$$

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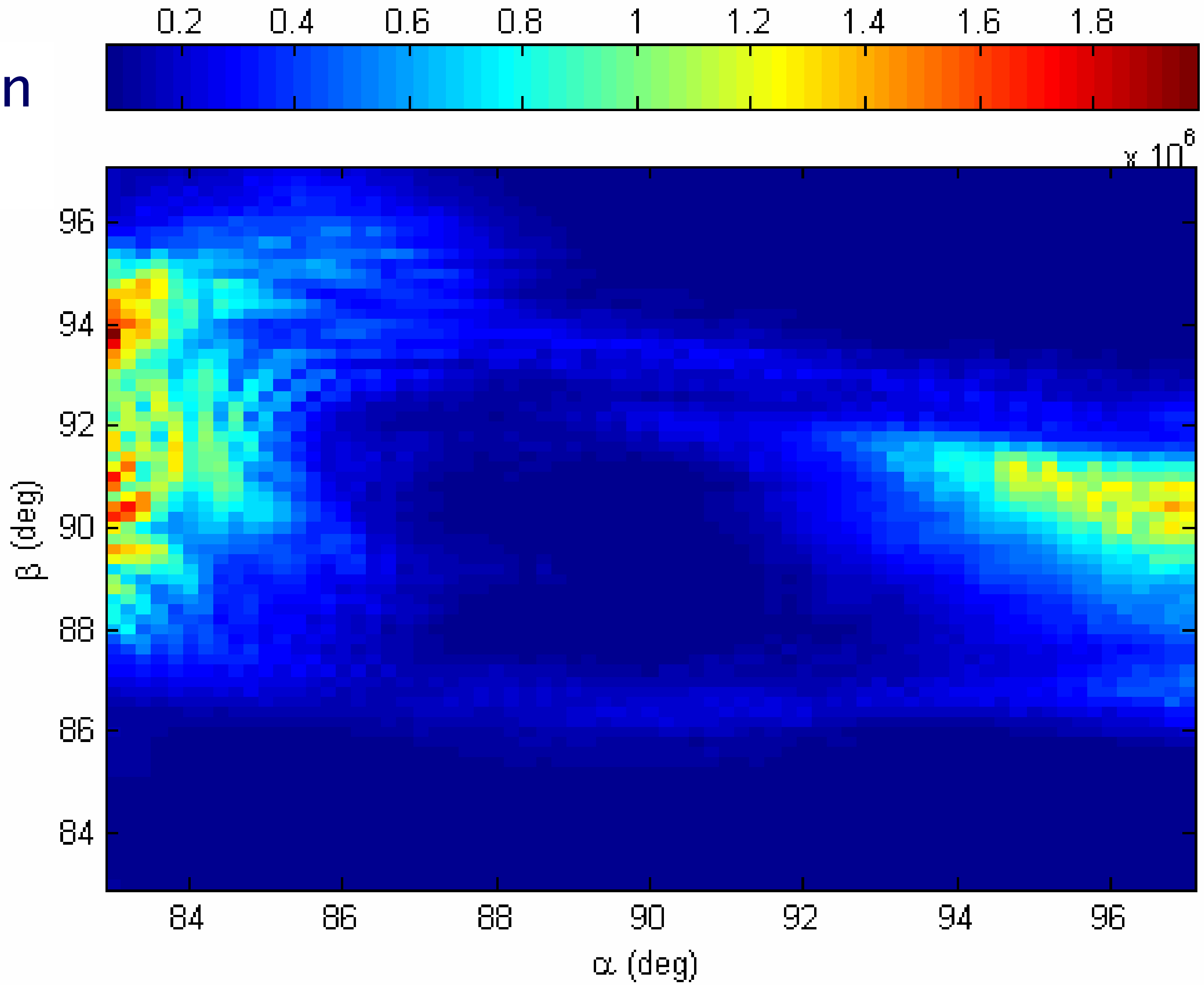
Results: Real astigmatic eye

First corneal surface R_x= 7.92 mm R_y= 7.82 mm

Merit function
$J\,(\alpha,\beta)$

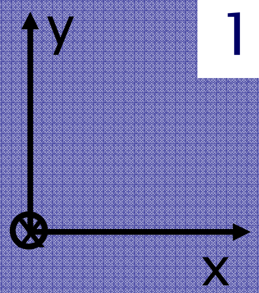


Results: Real astigmatic eye

Corneal heights from Pentacam

First corneal surface R_x= 7.92 mm R_y= 7.82 mm

γ from 0º to 7º



160 μm

Conclusions

- Oblique incidence can compensate corneal astigmatism.
- Tilting the incident beam introduce an aberration term that may cancel the existing one.
- Exists passive compensation of astigmatism.