Medida de aberraciones corneales y oculares

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Miembro del Consejo Editorial:

- **Journal of Cataract & Refractive Surgery**
- **Journal of Refractive Surgery**

Líneas de Investigación:

1.- Óptica Visual

2.- Calidad Óptica y Visual tras Cirugía Refractiva

3.- Presbicia y Acomodación.

Producción Científica:

Artículos Internacionales: 91

Patentes: 2

4 Proyectos de Investigación en marcha (IP)

Outline

1.- Fundamentals of elevation topography
2.- Irregular astigmatism: Fourier analysis
3.- Wavefront
4.- Wavefront sensing
5.- Zernike polynomials
6.- How does wavefront sensing relate to refractive surgery?
7.- Fourier versus Zernike

1.- FUNDAMENTALS OF ELEVATION MAP TOPOGRAPHY

Two Types

- **General: Placido Disc**
- **Orbscan/Pentacam**

ORBSCAN: MAIN FEATURES

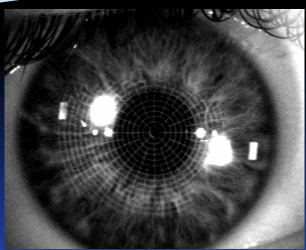
- Accurate elevation and curvature information
- Anterior and posterior cornea surface's
- Full cornea thickness

OPTICAL ADQUISITION HEAD

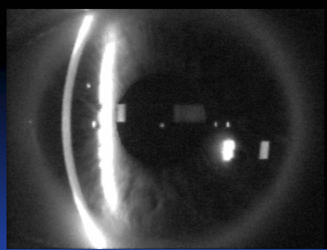
- Scans the eye using light slits that are projected at a 45-degree angle.
- 40 slits in total.
- Processing and construction of elevation maps of the anterior & posterior cornea.
- Pachimetry: Diferences in elevation between the anterior and posterior surface

HOW THE INFORMATION DIFFERS TO PLACIDO BASED SYSTEMS?

Reflective and Slit-scan



- One image, one surface.
- Angle-dependent specular reflection.
- Measures slope (as a function of distance).



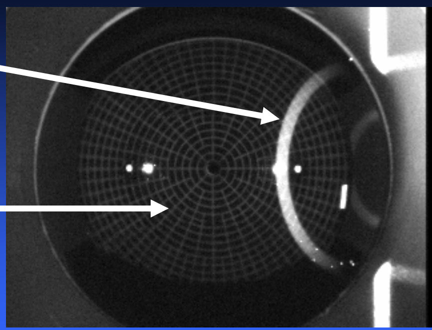
- Multiple images, multiple surfaces.
- Omni-directional diffuse backscatter.
- Triangulates elevation.

Placido reflective systems can only measure the anterior cornea. ORBSCAN measures the anterior cornea, posterior cornea, and the anterior lens and iris.

Hybrid Technology of ORBSCAN

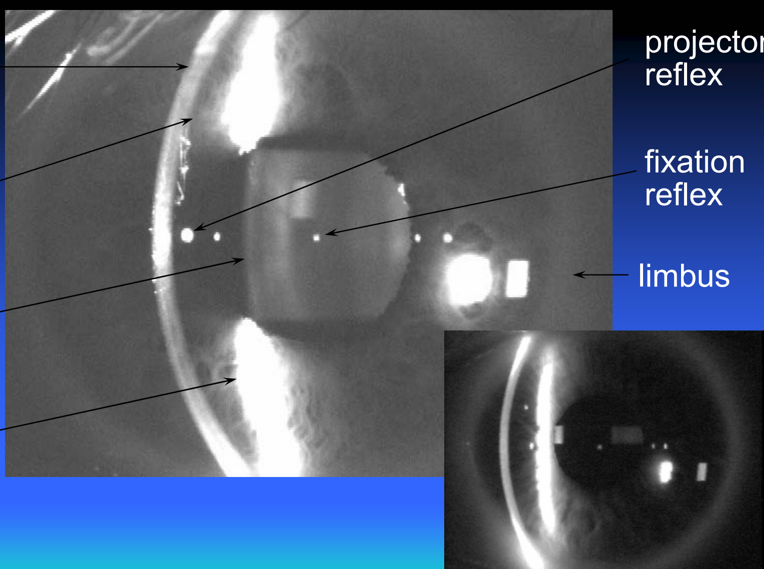
1. Measure **surface elevation directly** by triangulation of backscattered slit-beam.

2. Measure **surface slope directly** using specular reflection, supplemented with triangulated elevation.



3. **Unify triangulated and reflective data** to obtain accurate surfaces in elevation, slope, and curvature.

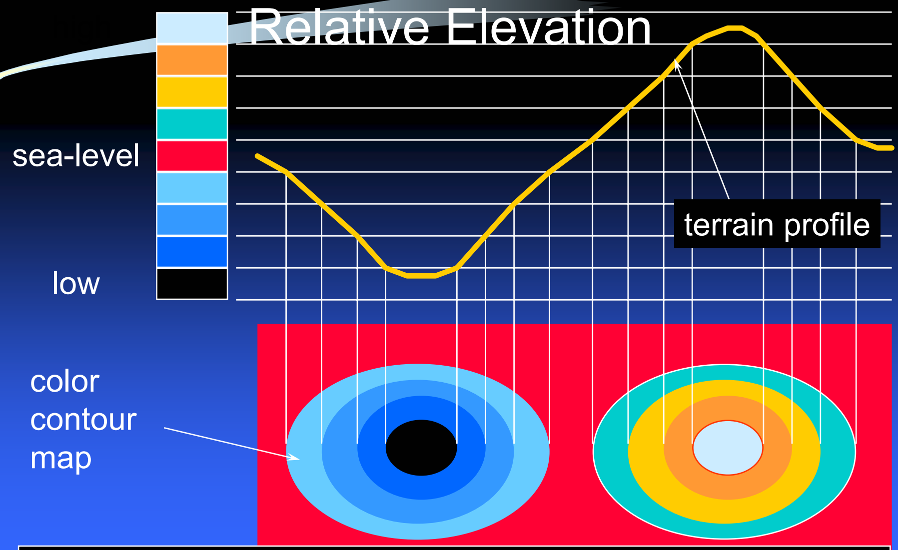
Scanning slits measure several surfaces



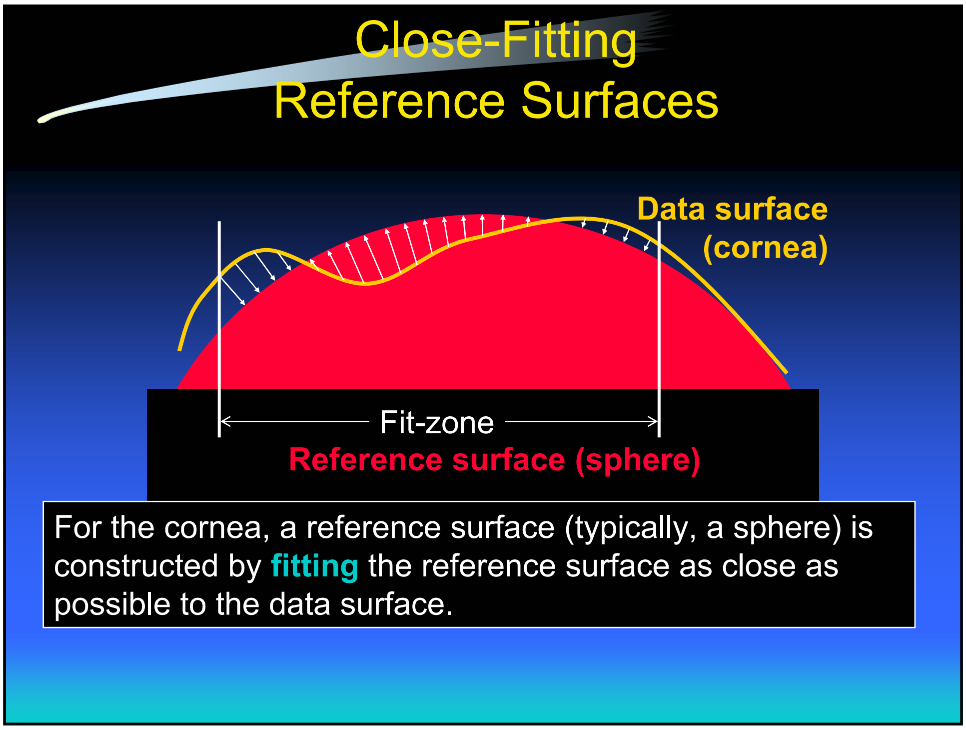
HOW TO READ CORNEAL ELEVATION MAPS

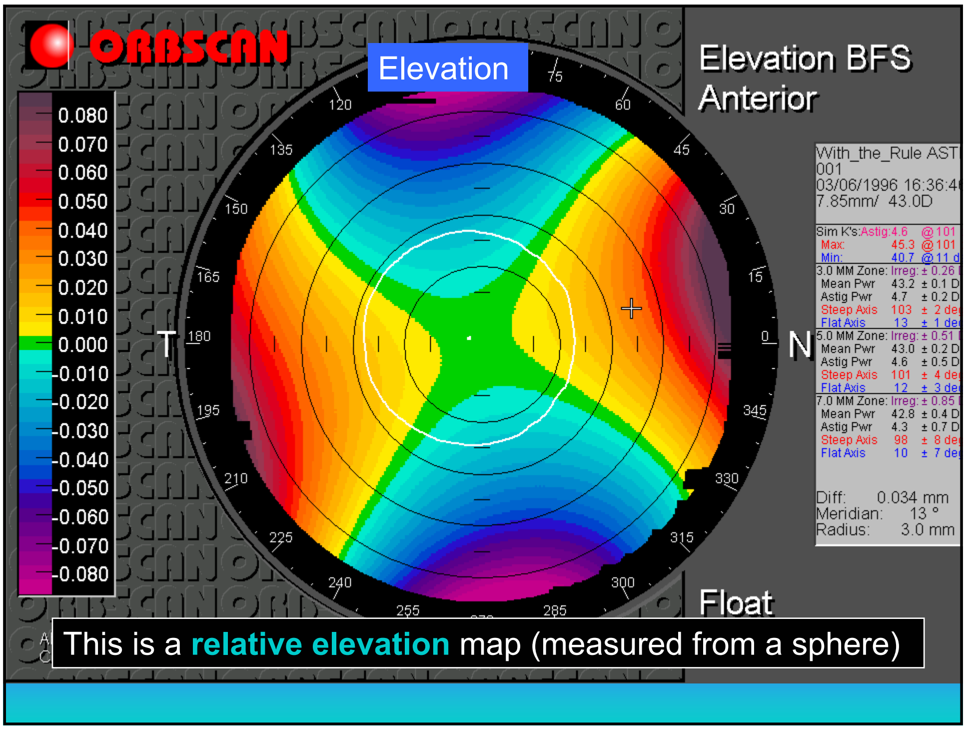
- Corneal Elevation Topography is viewed relative to a reference surface
- Standardization of the reference surface

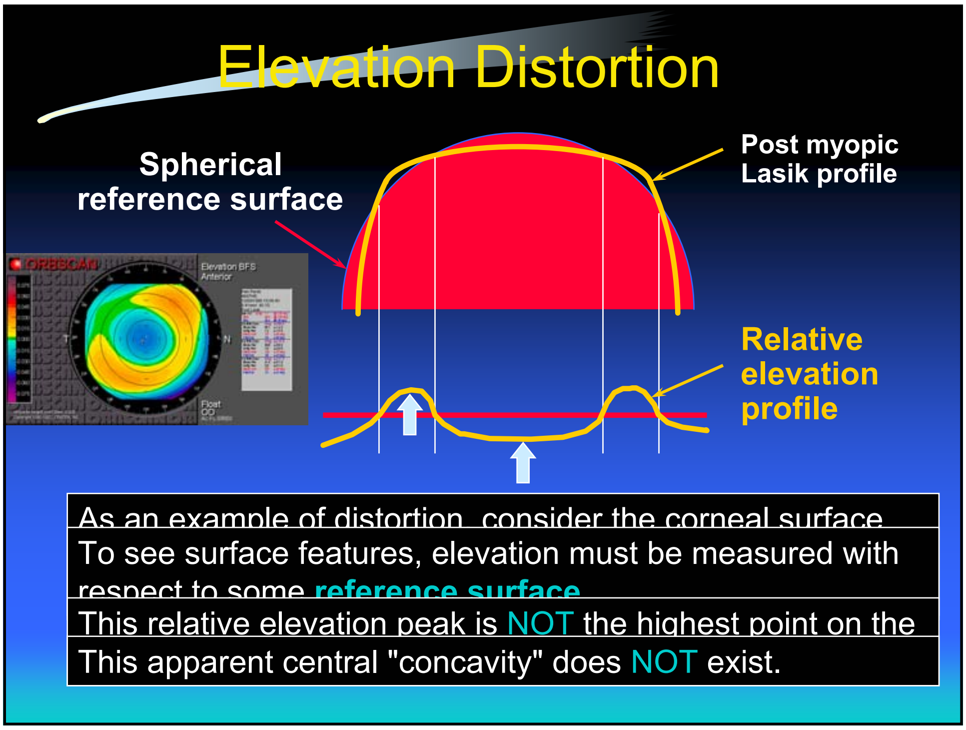
Relative Elevation



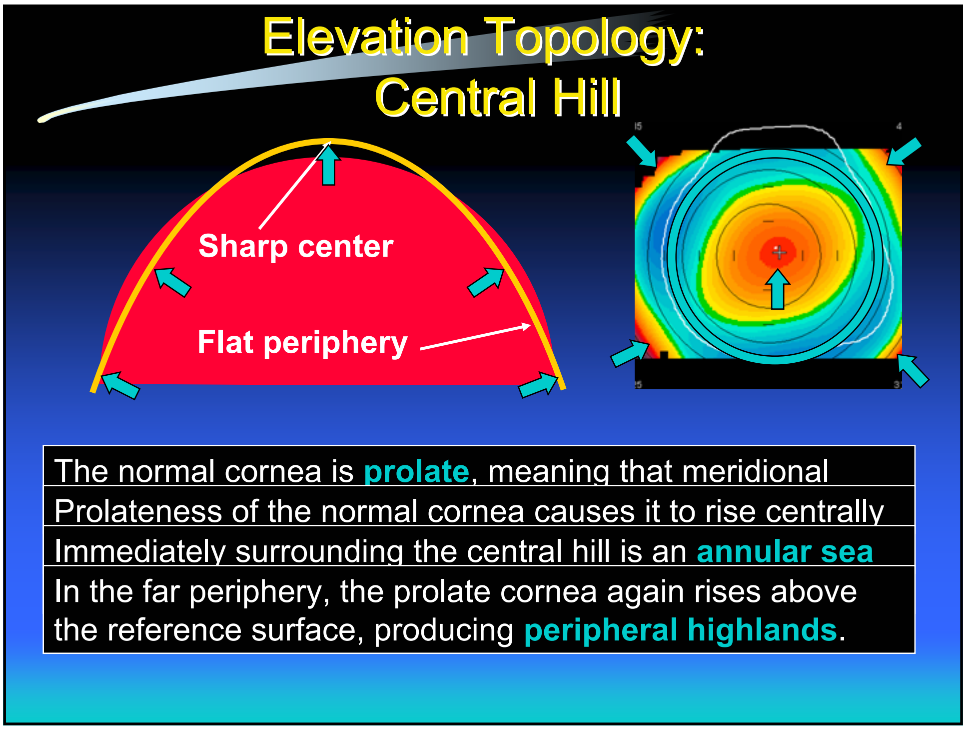
Elevation, whether of the earth or the cornea, is measured relative to some **reference surface**. The terrestrial reference surface is the "**mean sea level**".


Close-Fitting
Reference Surfaces
Data surface
(cornea)
Fit-zone
Reference surface (sphere)
For the cornea, a reference surface (typically, a sphere) is constructed by fitting the reference surface as close as possible to the data surface.


ORBSCAN
Elevation
Elevation BFS
Anterior
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
-0.070
-0.080
T
N
With_the_Rule AST
001
03/06/1996 16:36:4
7.85mm/ 43.0D
Diff: 0.034 mm
Meridian: 13 °
Radius: 3.0 mm
Float
This is a relative elevation map (measured from a sphere)



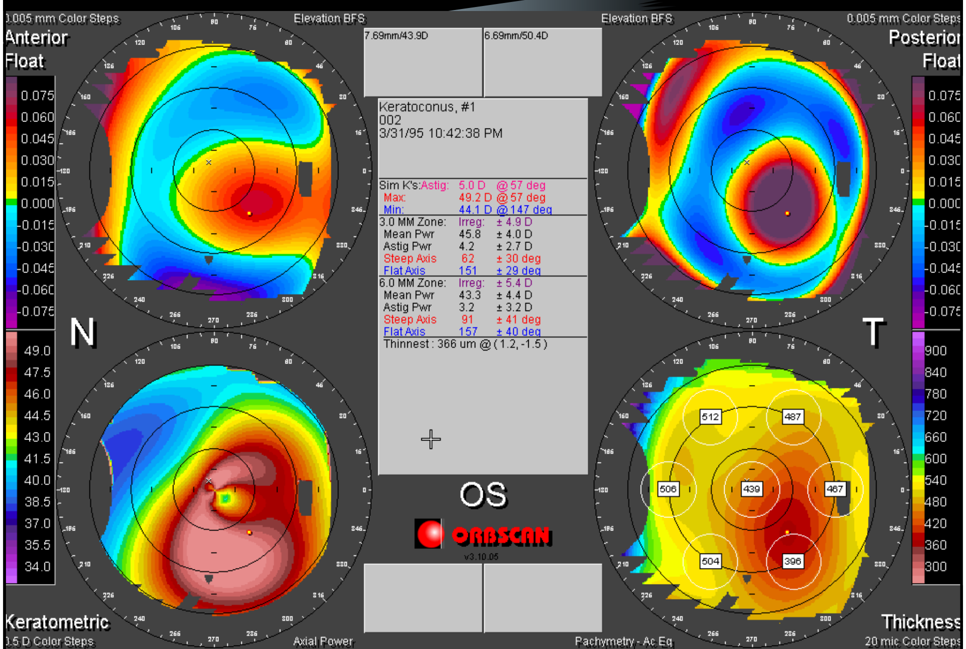
Elevation Distortion
Spherical reference surface
Post myopic Lasik profile
Relative elevation profile
As an example of distortion, consider the corneal surface
To see surface features, elevation must be measured with respect to some reference surface
This relative elevation peak is NOT the highest point on the
This apparent central "concavity" does NOT exist.



Elevation Topology: Central Hill
Sharp center
Flat periphery
The normal cornea is prolate, meaning that meridional
Prolateness of the normal cornea causes it to rise centrally
Immediately surrounding the central hill is an annular sea
In the far periphery, the prolate cornea again rises above the reference surface, producing peripheral highlands.

Importance of The Post Surface of The Cornea

- Keratoconus will show as localized posterior elevation with associated thinning. Patients with thin corneas without posterior elevation are unlikely to be keratoconic.



2.- IRREGULAR ASTIGMATISM: FOURIER ANALYSIS

ASTIGMATISMO IRREGULAR

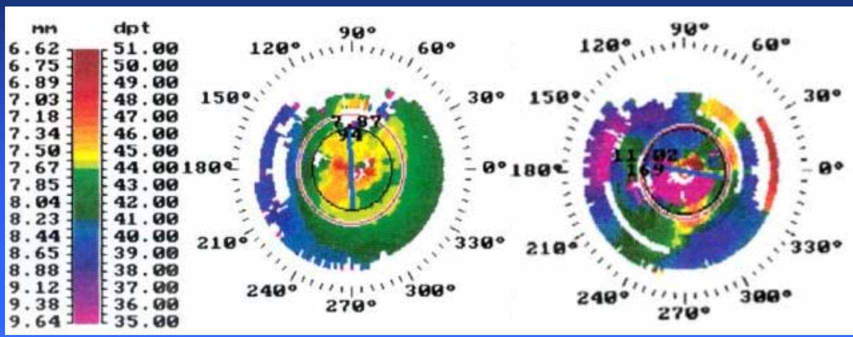
Astigmatismo regular ⇒ meridianos principales perpendiculares entre sí, y corrección con lentes esferoclíndricas

Cornea con forma irregular que no puede describirse con una sección esférica, tórica o cónica ⇒ Astismatismo irregular

Causas comunes: ojo seco, degeneraciones corneales, traumas, cirugía de la catarata y refractiva.

