DEPTH OF FIELD

OPTICAL ABERRATIONS

& PUPILLOMETRY

IN PRESBYOPIC PATIENTS

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AIV + CEROC

CRI Centre Recherches Interdisciplinaires

FONDATION BETTENCOURT SCHUELLER

CEROC

①

INTRODUCTION & CONTEXT

P H O T O G R A P H Y

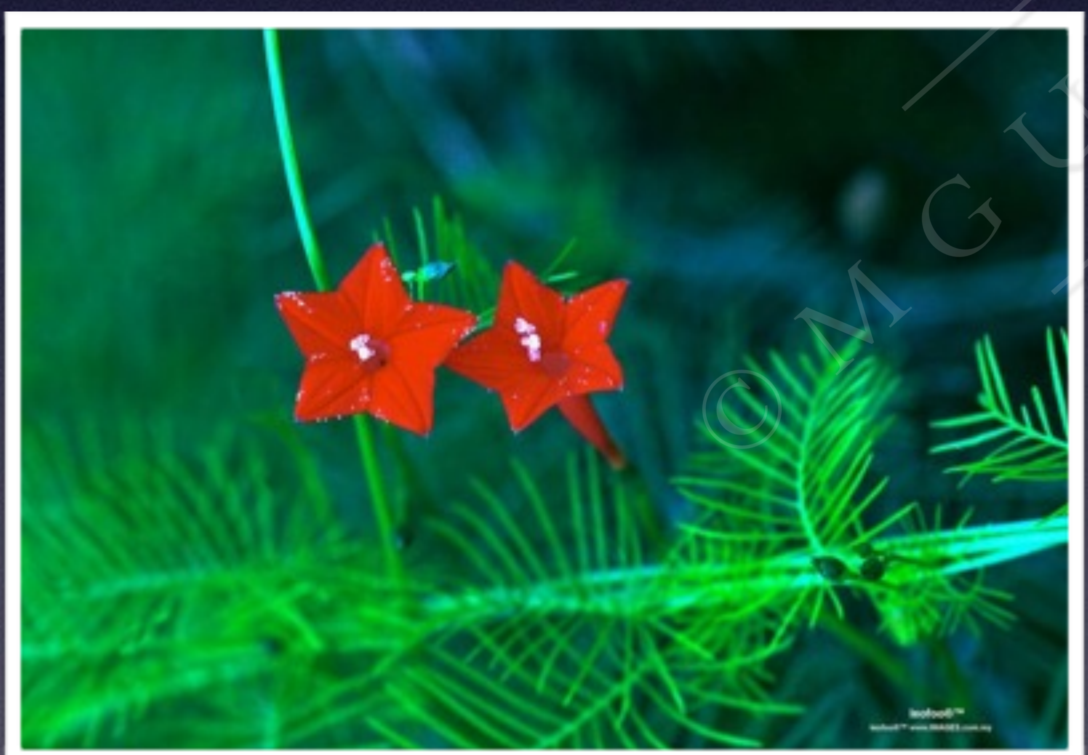
Depth of field

= amount of **<u>distance</u>** between nearest and farthest objects that appear in acceptably sharp focus in a photograph.

P H O T O G R A P H Y

Depth of field

= amount of **<u>distance</u>** between nearest and farthest objects that appear in acceptably sharp focus in a photograph.



SHALLOW DEPTH OF FIELD

EXTENDED DEPTH OF FIELD

P H O T O G R A P H Y

Depth of field ➪ **3 FACTORS :**

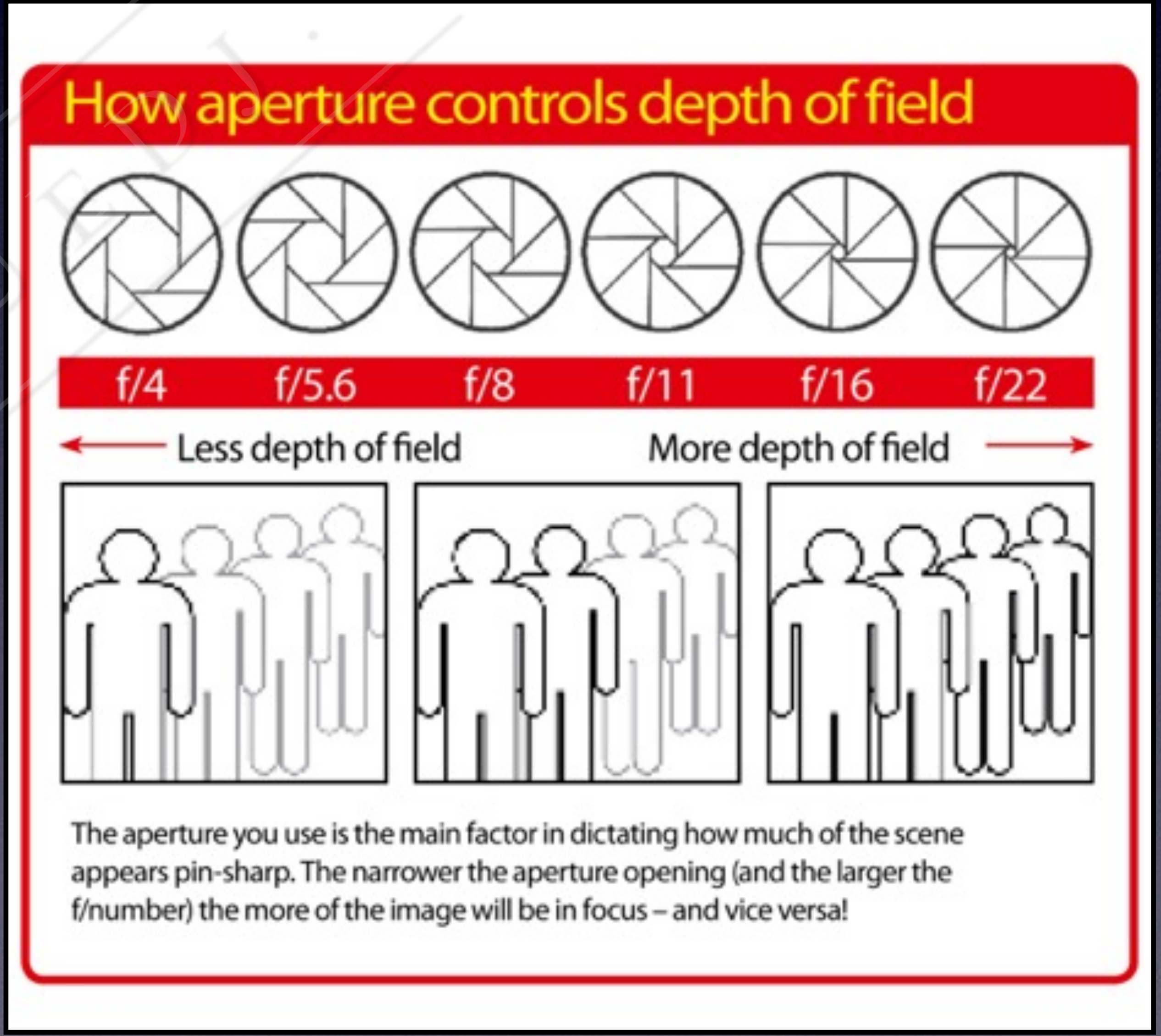
① <u>DIAPHRAGM</u> of the opening lens :

PHOTOGRAPHY

Depth of field ➪ 3 FACTORS :

① DIAPHRAGM of the opening lens : ↘ APERTURE

$$L_0 = \frac{f' D}{g} = \frac{f'^2}{g N}$$



P H O T O G R A P H Y

Depth of field ➯ **3 FACTORS :**

① **DIAPHRAGM** of the opening lens : ↘ **APERTURE**

② **SHOOTING DISTANCE** : **greater**

$$L_0 = \frac{f'D}{g} = \frac{f'^2}{g\,N}$$

PHOTOGRAPHY

Depth of field ➪ 3 FACTORS :

① DIAPHRAGM of the opening lens : ↘ APERTURE

② SHOOTING DISTANCE : greater

③ LENS FOCAL LENGTH : shorter

$$L_0 = \frac{f' D}{g} = \frac{f'^2}{g N}$$

P H O T O G R A P H Y

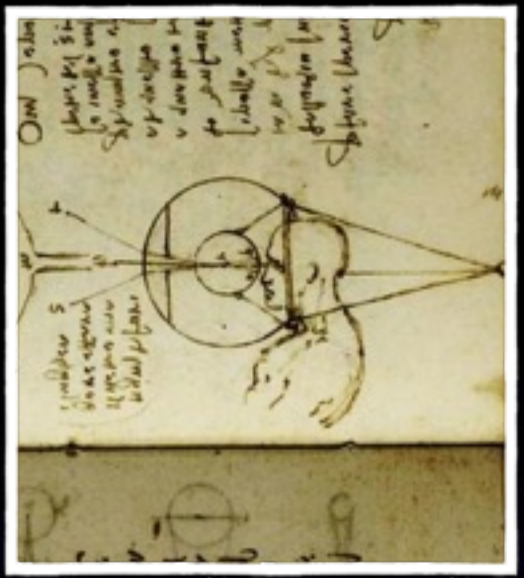
Depth of field ➩ **3 FACTORS :**

① <u>DIAPHRAGM</u> of the opening lens : ↘ APERTURE

② <u>SHOOTING DISTANCE</u> : **greater**

③ <u>LENS FOCAL LENGTH</u> : **shorter**

➩ Deeper DOF (background > foreground)



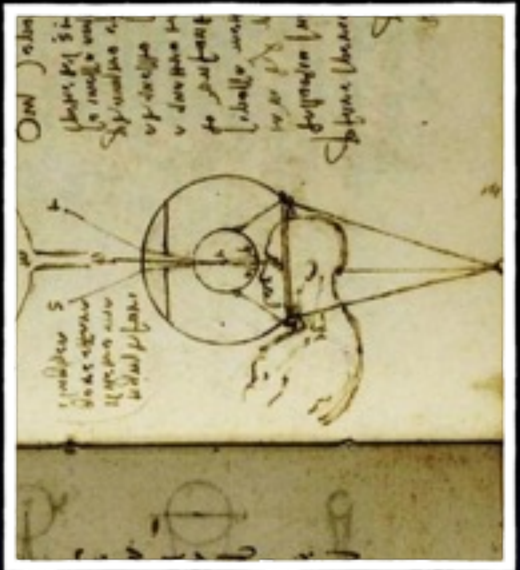
E Y E

Depth of field ➪ **3 FACTORS :**

① DIAPHRAGM ⇔ PUPIL DIAMETER

② SHOOTING DISTANCE ⇔ ACCOMMODATION

③ LENS FOCAL LENGTH ⇔ OPTICAL ABERRATIONS, ANTERIOR CHAMBER DEPTH & AXIAL LENGTH



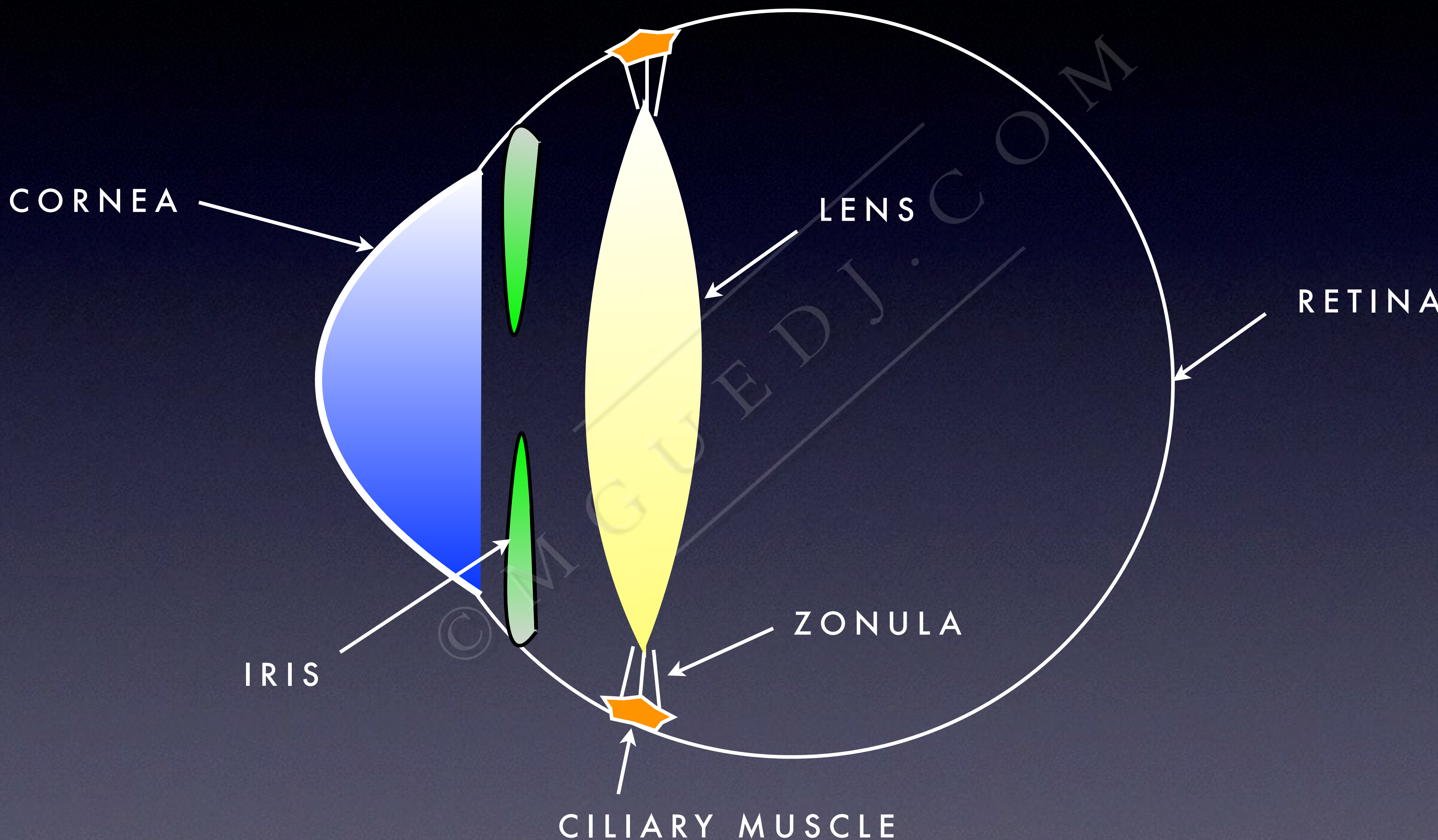
E Y E

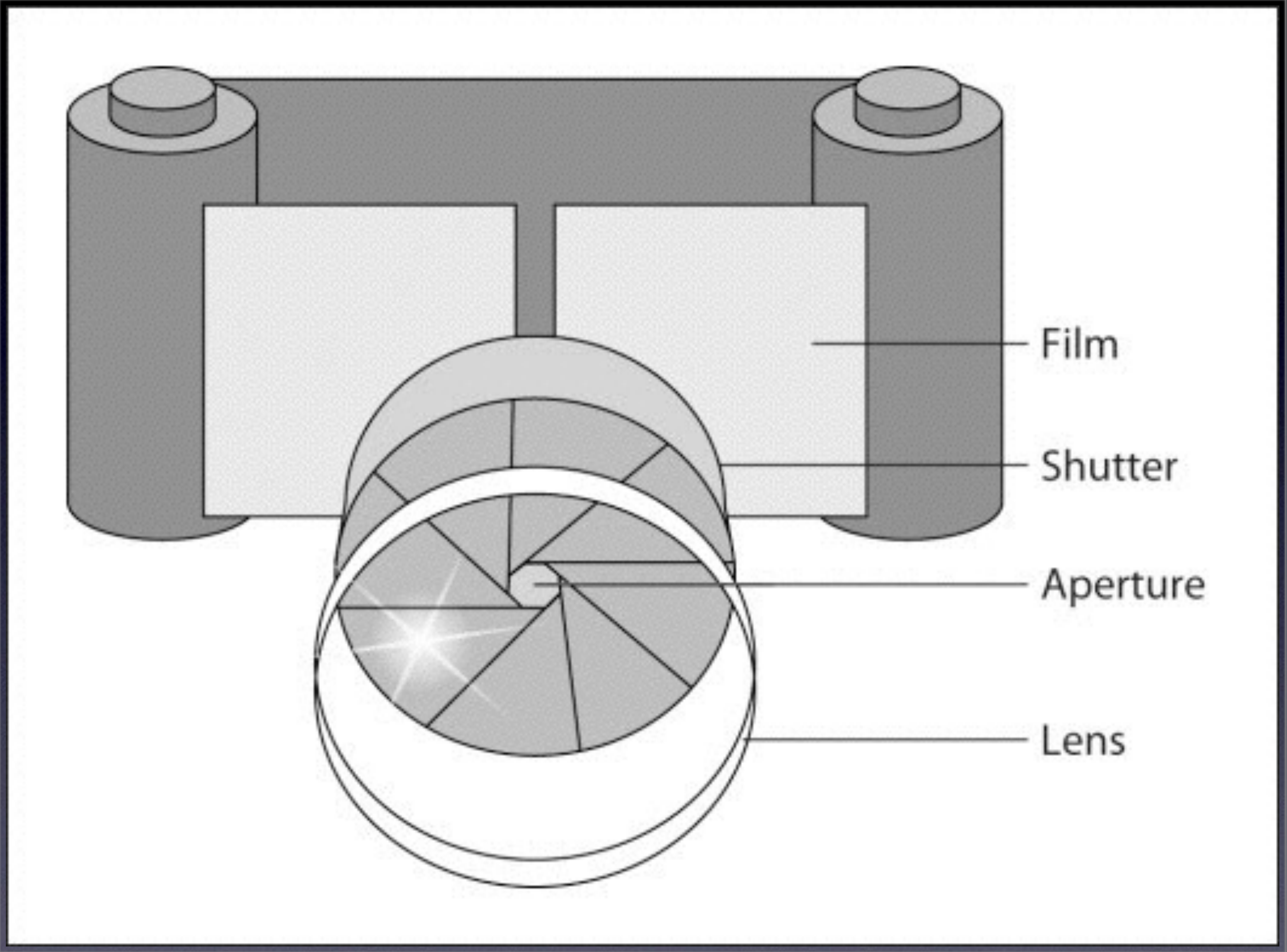
Depth of field ➩ **3 FACTORS :**

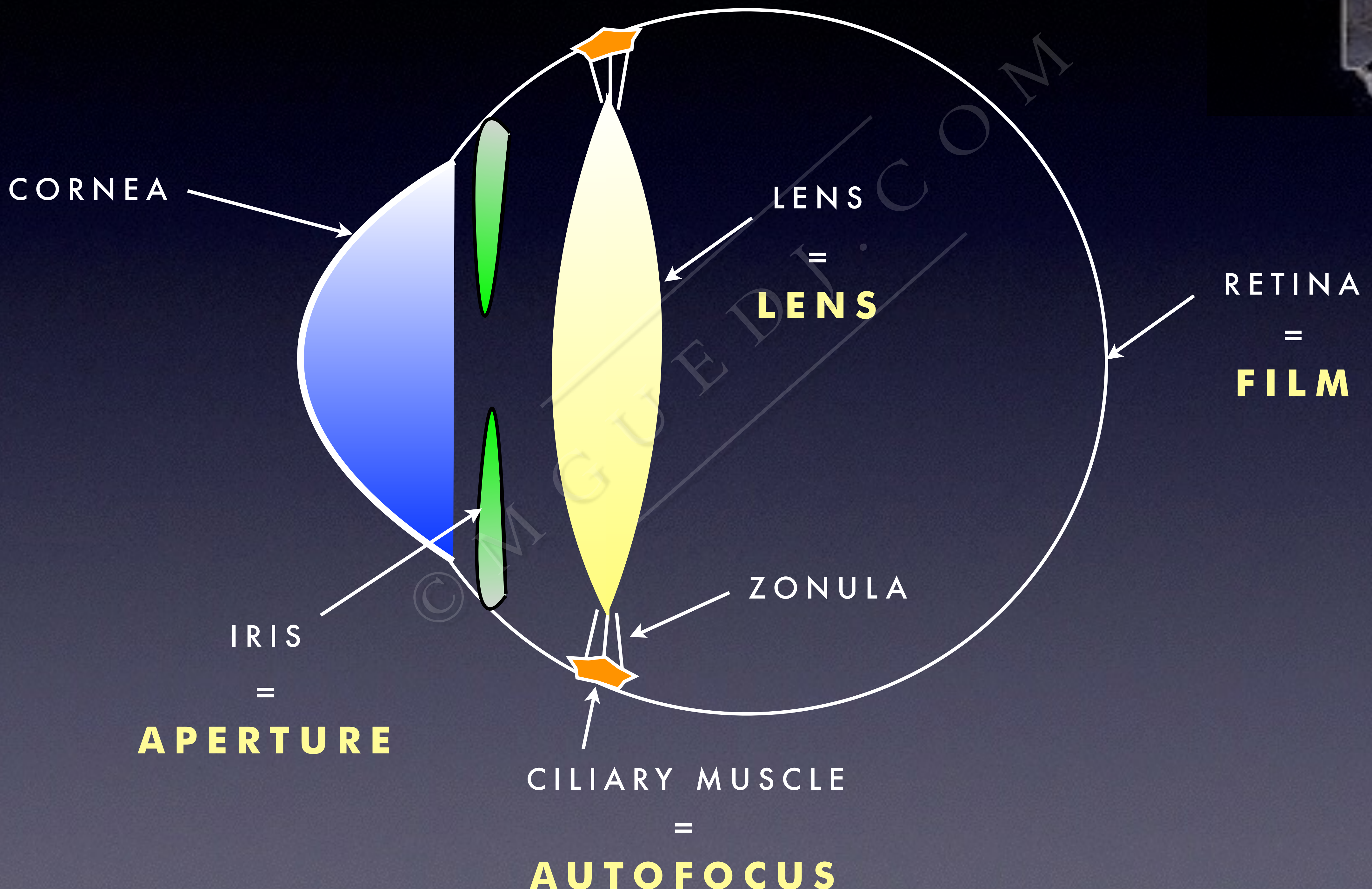
① DIAPHRAGM ⇔ PUPIL DIAMETER

② SHOOTING DISTANCE ⇔ ~~ACCOMMODATION~~

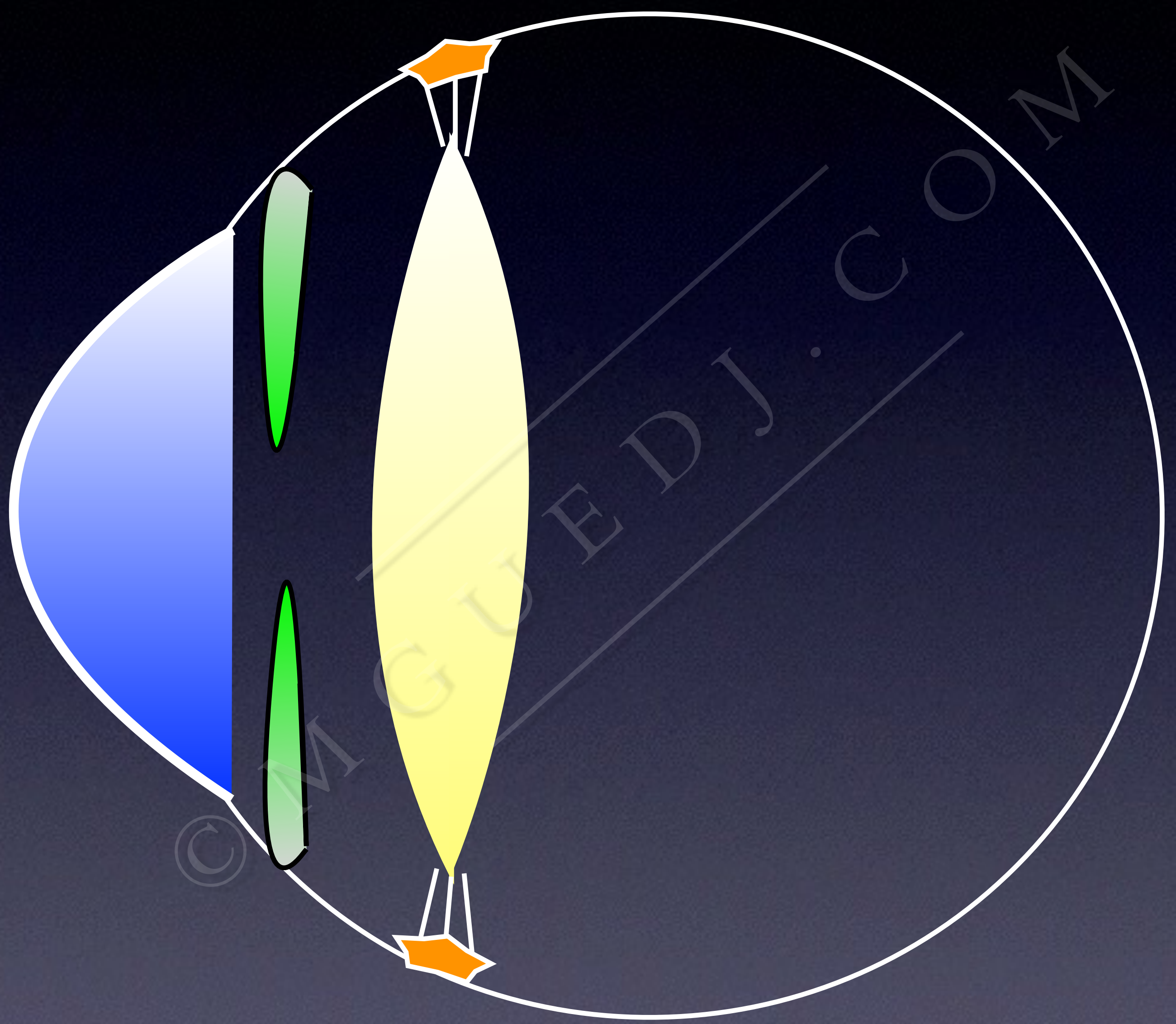
③ LENS FOCAL LENGTH ⇔ OPTICAL ABERRATIONS, ANTERIOR CHAMBER DEPTH & AXIAL LENGTH


CORNEA
LENS
RETINA
IRIS
ZONULA
CILIARY MUSCLE

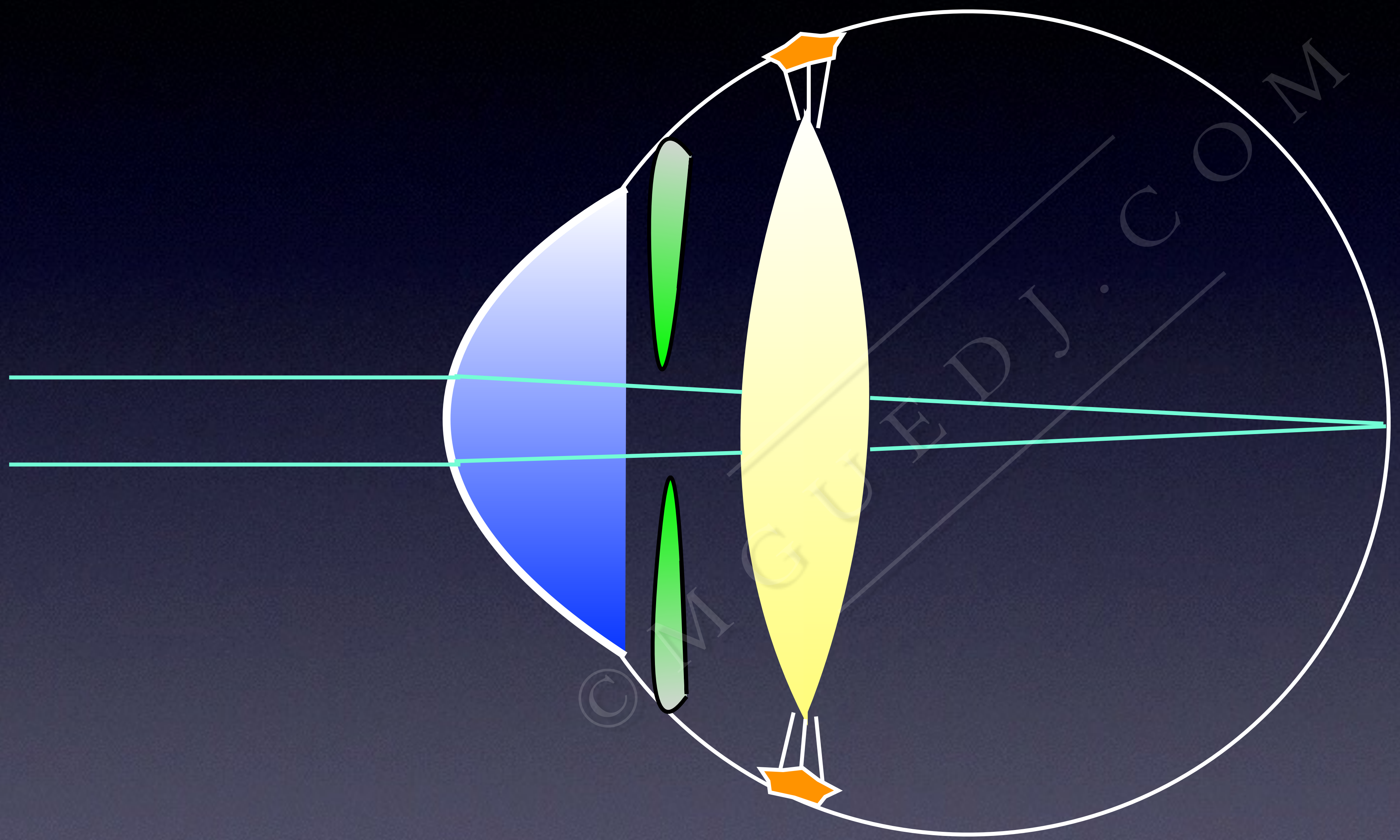

Film
Shutter
Aperture
Lens


CORNEA
LENS
=
LENS
RETINA
=
FILM
ZONULA
IRIS
=
APERTURE
CILIARY MUSCLE
=
AUTOFOCUS

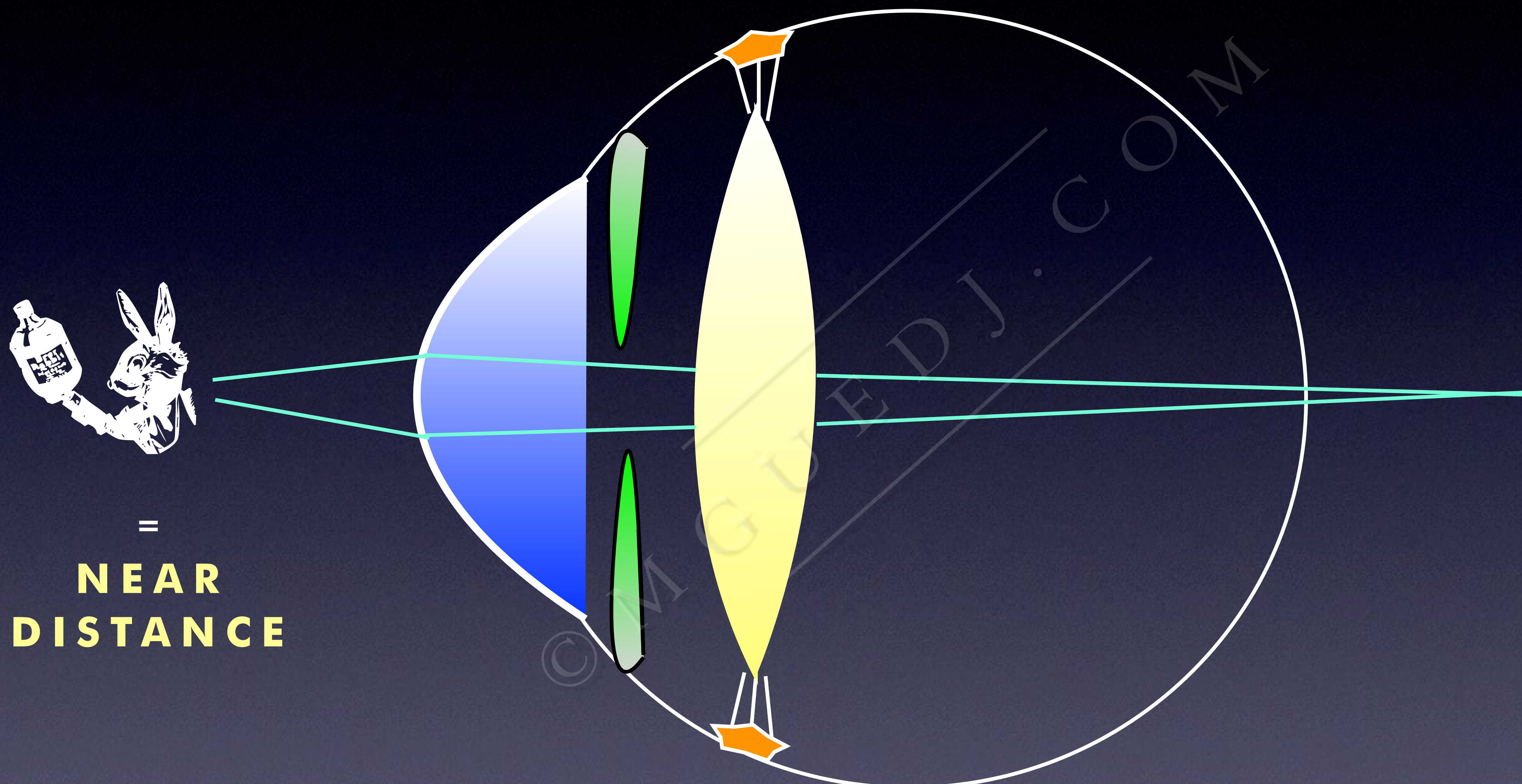
ACCOMMODATION



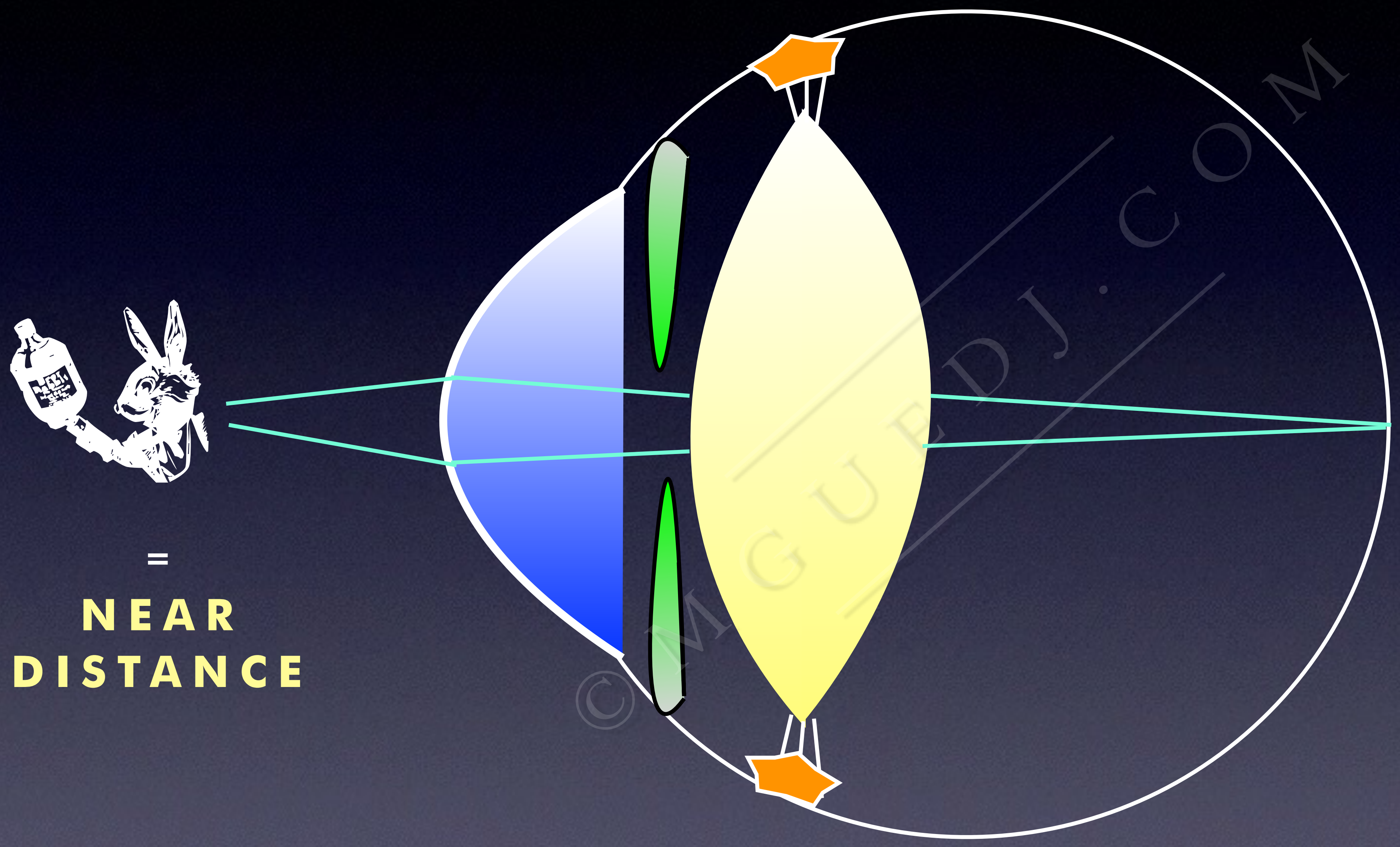
ACCOMMODATION



ACCOMMODATION



ACCOMMODATION



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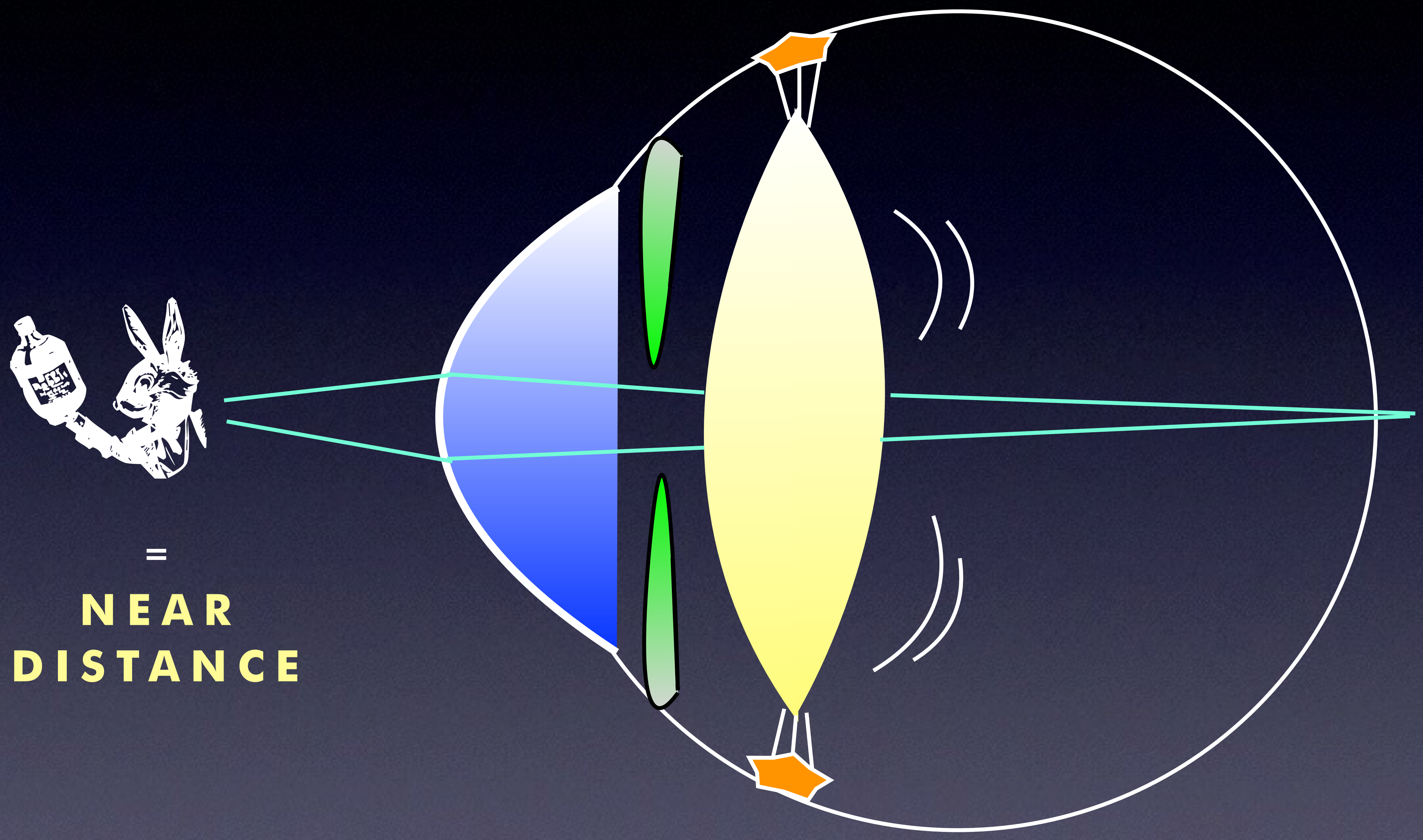
NEAR DISTANCE

ACCOMMODATION



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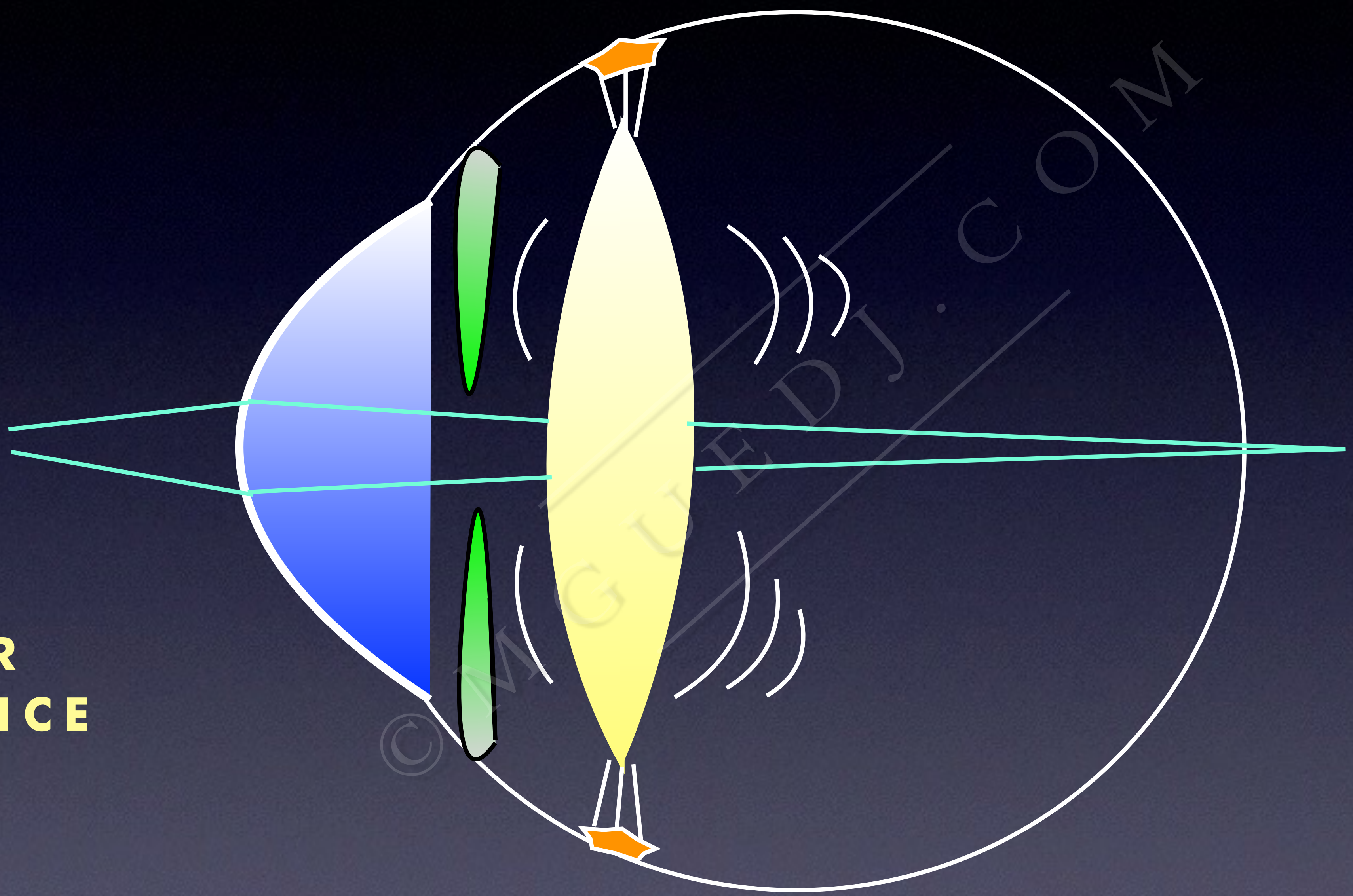
NEAR DISTANCE

ACCOMMODATION



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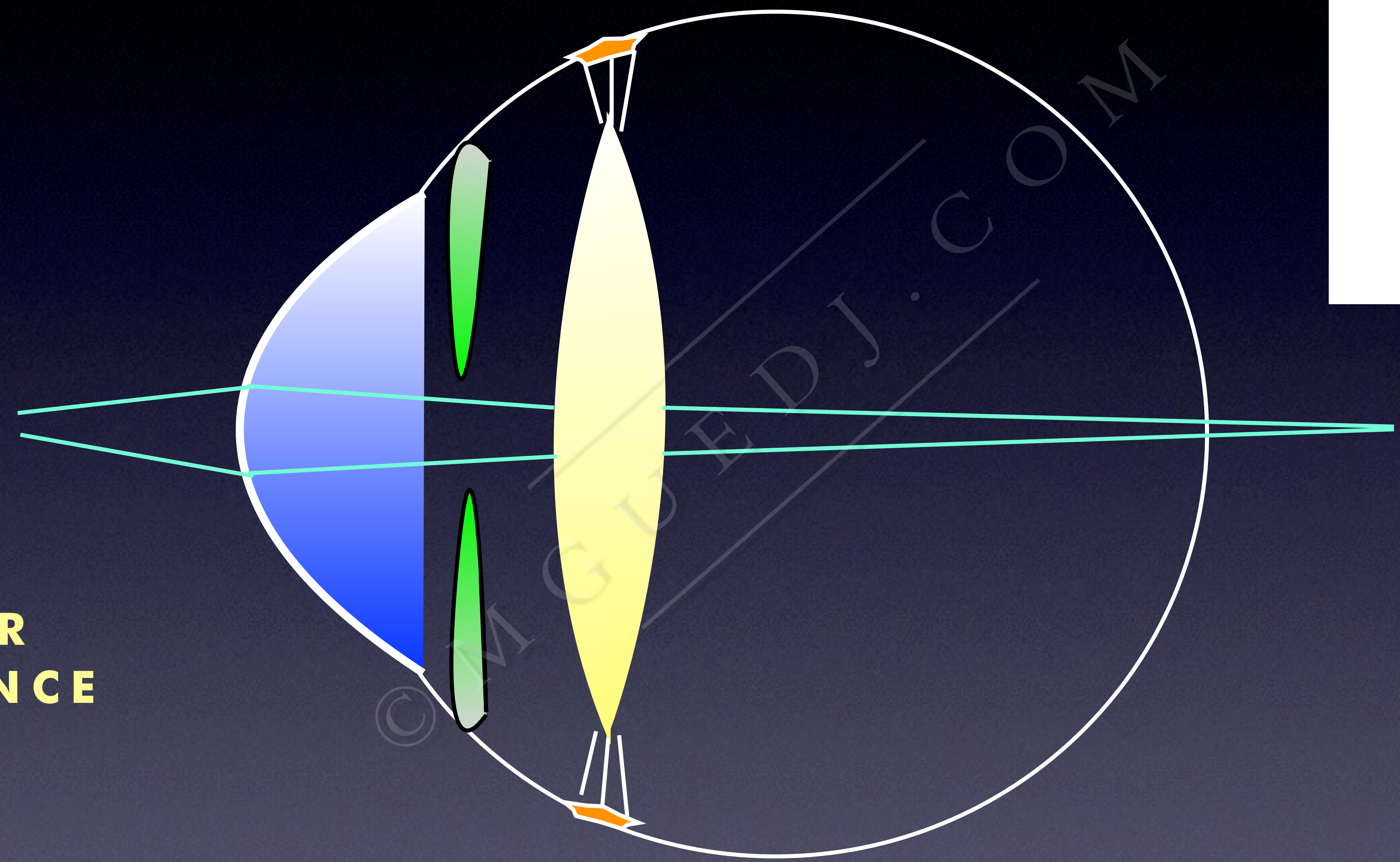
NEAR DISTANCE

ACCOMMODATION



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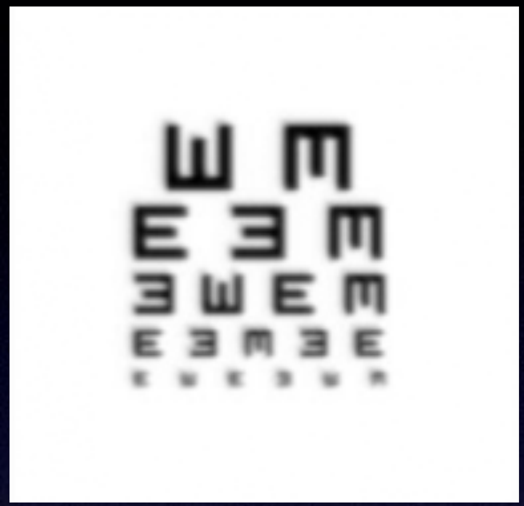
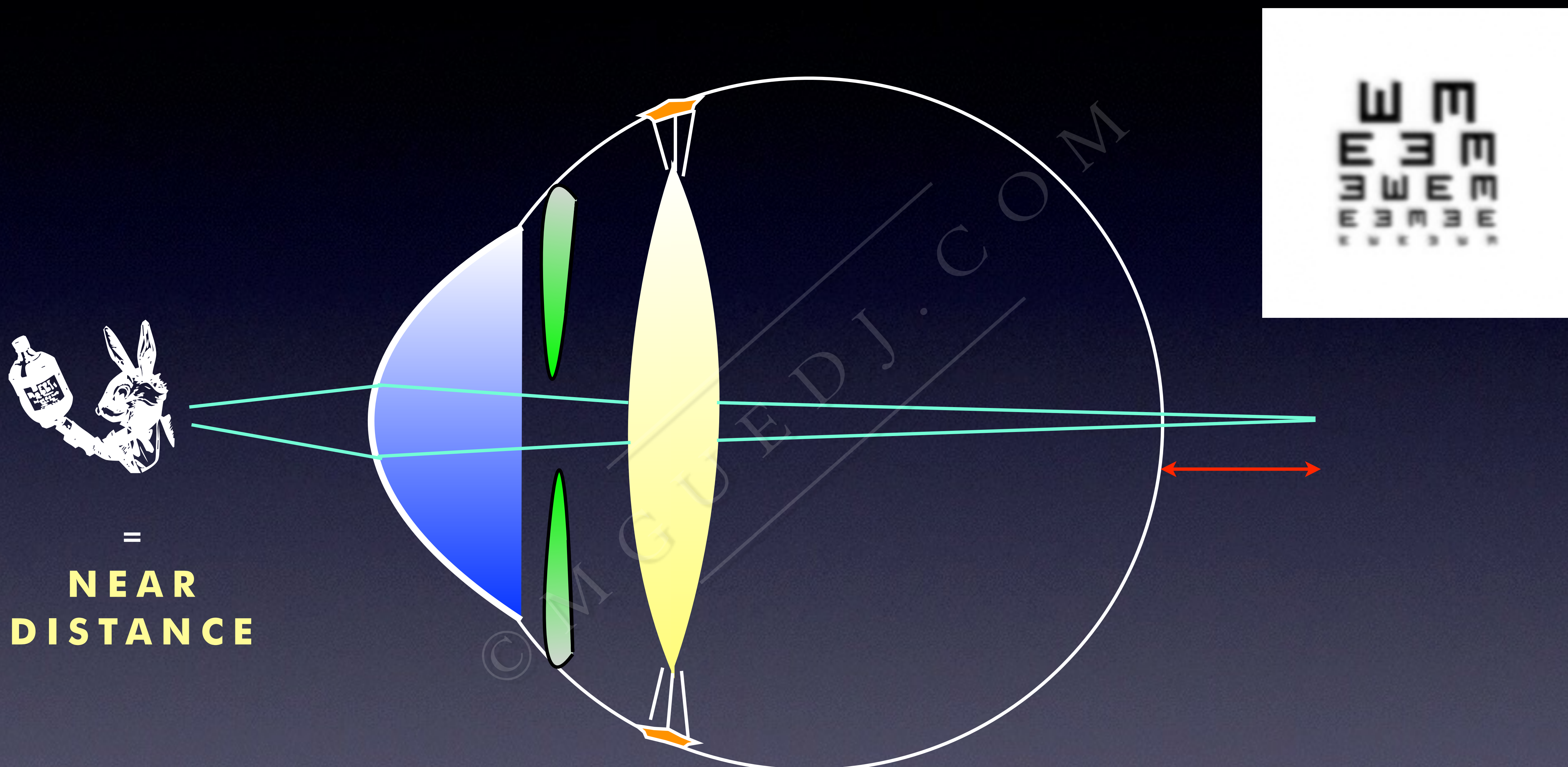
NEAR DISTANCE



ACCOMMODATION



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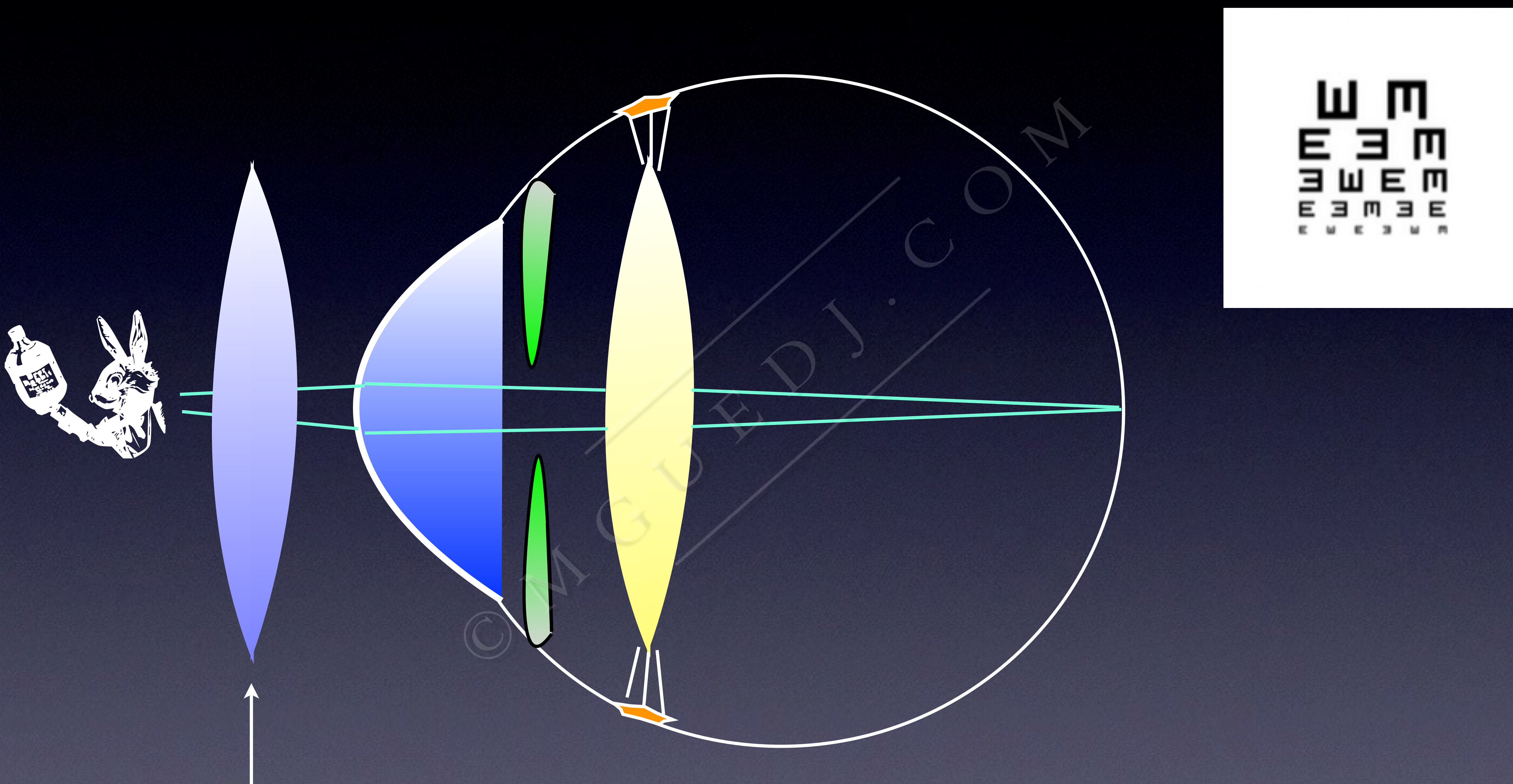
NEAR DISTANCE