Problem

Impossibility to evaluate topographies without pattern



Análisis de Fourier

Es un procedimiento matemático que permite la descomposición de cualquier objeto periódico en una suma de términos sinusoidales de frecuencias crecientes y amplitudes determinadas, lo que se conoce como espectro de Fourier de dicha función.

Solution

To apply Fourier Analysis to

videoqueratographic data

Serie of Fourier

Funtion f(x) periodical

↓

Sum of discrete function f(x)
Sinusoidal terms:

$$f(x) = a_0 + \sum_{n=1}^{\infty} a_n \bullet \cos(2\pi nx / p) + \sum_{n=1}^{\infty} b_n \bullet \sin(2\pi nx / p)$$

$$a_0 = \frac{1}{p}\int_0^p f(x)dx \quad a_n = \frac{1}{p}\int_0^p f(x) \bullet \cos(2\pi nx / p)dx \quad b_n = \frac{1}{p}\int_0^p f(x) \bullet \text{sen}(2\pi nx / p)dx$$

Fourier Transform

Possibility to apply to non-periodical functions using the Fourier Transform (FT):

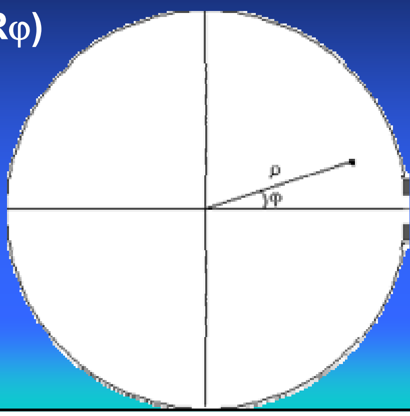
$$T.F.\{f(x)\} = F(w) = \int f(x) \bullet \exp(-i2\pi wx)dx$$

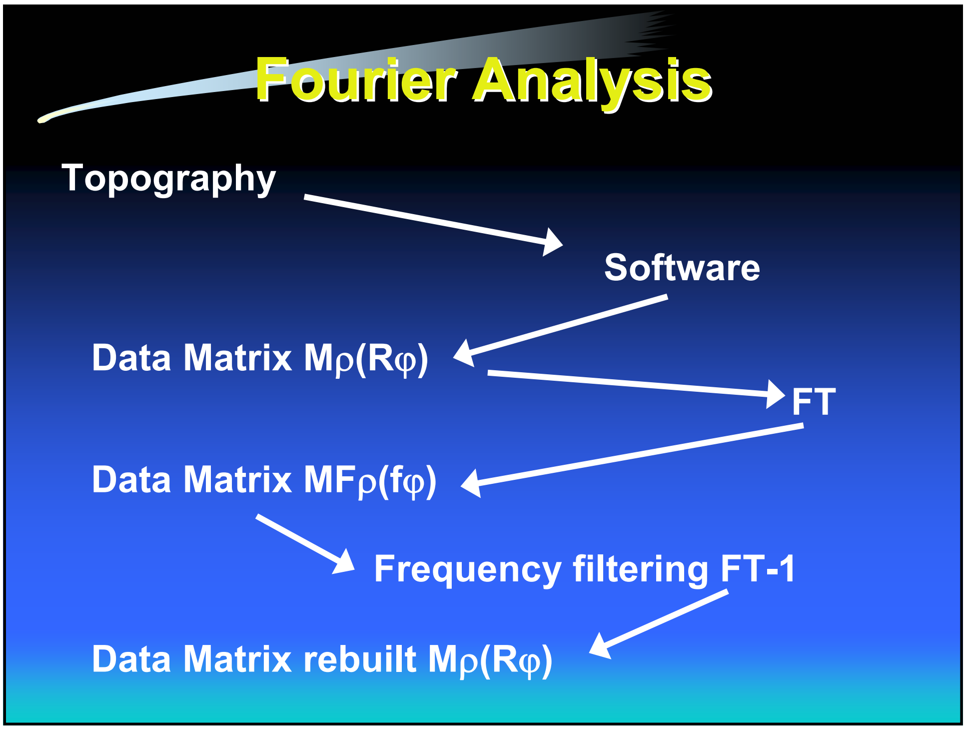
To rebuilt the original function f(x) we apply the inverse transform to the function F(W):

$$f(x) = T.F.^{-1}\{F(w)\} = \int F(w) \bullet \exp(i2\pi xw)dw$$

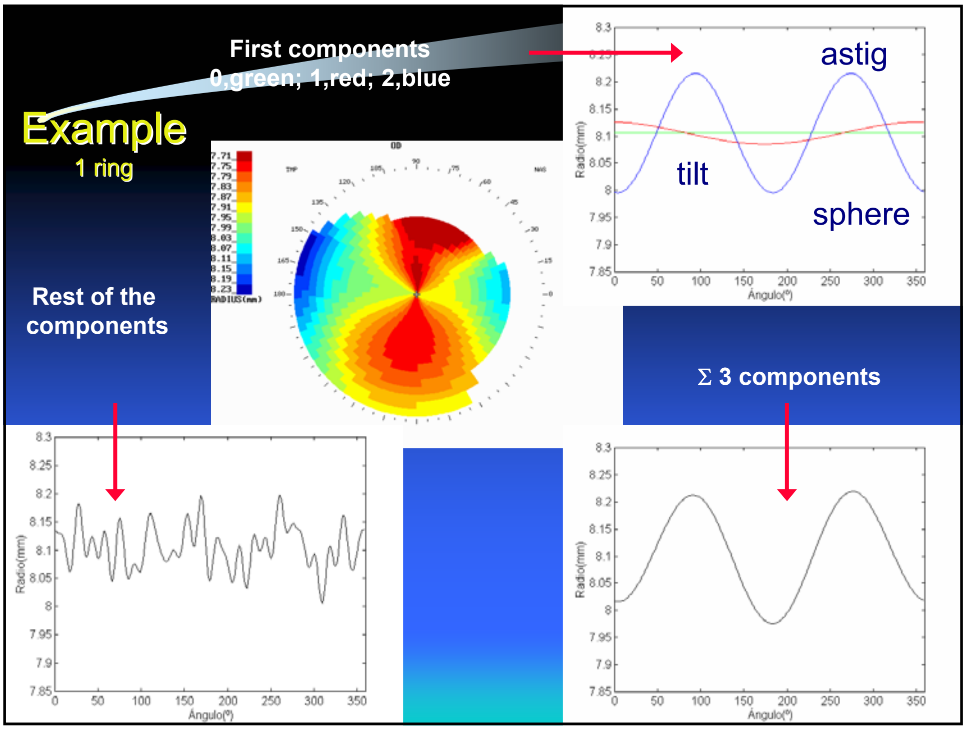
Fourier Analysis

Topographic image is a matrix of data $M\rho(R\varphi)$ containing radii as a function of the angle $(R\varphi)$ for each ring of radious ρ.

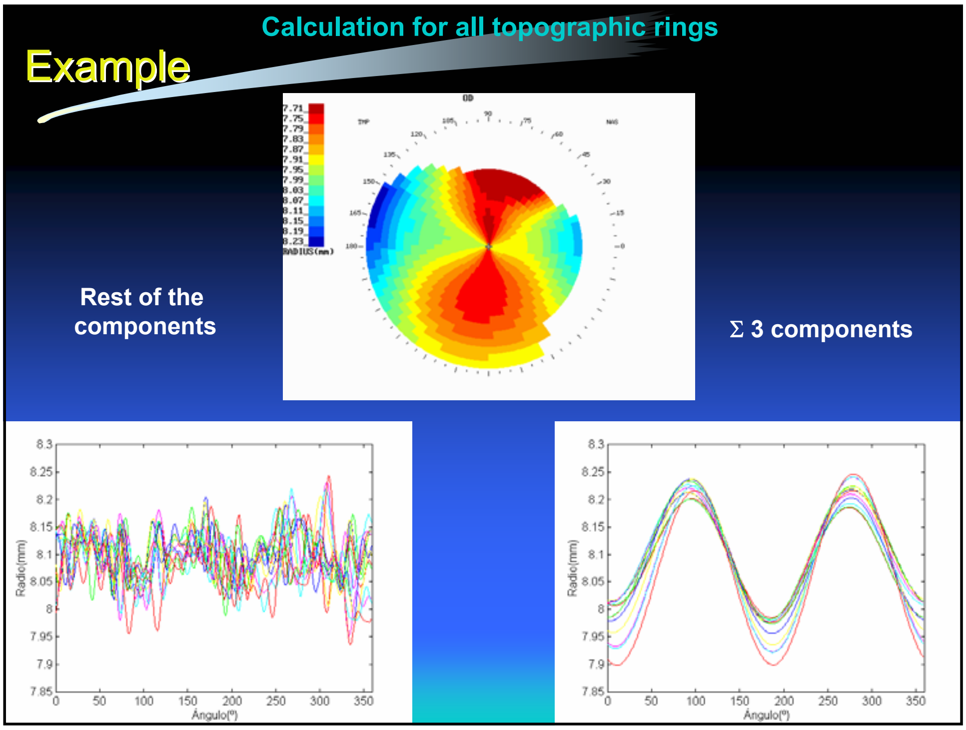


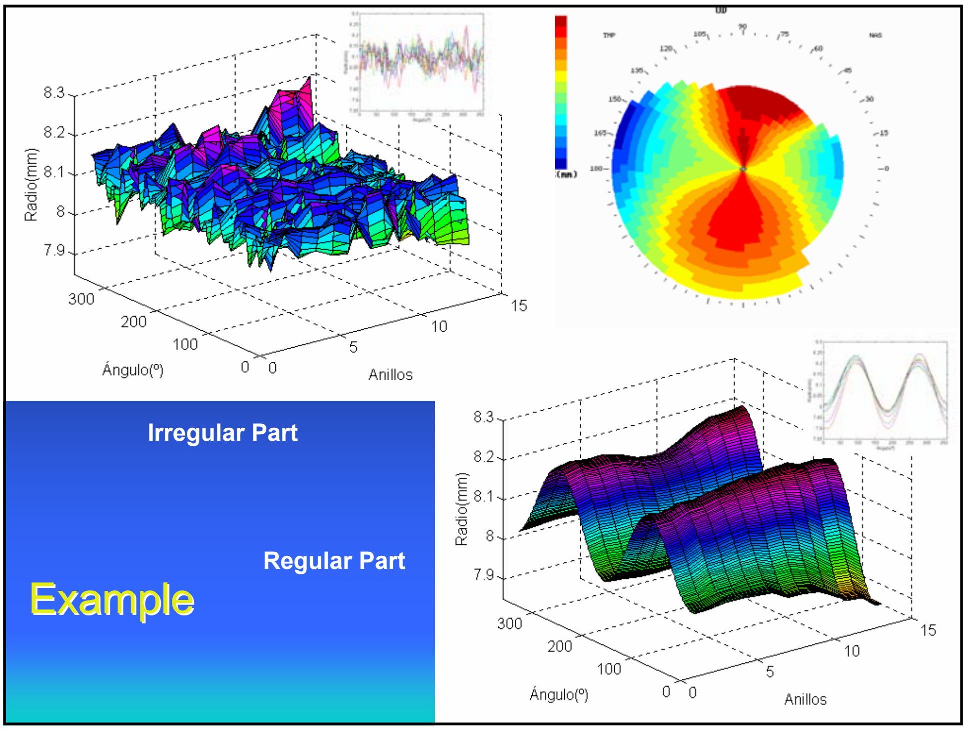


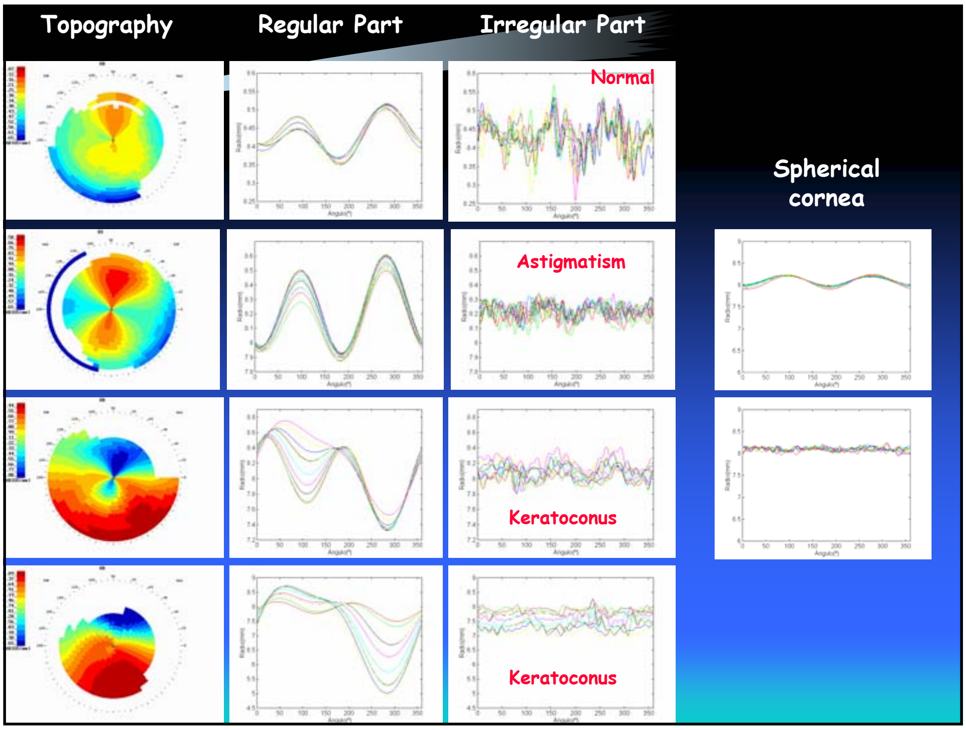
Fourier Analysis
Topography
Software
Data Matrix Mρ(Rφ)
FT
Data Matrix MFρ(fφ)
Frequency filtering FT-1
Data Matrix rebuilt Mρ(Rφ)

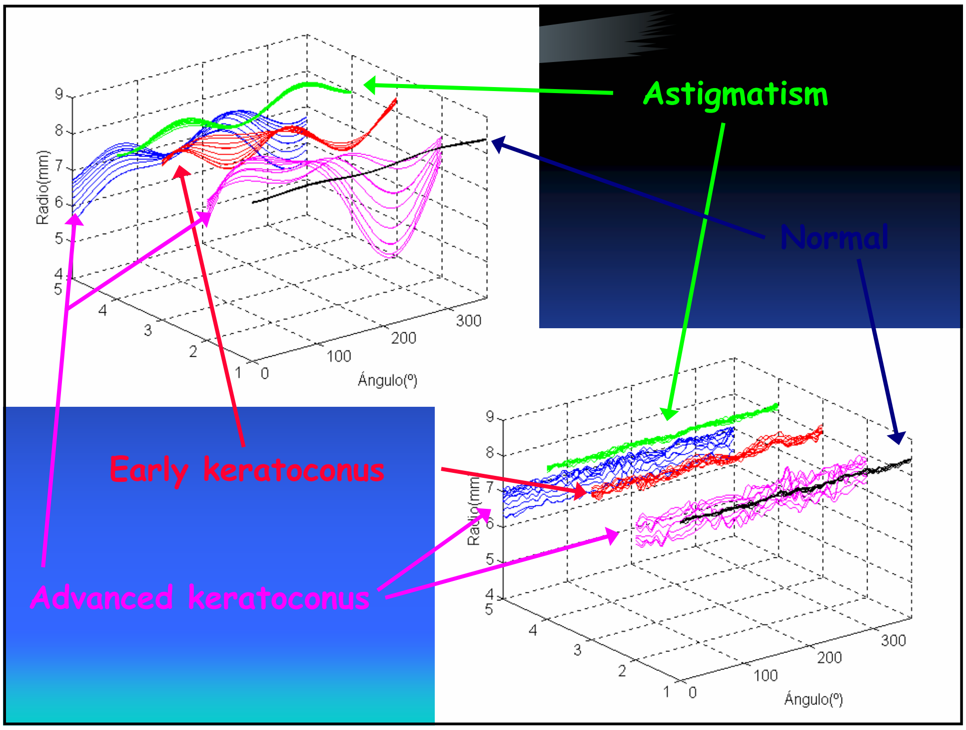


Example
1 ring
First components
0,green; 1,red; 2,blue
astig
tilt
sphere
Rest of the
components
Σ 3 components
Radio(mm)
Ángulo(º)


Example
Calculation for all topographic rings
Rest of the components
Σ 3 components
Radio(mm)
Ángulo(º)
Radio(mm)
Ángulo(º)


Radio(mm)
Ángulo(º)
Anillos
Irregular Part
Regular Part
Example
Radio(mm)
Ángulo(º)
Anillos


Topography
Regular Part
Irregular Part
Normal
Astigmatism
Keratoconus
Keratoconus
Spherical cornea


Astigmatism
Normal
Early keratoconus
Advanced keratoconus
Radio(mm)
Ángulo(º)

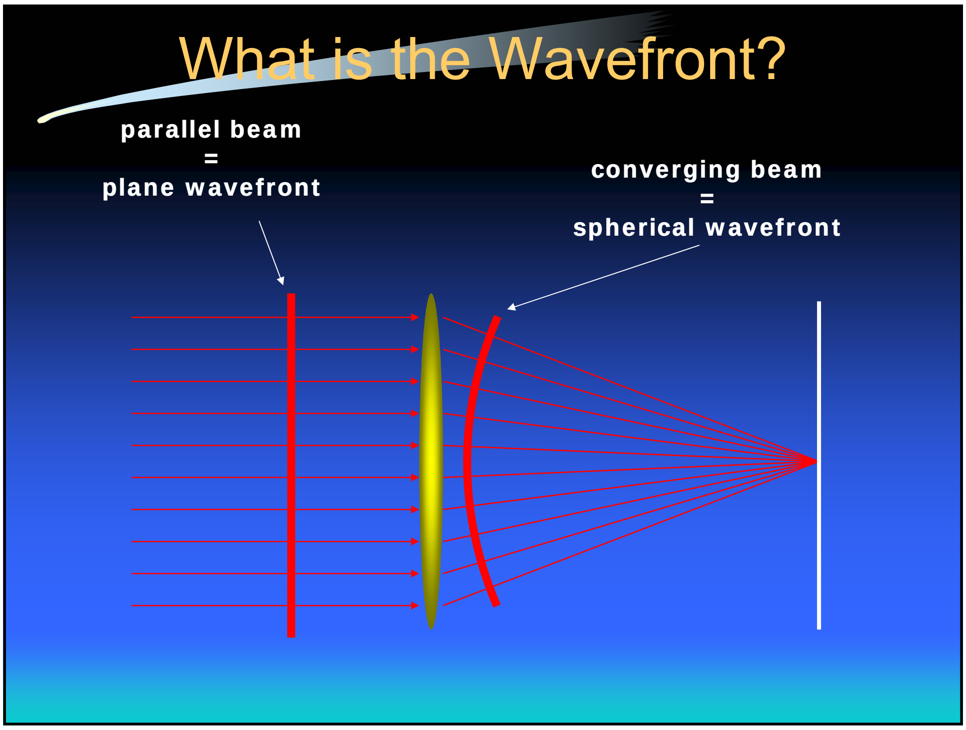
Conclusions

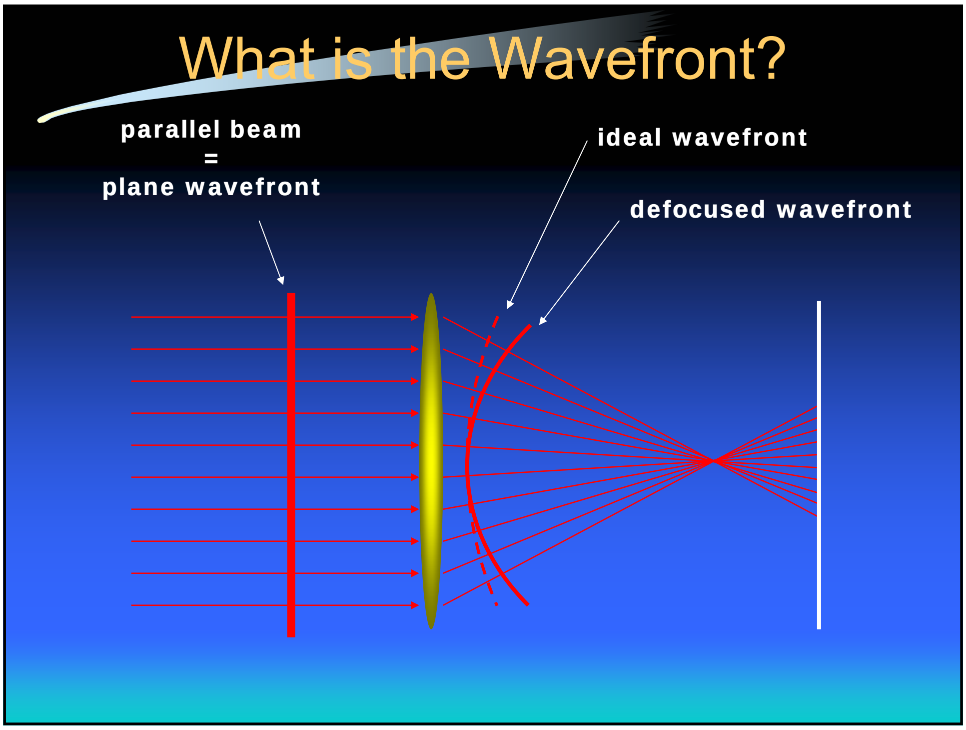
We can divide topographic information between regular and irregular parts

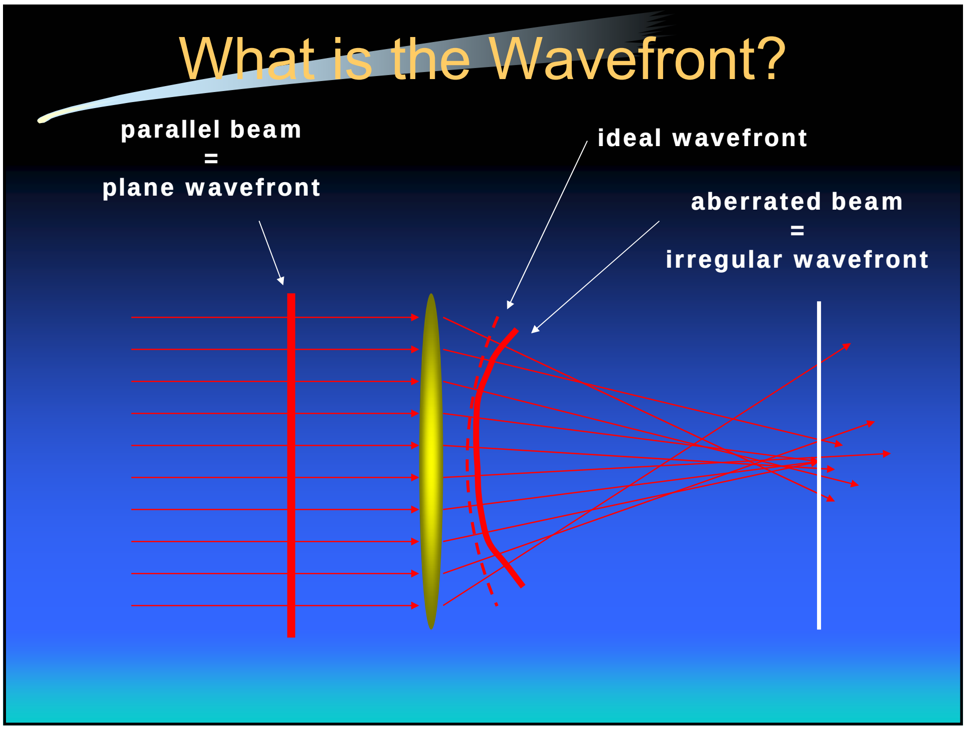
We can quantify the corneal irregularity by means two parameters, defined from the regular and irregular parts.

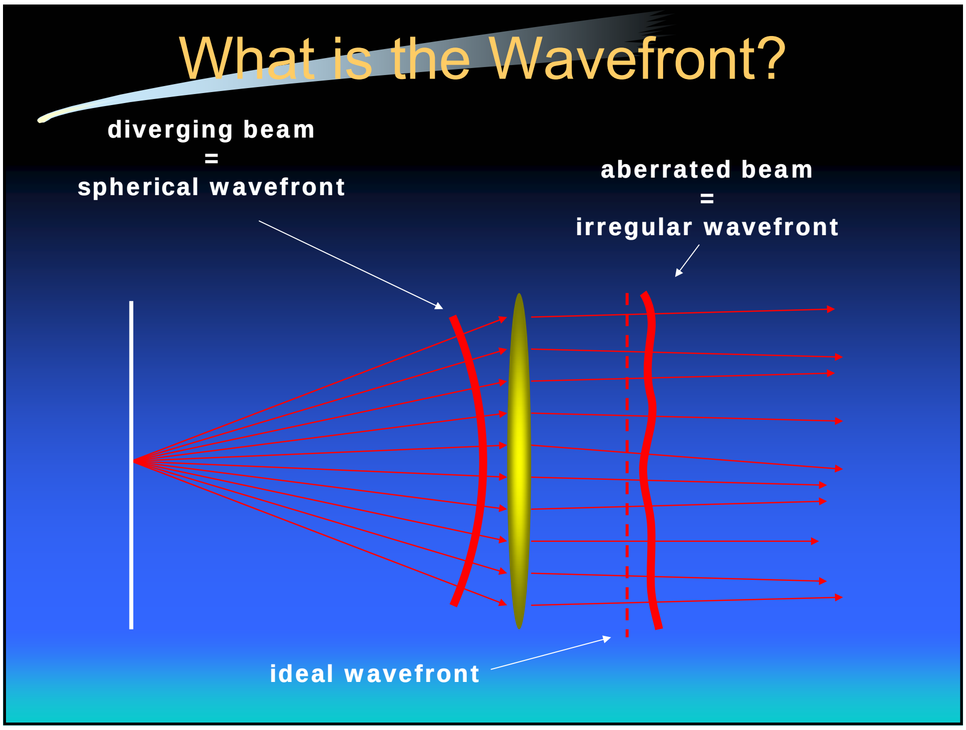
3.- Wavefront

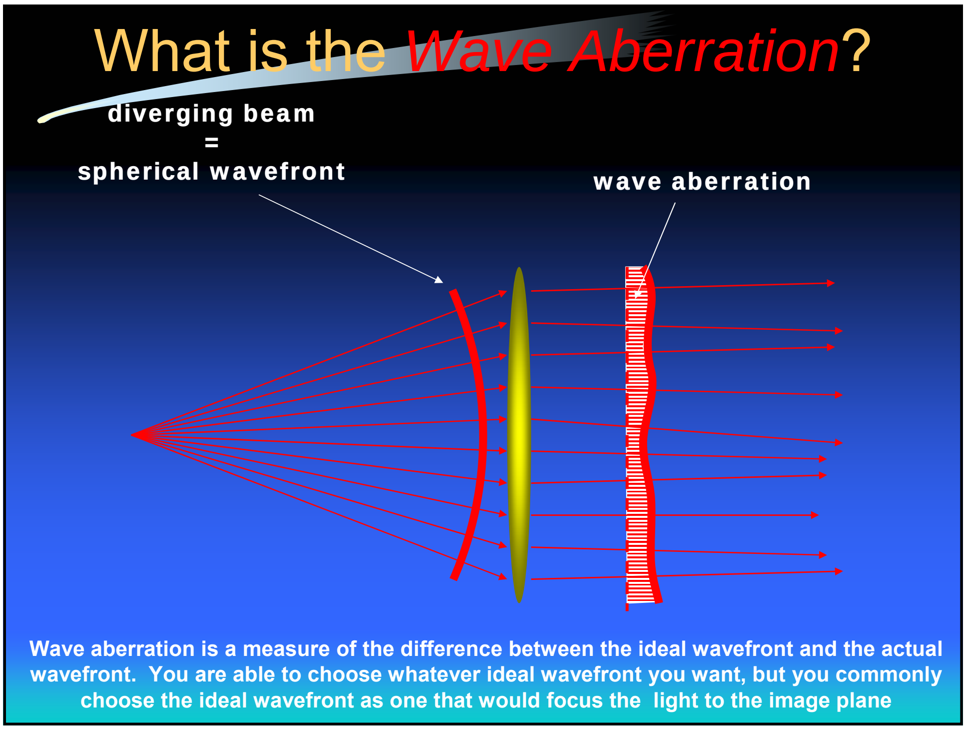
We will describe the wavefront. This is the one of the most fundamental and useful description of the optical properties of the eye, from which most of the image quality metrics can be derived.

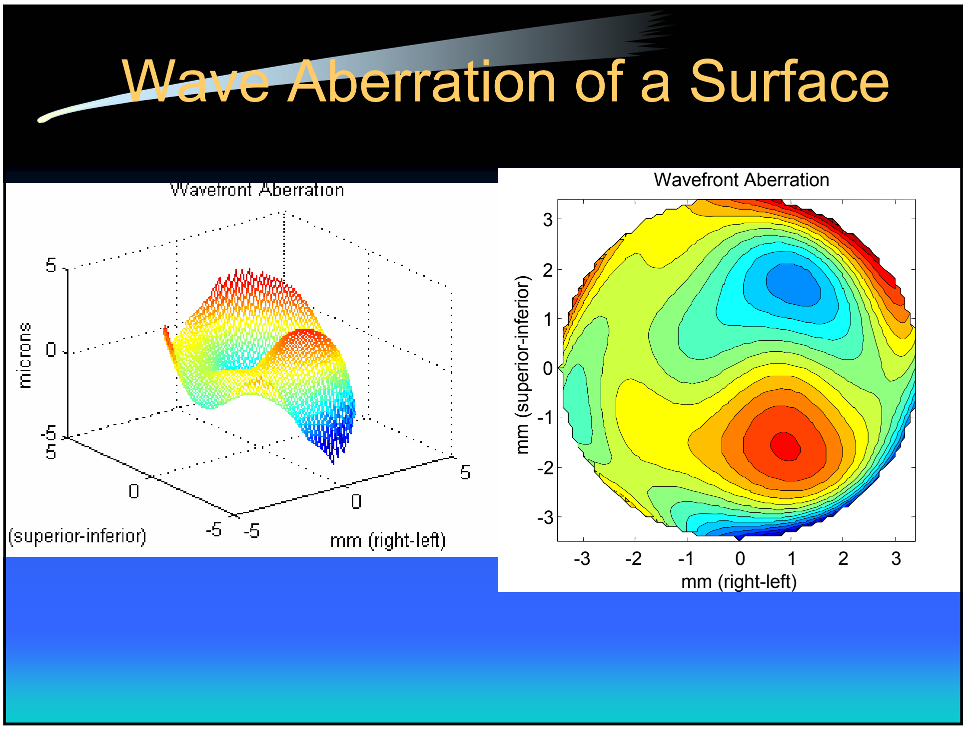

What is the Wavefront?
parallel beam
=
plane wavefront
converging beam
=
spherical wavefront


What is the Wavefront?
parallel beam
=
plane wavefront
ideal wavefront
defocused wavefront


What is the Wavefront?
parallel beam
=
plane wavefront
ideal wavefront
aberrated beam
=
irregular wavefront


What is the Wavefront?
diverging beam
=
spherical wavefront
aberrated beam
=
irregular wavefront
ideal wavefront

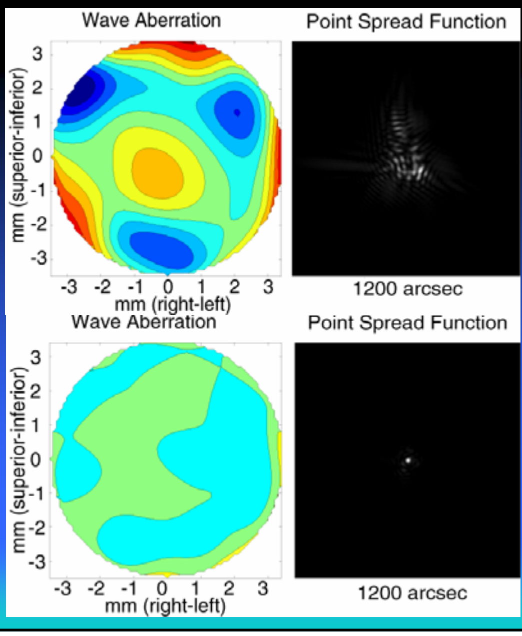

What is the Wave Aberration?
diverging beam
=
spherical wavefront
wave aberration
Wave aberration is a measure of the difference between the ideal wavefront and the actual wavefront. You are able to choose whatever ideal wavefront you want, but you commonly choose the ideal wavefront as one that would focus the light to the image plane


Wave Aberration of a Surface
Wavefront Aberration
microns
(superior-inferior)
mm (right-left)
Wavefront Aberration
mm (superior-inferior)
mm (right-left)

Adaptive Optics Flattens the Wave Aberration

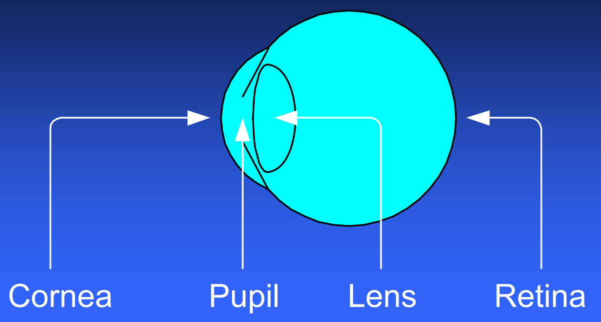
AO OFF

AO ON



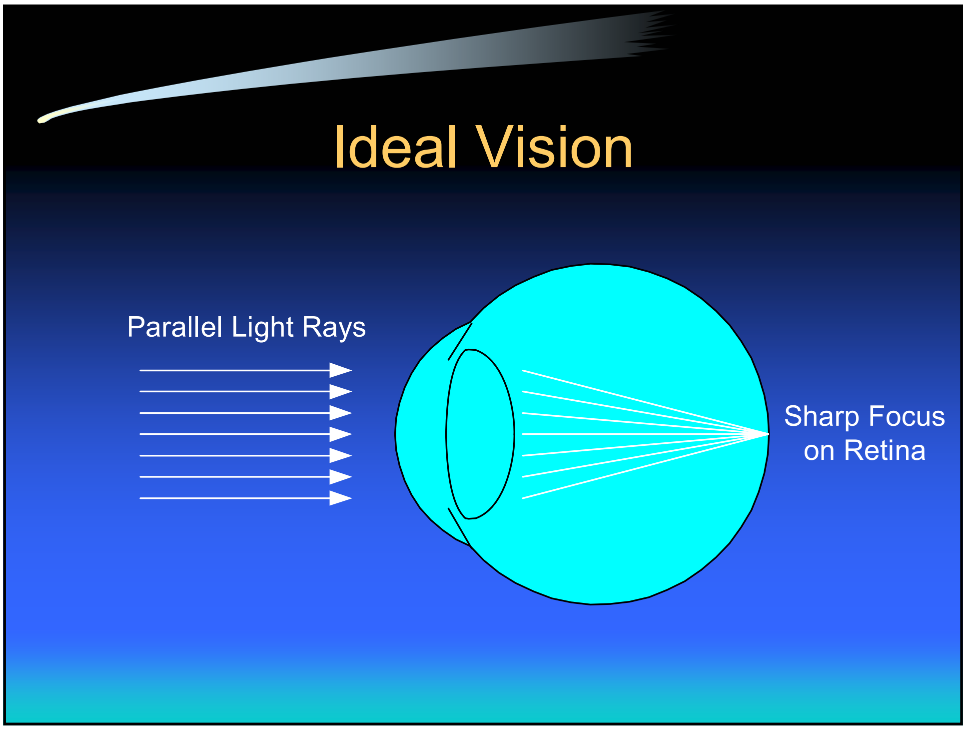
4.- Wavefront Sensing

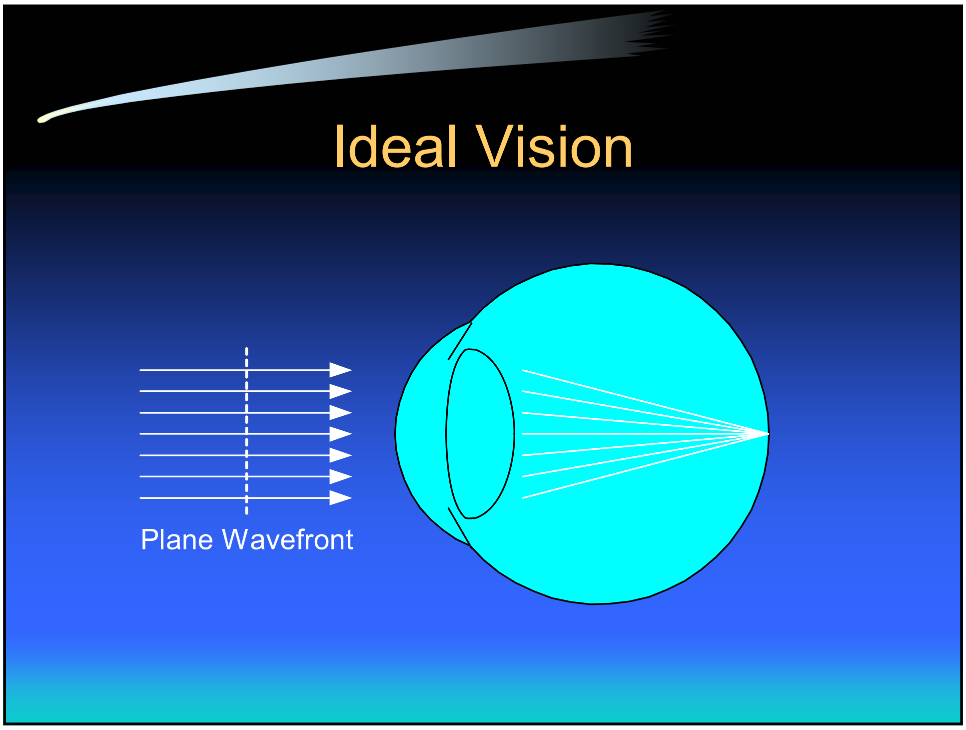
Optical Anatomy of the Eye

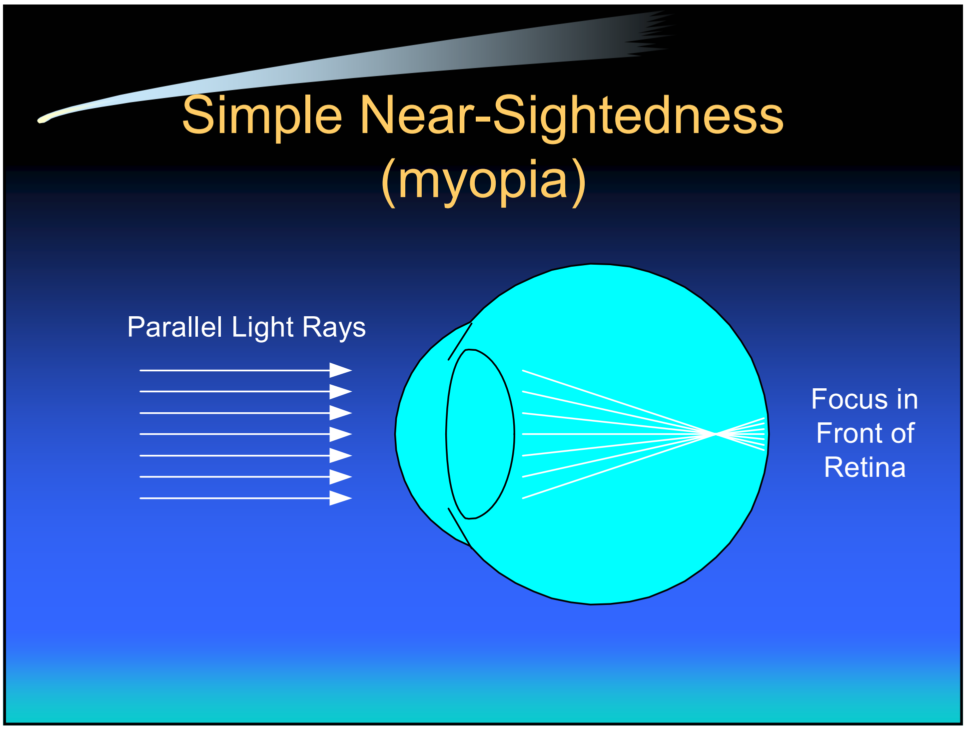


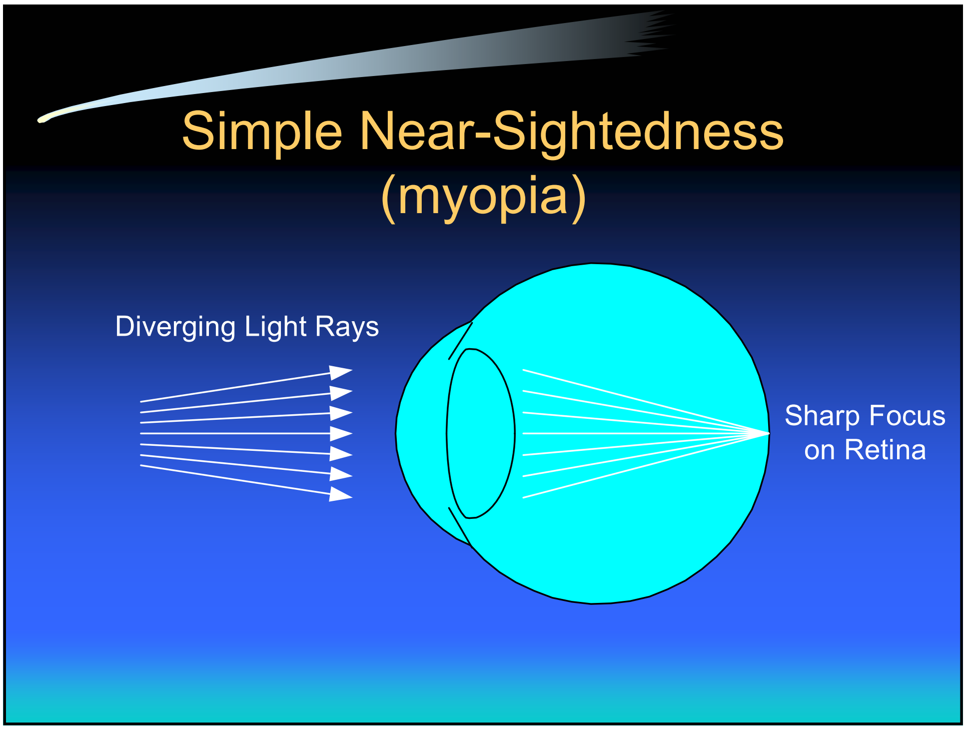
Wavefront Sensing Clinical Utility

- Measures integrated function of optical system
- Allows accurate calculation of effective clinical prescription
- Also provides details of higher order aberrations
- Quick measurement easily made in clinical setting