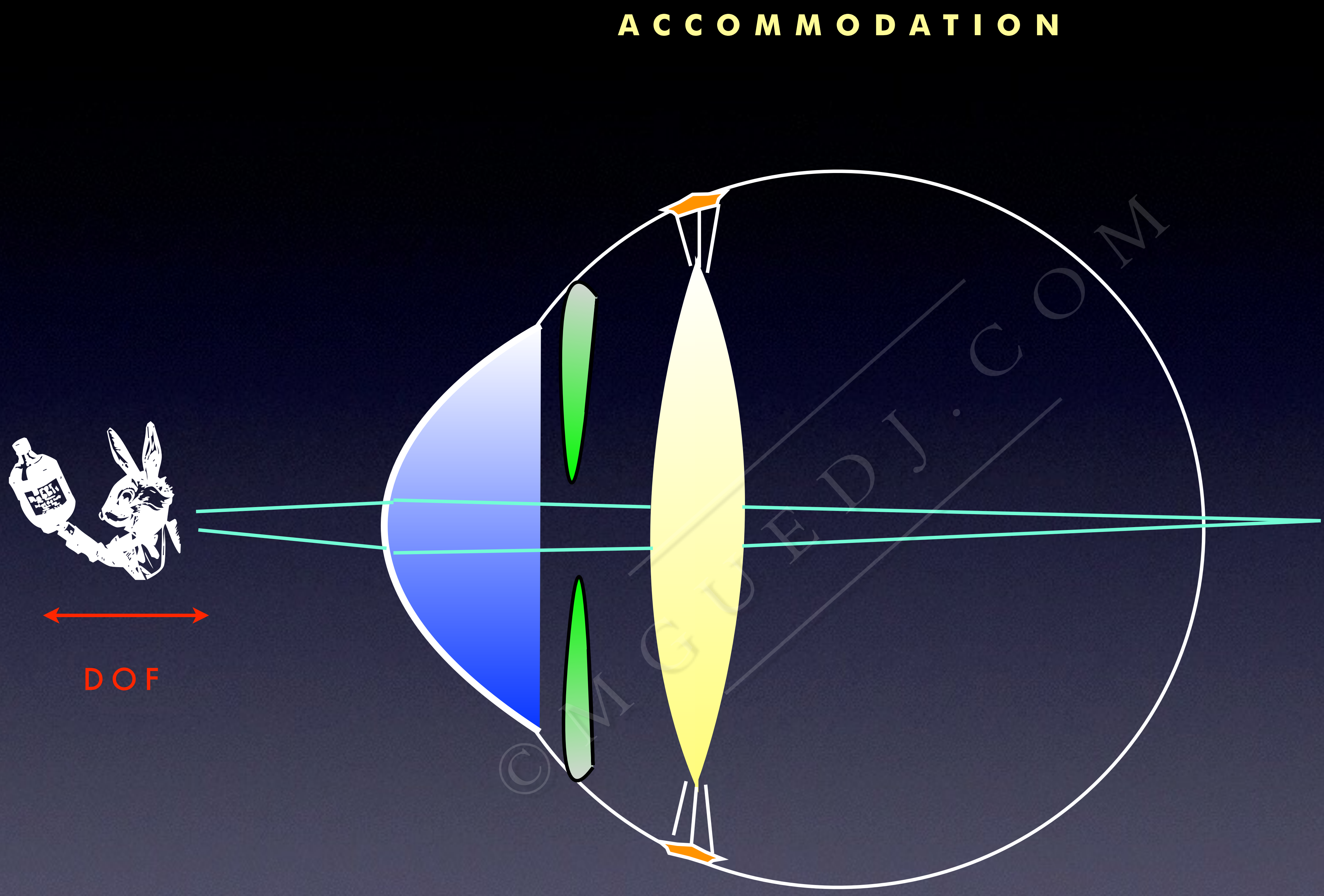
PRESBYOPIA

ACCOMMODATION

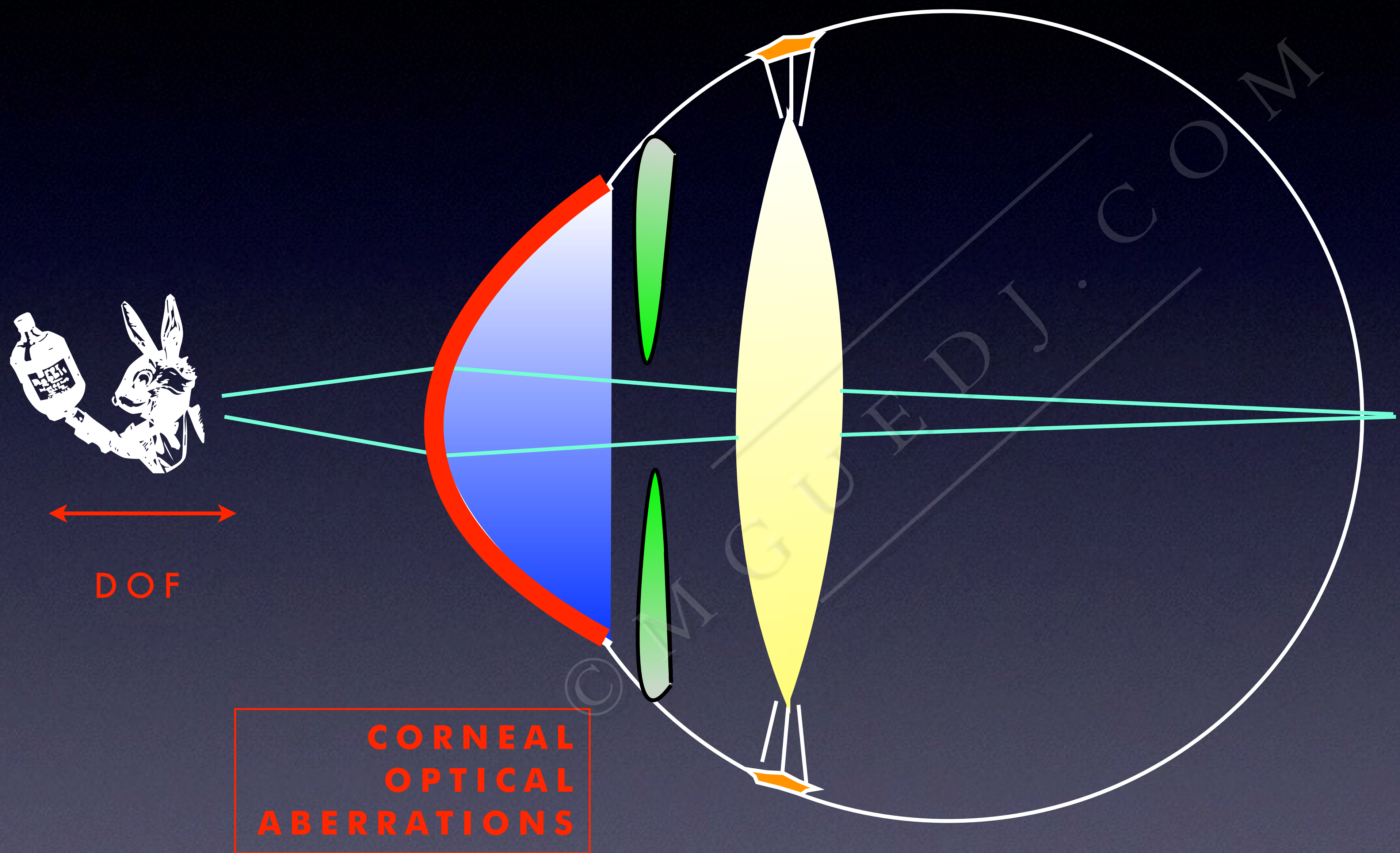


CONVERGING LENS

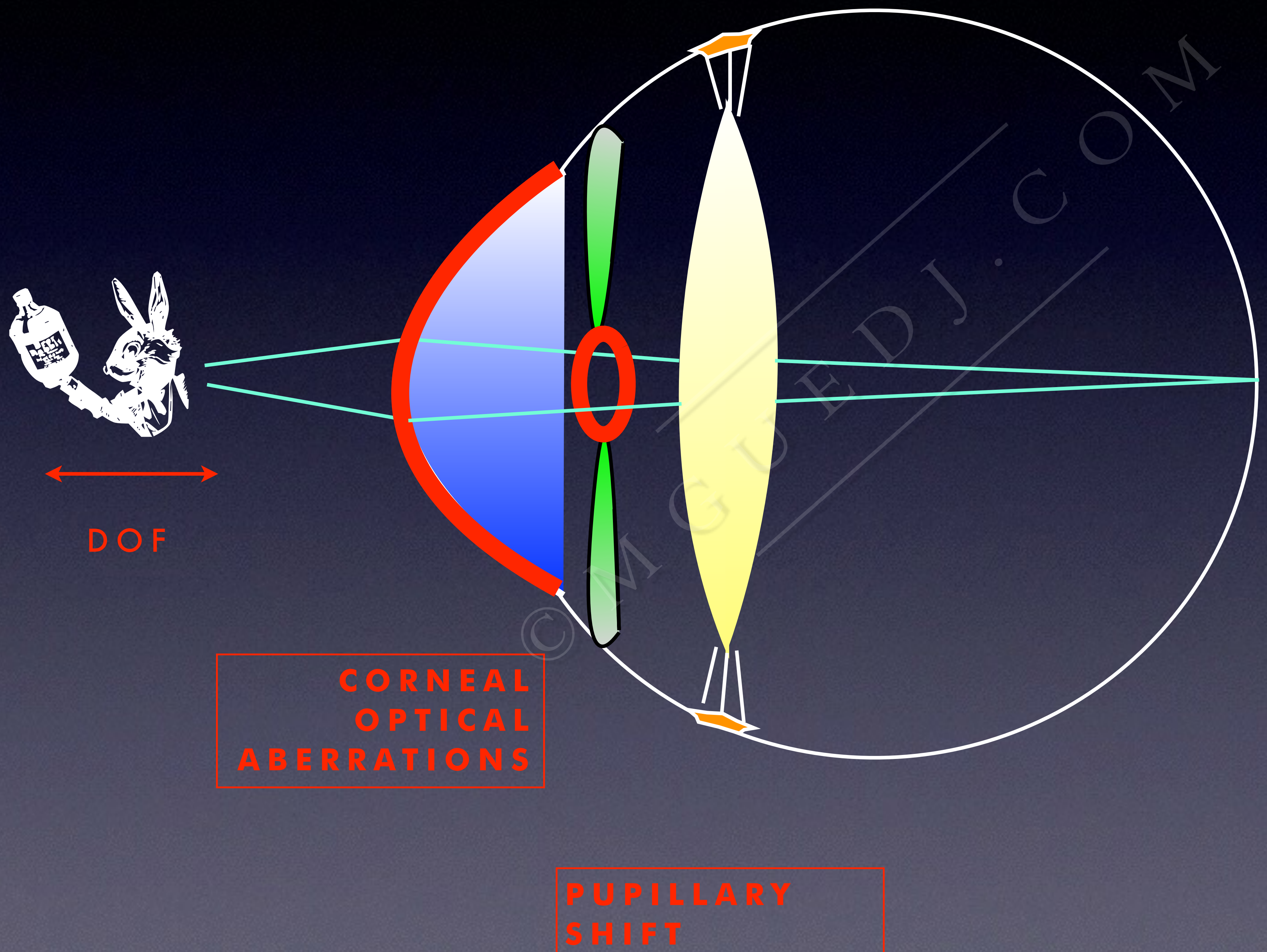
PRESBYOPIA


ACCOMMODATION
DOF

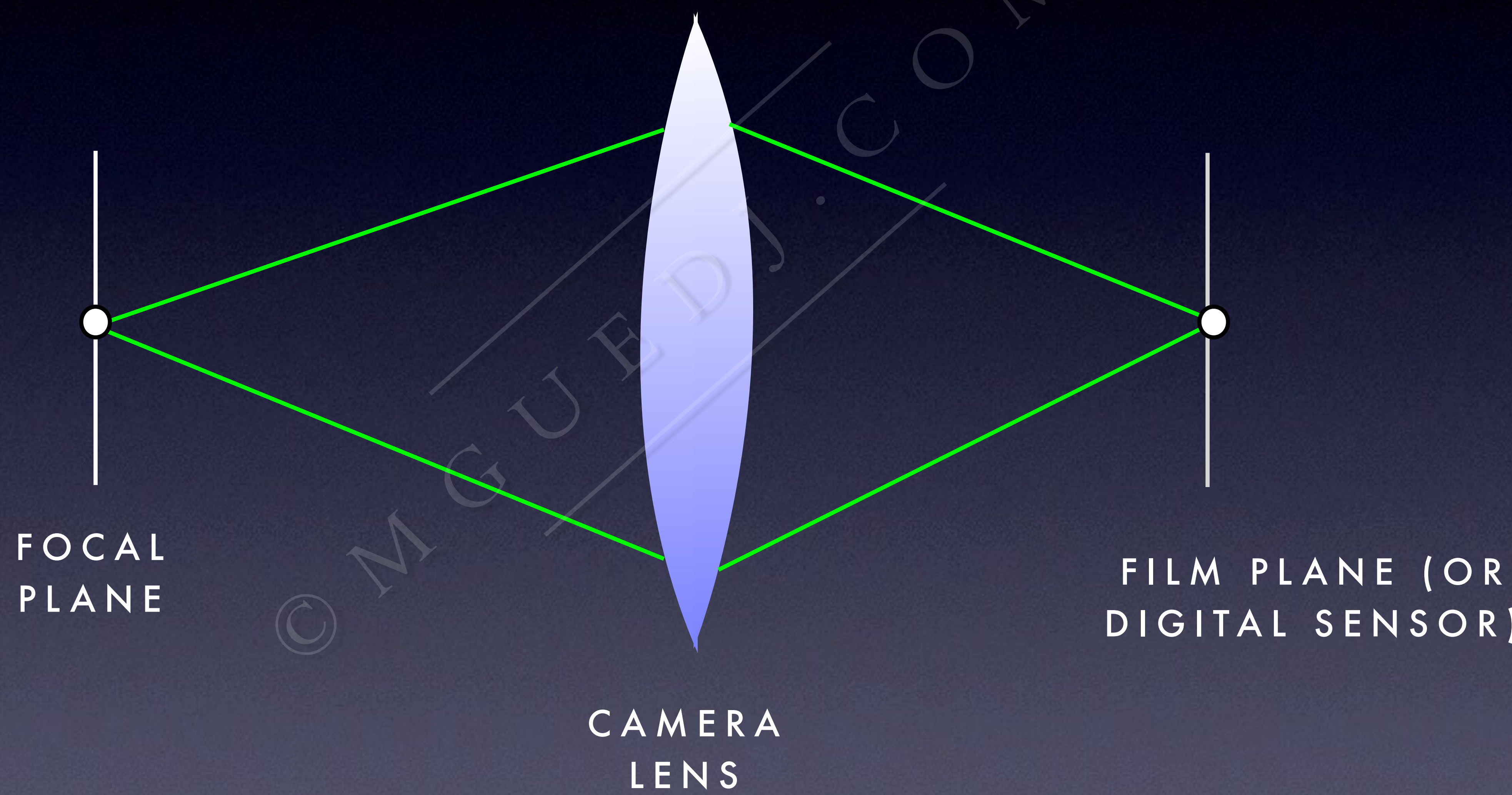
ACCOMMODATION



ACCOMMODATION



DEFINITIONS



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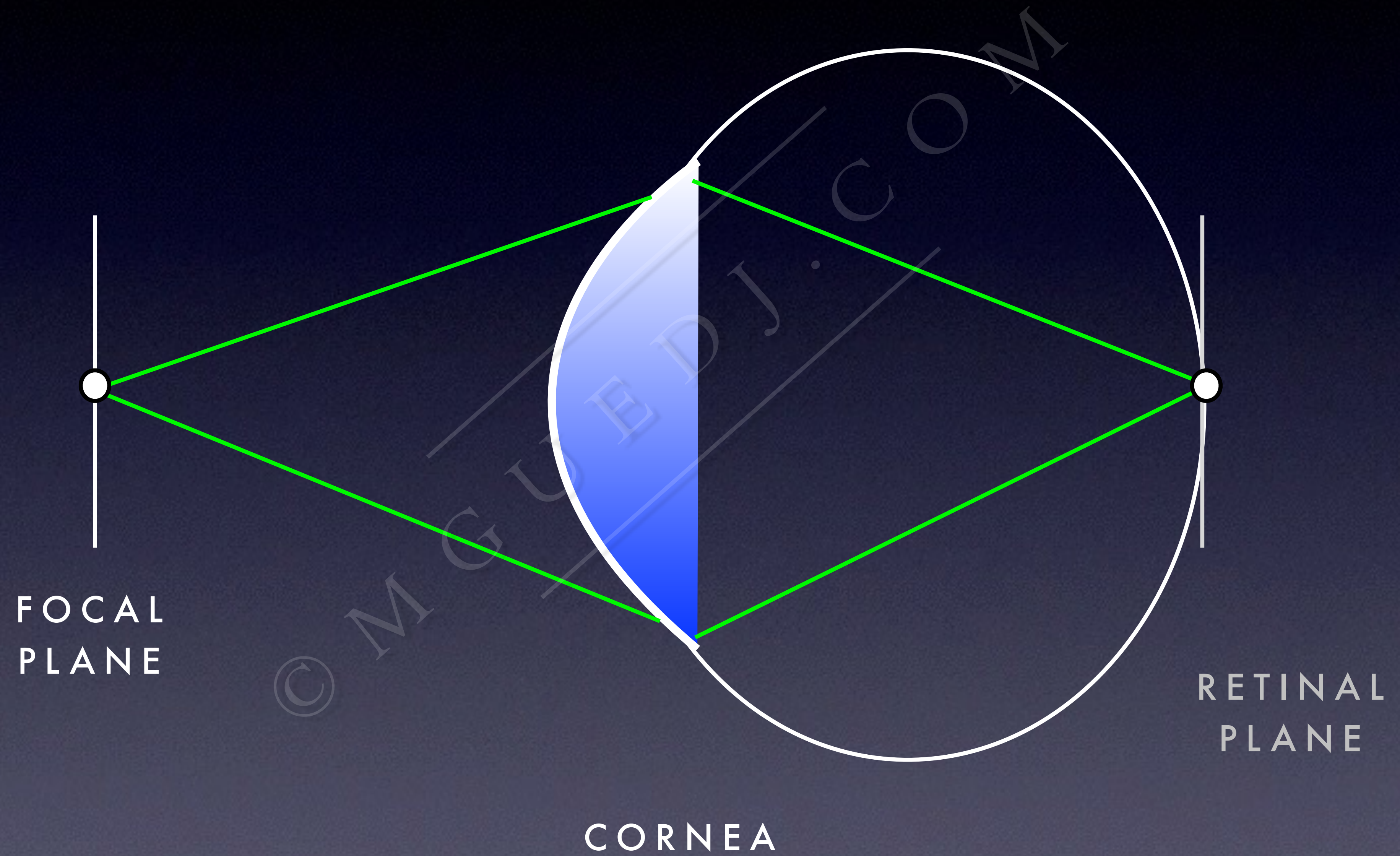
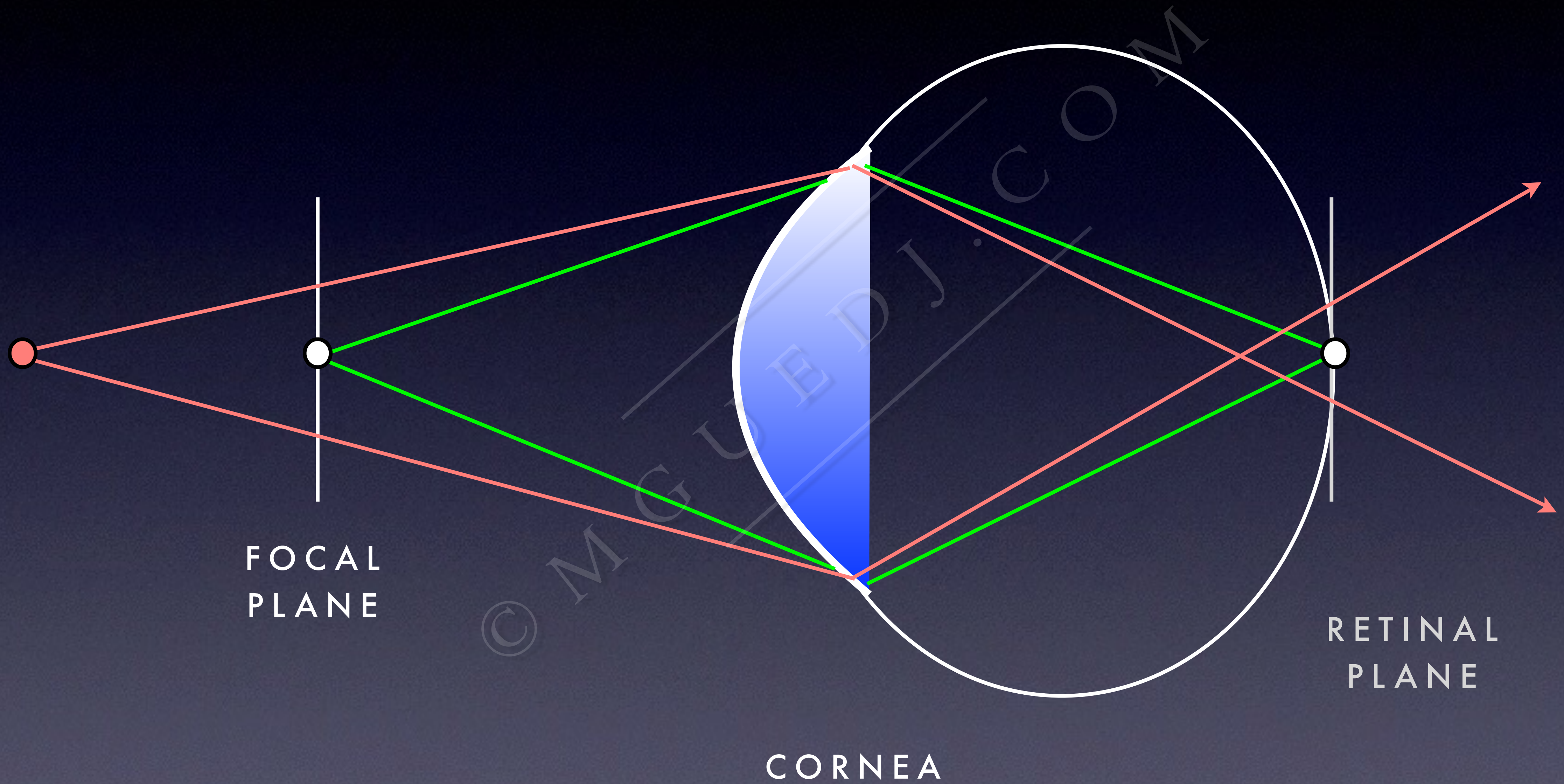
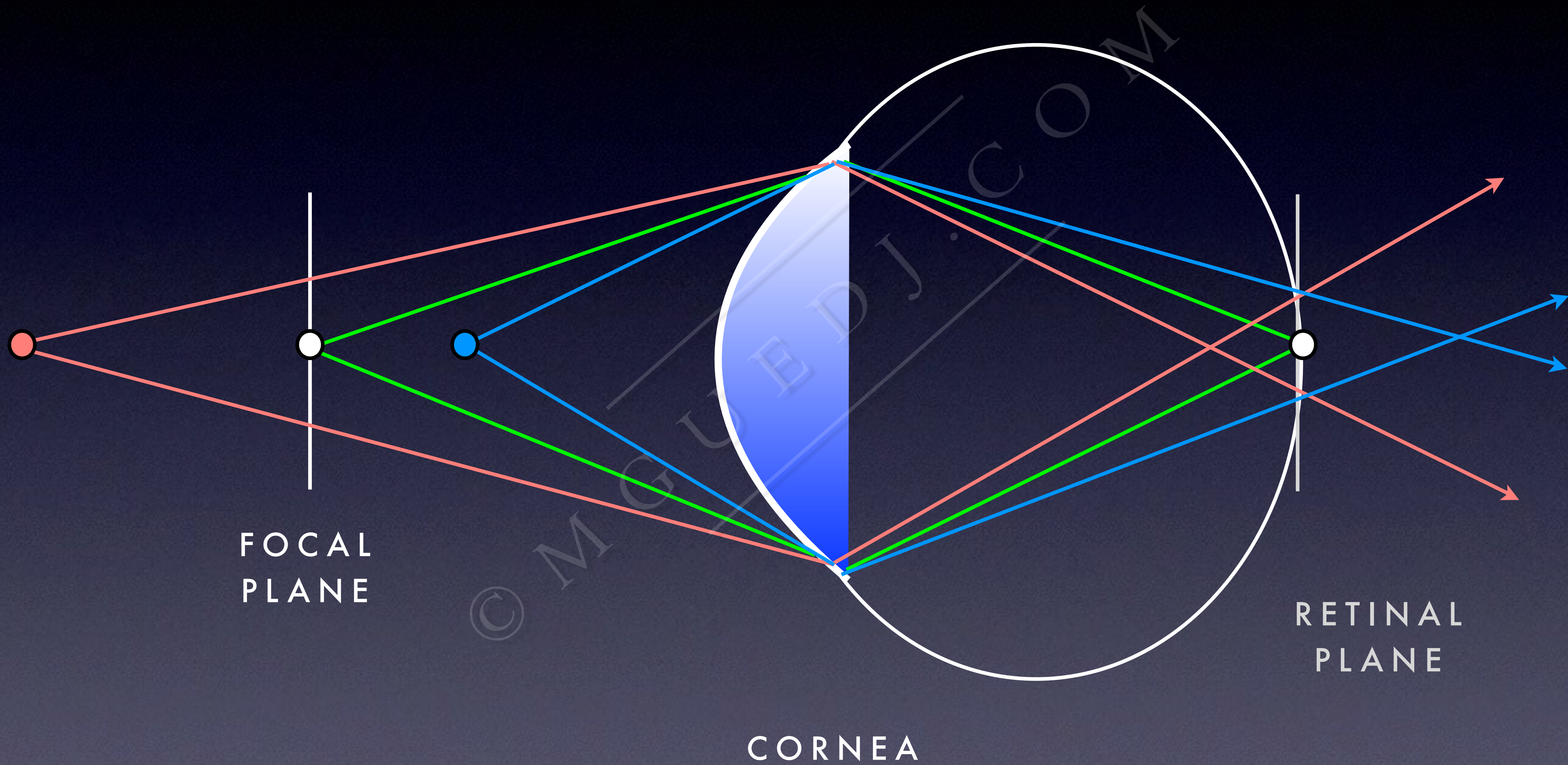


DEFINITIONS



DEFINITIONS



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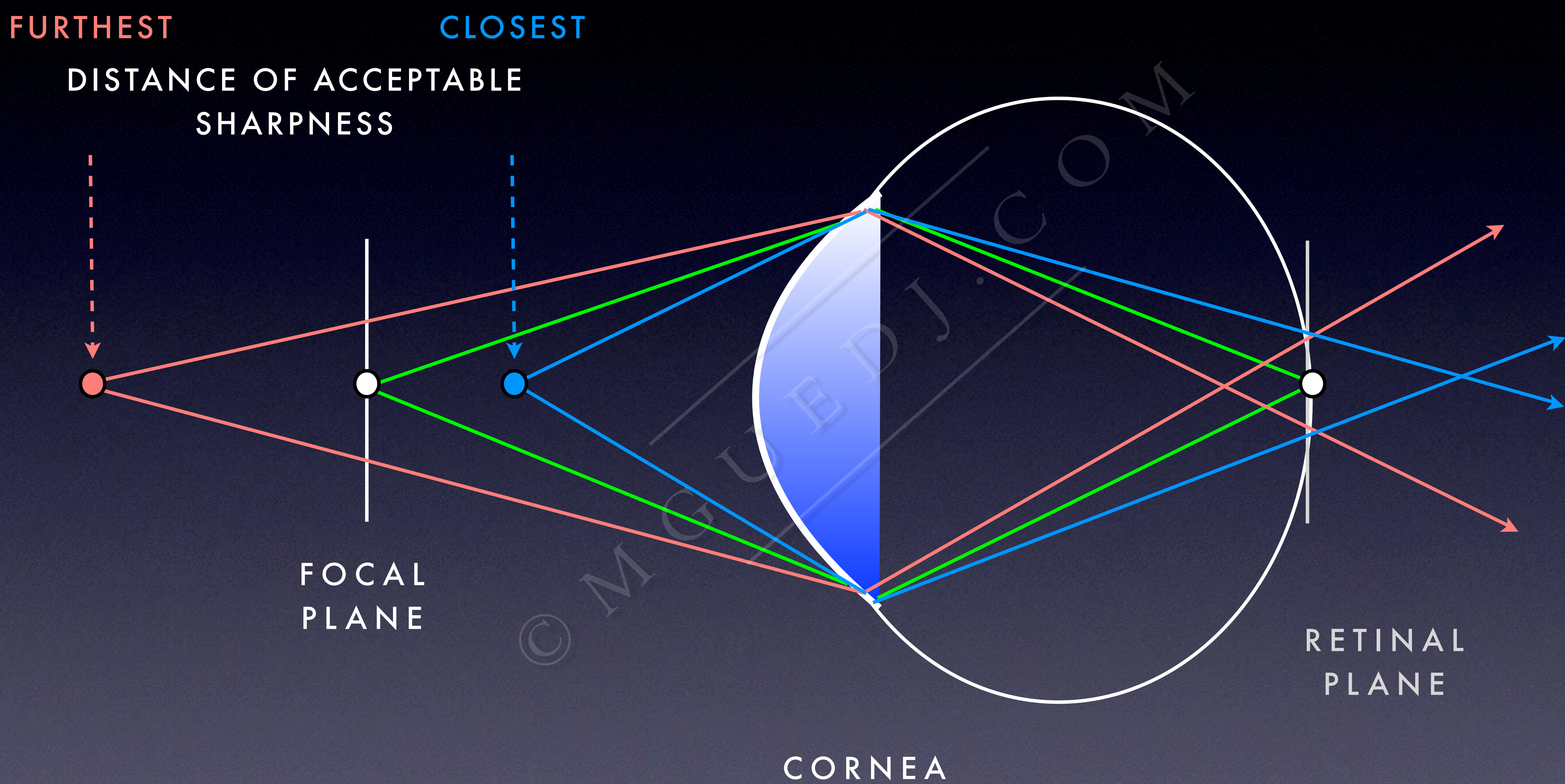

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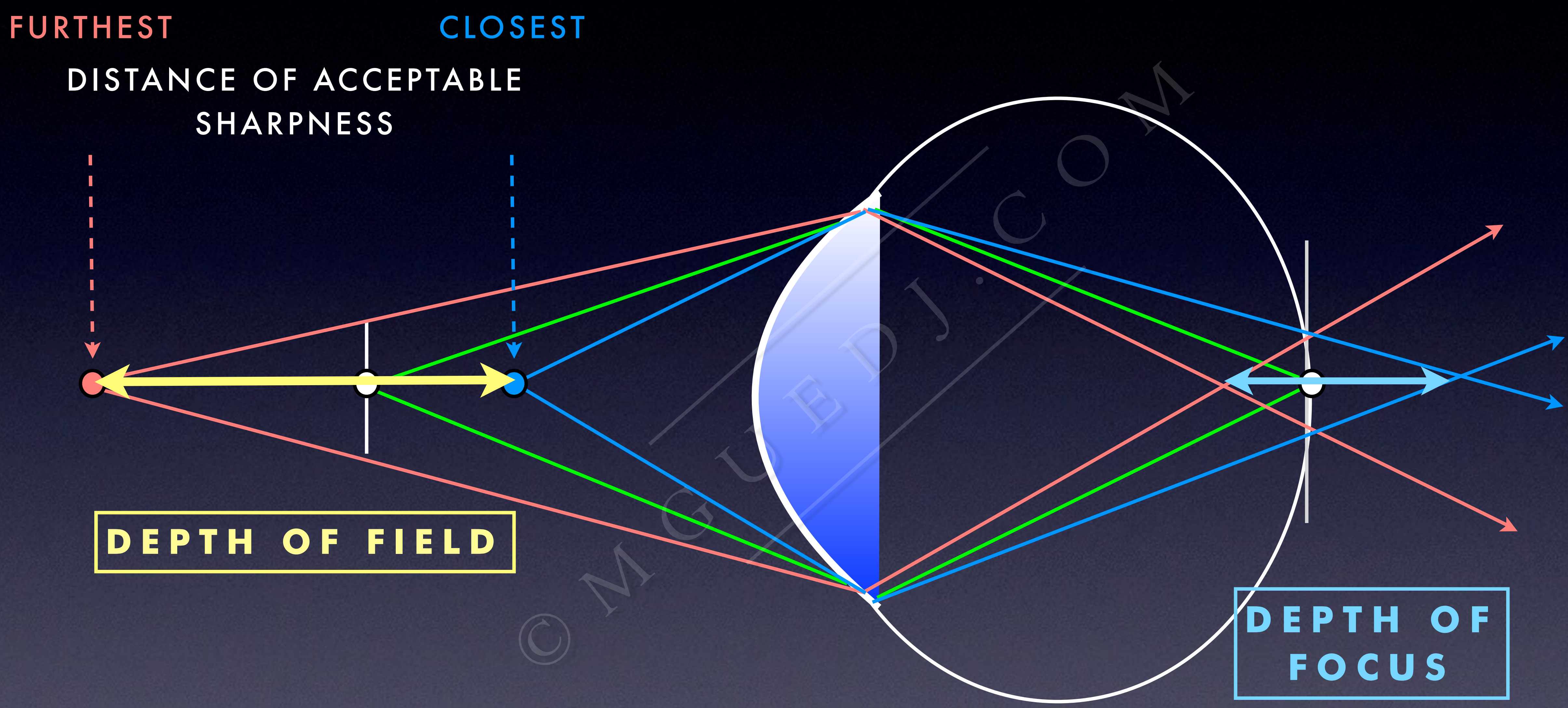

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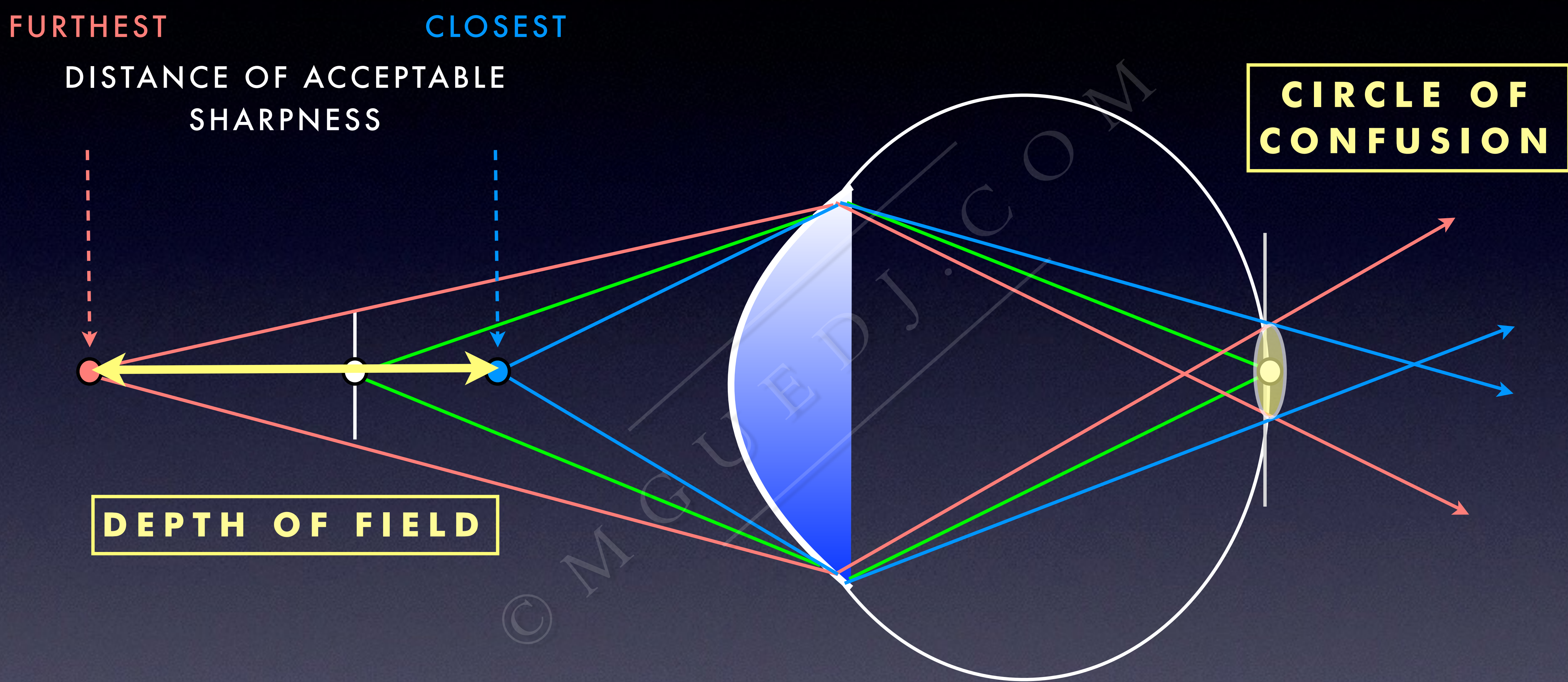
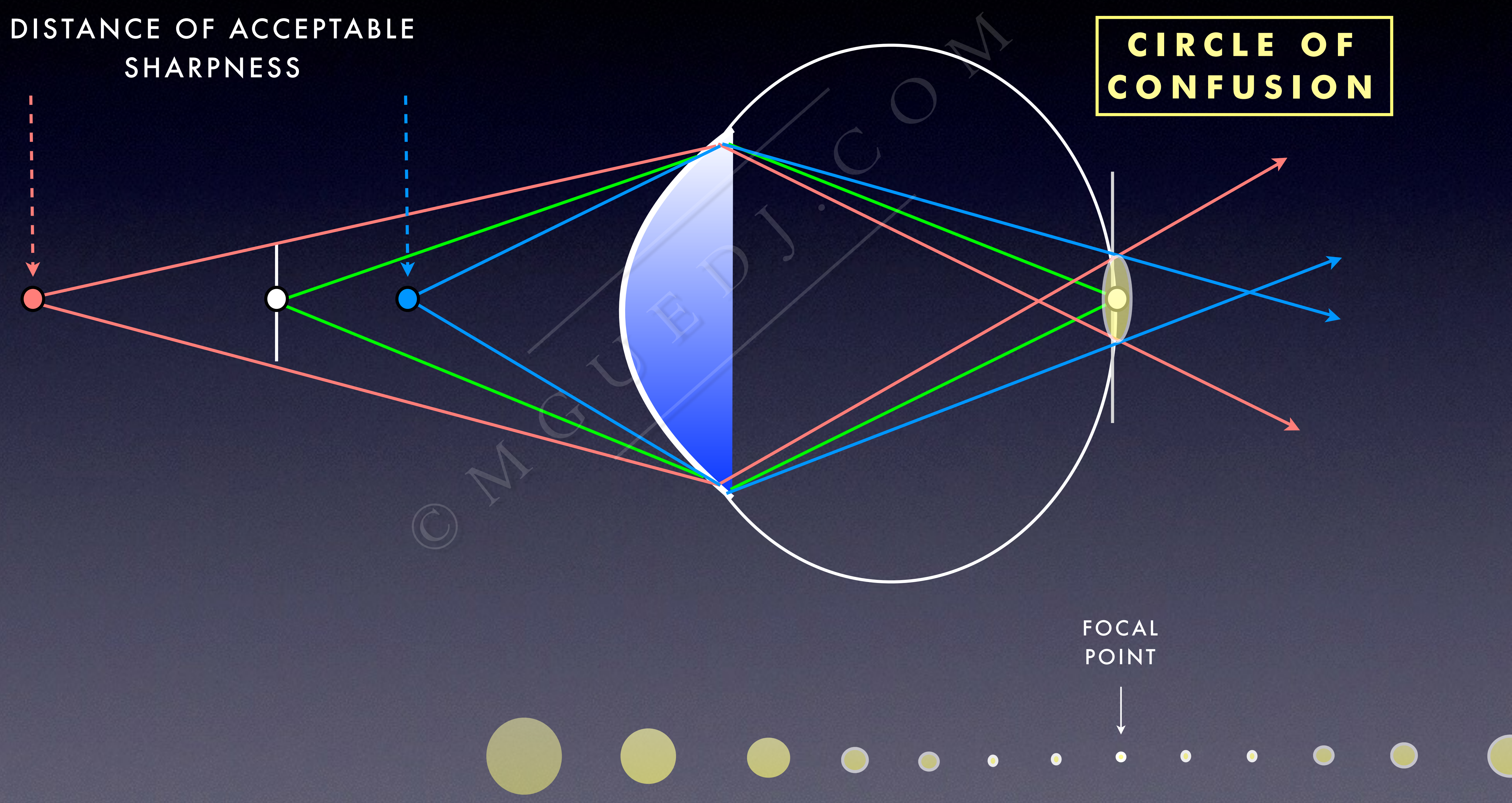


CIRCLES OF CONFUSION



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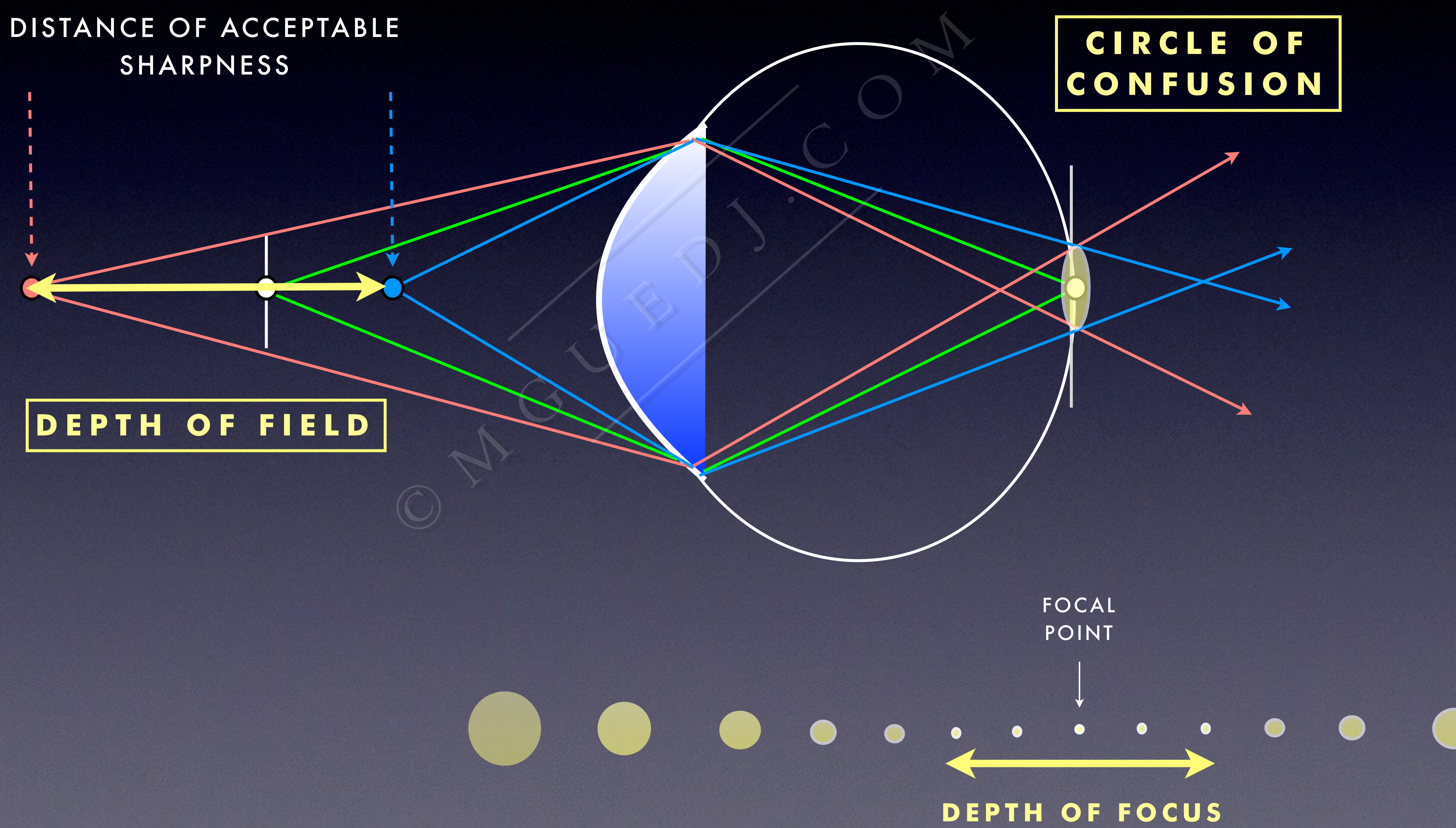

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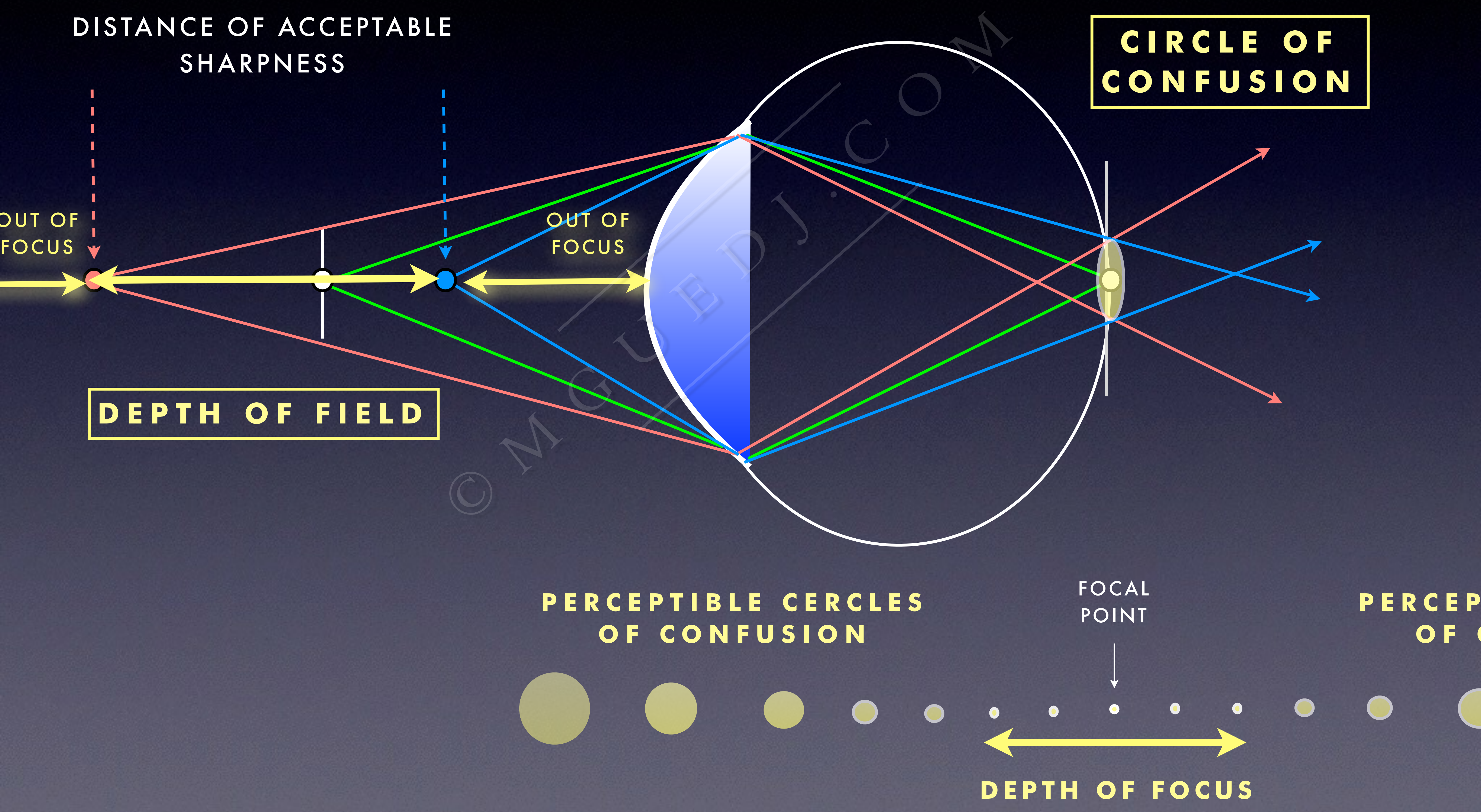
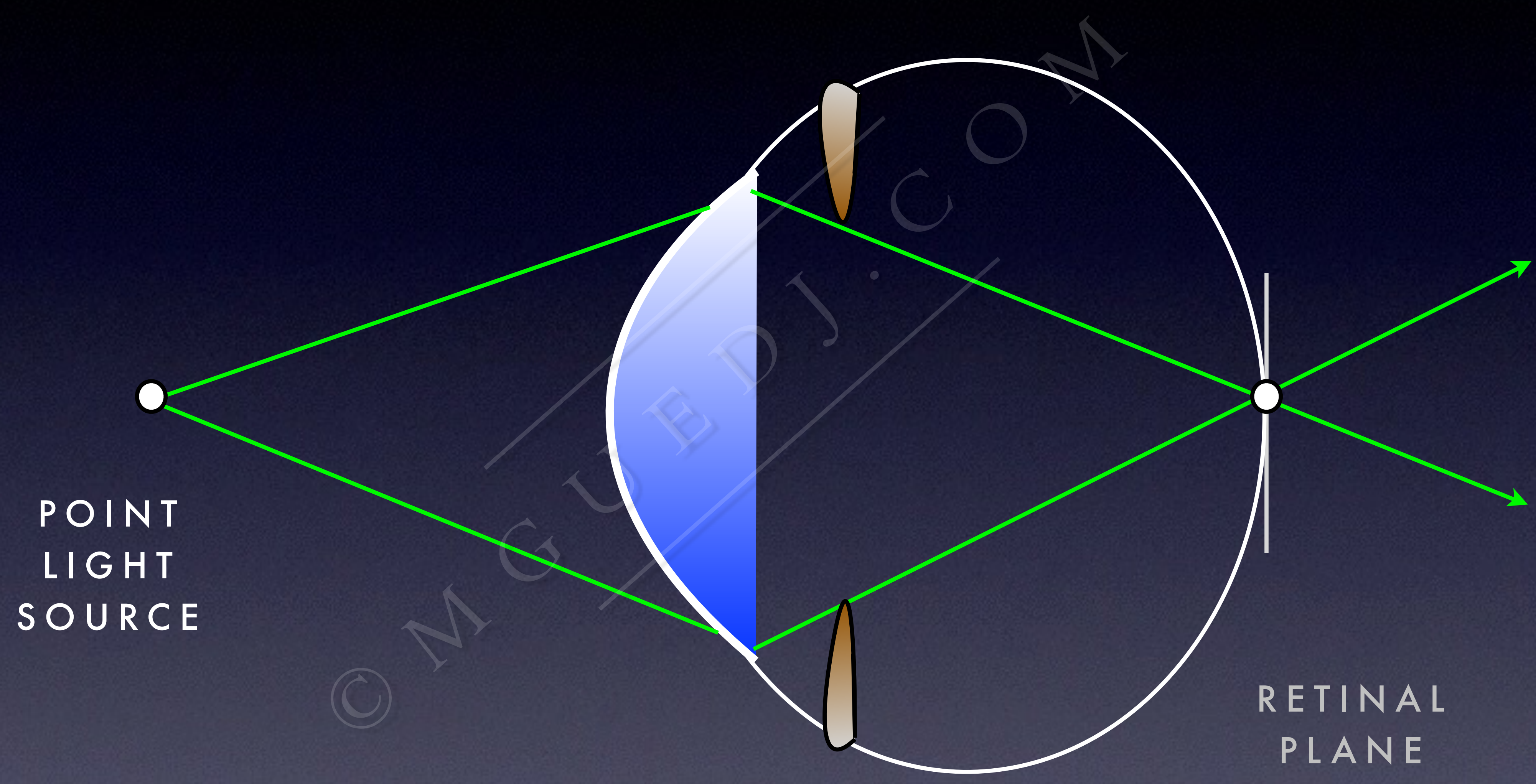
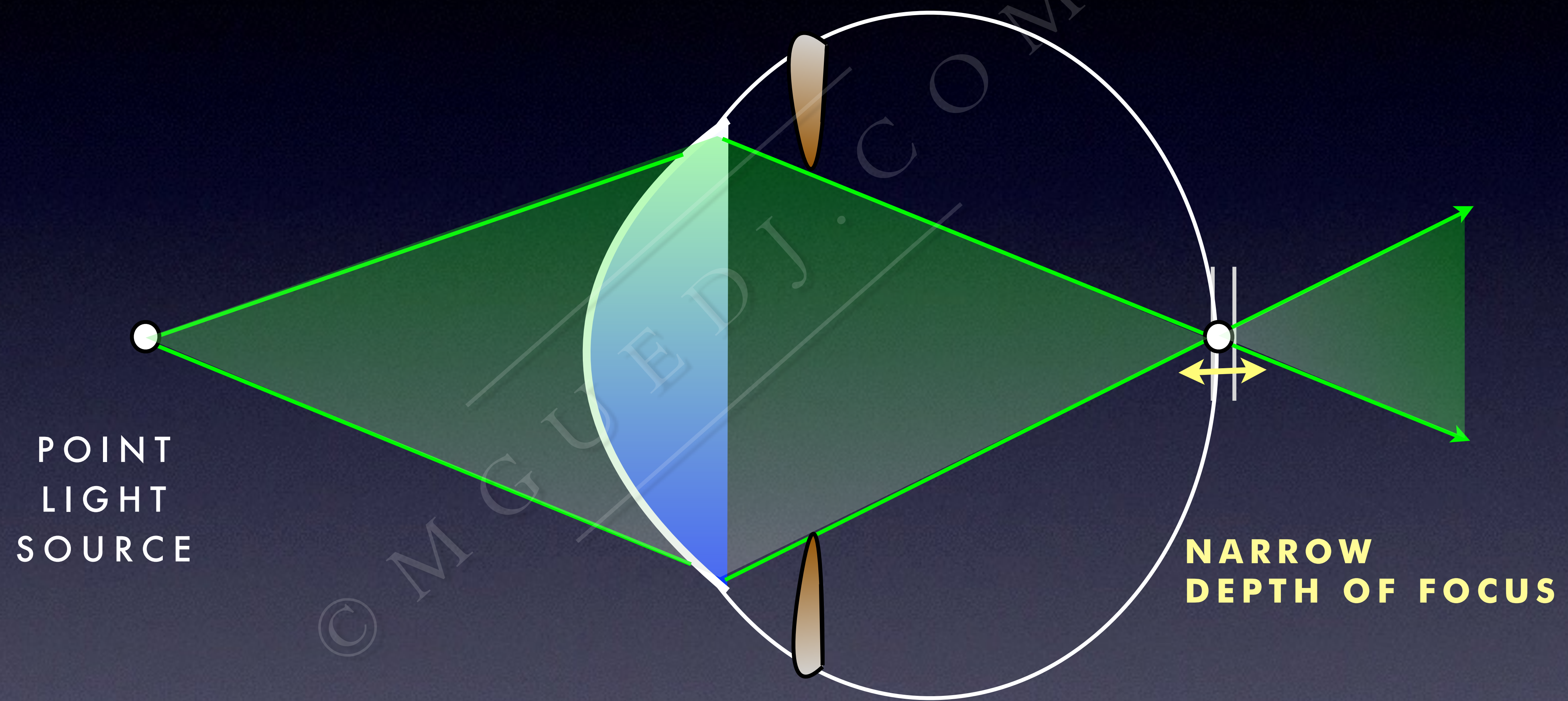


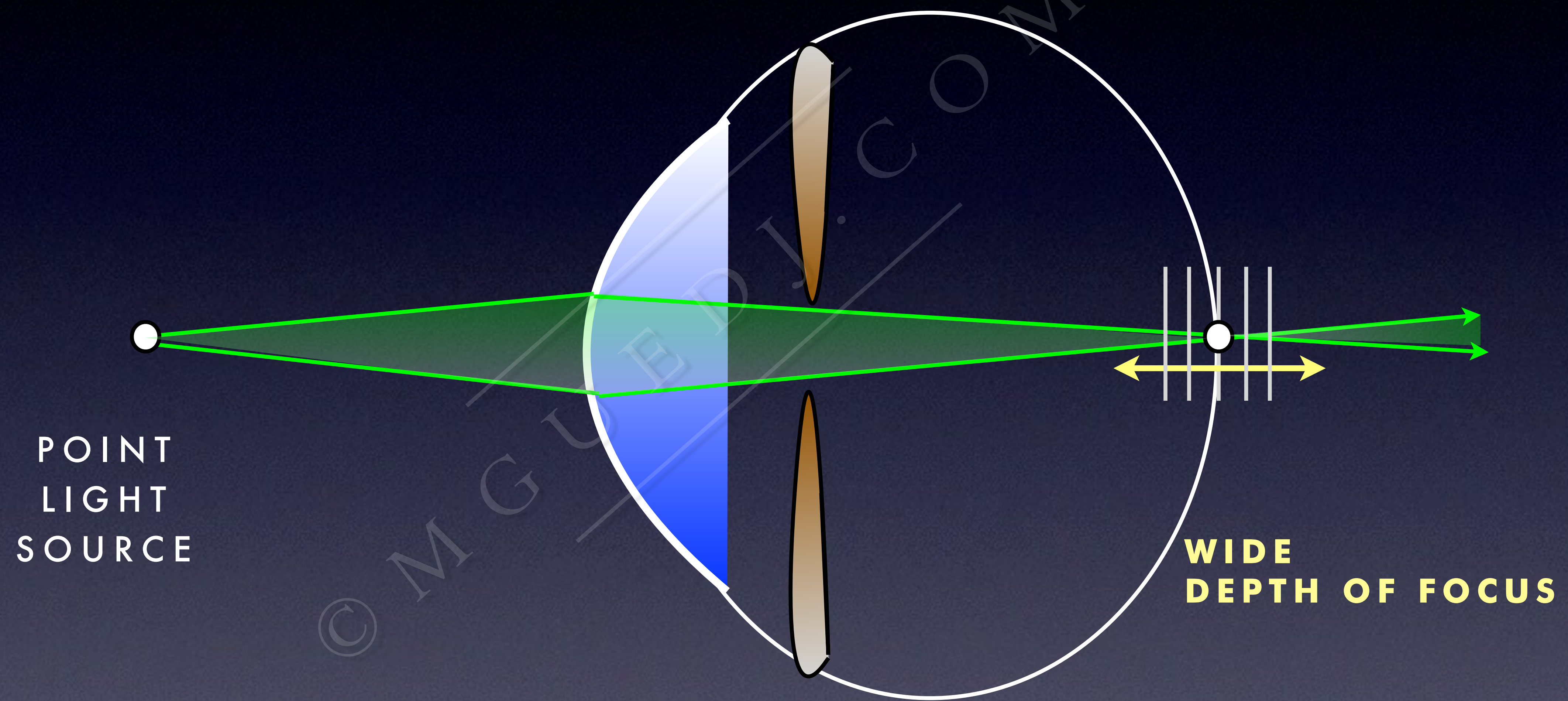
LARGE PUPIL



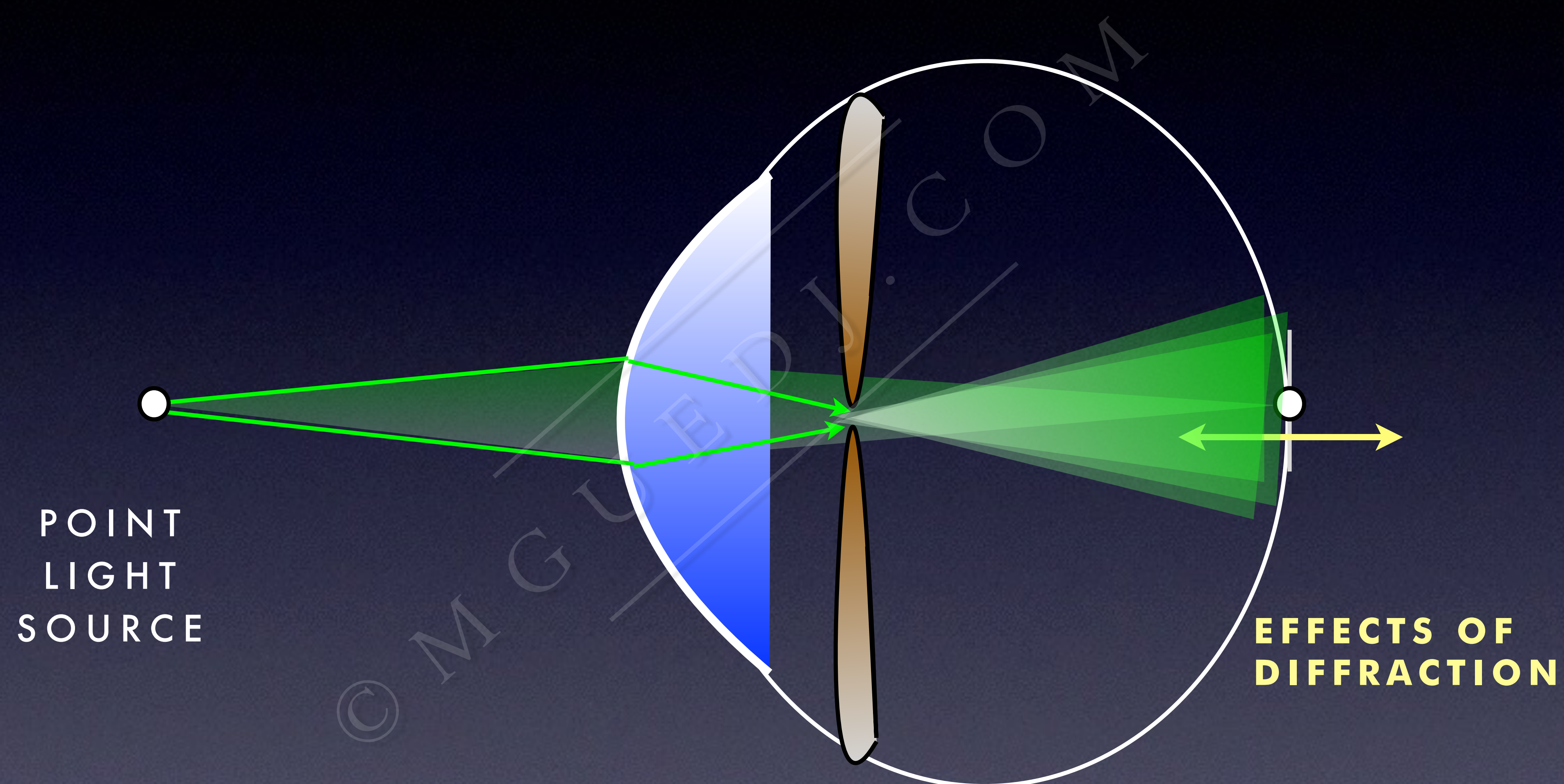
LARGE PUPIL



SMALL PUPIL



TOO SMALL PUPIL



②

P U R P O S E

THE QUESTIONS

What are the correlations between
depth of field,
optical aberrations
and **pupillometry** in presbyopic patients ?

Which aberrations are particularly involved
in an extended depth of field ?

Can we refine an eye model for corneal
multifocality ?

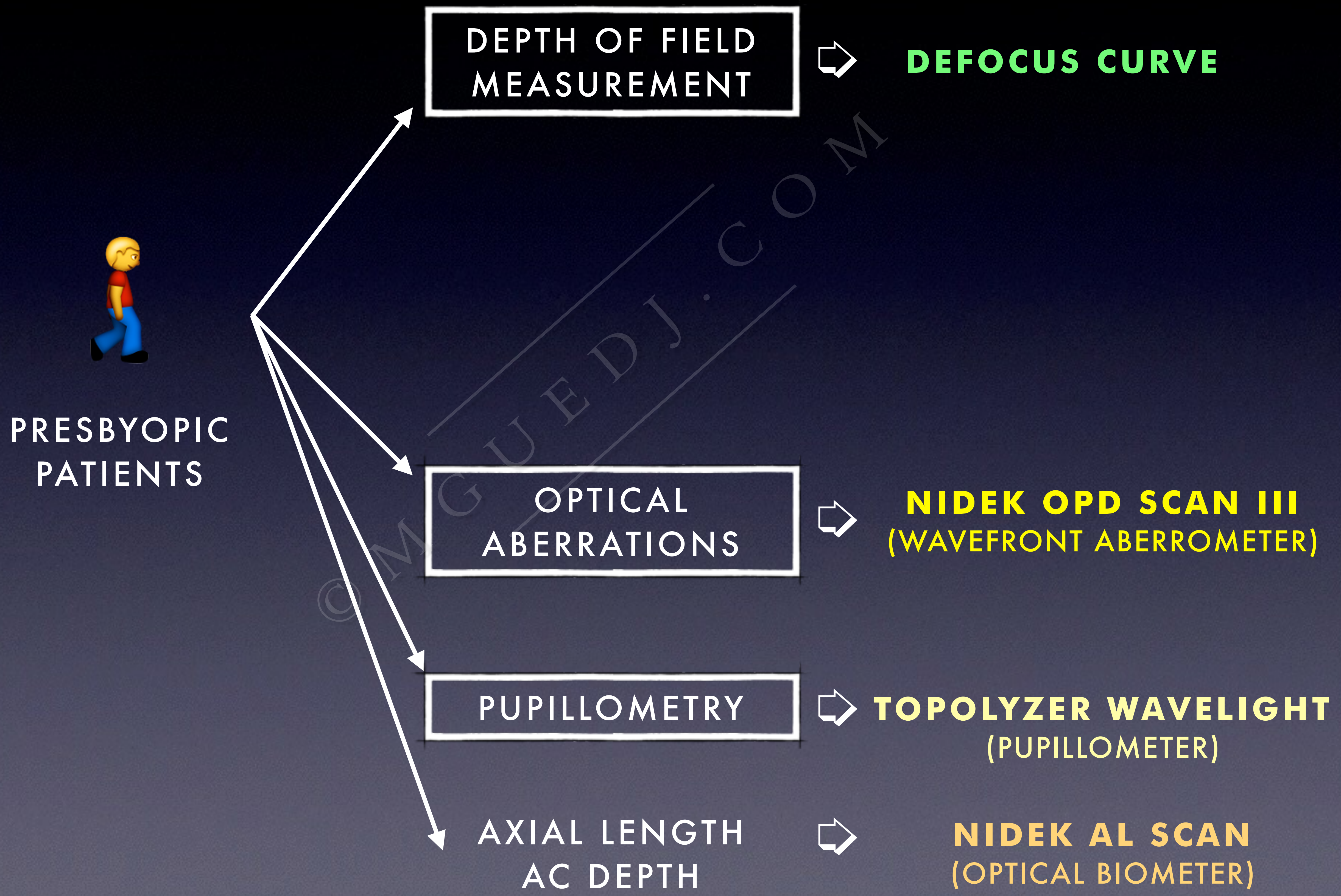
THE CONSEQUENCES

Given a particular patient's
corneal wavefront and **pupillary diameter,**
is it possible to predict his effective **depth of field** ?