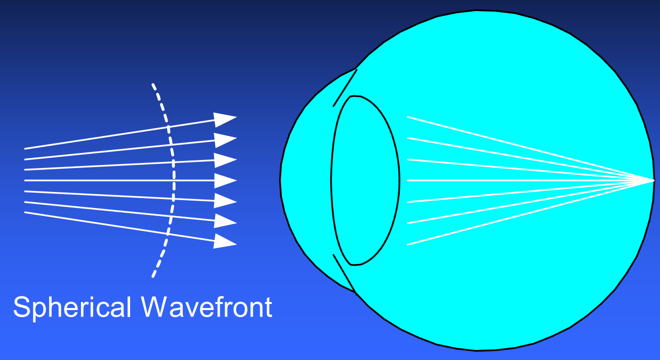

Ideal Vision
Parallel Light Rays
Sharp Focus
on Retina


Ideal Vision
Plane Wavefront

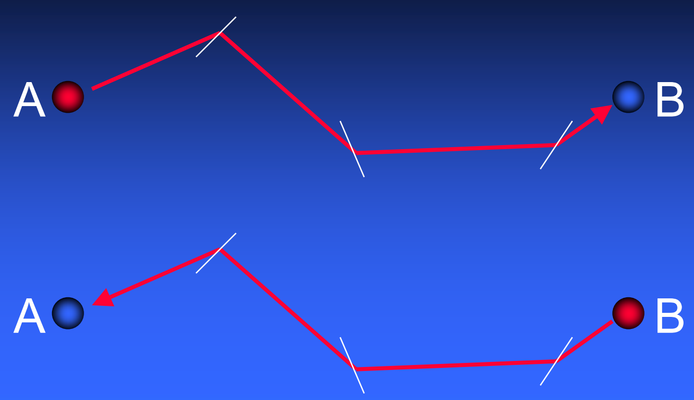

Simple Near-Sightedness
(myopia)
Parallel Light Rays
Focus in
Front of
Retina


Simple Near-Sightedness
(myopia)
Diverging Light Rays
Sharp Focus
on Retina

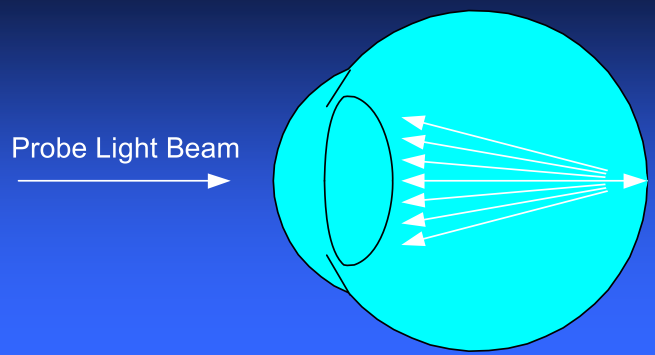
Simple Near-Sightedness (myopia)



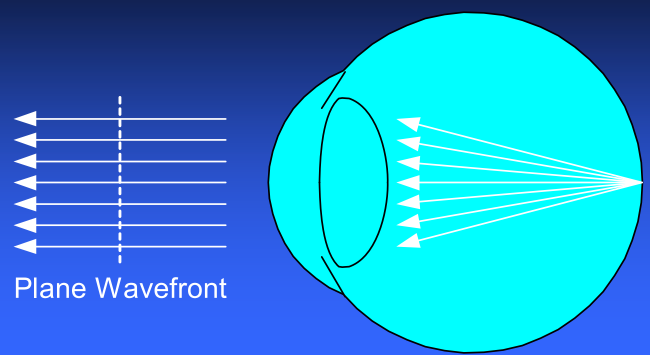
The Reversible Nature of Light Propagation



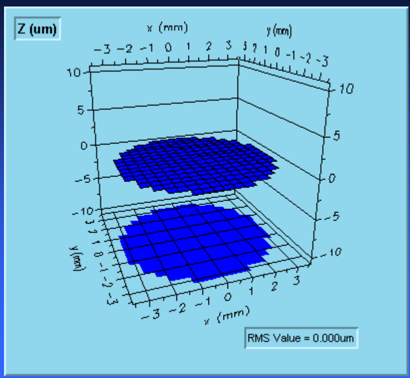
Wavefront Sensing: Turn the Rays Around!



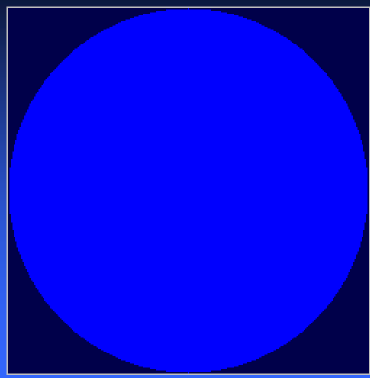
Re-Emitted Wavefront for an Ideal Eye



Wavefront Displays for Ideal Vision

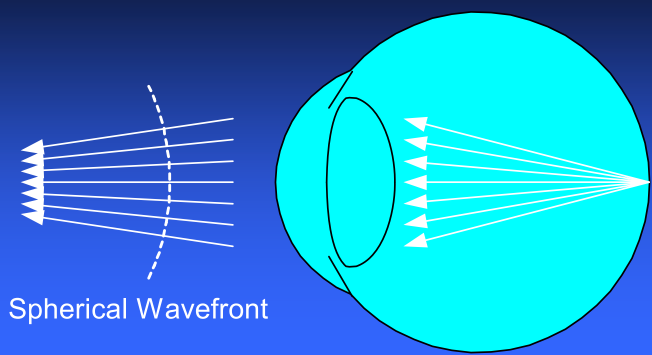


3-D Representation

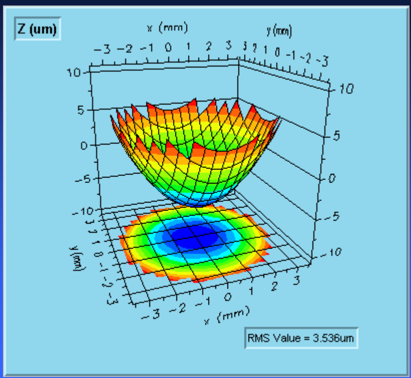


2-D Color Map

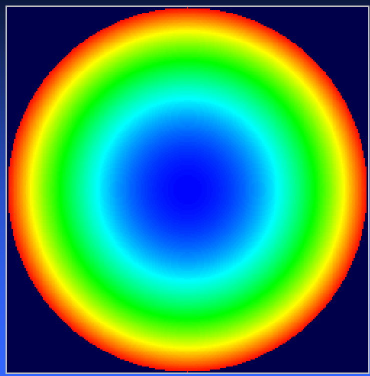
Re-Emitted Wavefront for an Near-Sighted Eye (myopic)



Wavefront Displays for Near-Sightedness



3-D Representation


2-D Color Map

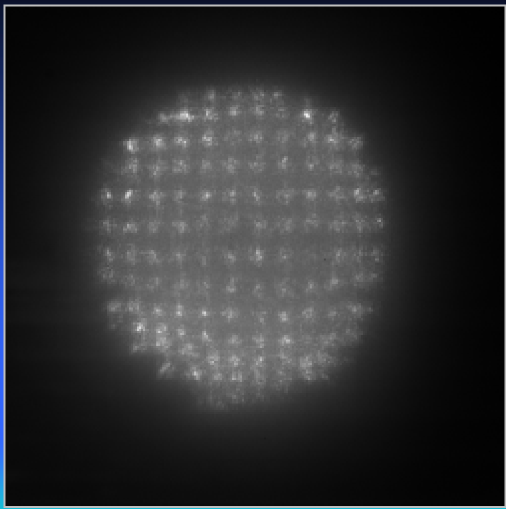
How do We Make the Wavefront Measurement? Wavefront sensors

Usually use ray-tracing methods to reconstruct the wavefront and are classified into the following 3 types:

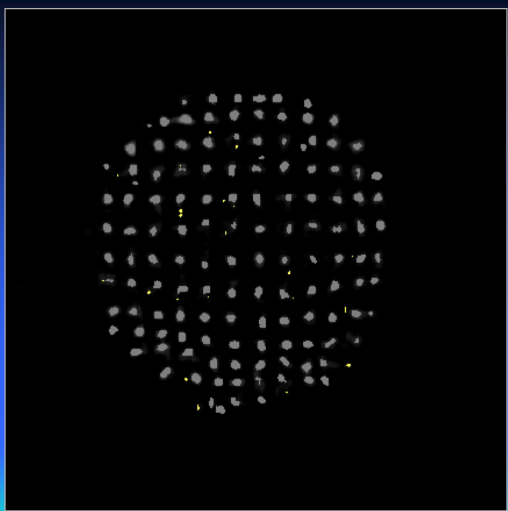
- Outgoing wavefront aberrometry
  (Hartmann-Shack)
- Ingoing retinal imaging aberrometry
  (cross cylinder, Tscherning aberroscope)
- Ingoing feedback aberrometer
  (spatially resolved refractometer, optical path difference)

The Wavefront Sensing Path

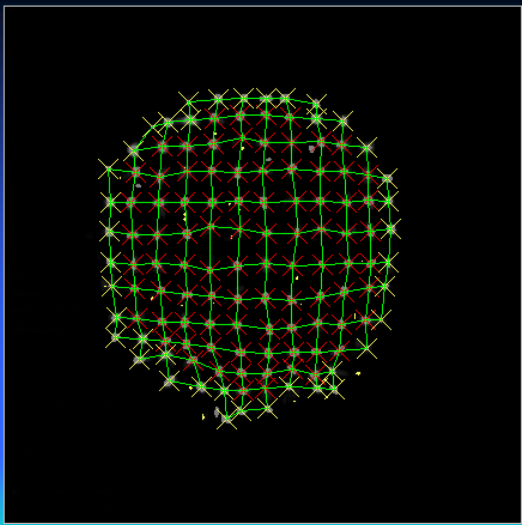
Direct CCD Image



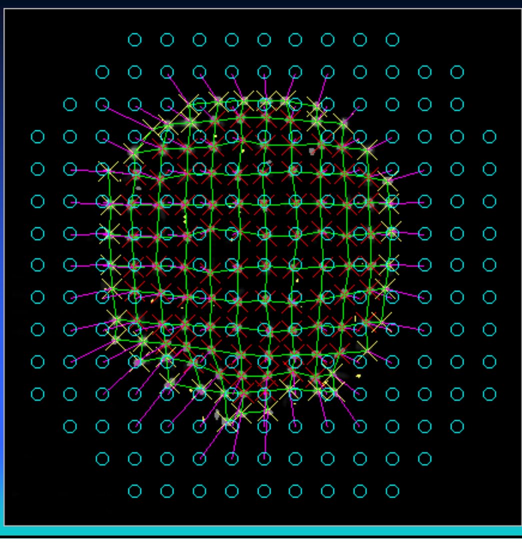
Enhanced CCD Image

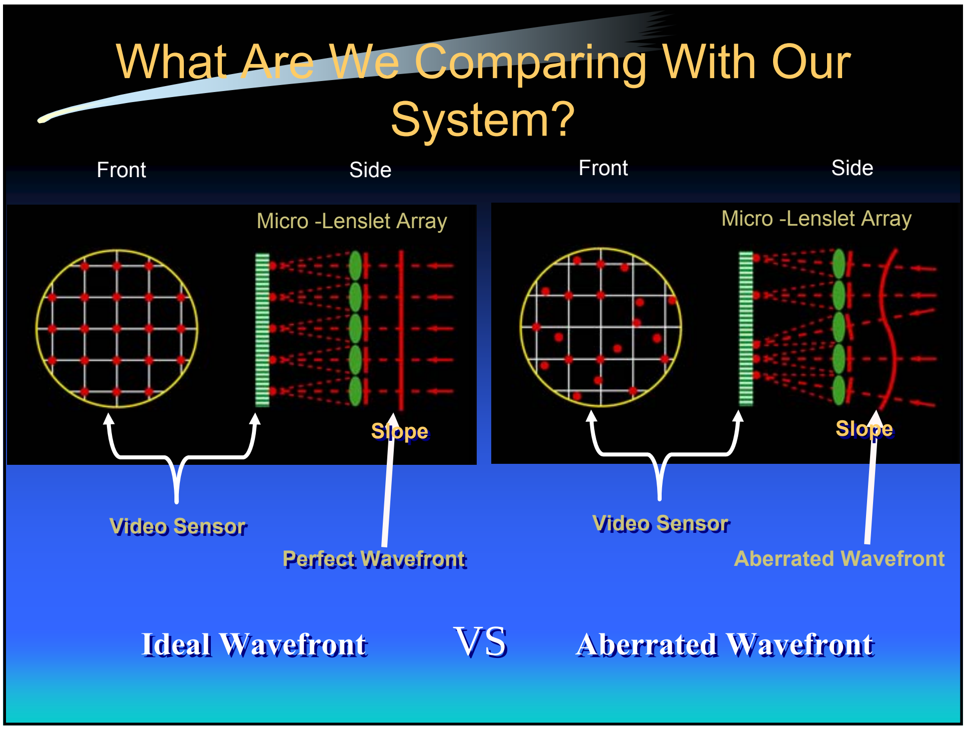


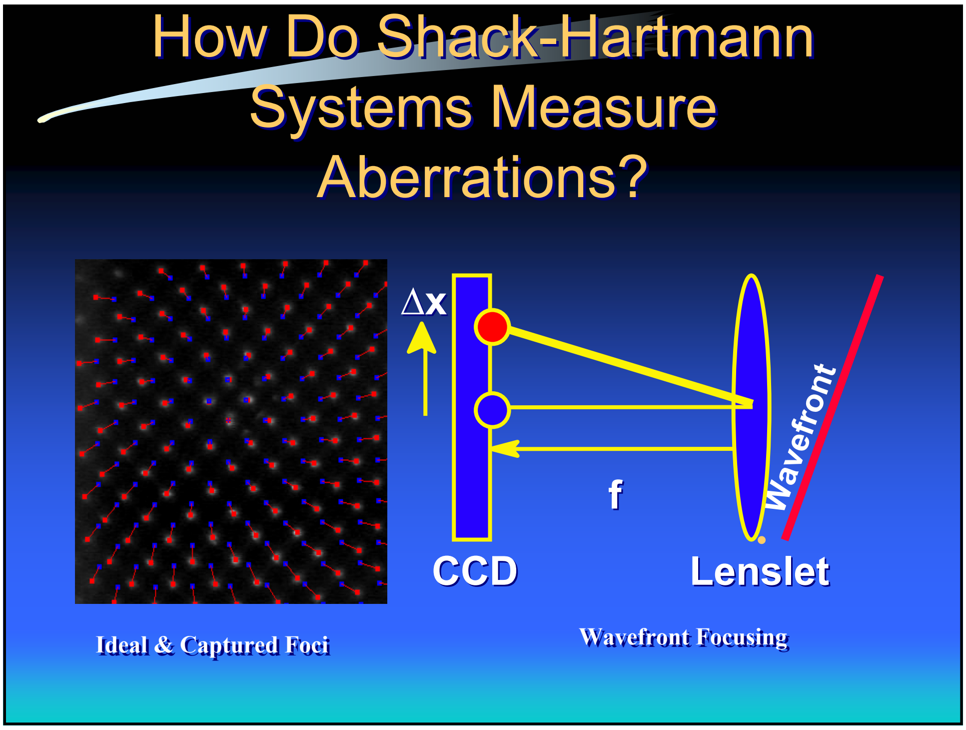
Focussed Spot Associations

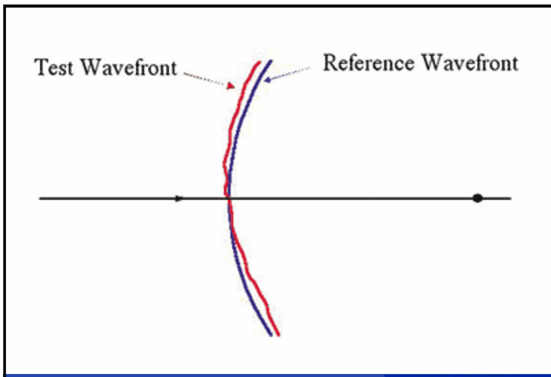


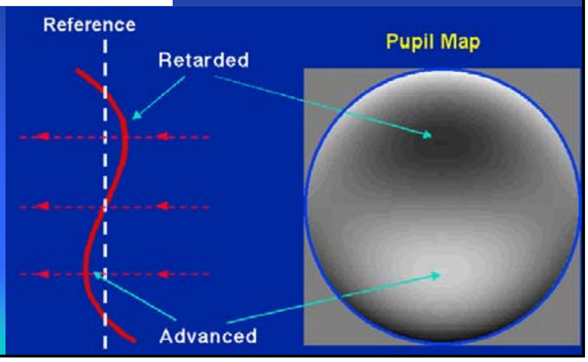
Comparison to Ideal Pattern



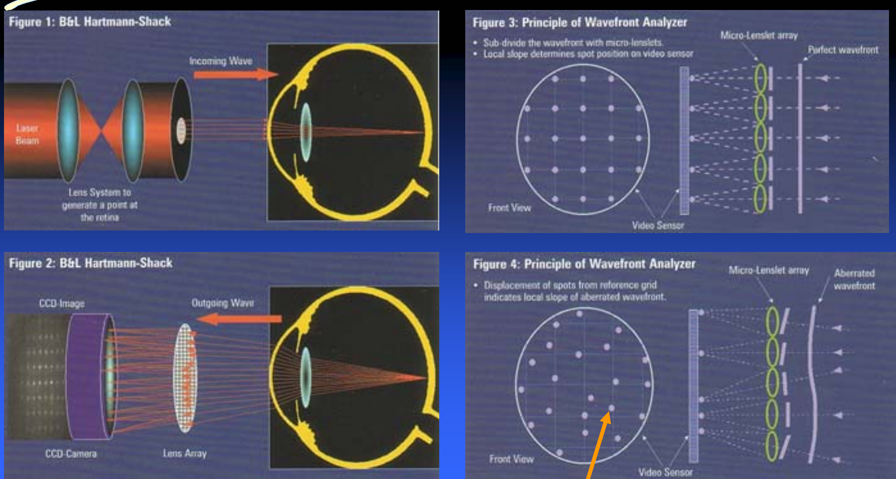

What Are We Comparing With Our System?
Front
Side
Front
Side
Micro -Lenslet Array
Micro -Lenslet Array
Slope
Slope
Video Sensor
Perfect Wavefront
Video Sensor
Aberrated Wavefront
Ideal Wavefront
VS
Aberrated Wavefront


How Do Shack-Hartmann Systems Measure Aberrations?
Δx
f
Wavefront
CCD
Lenslet
Ideal & Captured Foci
Wavefront Focusing



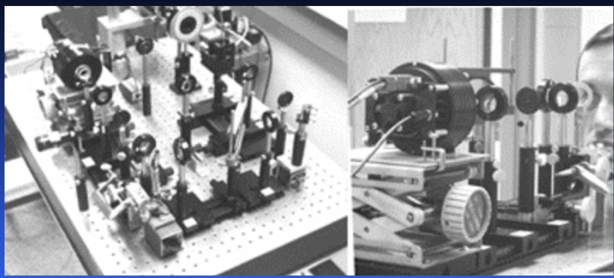


Principle of Outgoing Wavefront Analyzer Hartmann-Shack



Displacement of spots from reference grid
indicates local slope of aberrated wavefront

Wavefront Analyzer Hartmann-Shack

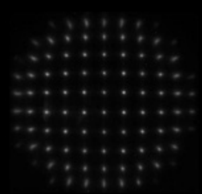


Montaje laboratorio en banco de óptica

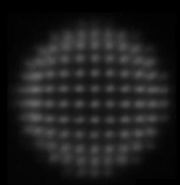
Comercial

Examples of spots position in a Hartmann-Shack

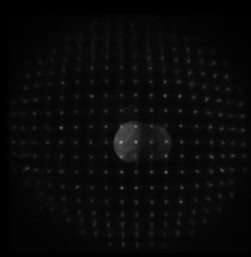
Emmetropic Model Eye



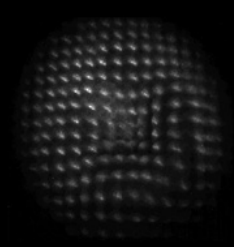
4D Myopic Model Eye



LASIK

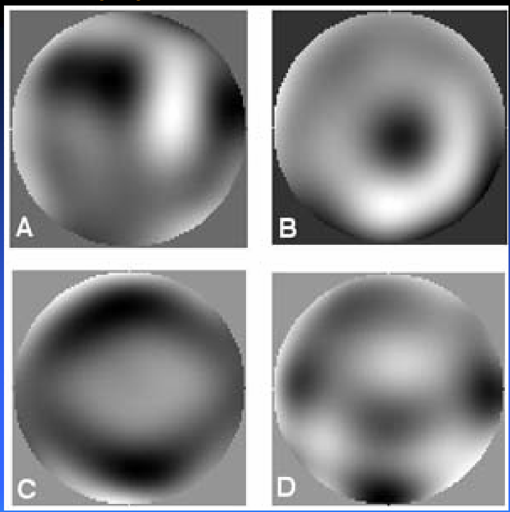


Keratoconus



Wavefront shape

Dry eye Keratoconus



Myopic-LASIK Cataract

Examples of higher-order aberration maps from eyes with four different clinical conditions.

Zernike orders 0-2 omitted for clarity.

5.- Zernike polynomials

Introducción

► La aproximación más familiar para cuantificar las aberraciones ópticas es la de Seidel, definida para sistemas rotacionalmente simétricos

► Cuando describimos las aberraciones oculares, Seidel no se utiliza ya que la óptica del ojo no es totalmente simétrica

► Los polinomios de Taylor tambien han sido utilizados para describir las aberraciones del ojo

► Recientemente se han utilizado los polinomios de Zernike debido a sus propiedades matemáticas adecuadas para pupilas circulares

Introducción

► Polinomios de Zernike: consisten en un conjunto ortogonal de polinómios que presentan las aberraciones y además están relacionados con las aberraciones ópticas clásicas

► Parecen el método más deseable para estimaciones precisas del error de frente de onda, debido a sus propiedades de ortogonalidad (independencia de los términos entre sí) y pueden ajustarse por el método de mínimos cuadrados, que es lineal en parámetros

Introducción: Topografía

► Los topógrafos miden la elevación corneal sólo en un número discreto de puntos y los polinómios de Zernike no son ortogonales sobre un conjunto discreto de puntos

► La técnica de ortogonalización de Gram-Smith permite expandir el conjunto discreto de datos de elevación corneal, en términos de polinómios de Zernike y conseguir las ventajas de una expansión ortogonal.
Una vez completada la expansión, las funciones ortogonales se transforman en términos de polinomios de Zernike, resultando un conjunto único de coeficientes de Zernike

Definición y notaciones

Los polinomios de Zernike son un conjunto infinito de funciones polinómicas, ortogonales en el circulo de radio unidad.

Son muy útiles para representar la forma del frente de onda en sistemas ópticos. Su uso está muy extendido y son muy comunes distintas notaciones, normalizaciones y criterios en la asignación de signos.

Los polinomios de Zernike pueden expresarse en coordenadas polares, siendo ρ la coordenada radial (intervalo de variación [0,1]) y θ la componente azimutal (intervalo de variación es [0,2π])

Distinguimos tres componentes

- el factor de normalización (N),
- la dependencia radial
- y la dependencia azimutal.

$$Z_n^{\pm m}(\rho,\theta) = \begin{cases} N_n^{\pm m} R_n^{|m|}(\rho)\cos m\theta & \text{for } m \geq 0 \\ -N_n^{\pm m} R_n^{|m|}(\rho)\sin m\theta & \text{for } m < 0 \end{cases}$$

La dependencia radial es polinómica y la azimutal es armónica.

$$N_n^m = \sqrt{\frac{2(n+1)}{1+\delta_{m0}}}$$

$$R_n^{|m|}(\rho) = \sum_{s=0}^{(n-|m|)/2} \frac{(-1)^s (n-s)!}{s![0.5(n+|m|)-s]![0.5(n-|m|)-s]!}\rho^{n-2s}$$

Se identifica al polinomio con dos índices "n" y "m", donde "n" indica la potencia más alta (orden) en la componente polinómica radial y "m" es la frecuencia azimutal en la componente armónica

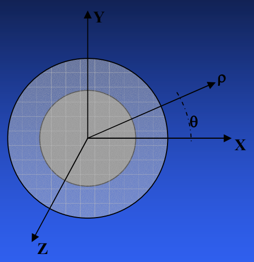
Representación de las aberraciones.

La función aberración de onda W (ρ, θ) puede expresarse como combinación lineal de los polinomios de Zernike:

$$W = \Sigma_{j=1\ldots N}\, C_j\, Z_j$$

donde C_j son los Coeficientes de Zernike que se expresan en micras y miden el valor de las distintas aberraciones presentes en el sistema.

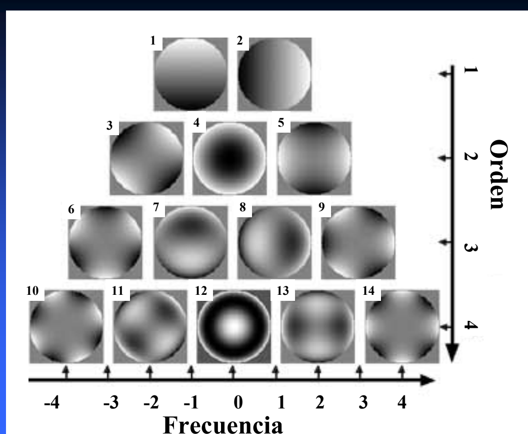
Para describir las aberraciones oculares se toma como sistema de referencia un triedro a derechas con origen en la pupila de entrada del ojo, el semieje positivo Y apuntando hacia arriba, el X apuntando hacia la izquierda del sujeto y Z apuntando en dirección emergente al ojo.



Sistema de referencia para la descripción de la aberración ocular en función de los polinomios de Zernike. Se muestra vista frontal del ojo. Los semiejes positivos se toman de la misma manera en ambos ojos.

Al usar coordenadas polares θ se mide respecto del semieje positivo X y ρ es la distancia respecto del origen medida en unidades normalizadas al radio pupilar

La siguiente figura muestra la forma del frente de onda representado por cada polinomio de Zernike, la aberración total se expresa como combinación lineal de esos patrones característicos



Visualización los 14 primeros polinomios de Zernike en escala de grises (color claro para adelanto de fase y oscuro para retraso). Cada patrón se identifica con su índice j, cada fila corresponde a un orden n y cada columna a una frecuencia m.

- Las aberraciones de bajo orden vienen representadas por los polinomios de ordenes n = 0,1 y 2.

- Para n = 0 tenemos un único polinomio de valor constante unidad y para n =1 encontramos dos polinomios denominados *"tilts"* Éstos representan traslaciones y rotaciones del sistema de referencia

- Las aberraciones de 2º orden están descritas por los 3 polinomios de Zernike correspondientes a n = 2. Estos polinomios representan el desenfoque (j=4) y astigmatismo (j=3 y 5)

- Las aberraciones de alto orden vienen representadas por los polinomios de Zernike de orden n ≥ 3. Son de tercer orden el astigmatismo triangular (j = 6 y 9) así como el coma vertical y el coma horizontal (j =7 y 8) mientras que la aberración esférica (j=12) es de cuarto orden.

Listado de polinomios de Zernike hasta 6º orden, notación estándar de la OSA

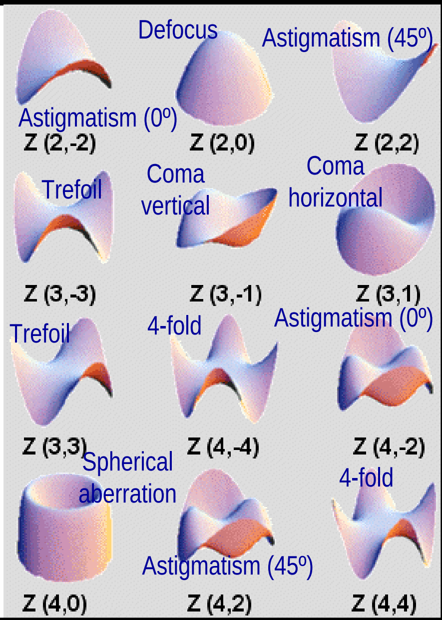
Z_n^f n: radial order
f: angular frequency

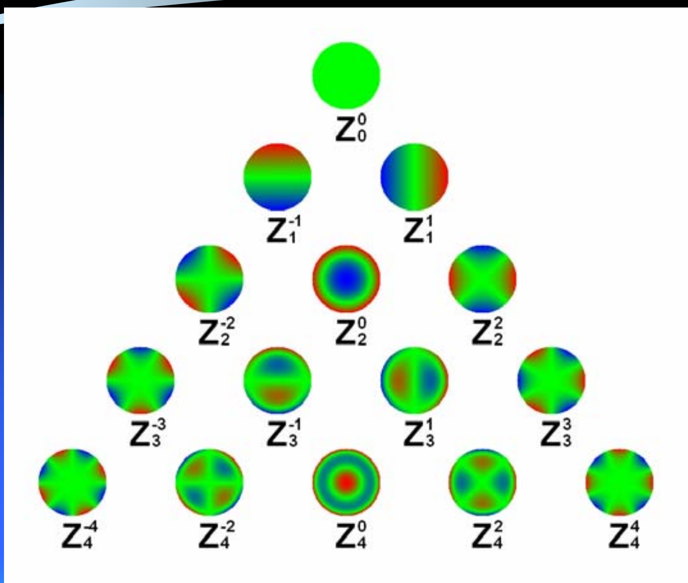
Zernike coefficient	Radial order	Angular frequency	Aberration
0	0	0	Piston
1	1	-1	Tip, Tilt (Prism)
2	1	1	
3	2	-2	Astigmatism
4	2	0	Defocus
5	2	2	Astigmatism
6	3	-3	Trefoil 3-fold
7	3	-1	Coma (vertical)
8	3	1	Coma (horizontal)
9	3	3	Trefoil 3-fold
10	4	-4	4-fold
11	4	-2	Astigmatism
12	4	0	Spherical Aberration
13	4	2	Astigmatism
14	4	4	4-fold
15	5	-5	5-fold
16	5	-3	3-fold
17	5	-1	Coma (vertical)
18	5	1	Coma (horizontal)
19	5	3	3-fold
20	5	5	5-fold
21	6	-6	6-fold
22	6	-4	4-fold
23	6	-2	Astigmatism
24	6	0	Spherical aberration
25	6	2	Astigmatism
26	6	4	4-fold
27	6	6	6-fold

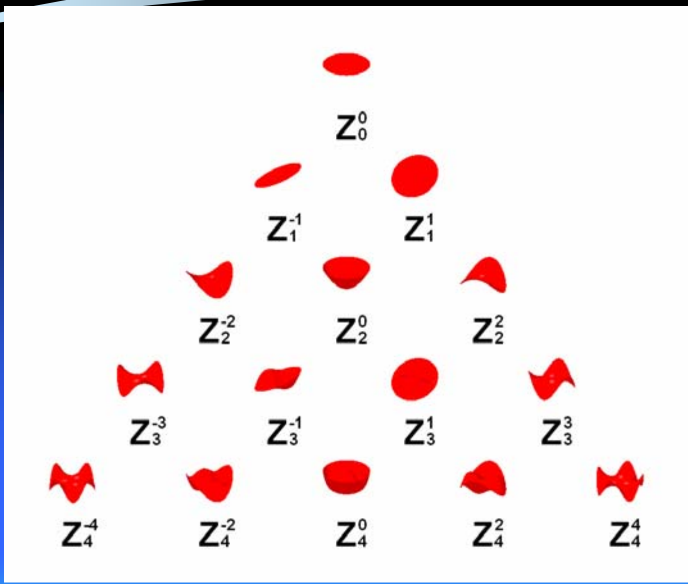
Zernike polynomials

Z_n^f n: radial order
f: angular frequency

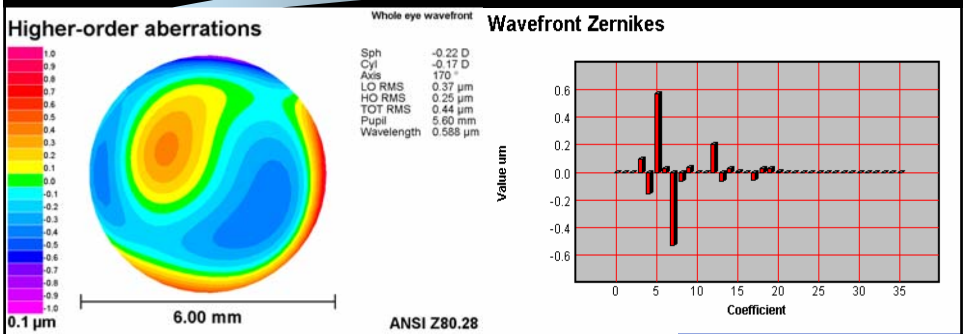
Zernike coefficient	Radial order	Angular frequency	Aberration
0	0	0	Piston
1	1	-1	Tip, Tilt (Prism)
2	1	1	
3	2	-2	Astigmatism
4	2	0	Defocus
5	2	2	Astigmatism
6	3	-3	Trefoil 3-fold
7	3	-1	Coma (vertical)
8	3	1	Coma (horizontal)
9	3	3	Trefoil 3-fold
10	4	-4	4-fold
11	4	-2	Astigmatism
12	4	0	Spherical Aberration
13	4	2	Astigmatism
14	4	4	4-fold
15	5	-5	5-fold
16	5	-3	3-fold
17	5	-1	Coma (vertical)
18	5	1	Coma (horizontal)
19	5	3	3-fold
20	5	5	5-fold
21	6	-6	6-fold
22	6	-4	4-fold
23	6	-2	Astigmatism
24	6	0	Spherical aberration
25	6	2	Astigmatism
26	6	4	4-fold
27	6	6	6-fold





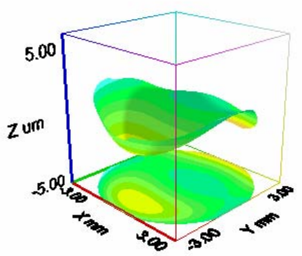


Zernike polynomials

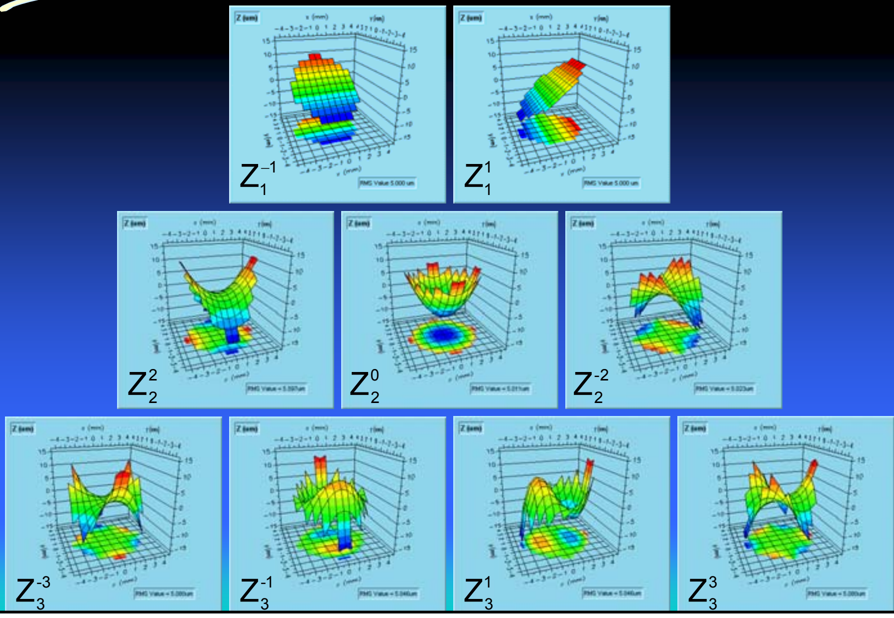


Wavefront 2-D Map

Wavefront 3-D Map

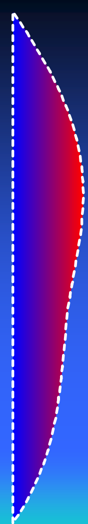


Zernike Polynomials



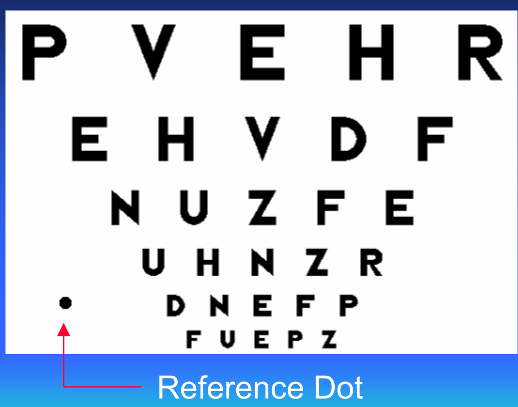
The Root-Mean-Square (RMS) Wavefront Error

The Root Mean Square Error (RMS) is a measure of the difference between the measured and ideal wavefronts.

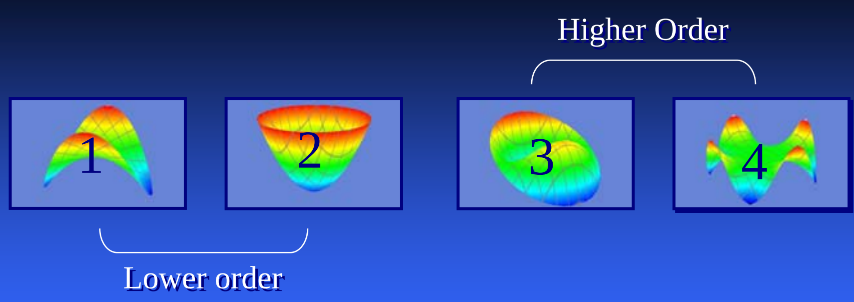


Visual Effects of Aberrations

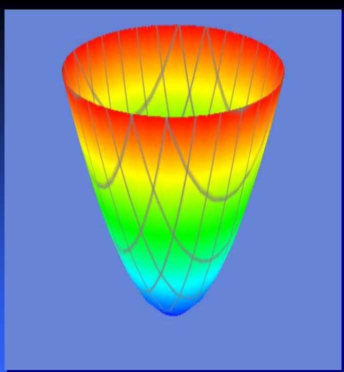
Visual Acuity Chart Image Used in Vision Simulation



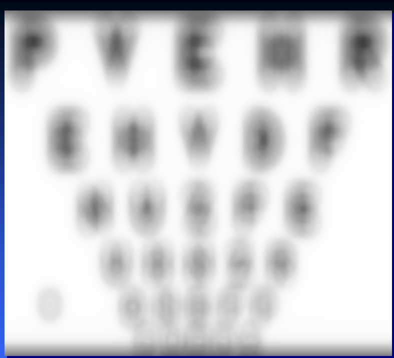
What Are The Visual Effects of Under Correcting Aberrations?