By inducing a change in the patient's corneal WF
(with **customised excimer laser treatment**),
is it possible to **increase his net depth of field** ?

③

STUDY DESIGN & METHODS


PRESBYOPIC PATIENTS
DEPTH OF FIELD MEASUREMENT
DEFOCUS CURVE
OPTICAL ABERRATIONS
NIDEK OPD SCAN III
(WAVEFRONT ABERROMETER)
PUPILLOMETRY
TOPOLYZER WAVELIGHT
(PUPILLOMETER)
AXIAL LENGTH
AC DEPTH
NIDEK AL SCAN
(OPTICAL BIOMETER)

PROSPECTIVE STUDY

PRESBYOPIC PATIENTS

DEPTH OF FIELD MEASUREMENT

Age, gender

\+

DEFOCUS CURVE

\+

UCVA, BCVA

- Far (5m)
- Near (33 cm)
- Intermediate (67 cm)

MONO & BINOCULAR

OPTICAL ABERRATIONS

NIDEK OPD SCAN III
(WAVEFRONT ABERROMETER)

\+ Q FACTOR
(CORNEAL ASPHERICITY)

PUPILLOMETRY

TOPOLYZER WAVELIGHT
(PUPILLOMETER)

AXIAL LENGTH
AC DEPTH

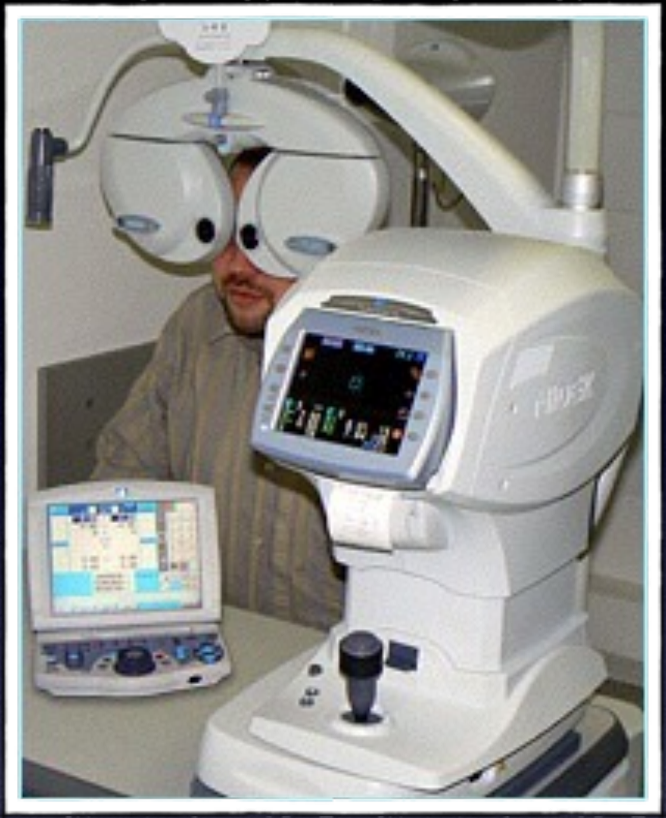
NIDEK AL SCAN
(OPTICAL BIOMETER)

1. THE DEFOCUS CURVE

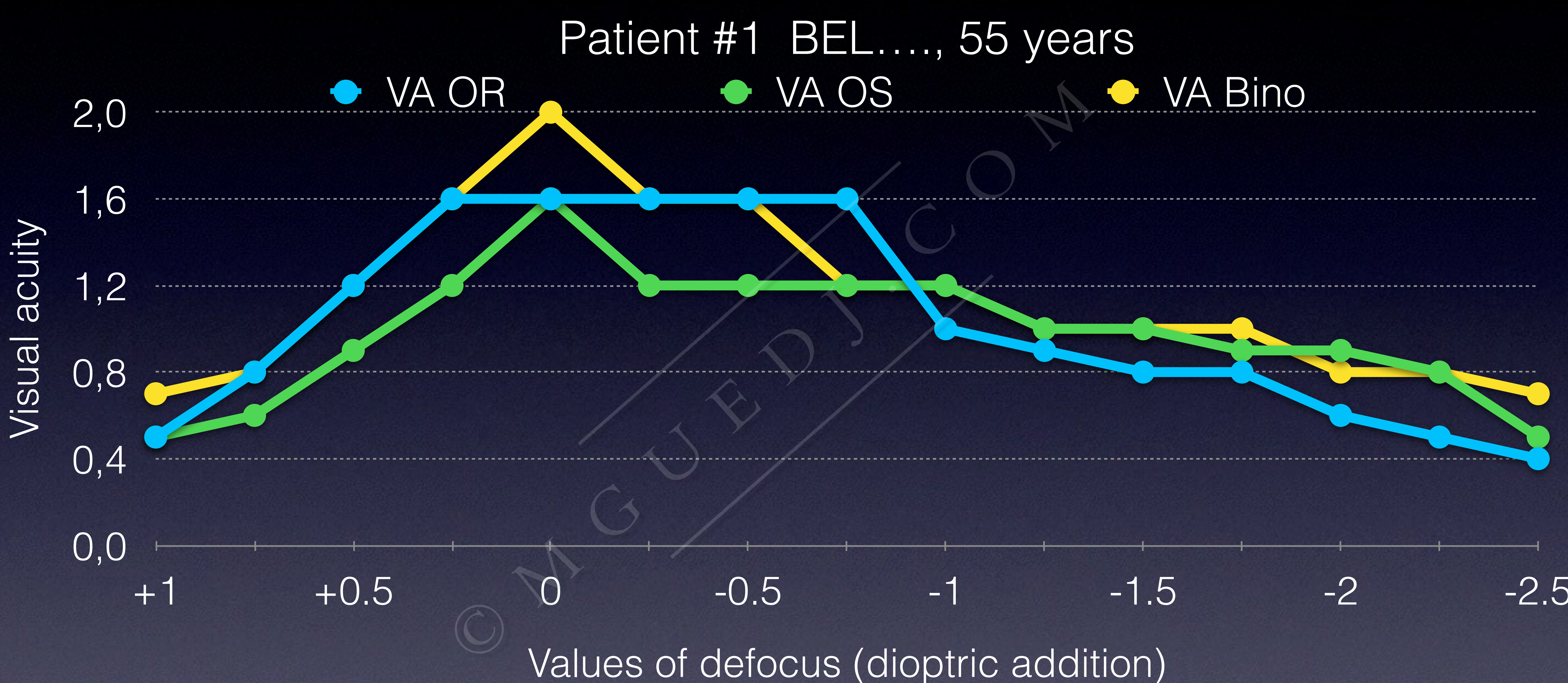
- Best spectacle correction (BCVA) placed in the trial frame (Nidek Smart Refractor RT-5100)

- Trial lenses ranging in power from +1D to -2.5 D added serially in front of each eye, decreasing in 0.25 steps.

- Distance vision recorded for each set of trial lenses, in mono and binocular.

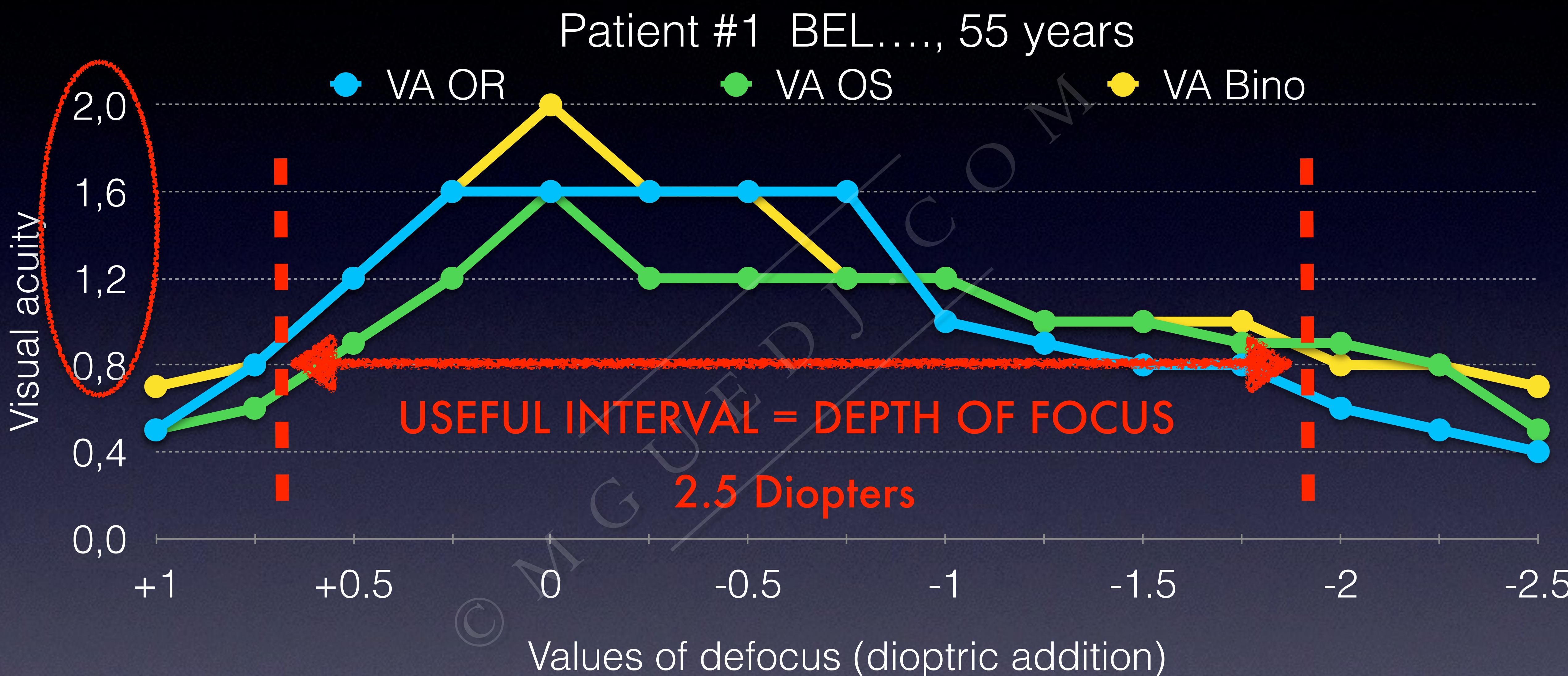


1. THE DEFOCUS CURVE



⇨ obtained by plotting the mean monocular and binocular visual acuities against **15 values of defocus** (ranging from + 1.0 to -2.5 D in 0.25 D steps)

1. THE DEFOCUS CURVE



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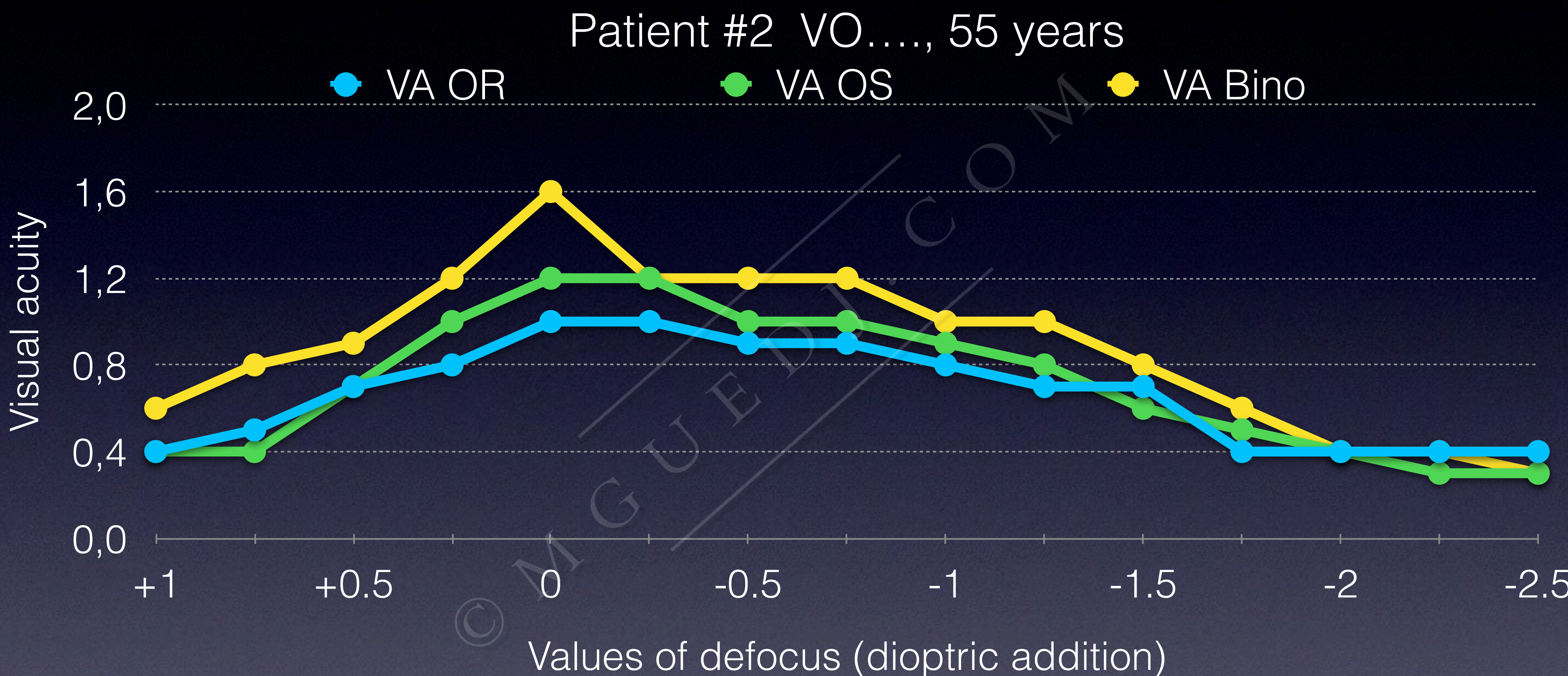

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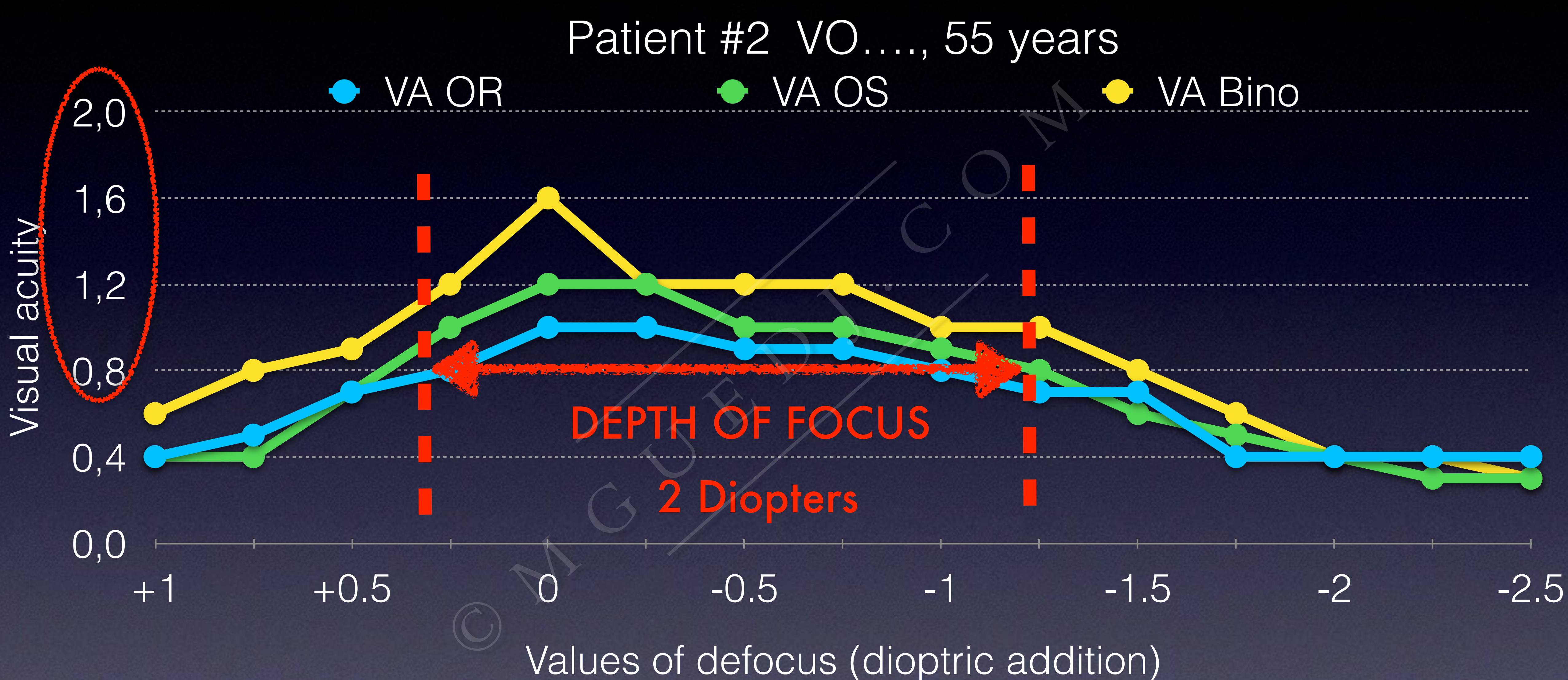
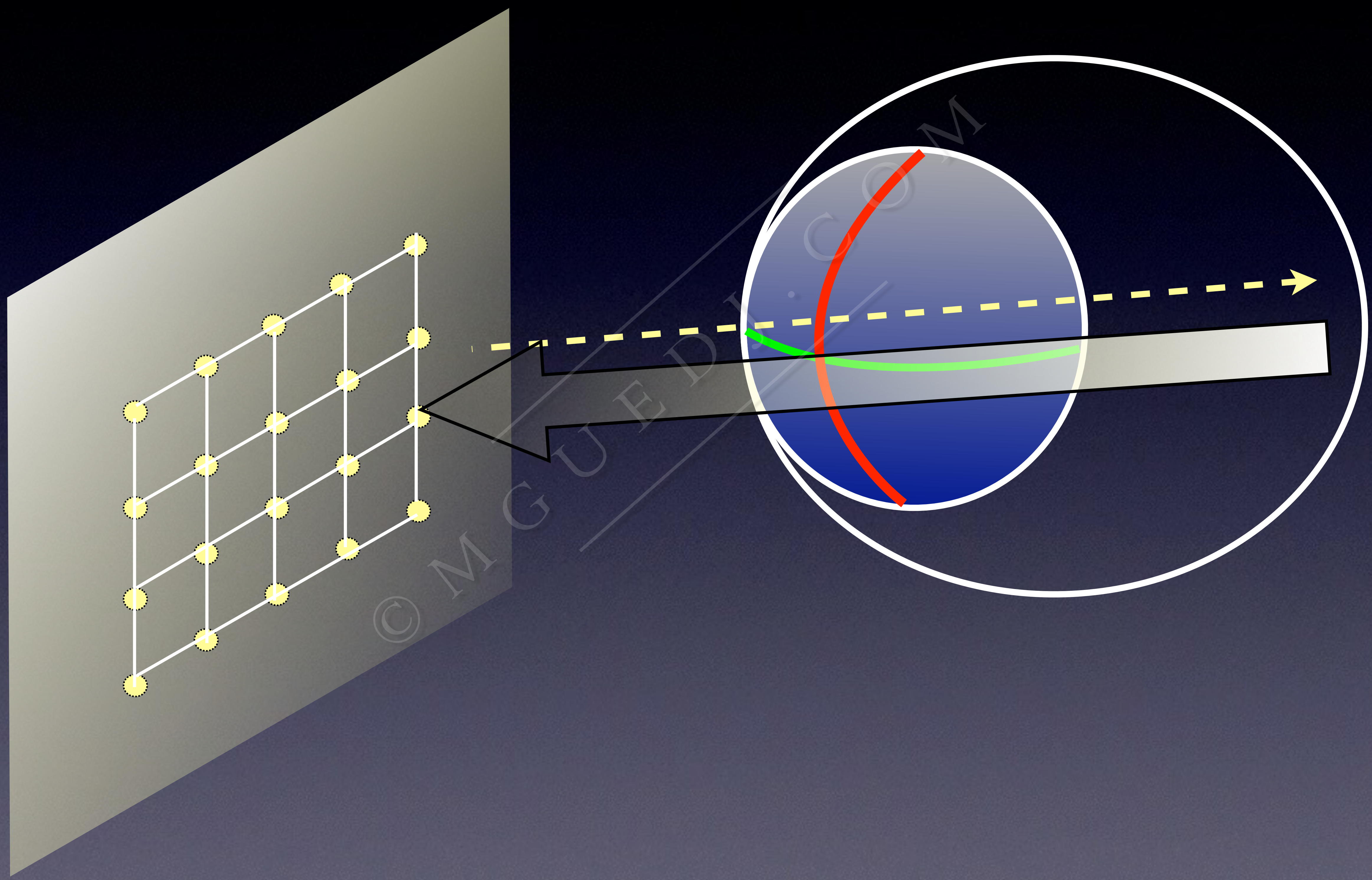
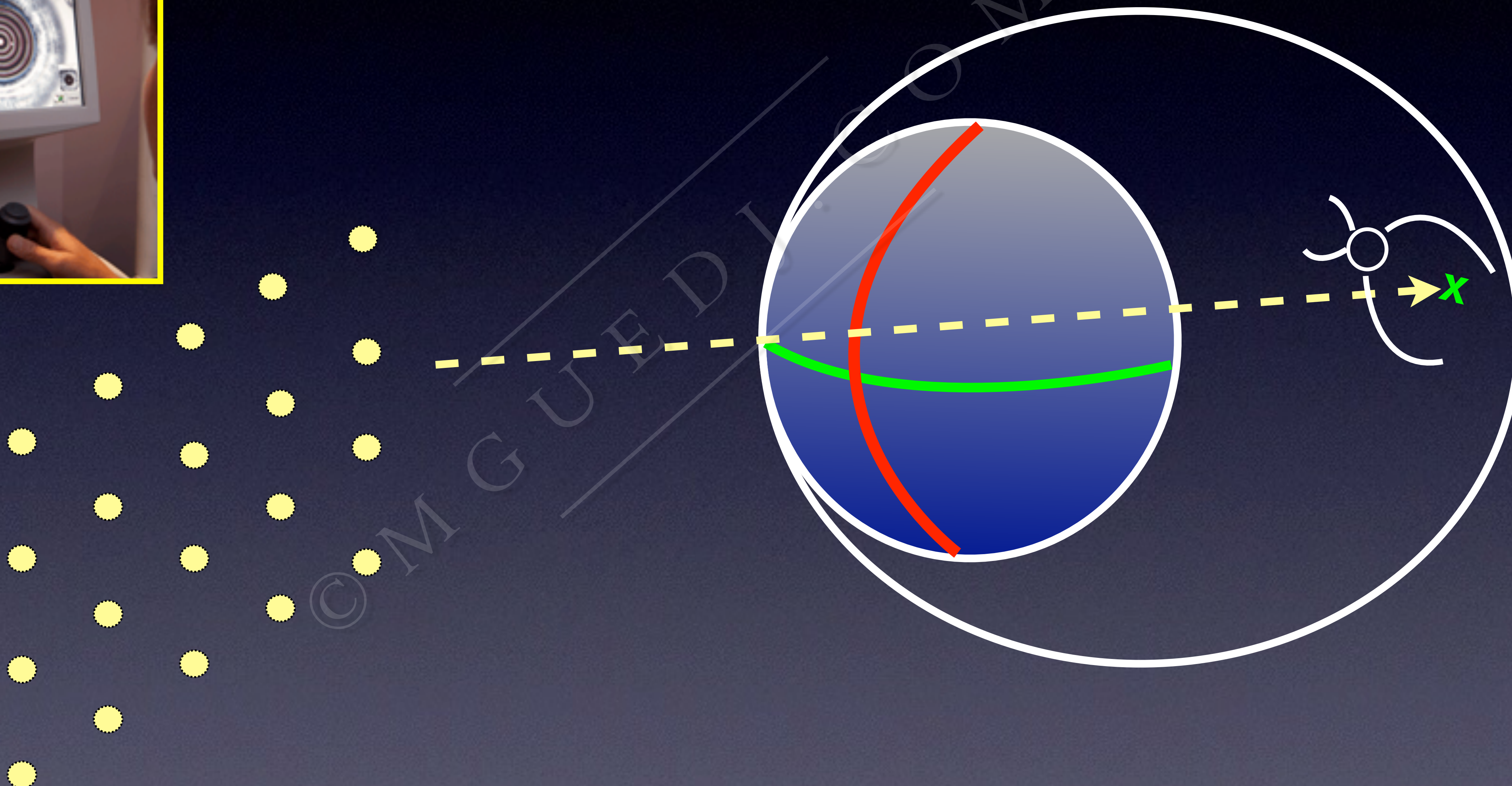


2. THE WAVEFRONT ANALYSIS



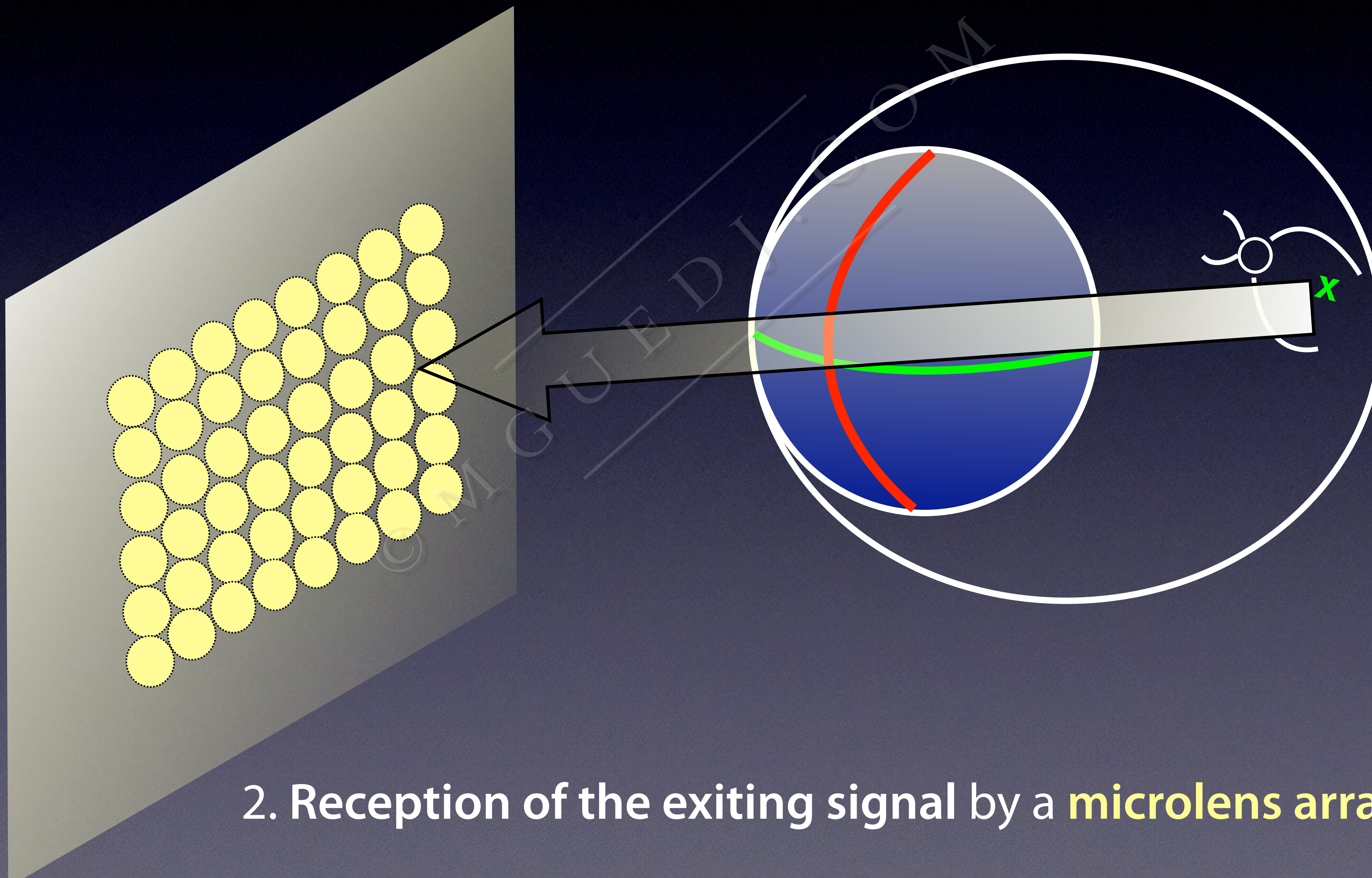
2. THE WAVEFRONT ANALYSIS

OPD SCAN III - NIDEK



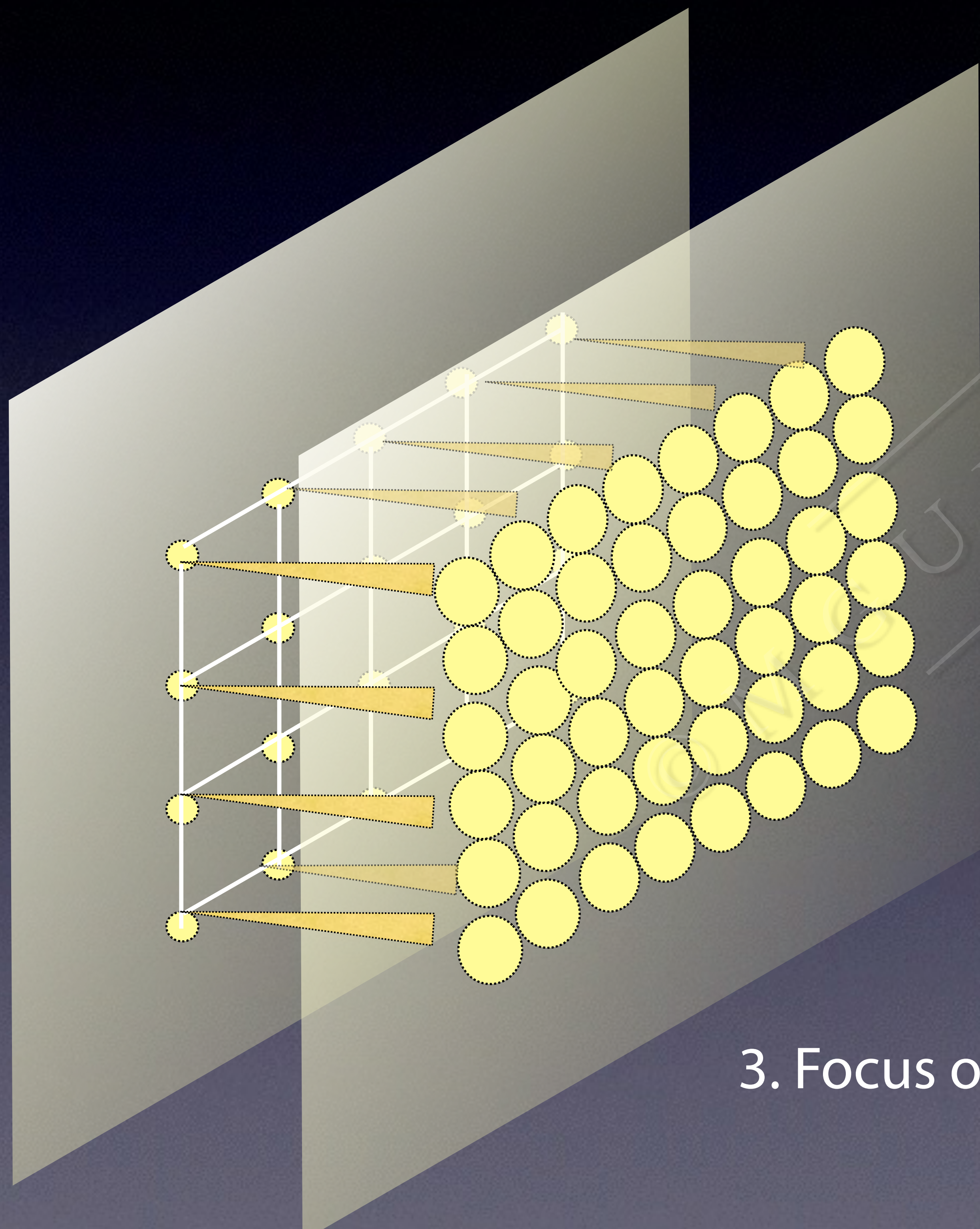
1. **Emission of an incident laser beam** focused on the fovea