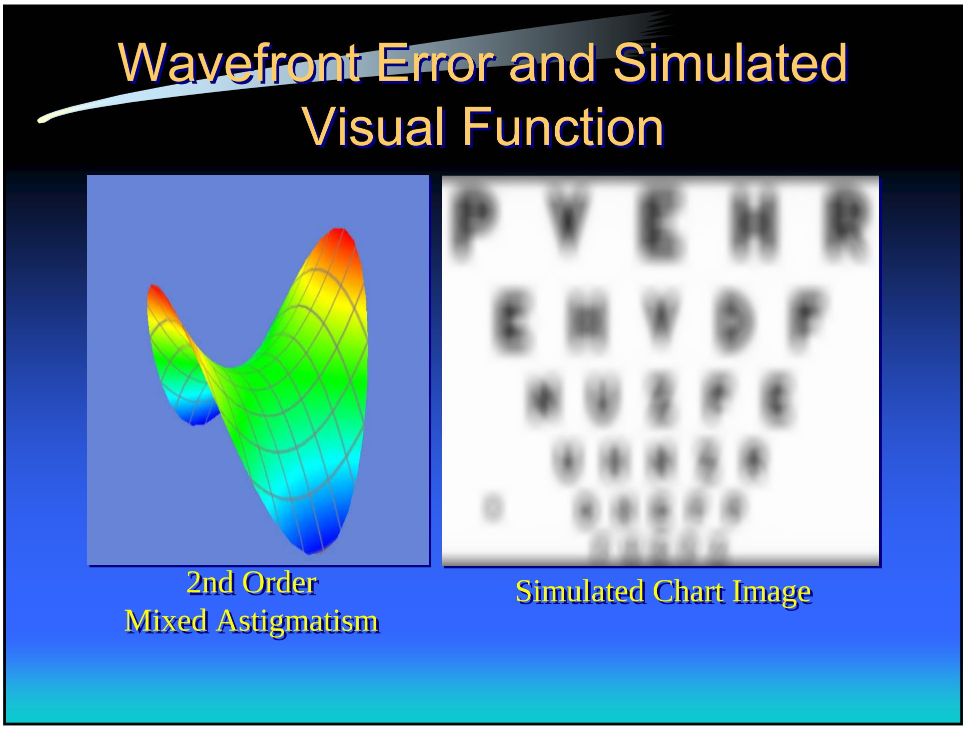
Wavefront Error and Simulated Visual Function

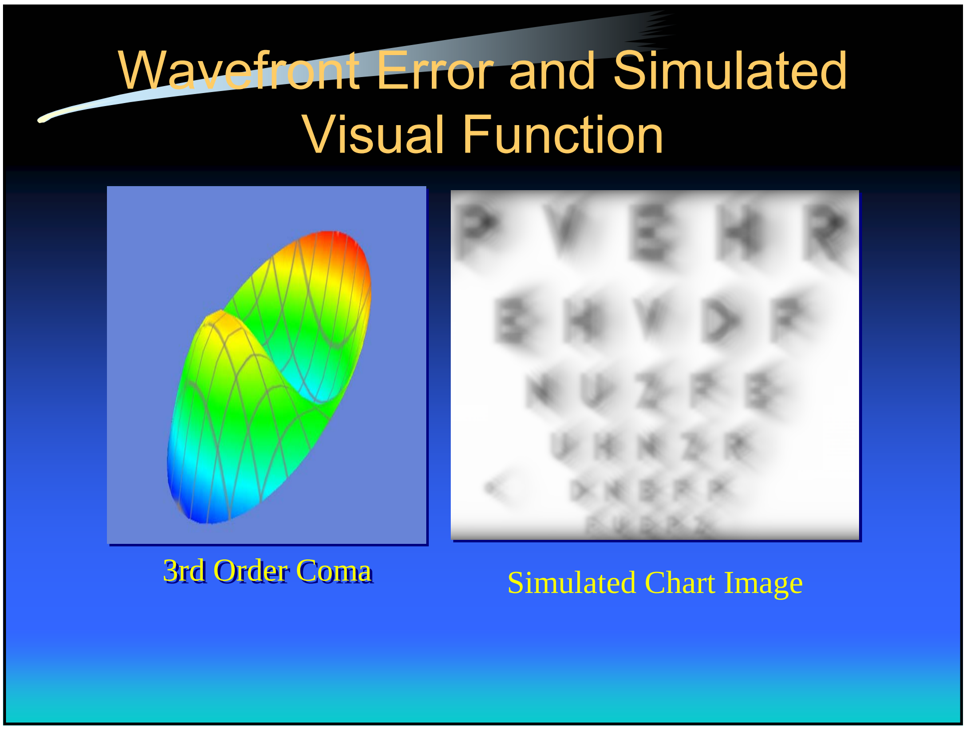


2nd Order Defocus

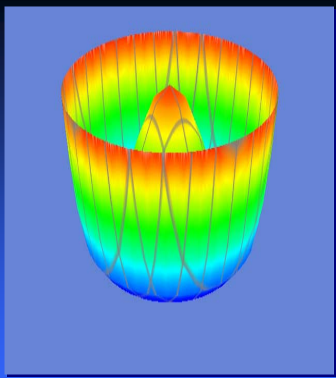


Simulated Chart Image

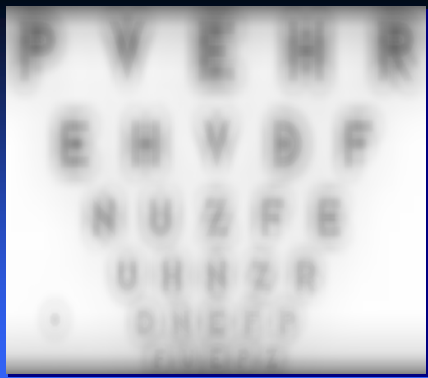

Wavefront Error and Simulated Visual Function
2nd Order
Mixed Astigmatism
Simulated Chart Image


Wavefront Error and Simulated Visual Function
3rd Order Coma
Simulated Chart Image

Wavefront Error and Simulated Visual Function

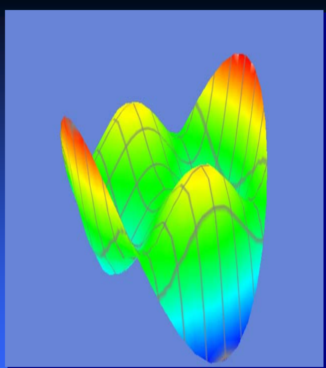


4th Order Spherical Aberration

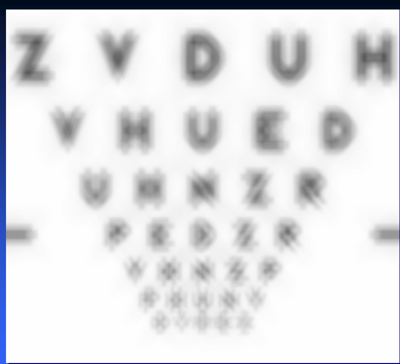


Simulated Chart Image

Wavefront Error and Simulated Visual Function

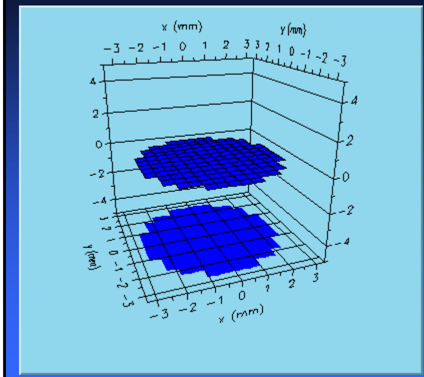


4th Order
Secondary Astigmatism



Simulated Chart Image

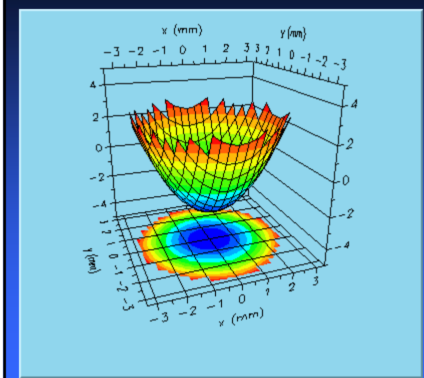
Wavefront Error and Simulated Visual Function



Flat Wavefront

Simulated Chart Image

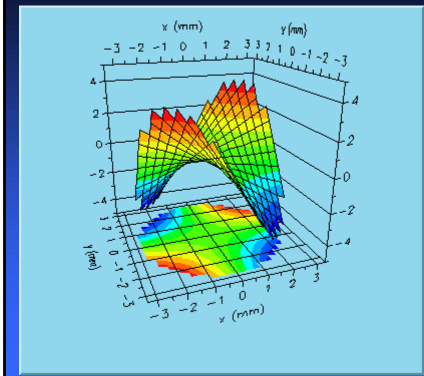
Wavefront Error and Simulated Visual Function



Defocus Error

Simulated Chart Image

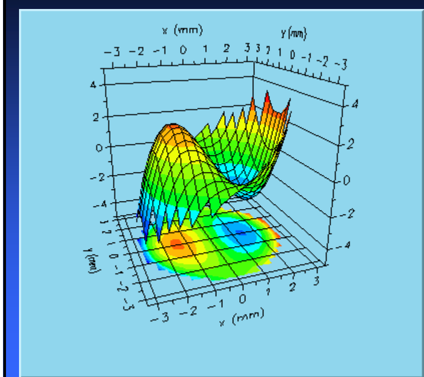
Wavefront Error and Simulated Visual Function



Mixed Astigmatism

Simulated Chart Image

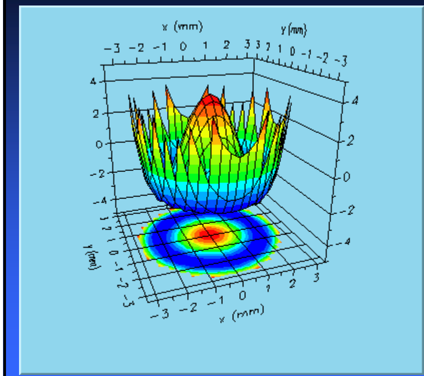
Wavefront Error and Simulated Visual Function



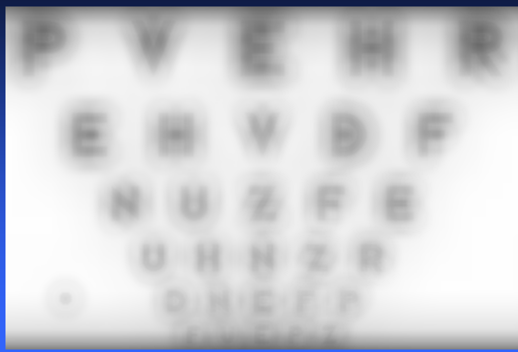
Coma

Simulated Chart Image

Wavefront Error and Simulated Visual Function

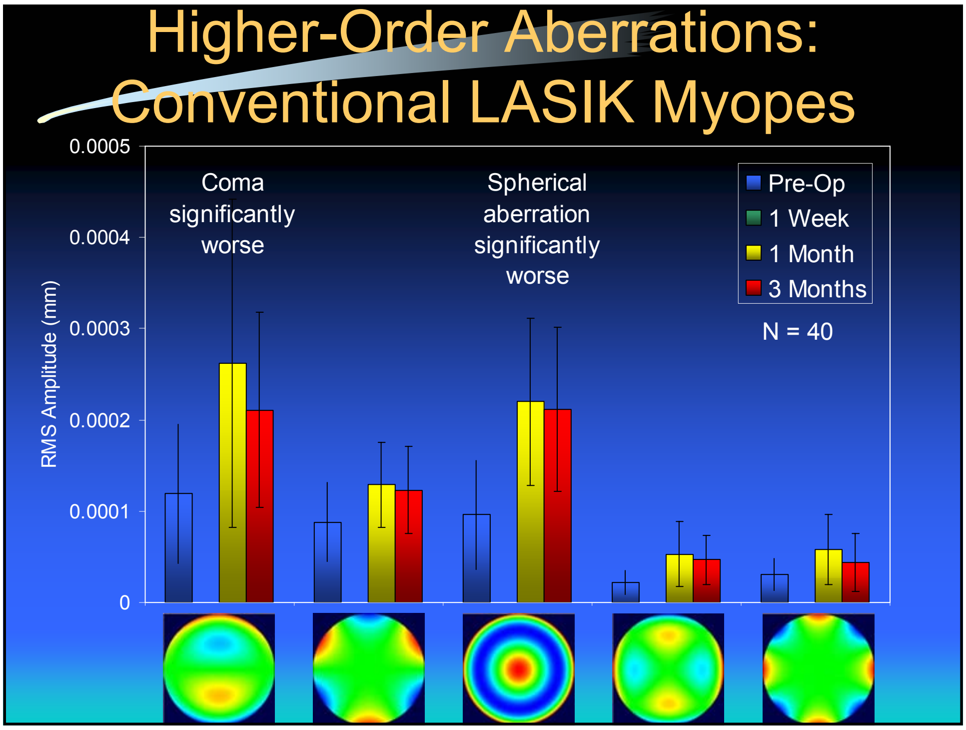


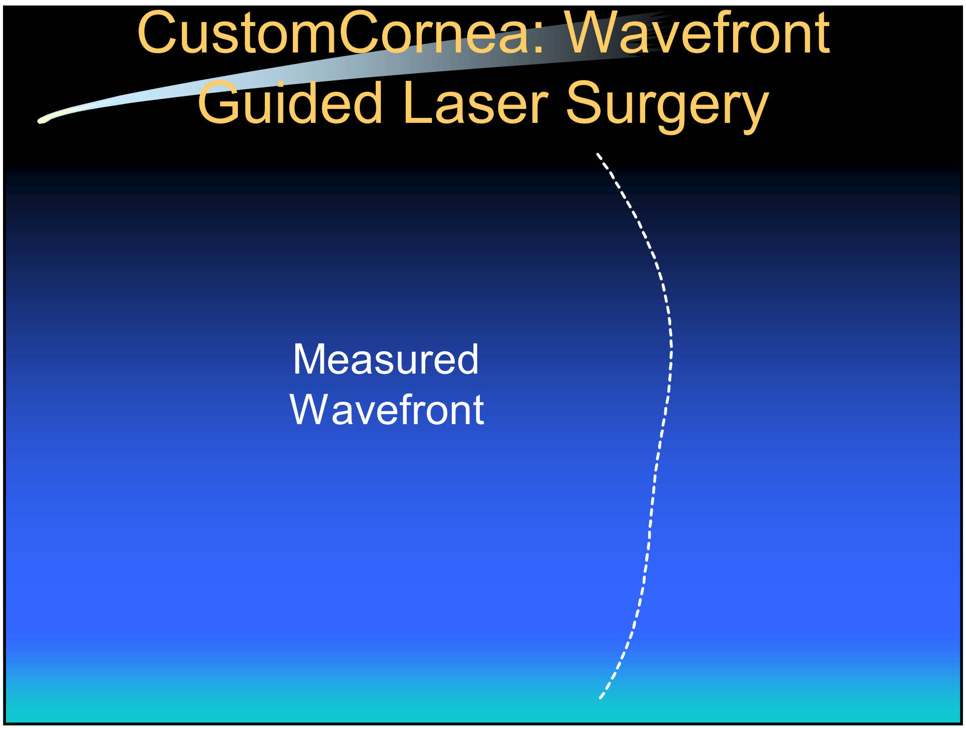
Spherical Aberration

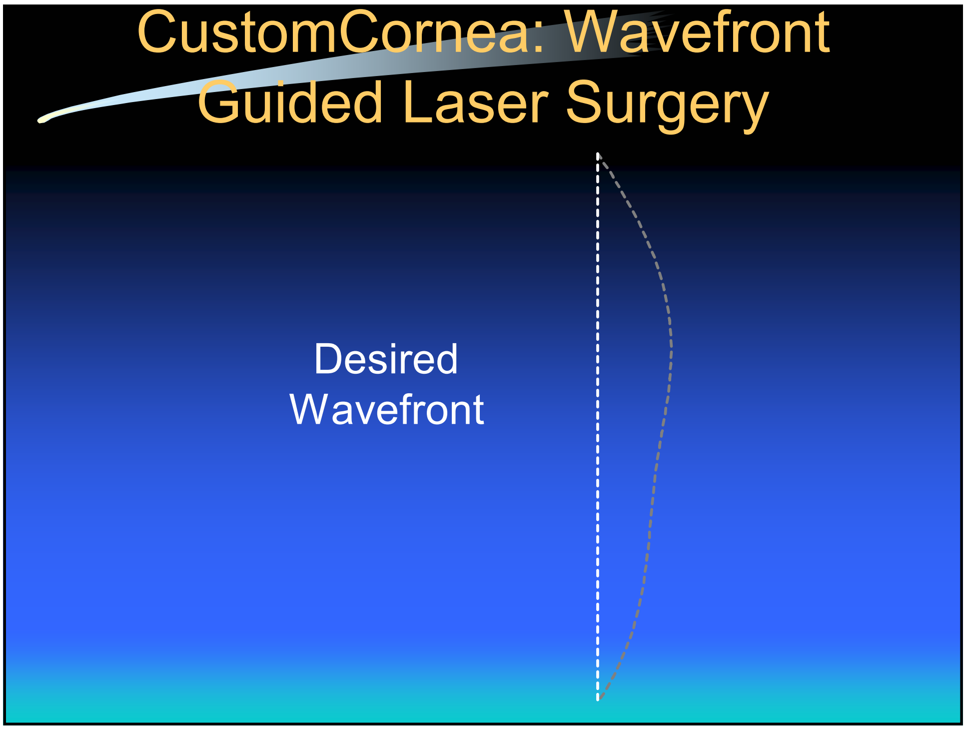


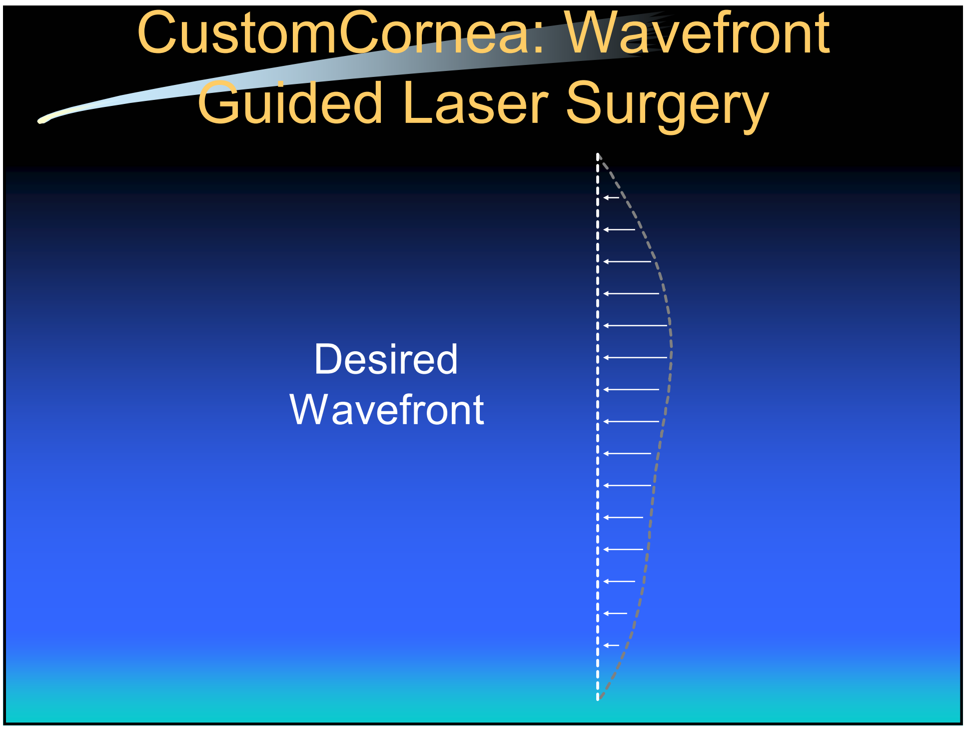
Simulated Chart Image

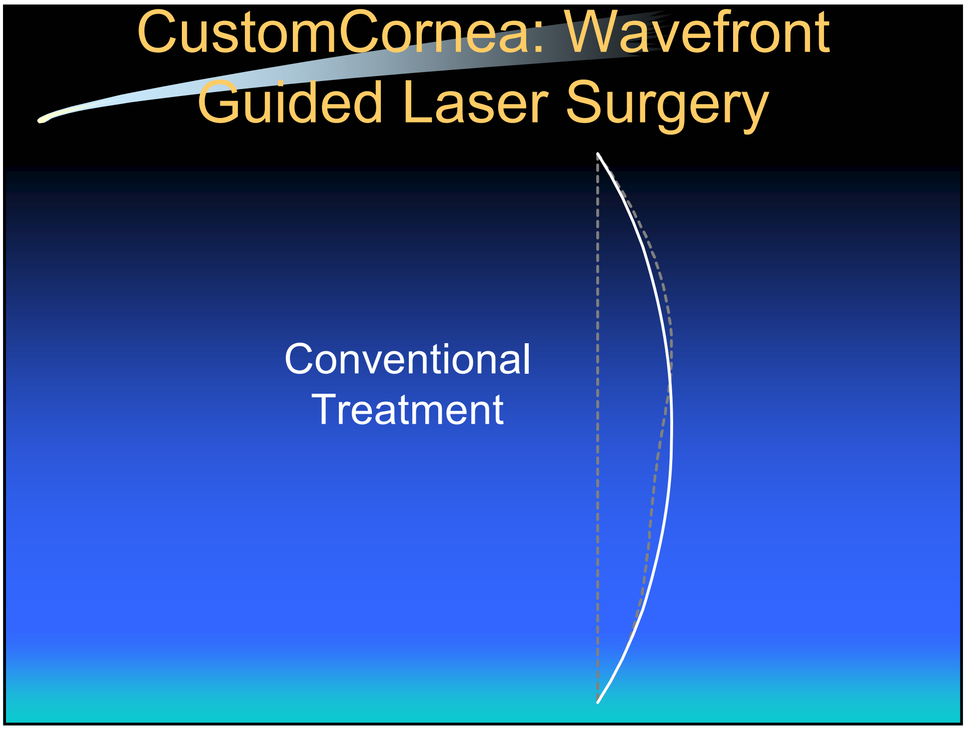
6.- How Does Wavefront Sensing Relate to Refractive Surgery?

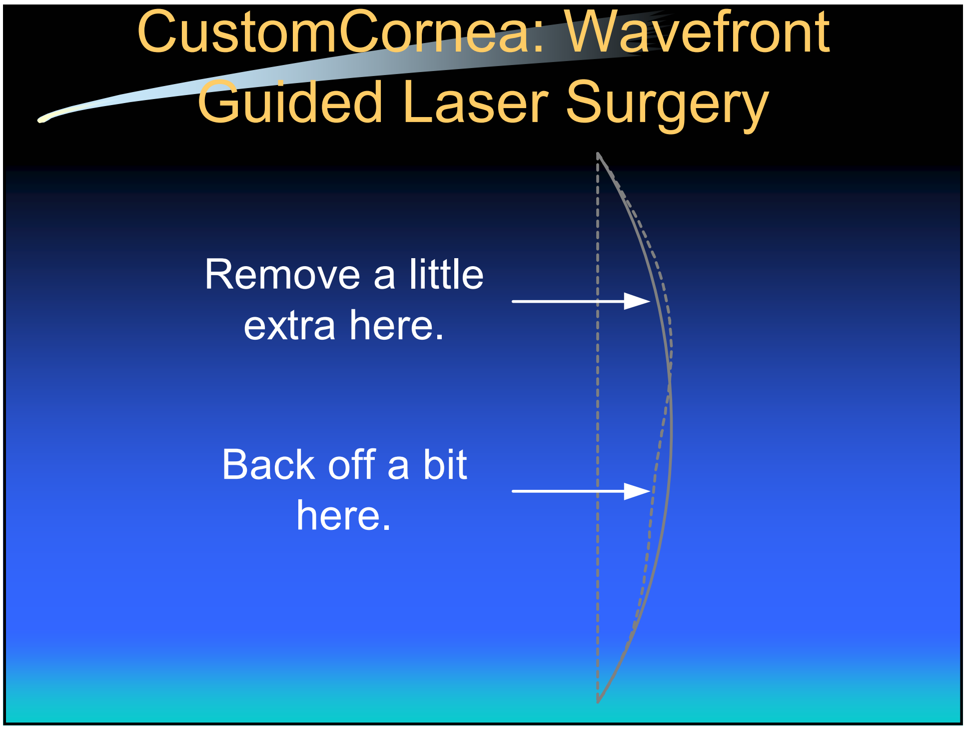

Higher-Order Aberrations: Conventional LASIK Myopes
0.0005
0.0004
0.0003
0.0002
0.0001
0
RMS Amplitude (mm)
Coma significantly worse
Spherical aberration significantly worse
Pre-Op
1 Week
1 Month
3 Months
N = 40


CustomCornea: Wavefront Guided Laser Surgery
Measured Wavefront

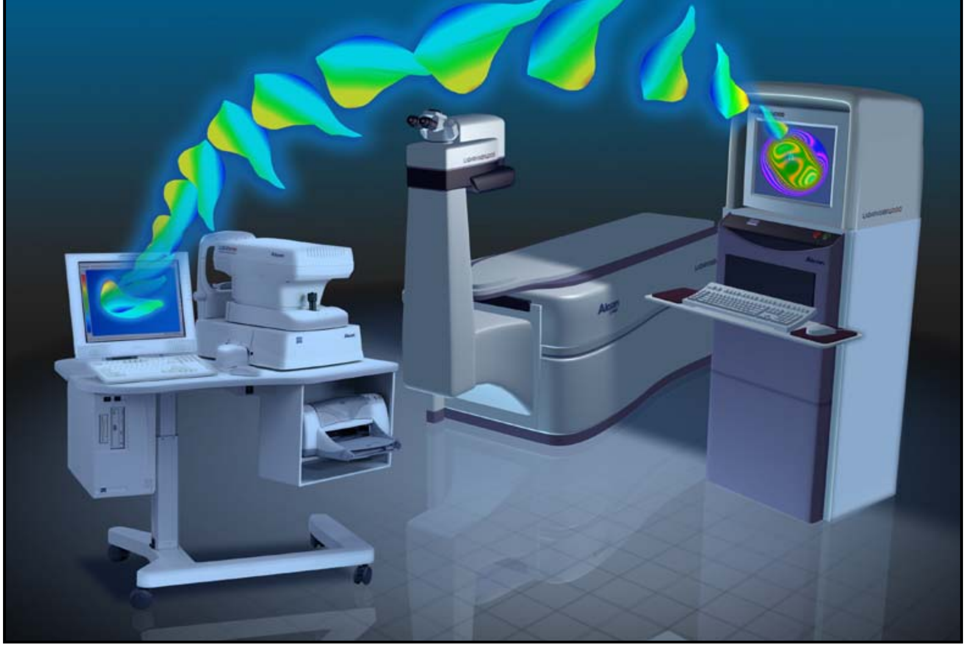

CustomCornea: Wavefront Guided Laser Surgery
Desired Wavefront


CustomCornea: Wavefront Guided Laser Surgery
Desired Wavefront

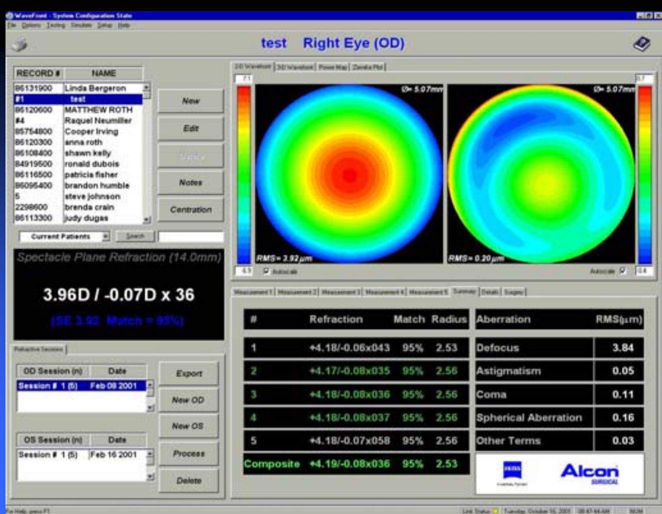

CustomCornea: Wavefront
Guided Laser Surgery
Conventional
Treatment

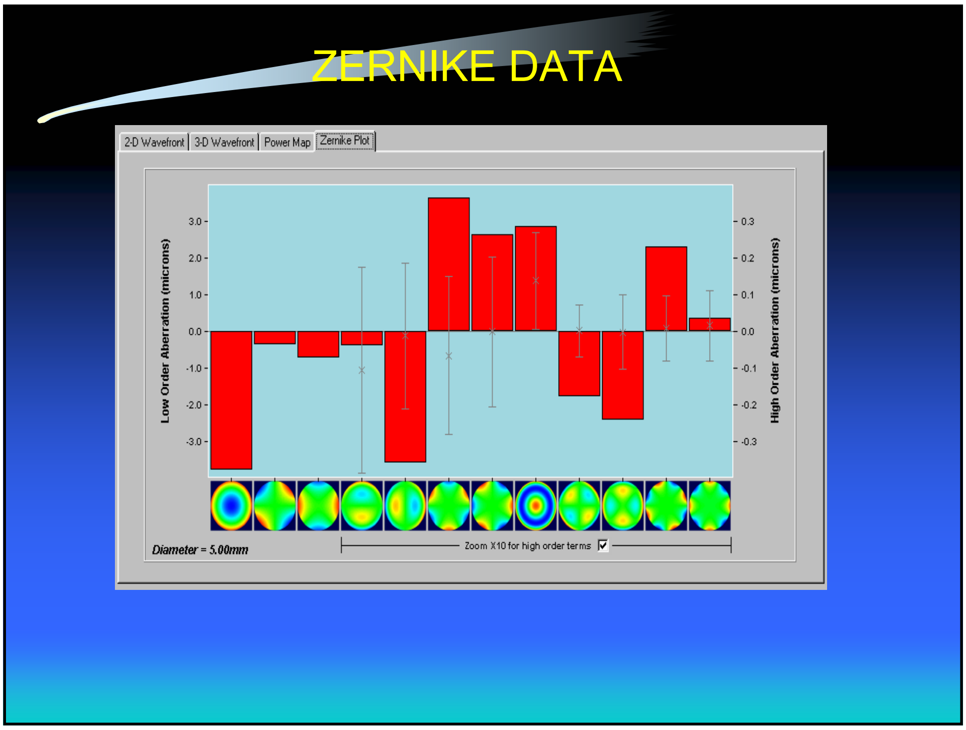

CustomCornea: Wavefront
Guided Laser Surgery
Remove a little
extra here.
Back off a bit
here.

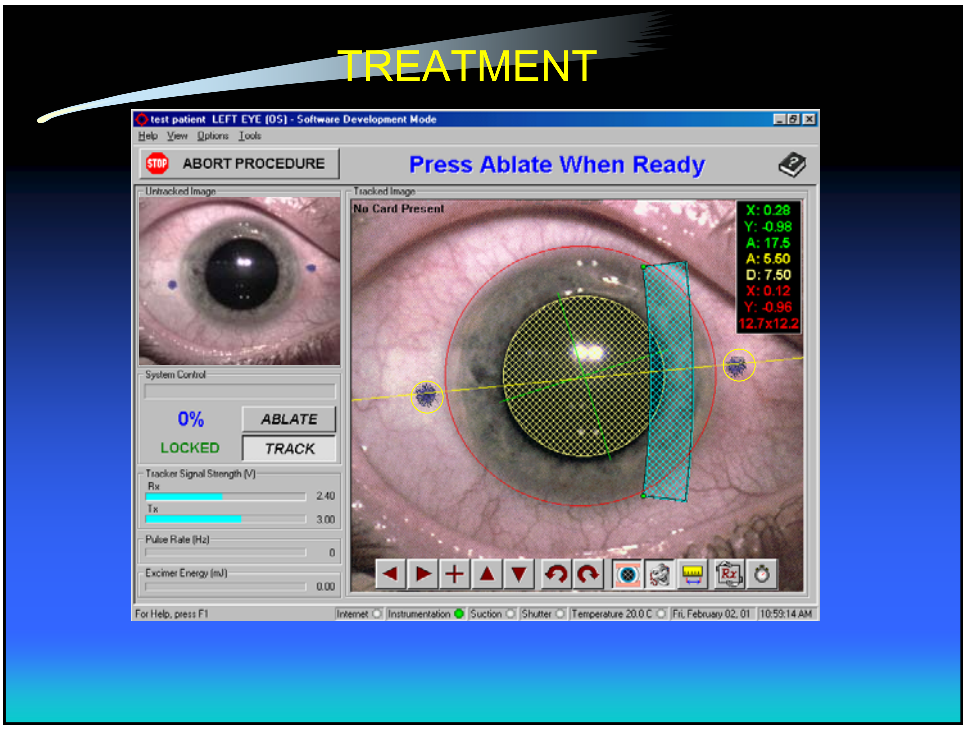
Wavefront-Guided Myopic Results



REFRACTION

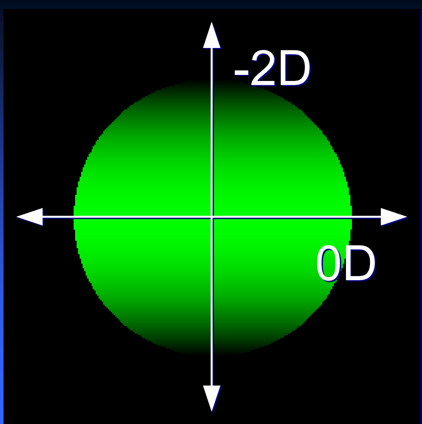



ZERNIKE DATA
2-D Wavefront
3-D Wavefront
Power Map
Zernike Plot
Low Order Aberration (microns)
High Order Aberration (microns)
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
Diameter = 5.00mm
Zoom X10 for high order terms

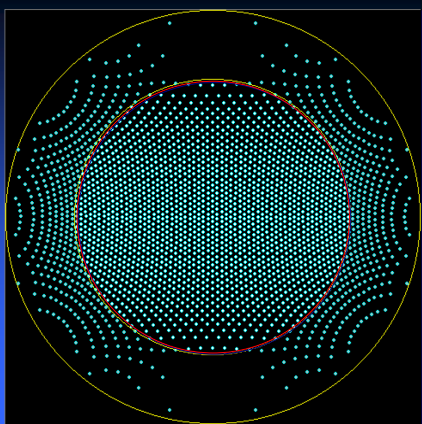

TREATMENT
test patient LEFT EYE (OS) - Software Development Mode
Help View Options Tools
STOP
ABORT PROCEDURE
Press Ablate When Ready
Untracked Image
Tracked Image
No Card Present
X: 0.28
Y: -0.98
A: 17.5
A: 5.60
D: 7.50
X: 0.12
Y: -0.96
12.7x12.2
System Control
0%
ABLATE
LOCKED
TRACK
Tracker Signal Strength (V)
Rx
2.40
Tx
3.00
Pulse Rate (Hz)
0
Excimer Energy (mJ)
0.00
For Help, press F1
Internet
Instrumentation
Suction
Shutter
Temperature 20.0 C
Fri, February 02, 01
10:59:14 AM

VIDEO

-2 D × 180° Simple Myopic Astigmatism 6 mm OZ, 1.0 mm Blend



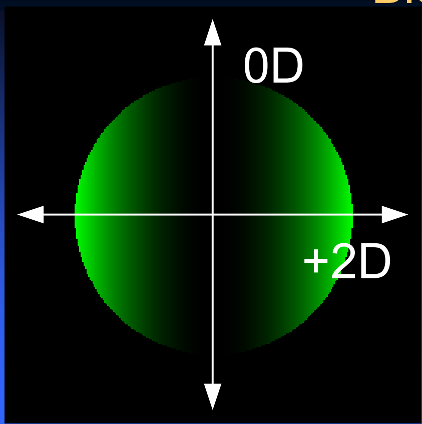
Ablation Profile



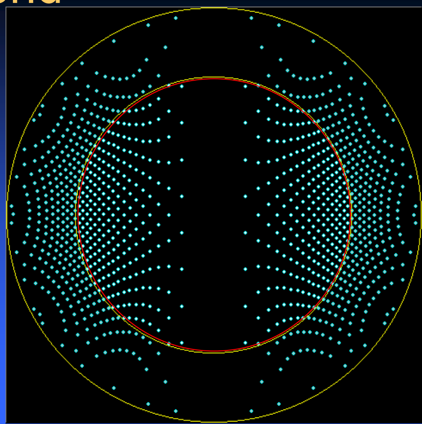
Laser Shot Pattern

Treatment Zone 6 x 8mm

+2D, -2 D × 180°, Simple Hyperopic Astigmatism, 6.5 mm OZ, 1.25 mm Blend



Ablation Profile

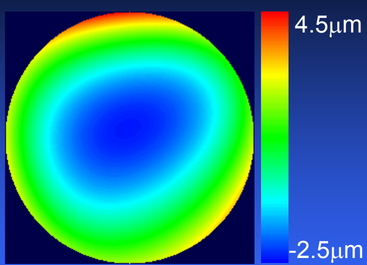


Laser Shot Pattern

Treatment Zone 9mm

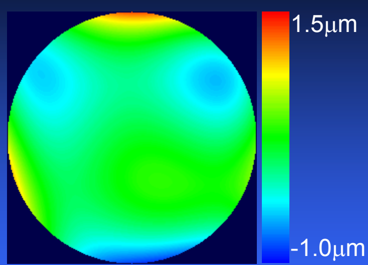
Customized LASIK Example: Pre-Op Aberrations