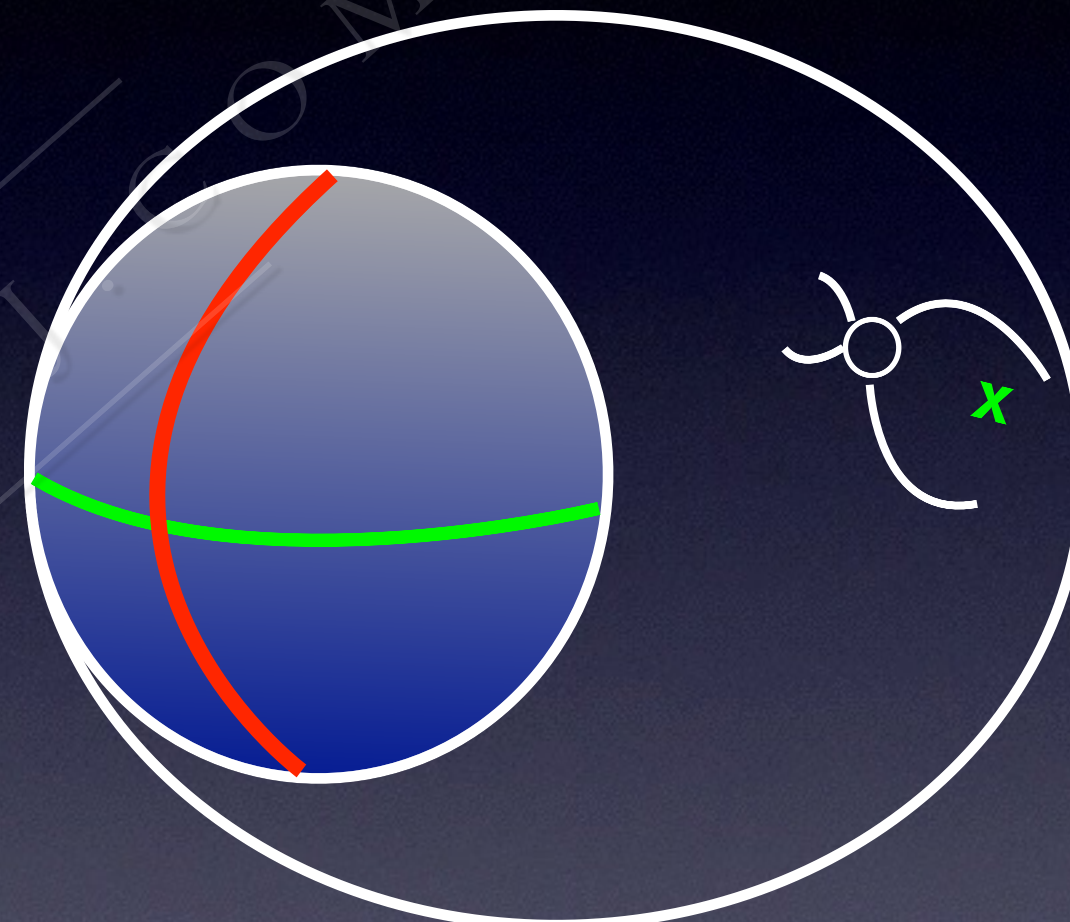
2. THE WAVEFRONT ANALYSIS



2. **Reception of the exiting signal** by a **microlens array**

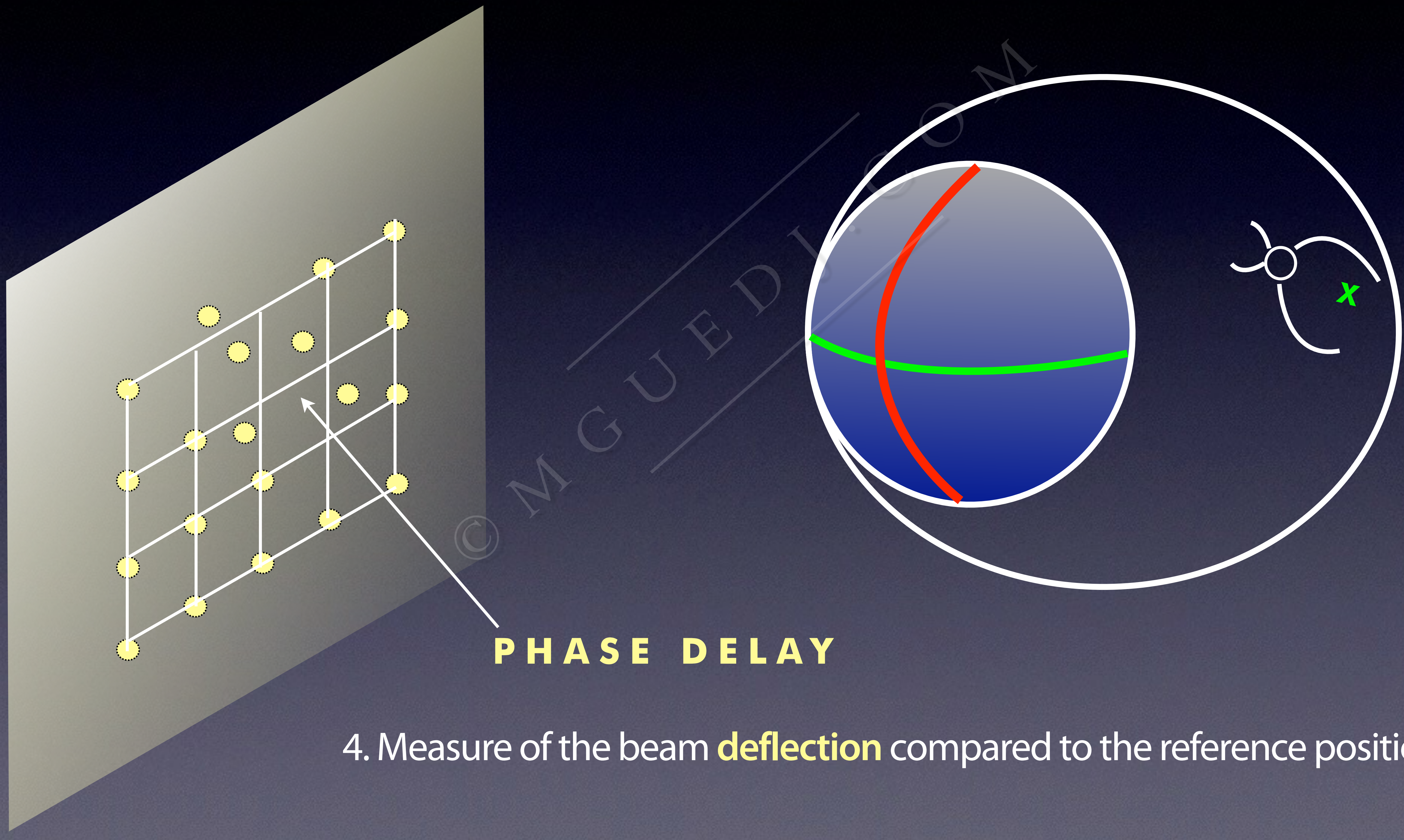
2. THE WAVEFRONT ANALYSIS





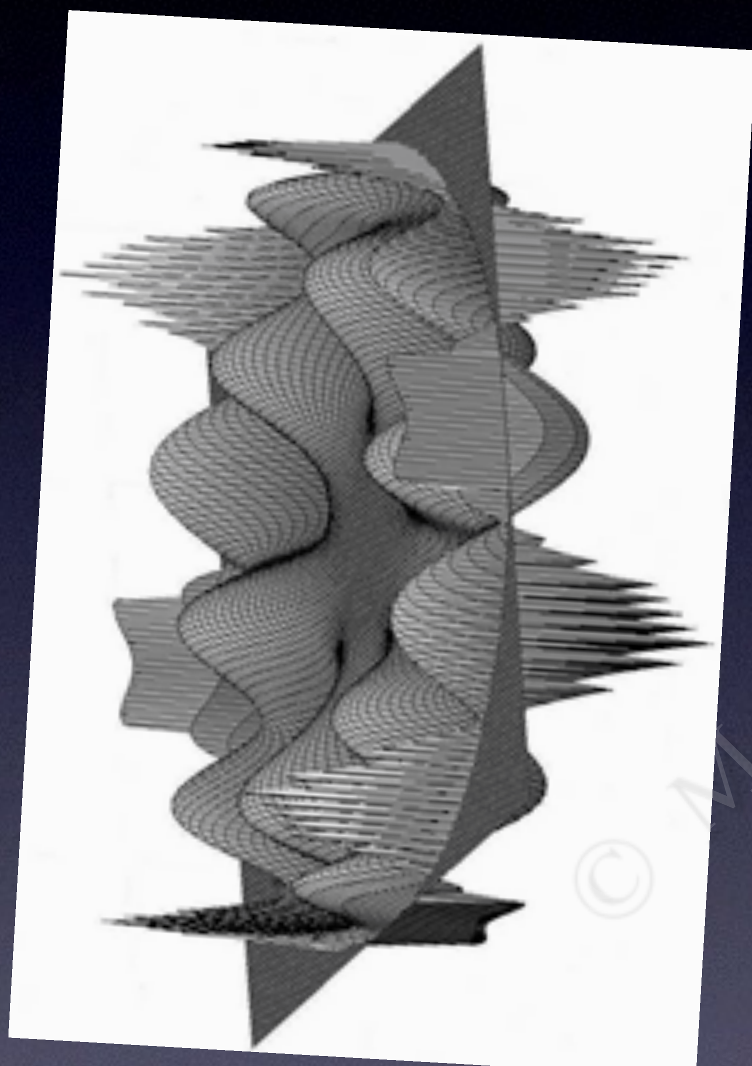
3. Focus on a digital sensor from the microlens array
➪ "**fragmentation**" of the wavefront

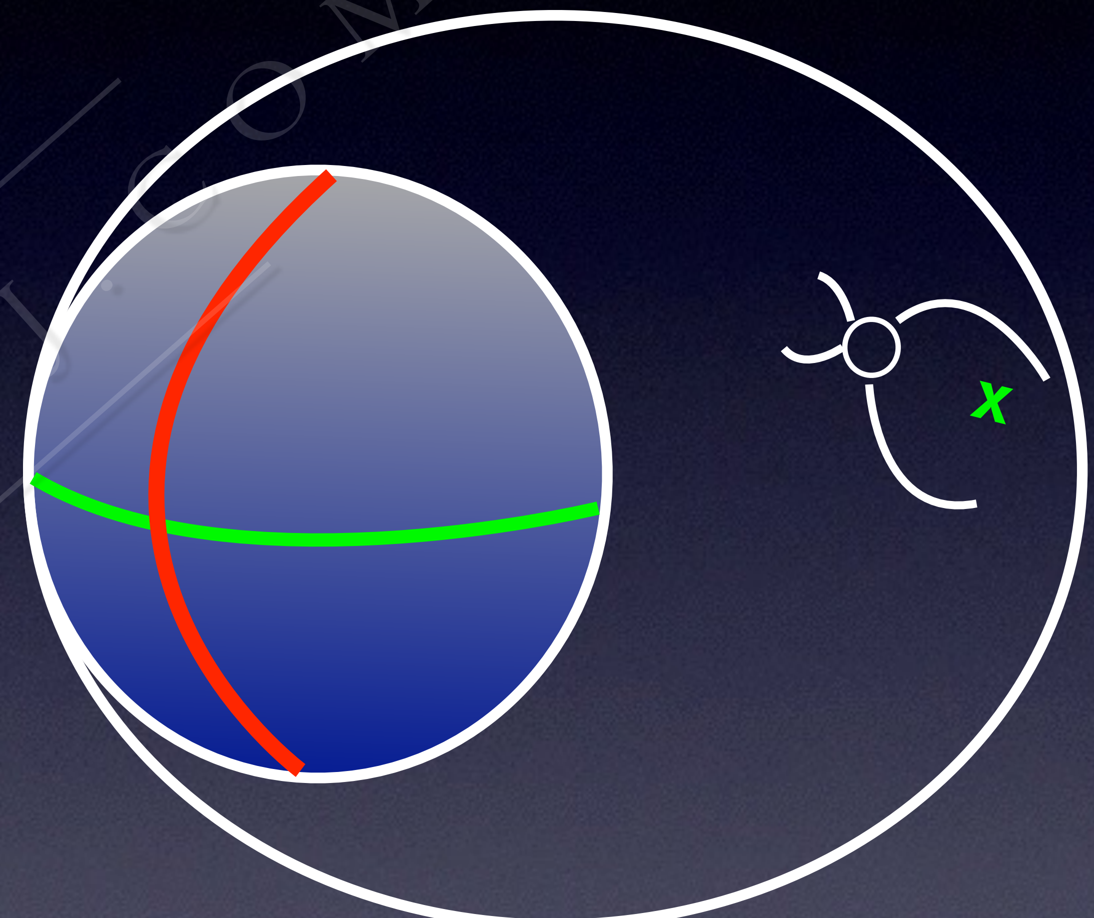
2. THE WAVEFRONT ANALYSIS



4. Measure of the beam **deflection** compared to the reference position

2. THE WAVEFRONT ANALYSIS



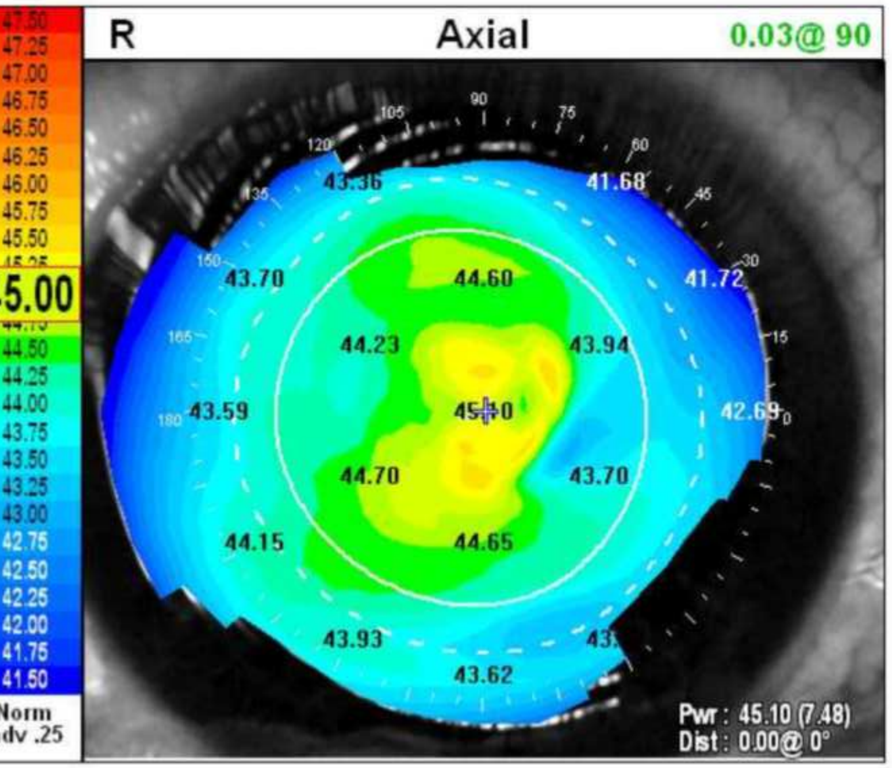


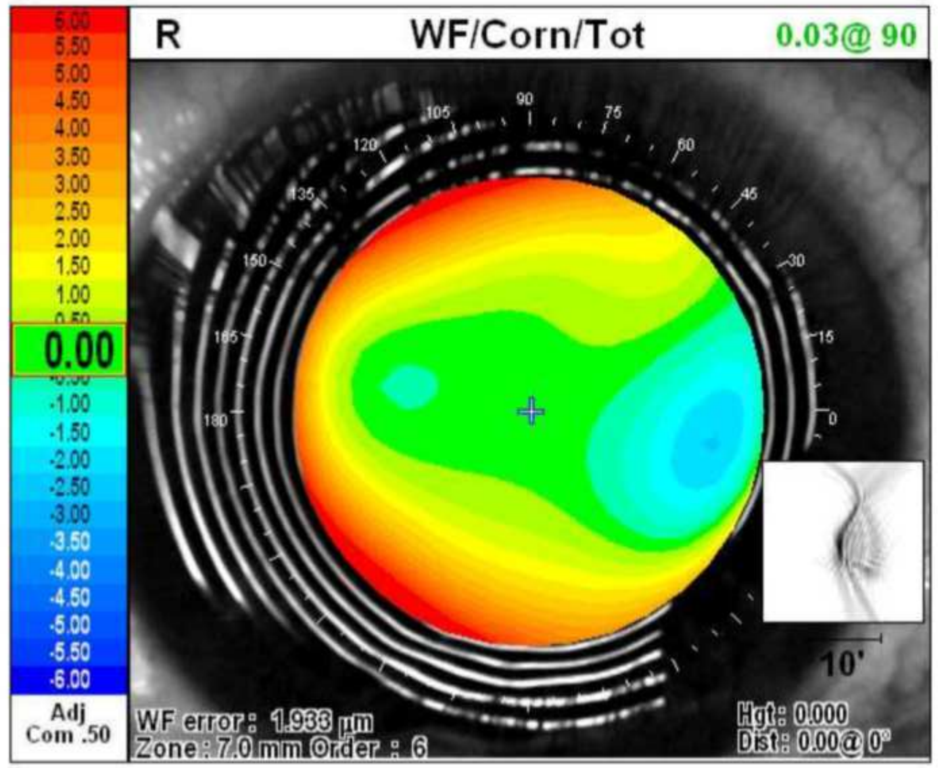
5. Mathematical integration for a **3D plotting** of the WF.
(decomposition using **Zernike polynomials**)

NIDEK		FOR 1	12/11/2013 14:47 / Ver.1.05.S1

ID	006152		Physician	
Name	[redacted]		Technician	

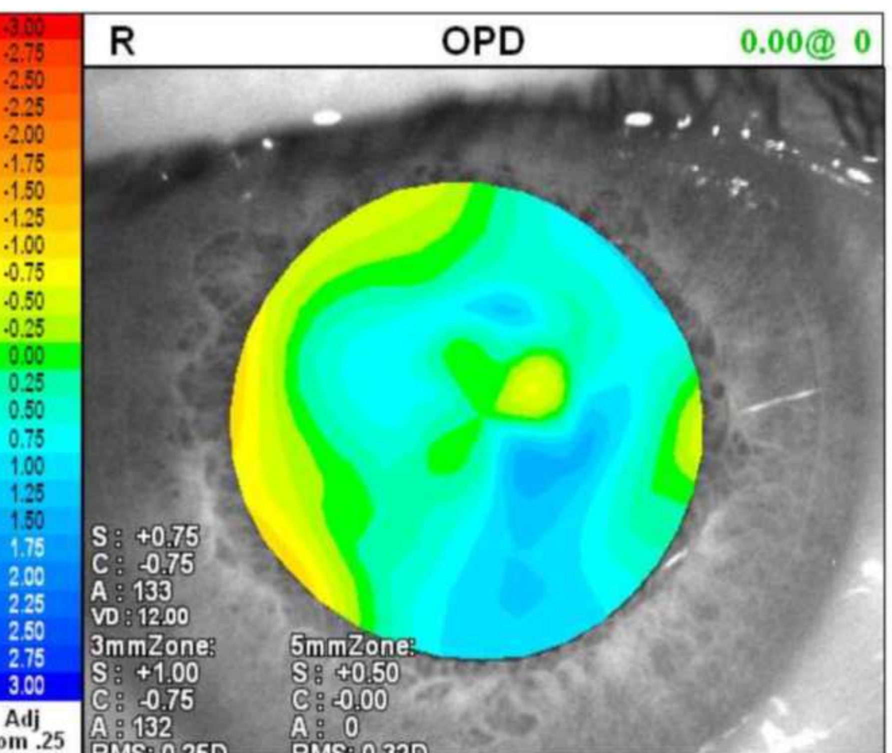
ExamNo	1	Date	12/11/2013 15:03	Comment		Diagnosis	

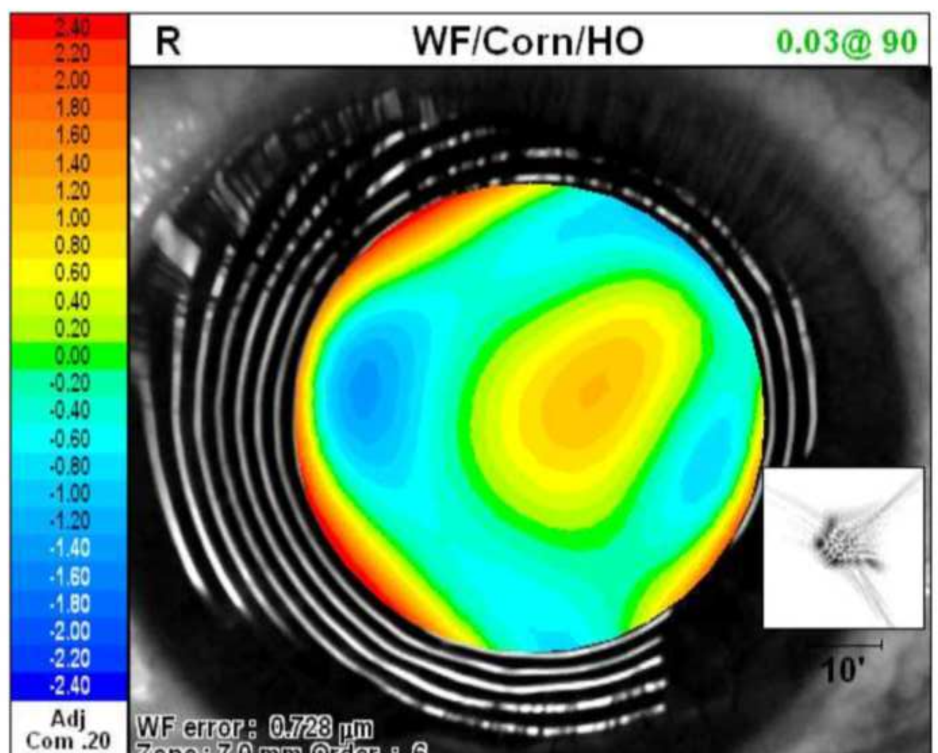


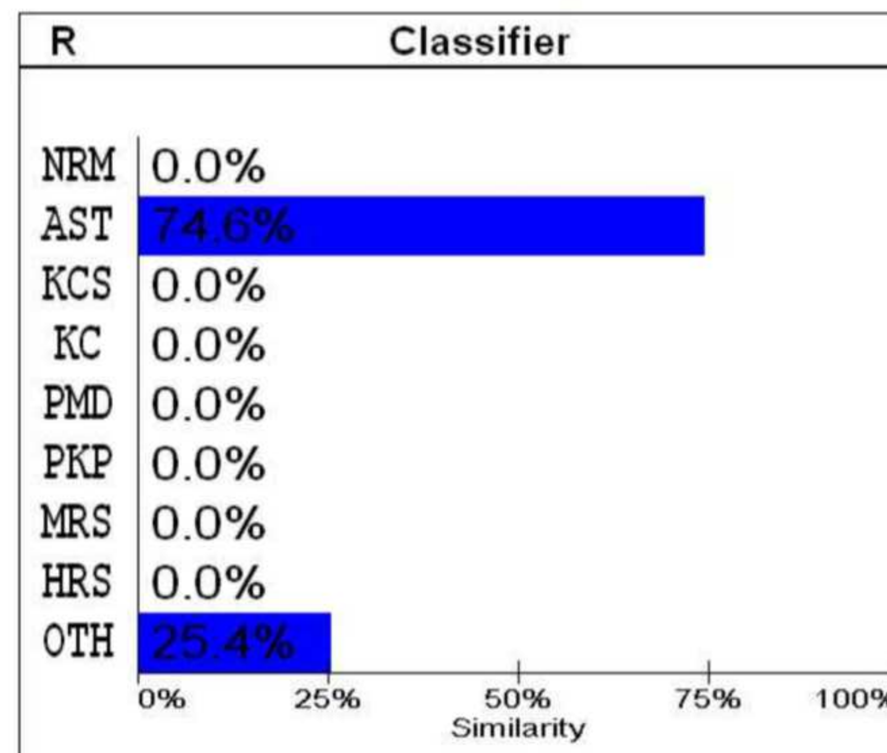


R — Zernike/OPD — Z: 7.04 O:

Total	
0.Piston	-1.587
1.Tilt	0.430
2.Tilt	-0.529
3.Astigm...	0.565
4.Defocus	-0.789
5.Astigm...	0.267
6.Trefoil	-0.231
7.Coma	0.117
8.Coma	-0.212
9.Trefoil	0.351
10.Tetrafoil	0.151
11.Astig...	-0.202
12.Spheri...	0.175
13.Astig...	0.086
14.Tetrafoil	-0.138
15.Pentaf...	-0.076
16.Trefoil	-0.171
17.Coma	-0.006
18.Coma	-0.007
19.Trefoil	-0.060
20.Pentaf...	-0.184
21.Hexafoil	-0.069
22.Tetrafoil	-0.103
23.Astig...	0.020
24.Spheri...	0.065
25.Astig...	0.019
26.Tetrafoil	0.010
27.Hexafoil	-0.018







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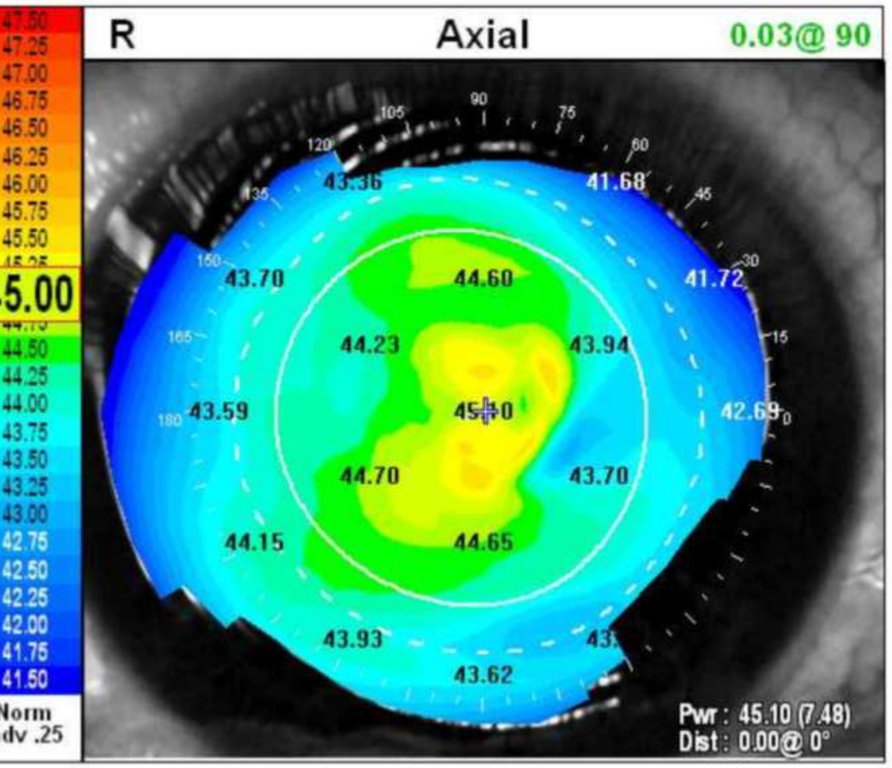
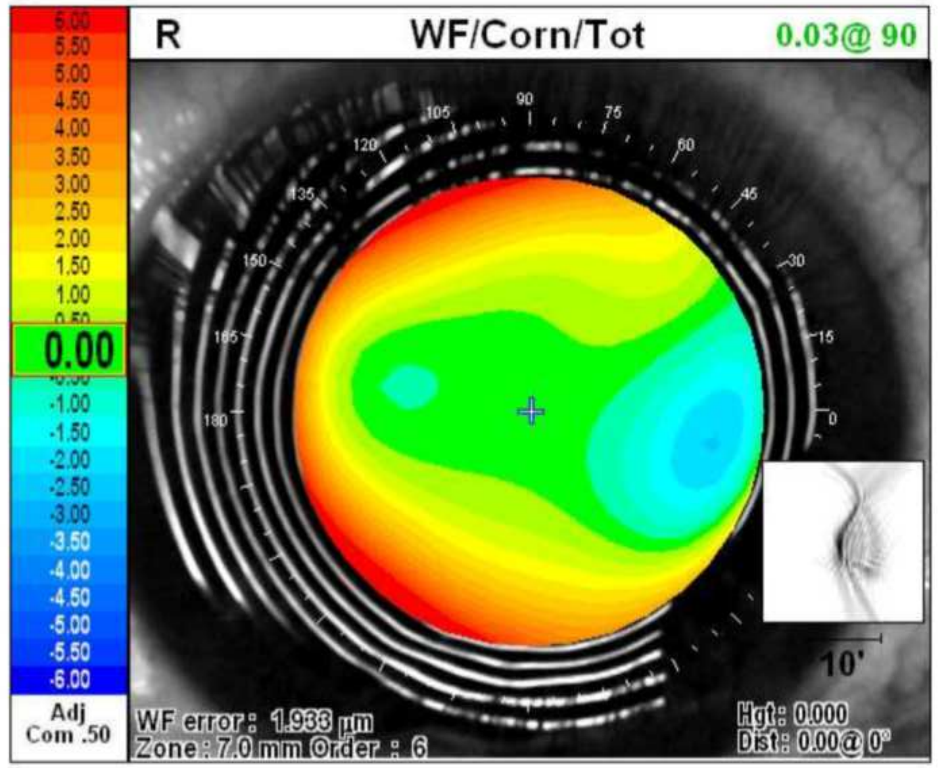
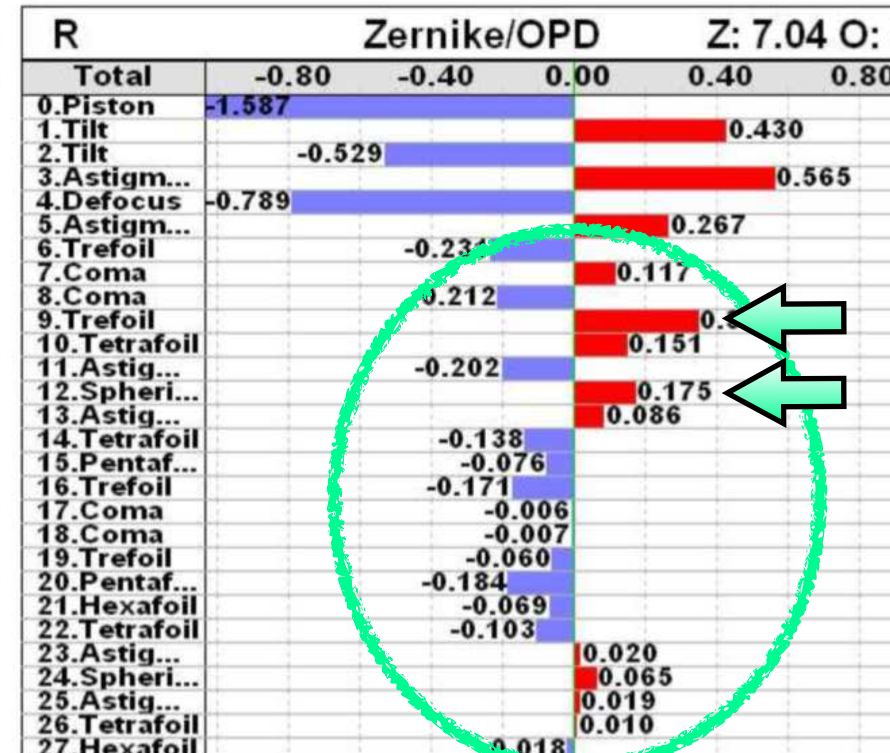
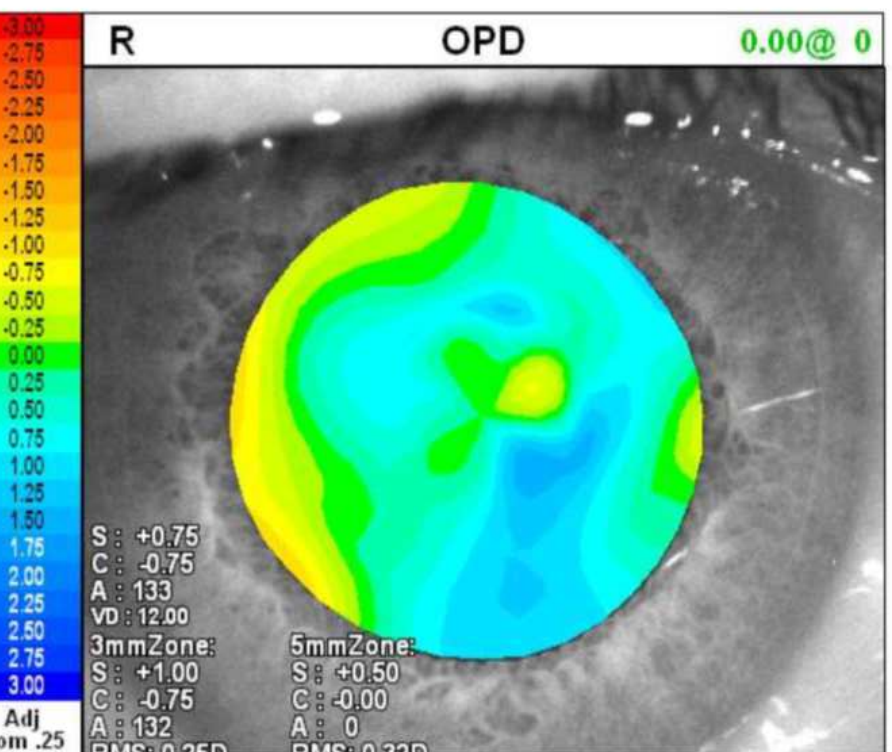
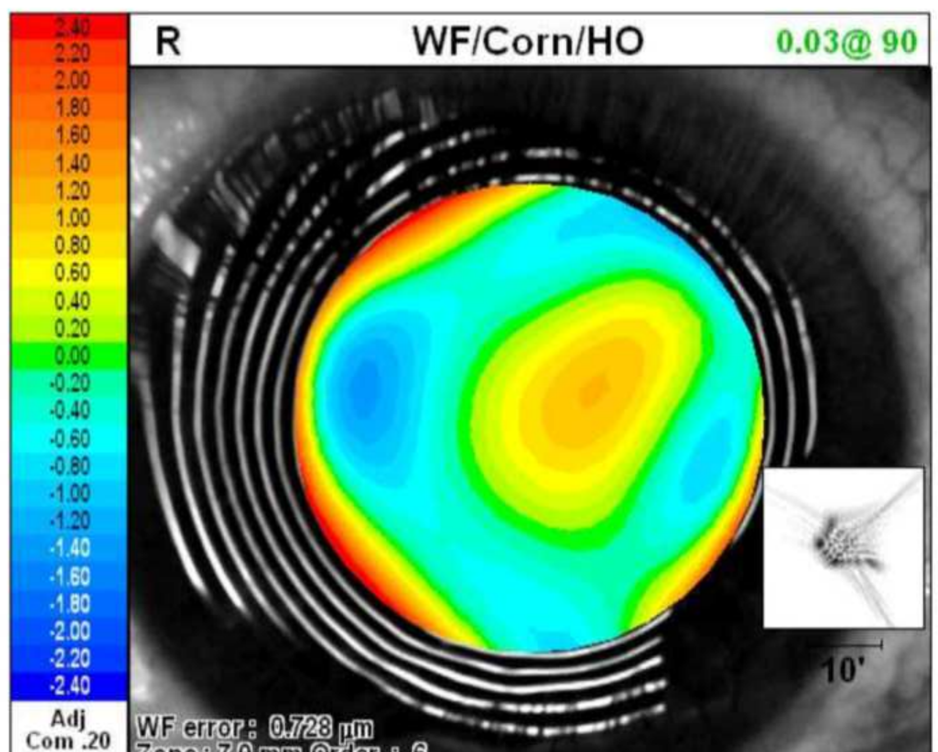
ExamNo	1	Date	12/11/2013 15:03	Comment	Diagnosis	

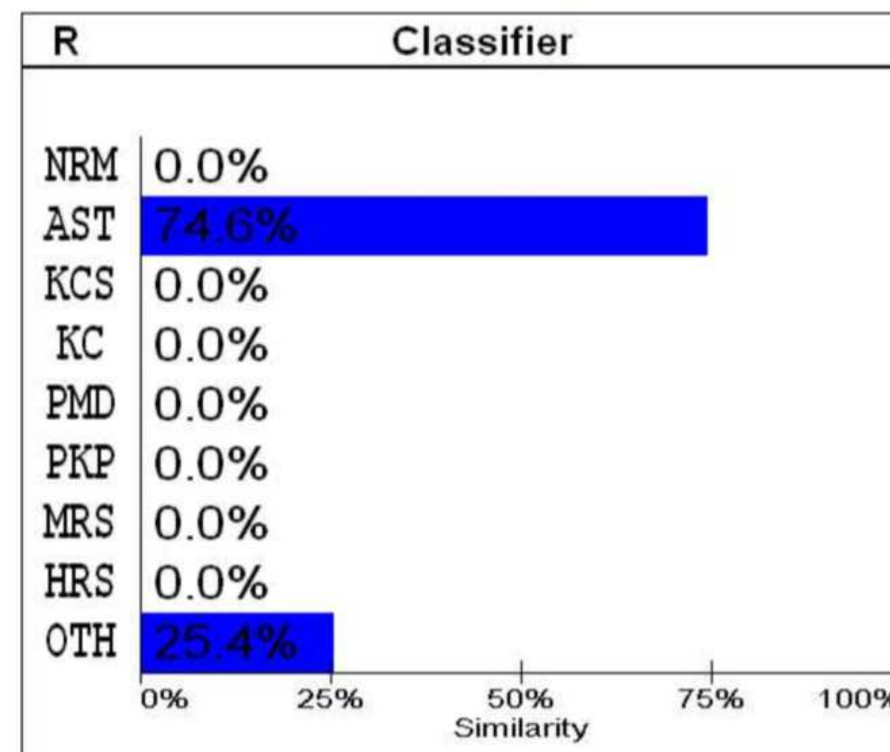










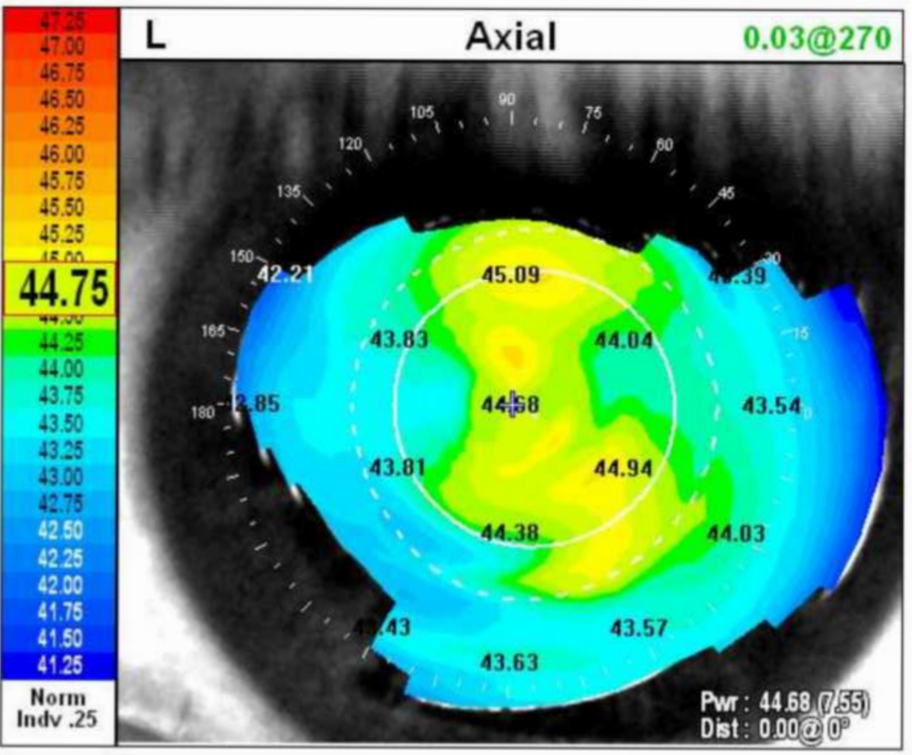


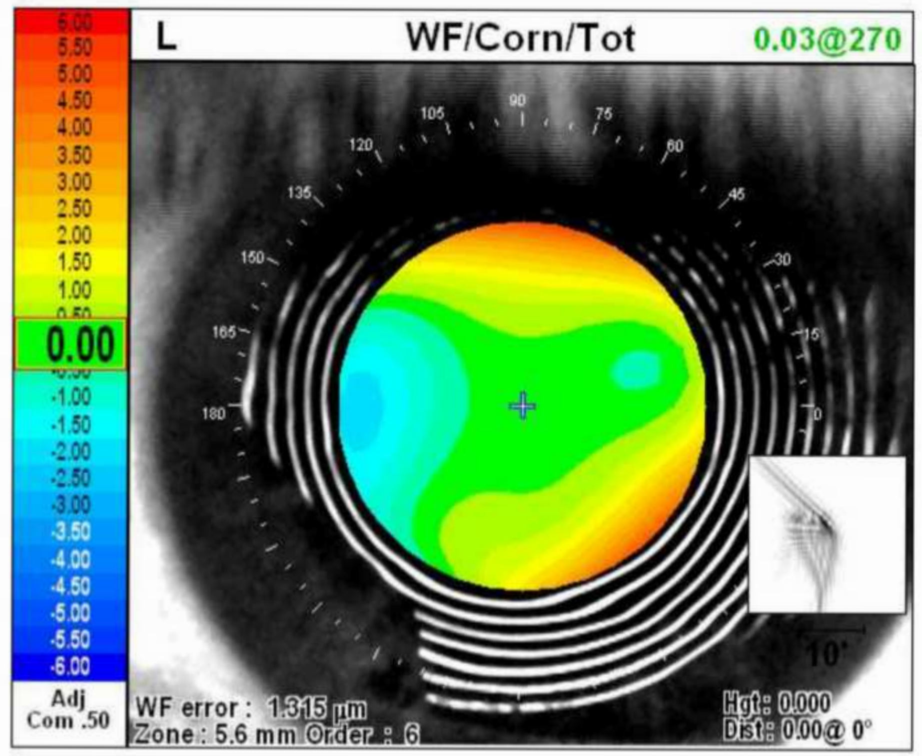
2. THE WAVEFRONT ANALYSIS

ROOT MEAN SQUARE

$$\mathrm{RMS} = \sqrt{\frac{\sum n^2}{n}}$$

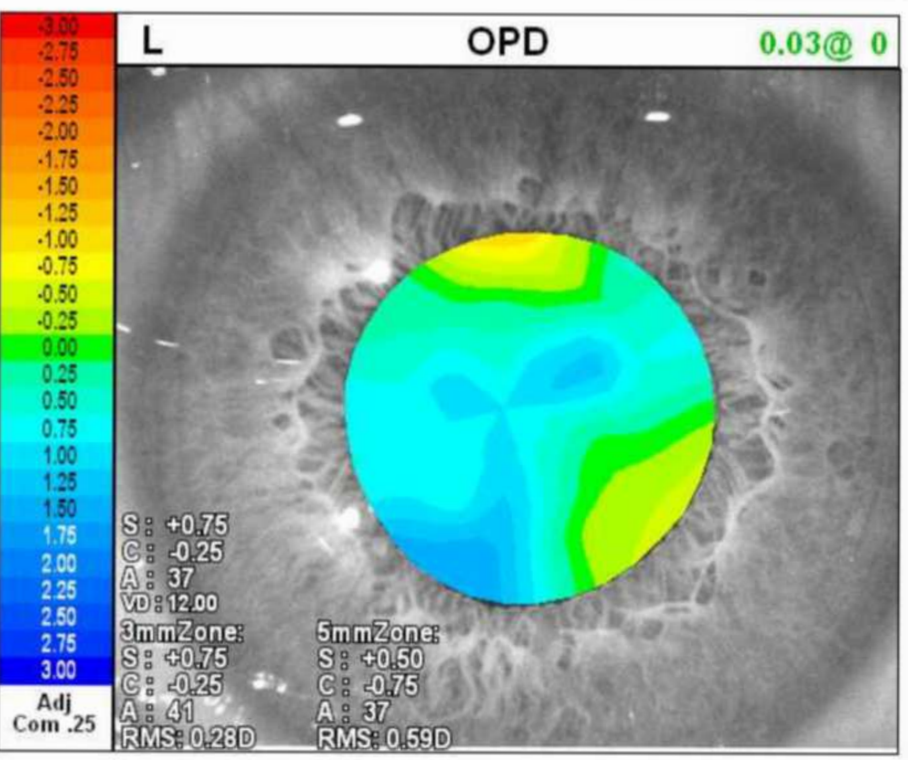
NIDEK				FOR 1	12/11/2013 14:47 Ver.1.05.S1
ID	006152			Physician	
Name	[redacted]			Technician	
ExamNo	1	Date	12/11/2013 15:03	Comment	Diagnosis

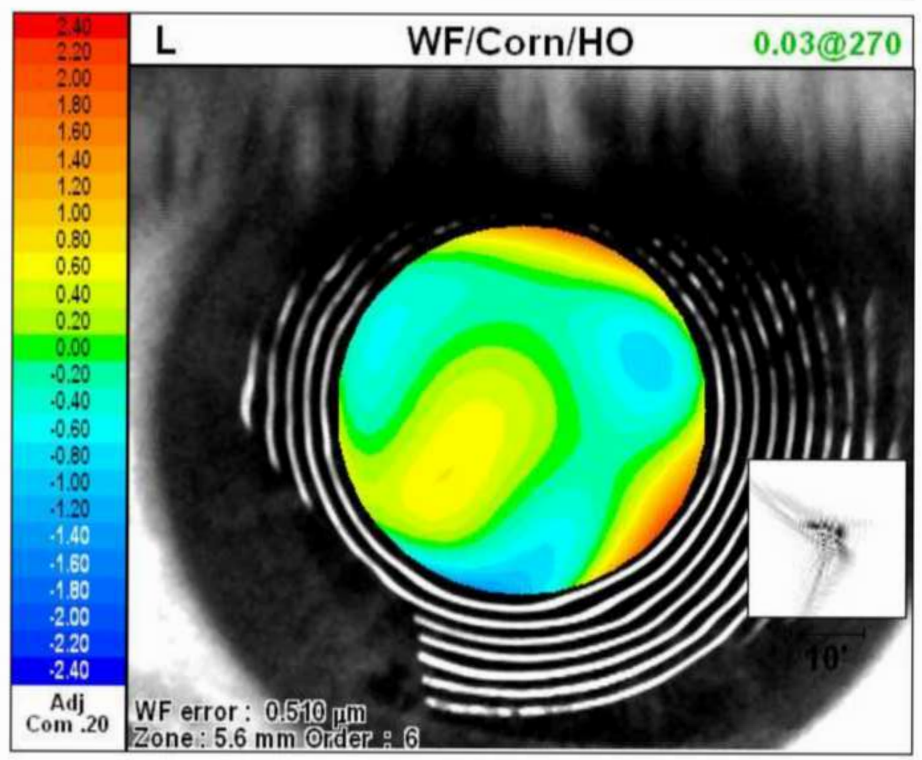


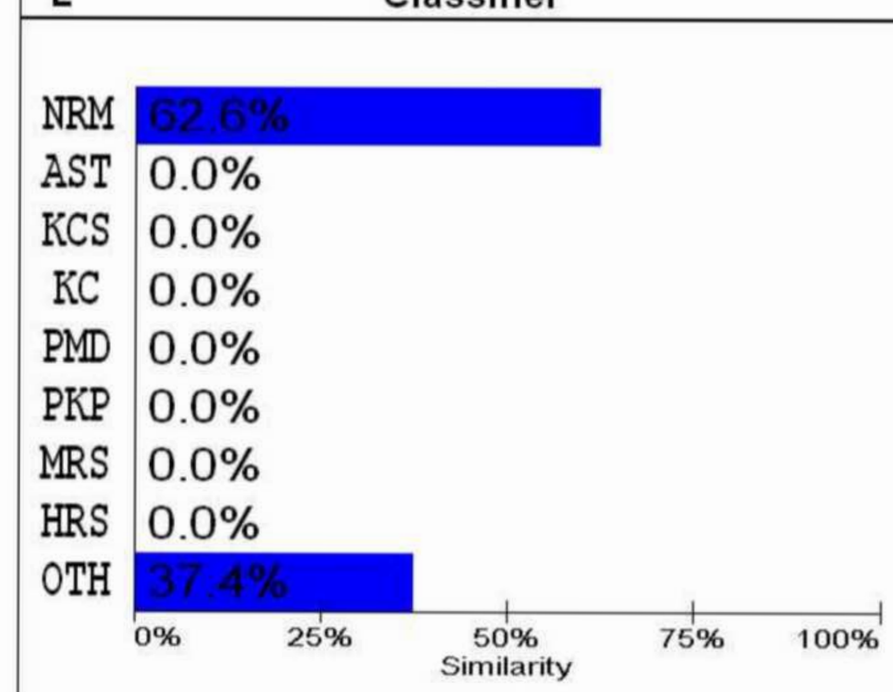


L Zernike/OPD Z: 5.62 O: 6

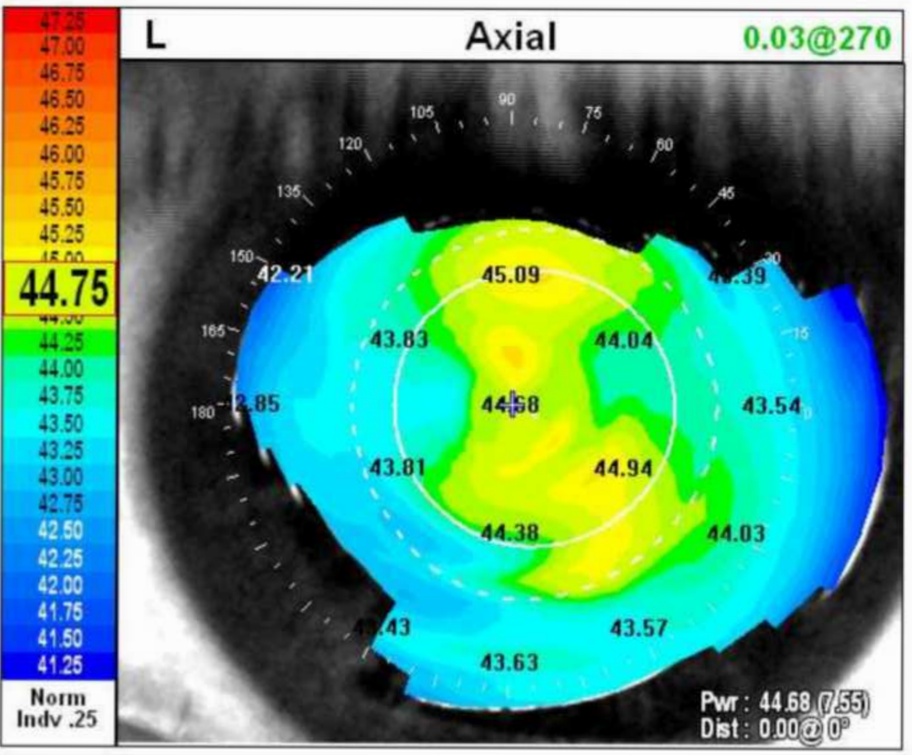
Total	-0.80 / -0.40 / 0.00 / 0.40 / 0.80
0.Piston	-1.178
1.Tilt	0.360
2.Tilt	0.212
3.Astigm...	-0.408
4.Defocus	-0.548
5.Astigm...	-0.096
6.Trefoil	-0.496
7.Coma	0.179
8.Coma	0.119
9.Trefoil	-0.105
10.Tetrafoil	-0.095
11.Astig...	-0.072
12.Spheri...	0.073
13.Astig...	-0.011
14.Tetrafoil	-0.074
15.Pentaf...	0.044
16.Trefoil	0.046
17.Coma	0.024
18.Coma	0.029
19.Trefoil	-0.029
20.Pentaf...	0.032
21.Hexafoil	-0.043
22.Tetrafoil	0.026
23.Astig...	-0.002
24.Spheri...	-0.025
25.Astig...	-0.007
26.Tetrafoil	0.010
27.Hexafoil	0.071

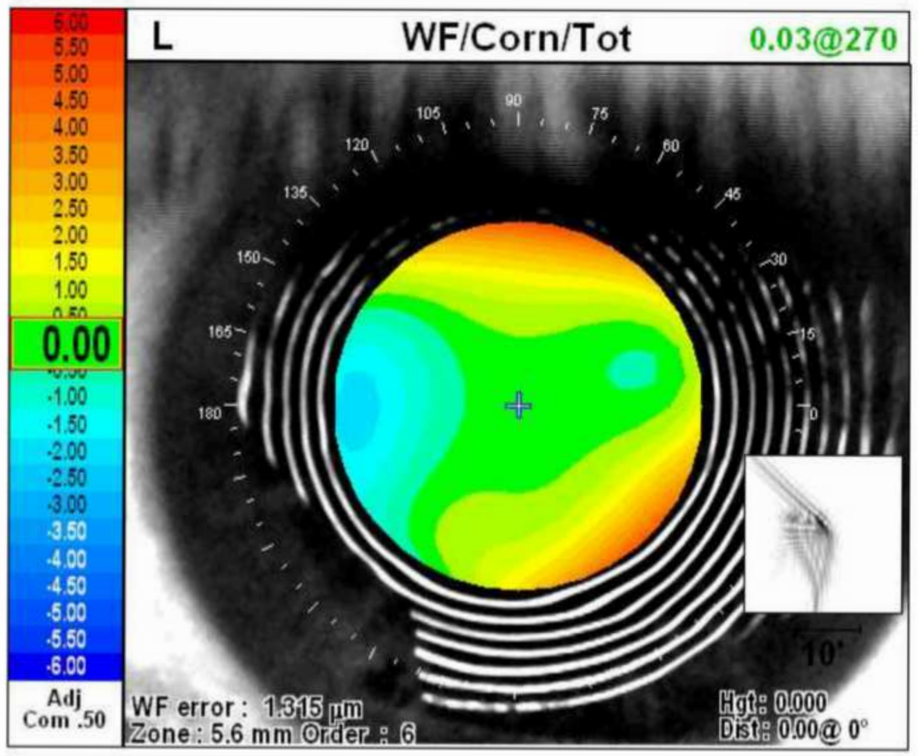






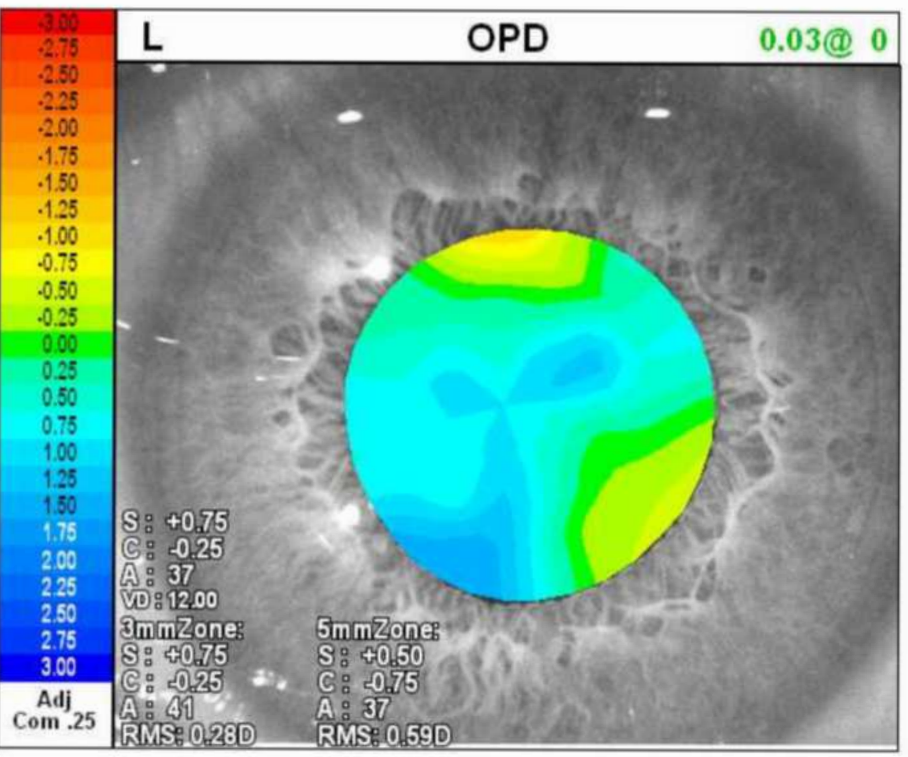
NIDEK				FOR 1	12/11/2013 14:47 Ver.1.05.S1
ID	006152			Physician	
Name	[redacted]			Technician	
ExamNo	1	Date	12/11/2013 15:03	Comment	Diagnosis