Total Aberration



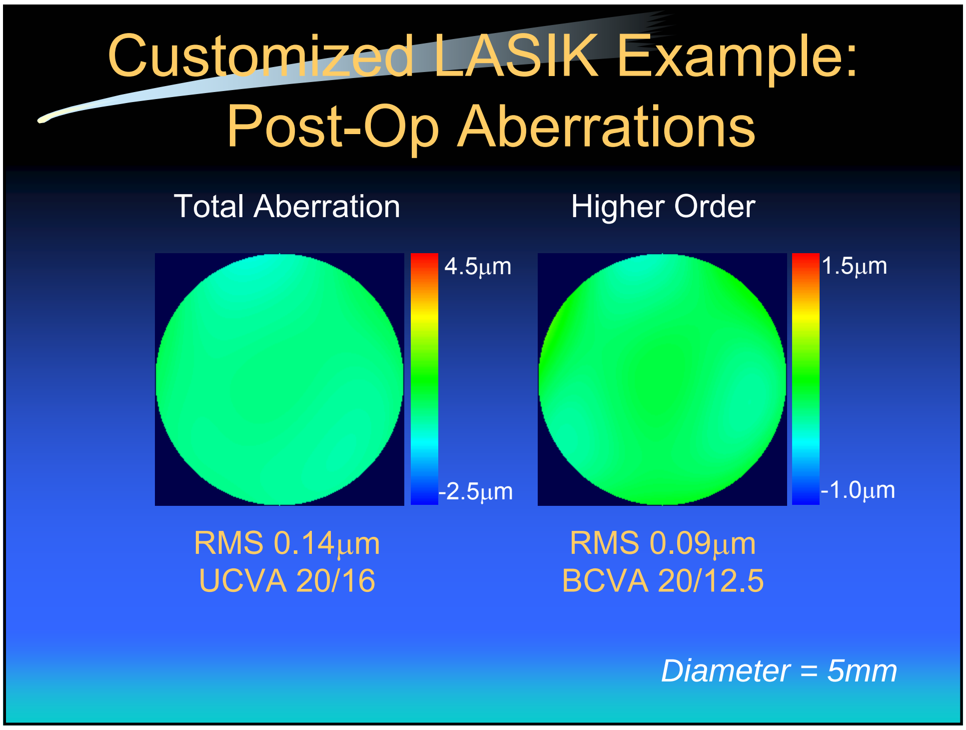
RMS 1.51μm
UCVA 20/200

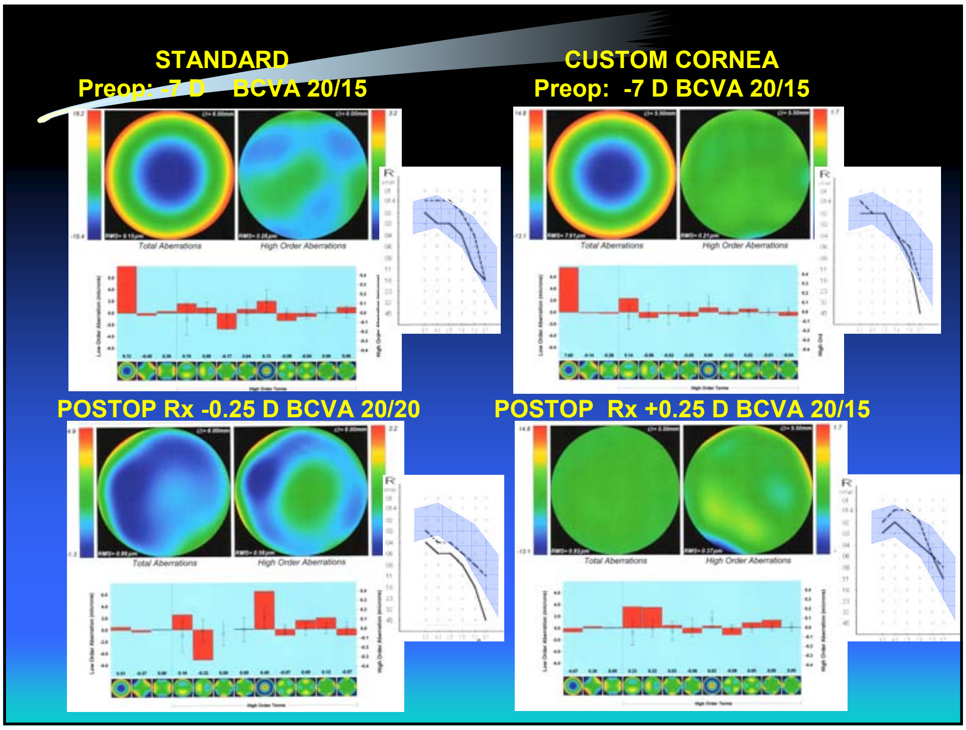
Higher Order

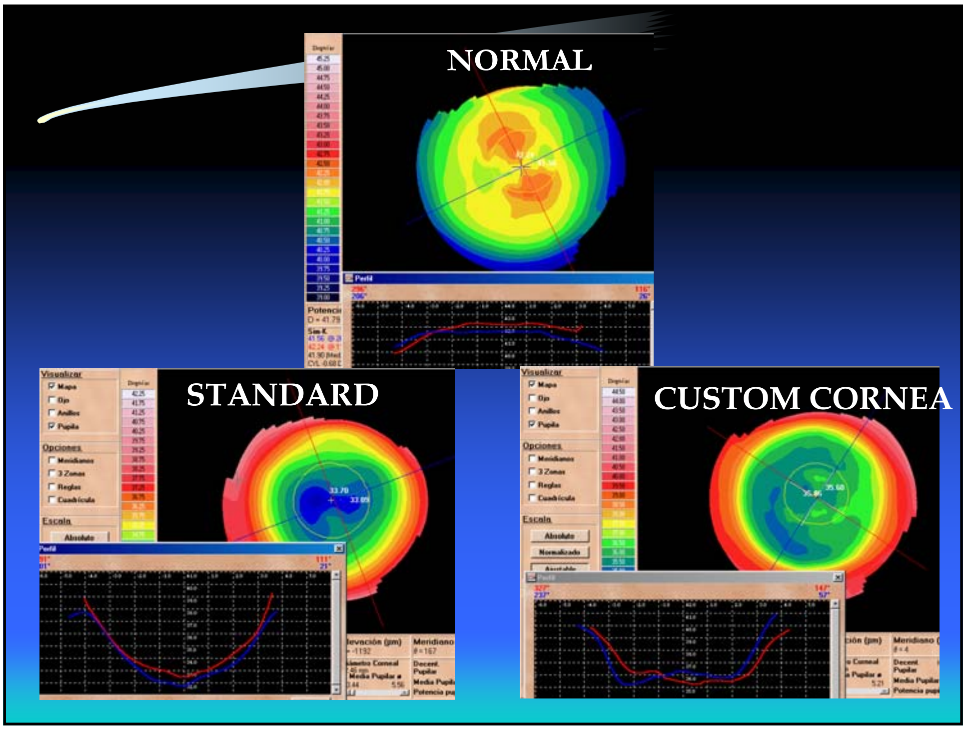


RMS 0.31μm
BCVA 20/20

Diameter = 5mm


Customized LASIK Example:
Post-Op Aberrations
Total Aberration
Higher Order
4.5µm
-2.5µm
1.5µm
-1.0µm
RMS 0.14µm
UCVA 20/16
RMS 0.09µm
BCVA 20/12.5
Diameter = 5mm

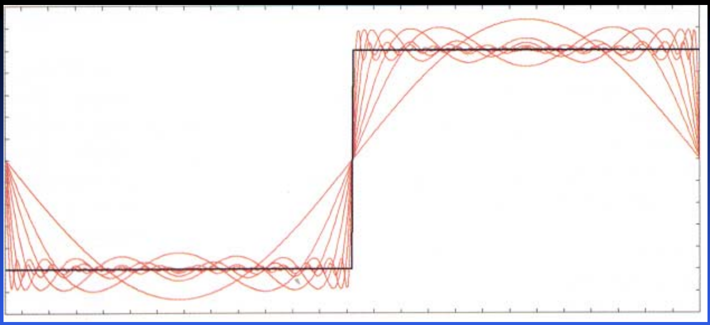

STANDARD
Preop: -7 D BCVA 20/15
CUSTOM CORNEA
Preop: -7 D BCVA 20/15
POSTOP Rx -0.25 D BCVA 20/20
POSTOP Rx +0.25 D BCVA 20/15



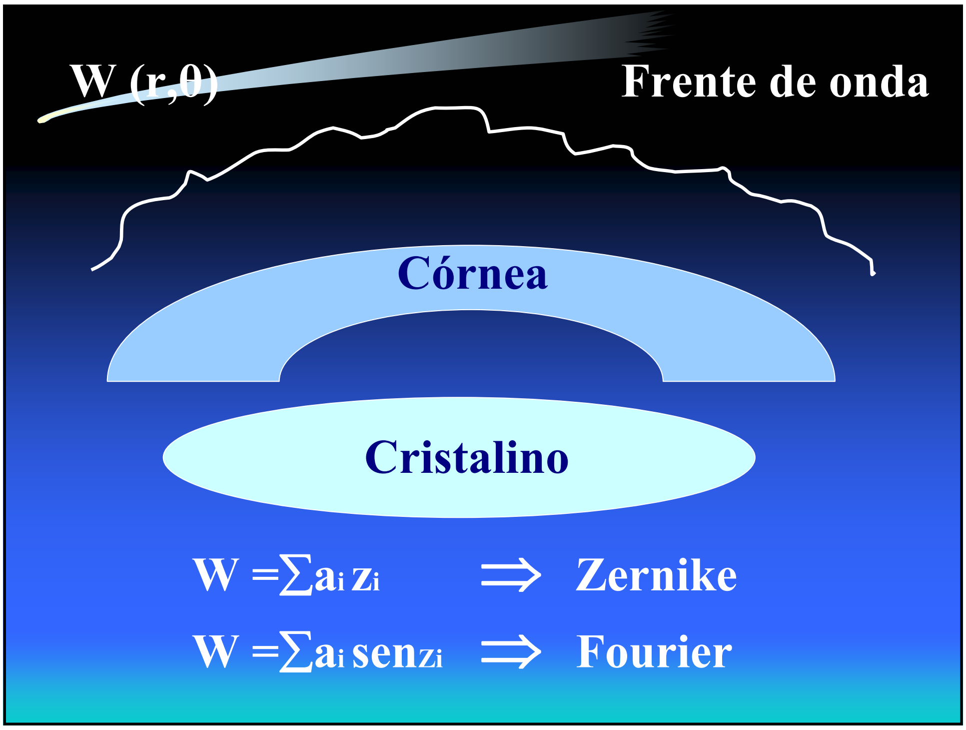
Summary

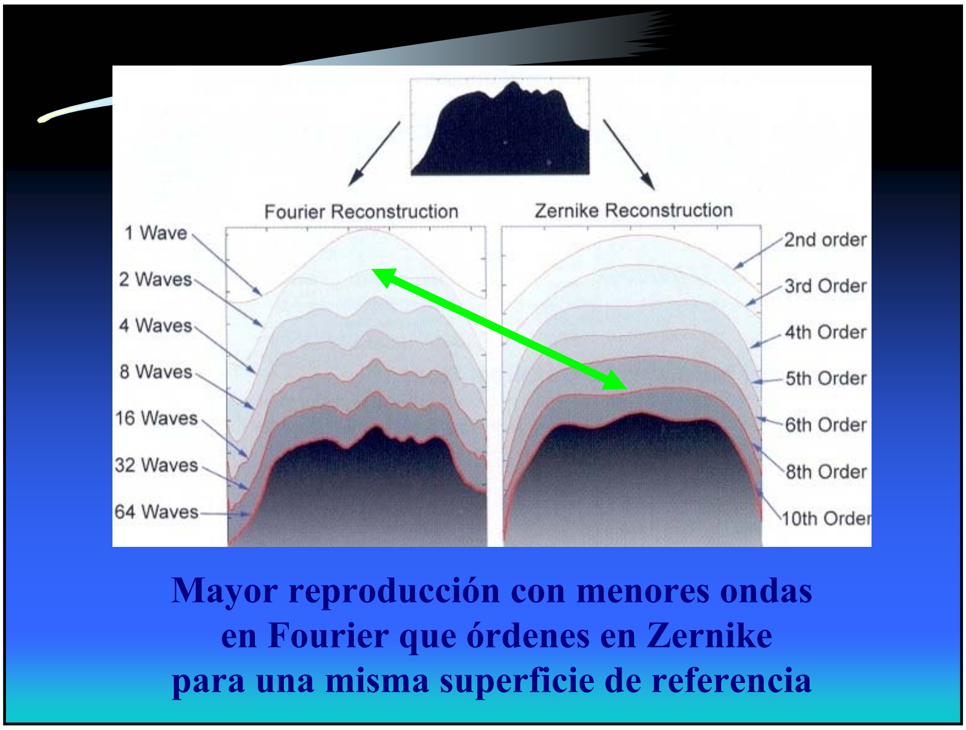
- Wavefront sensing is a powerful tool for understanding the optical functioning of the eye.
- With the right technology, measurement of the wavefront can readily be accomplished in the clinical setting.
- Wavefront data has powerful clinical utility, both in diagnosing visual complaints and in customizing refractive procedures.

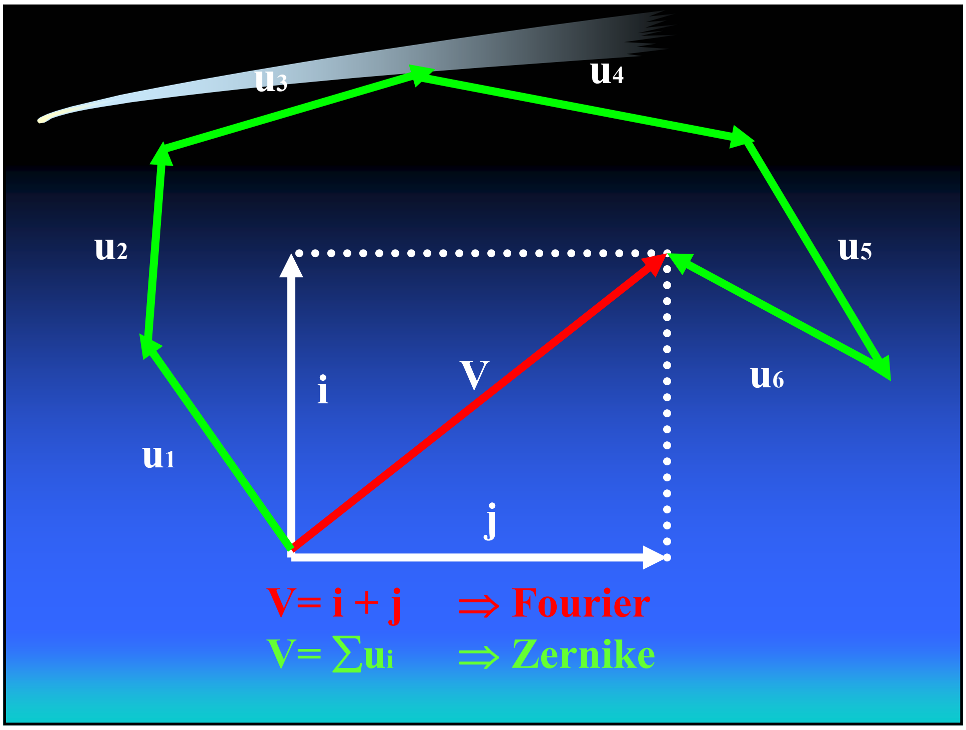
7.- J B Joseph Fourier versus Frits Zernike



Mediante un número determinado de ondas sinusoidales podemos describir una onda cuadrada


W (r,θ)
Frente de onda
Córnea
Cristalino
W =∑aᵢ zᵢ ⇒ Zernike
W =∑aᵢ senzᵢ ⇒ Fourier

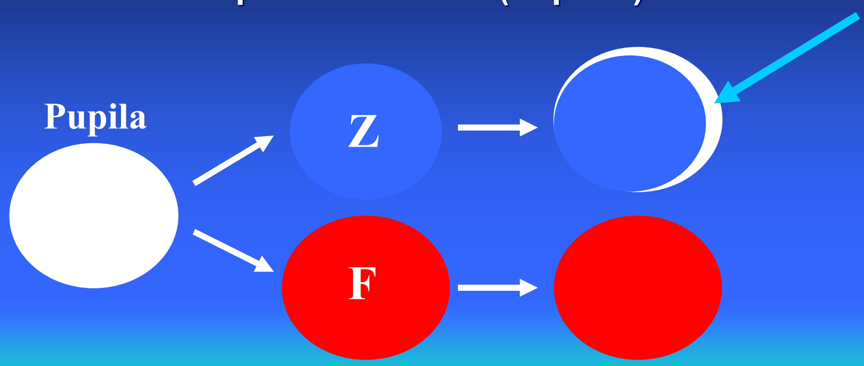

Fourier Reconstruction
Zernike Reconstruction
1 Wave
2 Waves
4 Waves
8 Waves
16 Waves
32 Waves
64 Waves
2nd order
3rd Order
4th Order
5th Order
6th Order
8th Order
10th Order
Mayor reproducción con menores ondas
en Fourier que órdenes en Zernike
para una misma superficie de referencia

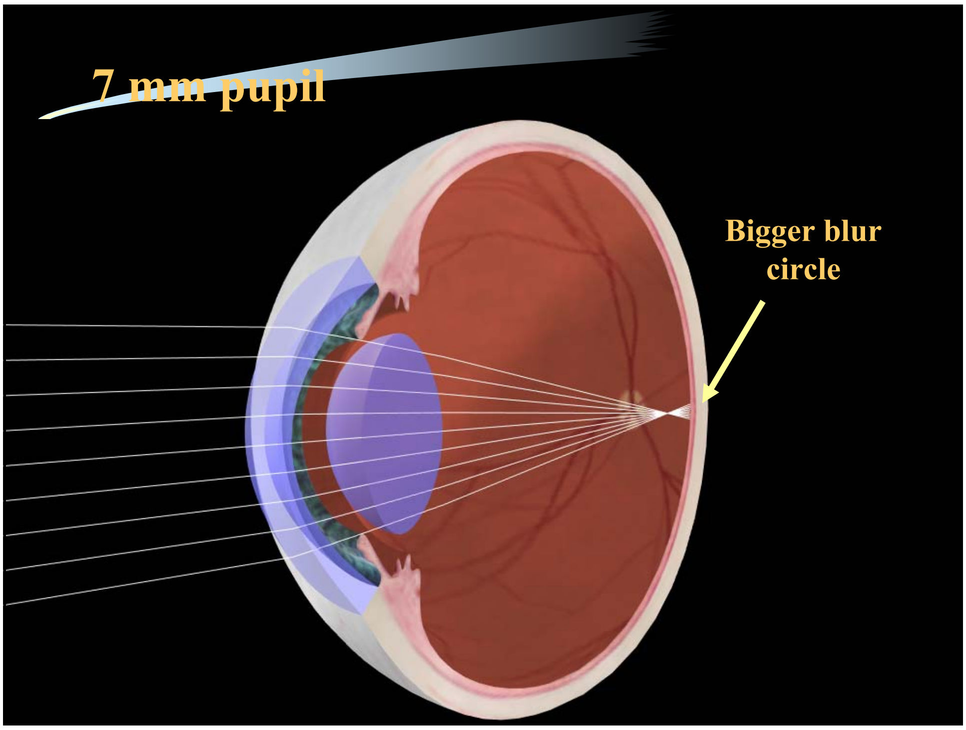


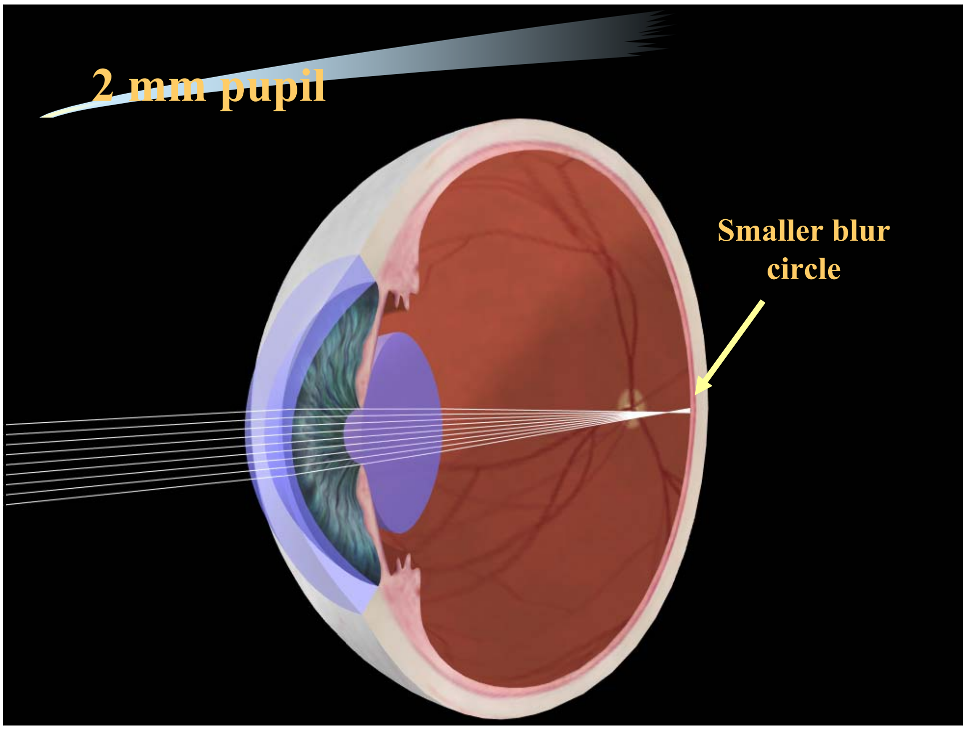
Reconstrucción de la Pupila

1.- Zernike necesita de una simetría de revolución
Pupila Circular

2.- Fourier no necesita de una simetría de revolución
Pupila no Circular (Elíptica)




7 mm pupil
Bigger blur circle


2 mm pupil
Smaller blur circle

Posibles Ventajas Fourier

1.- Menos cálculos de computación

2.- Mayor resolución con menos órdenes
(o menor información)

3.- Aplicable a pupilas más reales

4.- Reconstrucción más real del frente de onda

Thank you

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