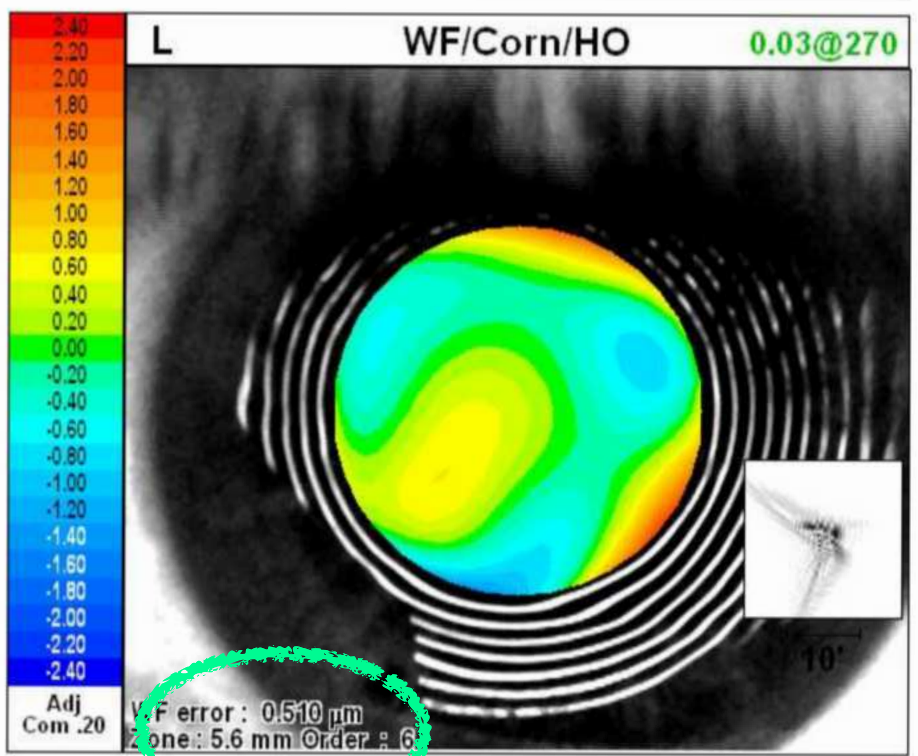


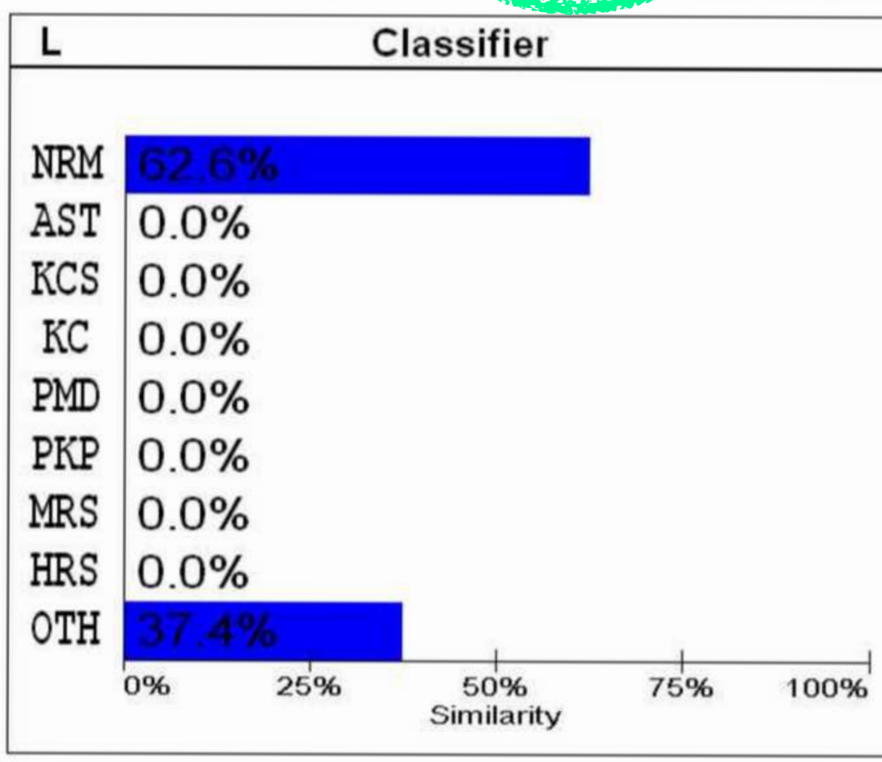


L Zernike/OPD Z: 5.62 O: 6

Total	-0.80 -0.40 0.00 0.40 0.80
0.Piston	-1.178
1.Tilt	0.360
2.Tilt	0.212
3.Astigm...	-0.408
4.Defocus	-0.548
5.Astigm...	-0.096
6.Trefoil	-0.496
7.Coma	0.179
8.Coma	0.119
9.Trefoil	-0.105
10.Tetrafoil	-0.095
11.Astig...	-0.072
12.Spheri...	0.073
13.Astig...	-0.011
14.Tetrafoil	-0.074
15.Pentaf...	0.044
16.Trefoil	0.046
17.Coma	0.024
18.Coma	0.029
19.Trefoil	-0.029
20.Pentaf...	0.032
21.Hexafoil	-0.043
22.Tetrafoil	0.026
23.Astig...	-0.002
24.Spheri...	-0.025
25.Astig...	-0.007
26.Tetrafoil	0.010
27.Hexafoil	0.071

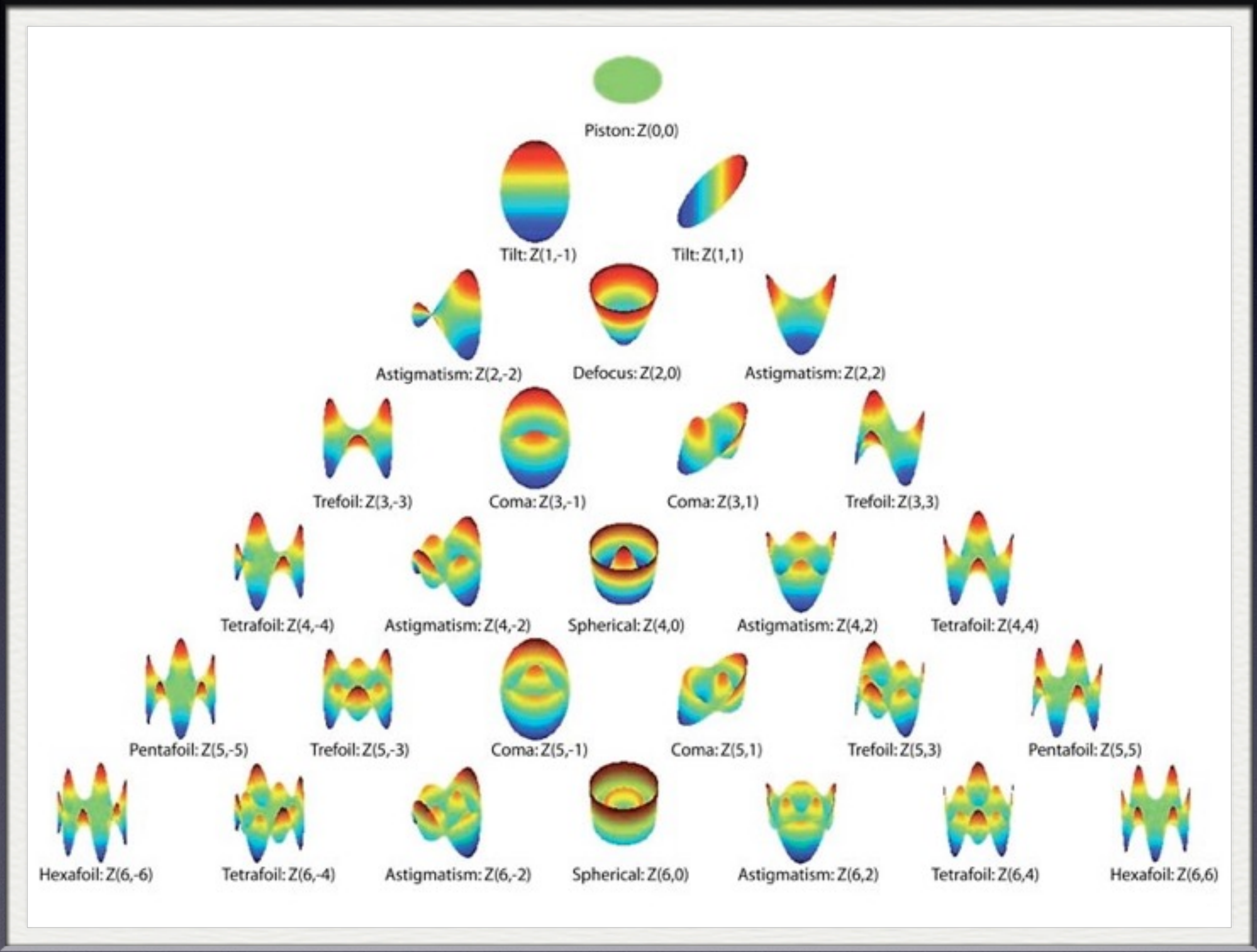




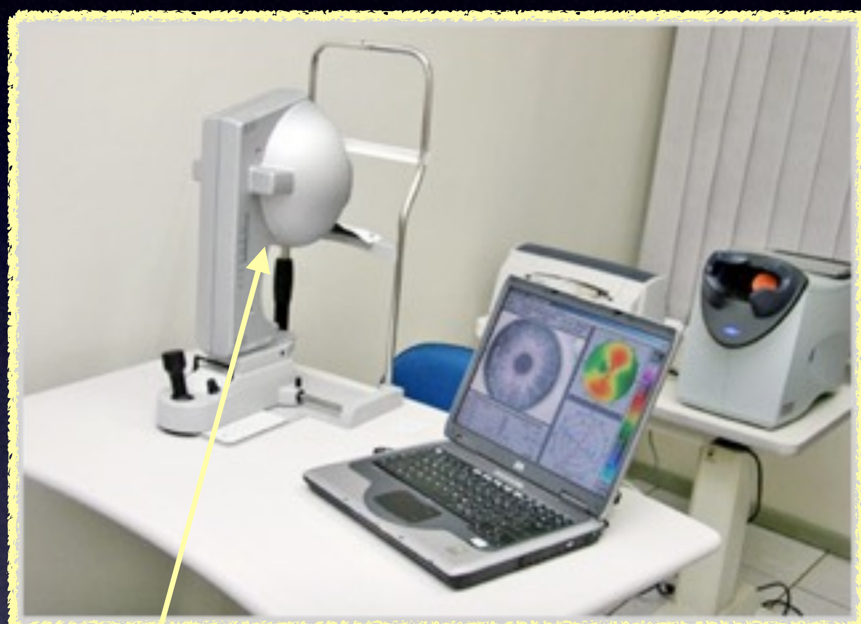


2. THE WAVEFRONT ANALYSIS

ZERNIKE POLYNOMIALS



3. THE PUPILLOMETRY



WAVELIGHT ALLEGRO
TOPOLYZER 2

- MESOPIC PUPIL SIZE
- PHOTOPIC PUPIL SIZE
- PUPILLARY SHIFT

WAVELIGHT - ALLEGRO TOPOLYZER VARIO

Patient Examen Affichage Paramètres T-CAT Divers

Nom: [redacted]		Date ex.: 12.11.13	N° ID:
Né(e) le: 18.03.58	Oeil: Droit	Heure ex.: 15:06:47	Notes: Pupil Center Shift

Small pupil:

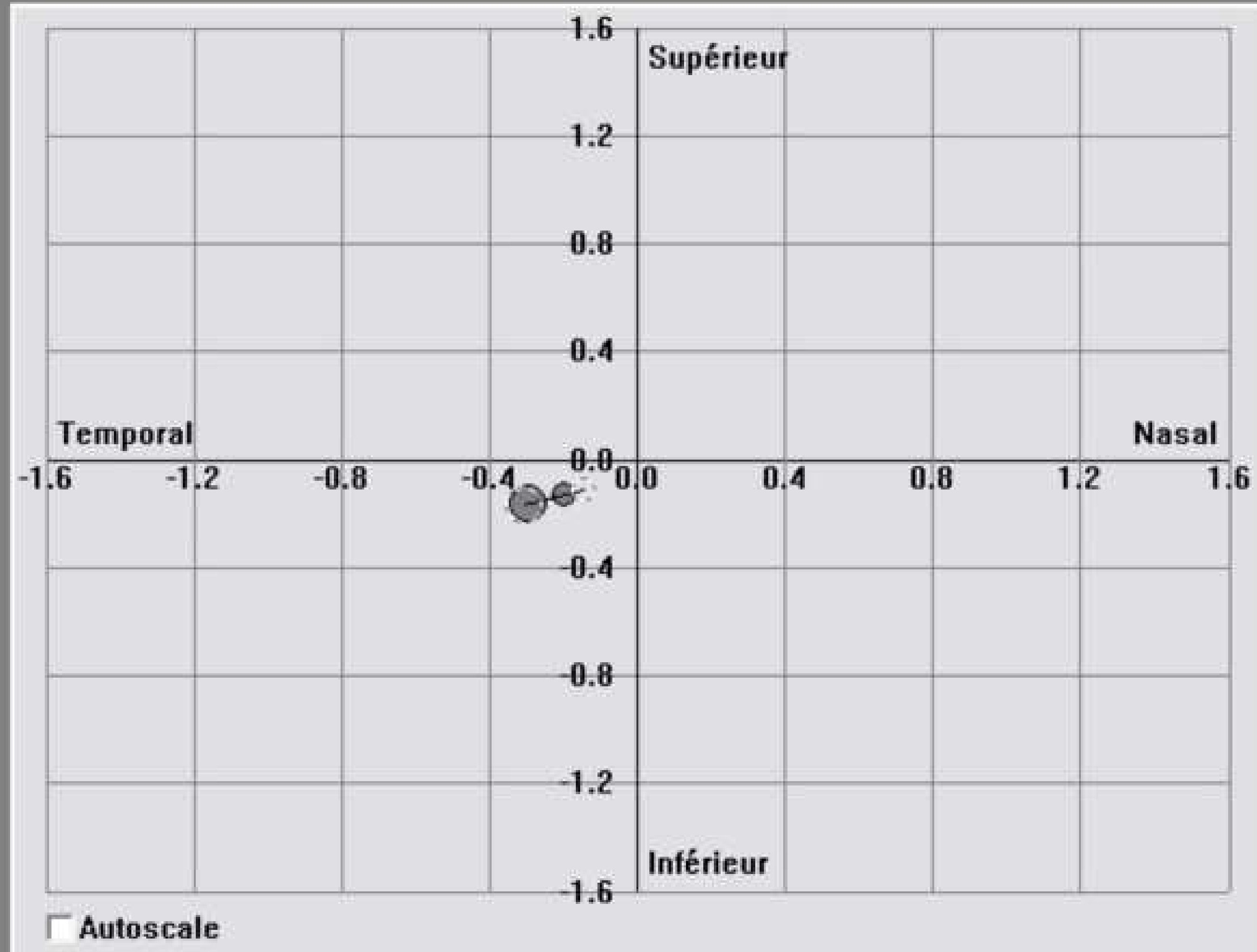
Moy.:	3.72mm
Minimum:	3.49mm
X:	-0.20mm
Y:	-0.13mm
Dist. to Apex:	0.24mm

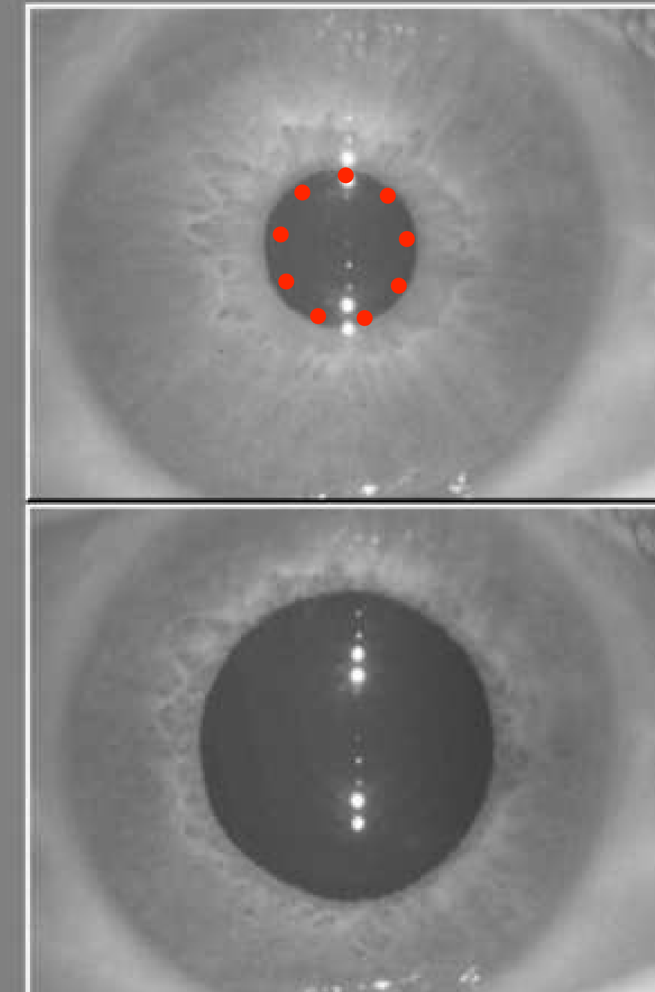
Pupil Center Shift:

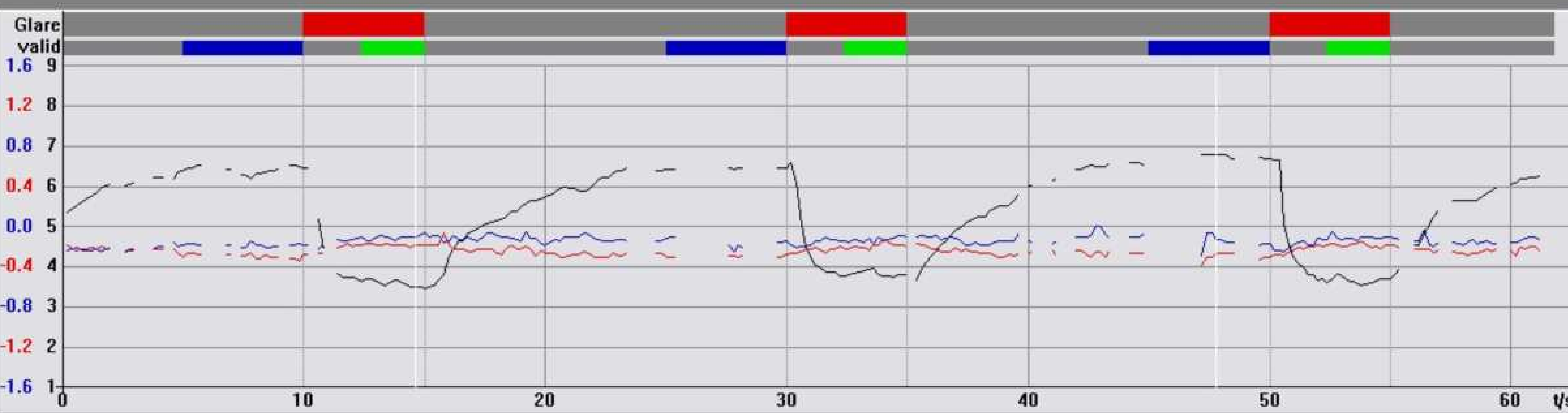
Interpolated:	0.18mm (2-7mm)
Measured:	0.10mm

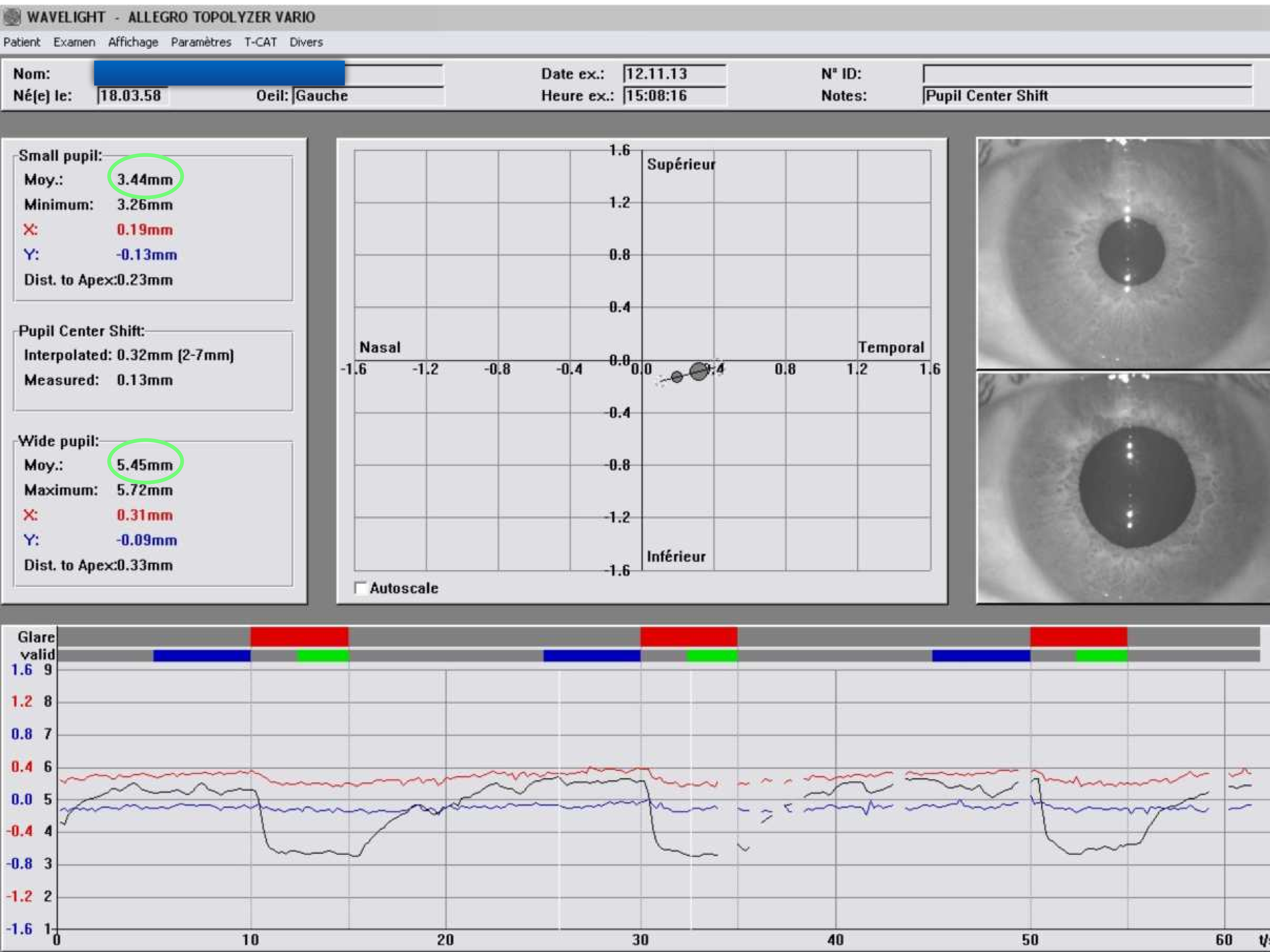
Wide pupil:

Moy.:	6.52mm
Maximum:	6.81mm
X:	-0.30mm
Y:	-0.16mm
Dist. to Apex:	0.34mm








WAVELIGHT - ALLEGRO TOPOLYZER VARIO
Patient Examen Affichage Paramètres T-CAT Divers
Nom: [redacted]
Né(e) le: 18.03.58
Oeil: Gauche
Date ex.: 12.11.13
Heure ex.: 15:08:16
N° ID:
Notes: Pupil Center Shift
Small pupil:
Moy.: 3.44mm
Minimum: 3.26mm
X: 0.19mm
Y: -0.13mm
Dist. to Apex: 0.23mm
Pupil Center Shift:
Interpolated: 0.32mm (2-7mm)
Measured: 0.13mm
Wide pupil:
Moy.: 5.45mm
Maximum: 5.72mm
X: 0.31mm
Y: -0.09mm
Dist. to Apex: 0.33mm
Supérieur
Inférieur
Nasal
Temporal
1.6
1.2
0.8
0.4
0.0
-0.4
-0.8
-1.2
-1.6
-1.6 -1.2 -0.8 -0.4 0.0 0.4 0.8 1.2 1.6
Autoscale
Glare
valid
1.6 9
1.2 8
0.8 7
0.4 6
0.0 5
-0.4 4
-0.8 3
-1.2 2
-1.6 1
0 10 20 30 40 50 60 t/s

WAVELIGHT - ALLEGRO TOPOLYZER VARIO

Patient Examen Affichage Paramètres T-CAT Divers

Nom:	[redacted]	Date ex.:	08.11.13	N° ID:	
Né(e) le:	20.12.61 Oeil: Droit	Heure ex.:	14:04:37	Notes:	Pupil Center Shift

Small pupil:

Moy.: 2.05mm

Minimum: 1.88mm

X: -0.19mm

Y: -3.80mm

Dist. to Apex:3.80mm

Pupil Center Shift:

Interpolated: 5.13mm (2-7mm)

Measured: 2.29mm

Wide pupil:

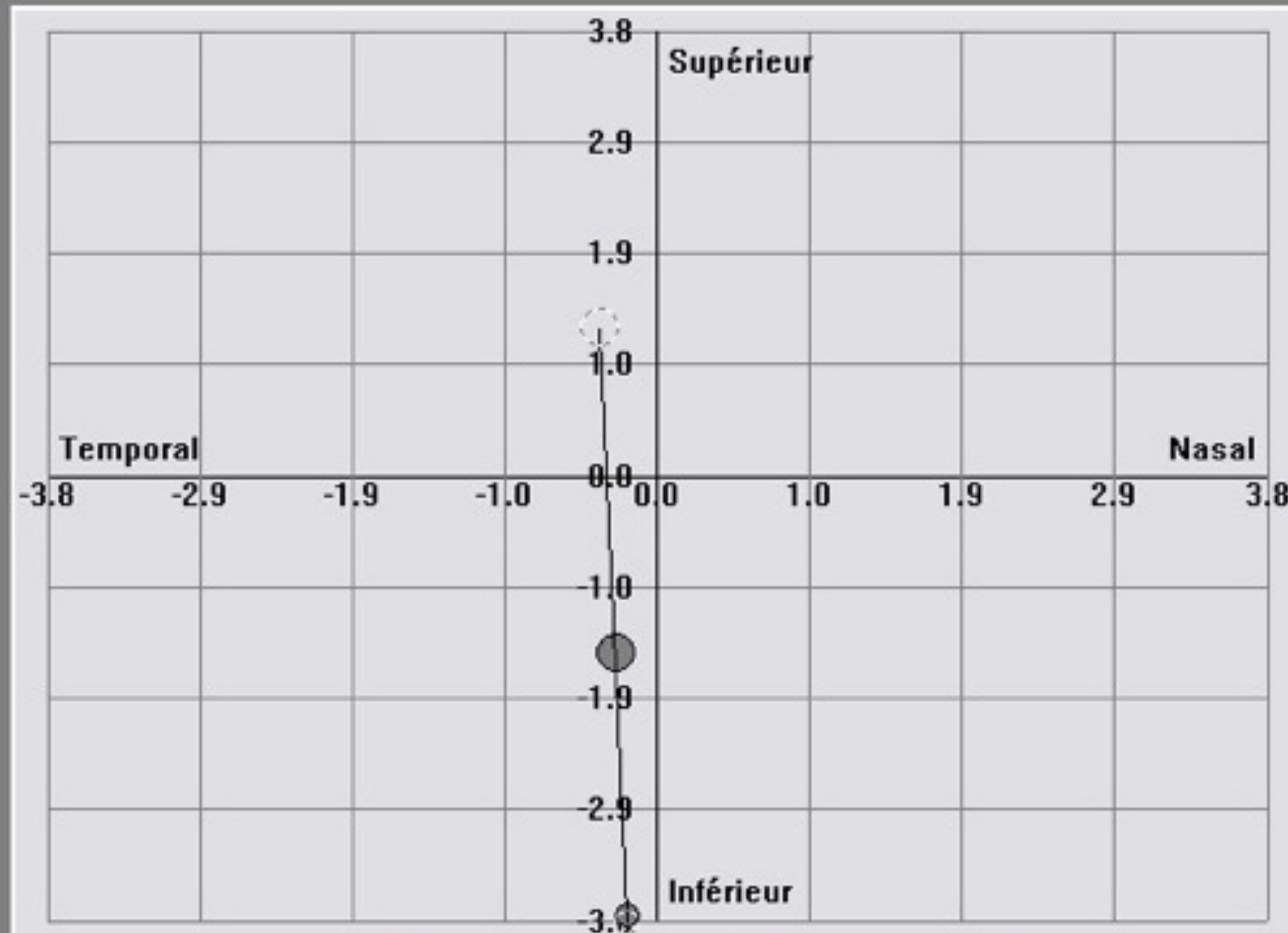
Moy.: 4.27mm

Maximum: 4.54mm

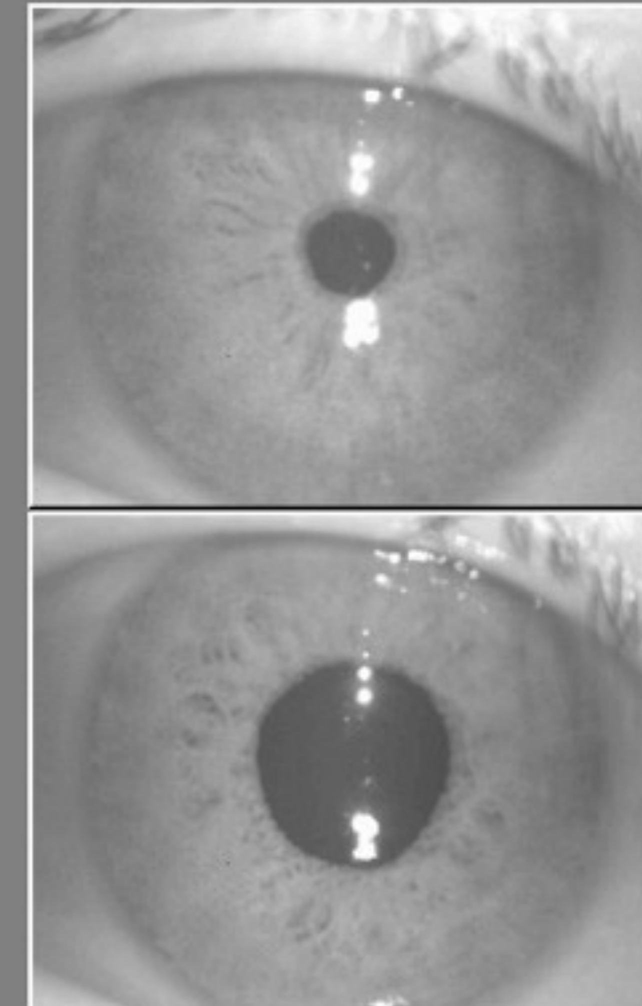
X: -0.26mm

Y: -1.52mm

Dist. to Apex:1.54mm



Autoscale Pupil Center Shift > 400µm Pupildiameter difference > 12%



WAVELIGHT - ALLEGRO TOPOLYZER VARIO

Patient Examen Affichage Paramètres T-CAT Divers

Nom:	[redacted]	Date ex.:	08.11.13	N° ID:	
Né(e) le: 20.12.61	Oeil: Gauche	Heure ex.:	14:06:09	Notes:	Pupil Center Shift

Small pupil:

Moy.: 1.93mm

Minimum: 1.76mm

X: -0.01mm

Y: -0.38mm

Dist. to Apex:0.38mm

Pupil Center Shift:

Interpolated: 0.74mm (2-7mm)

Measured: 0.30mm

Wide pupil:

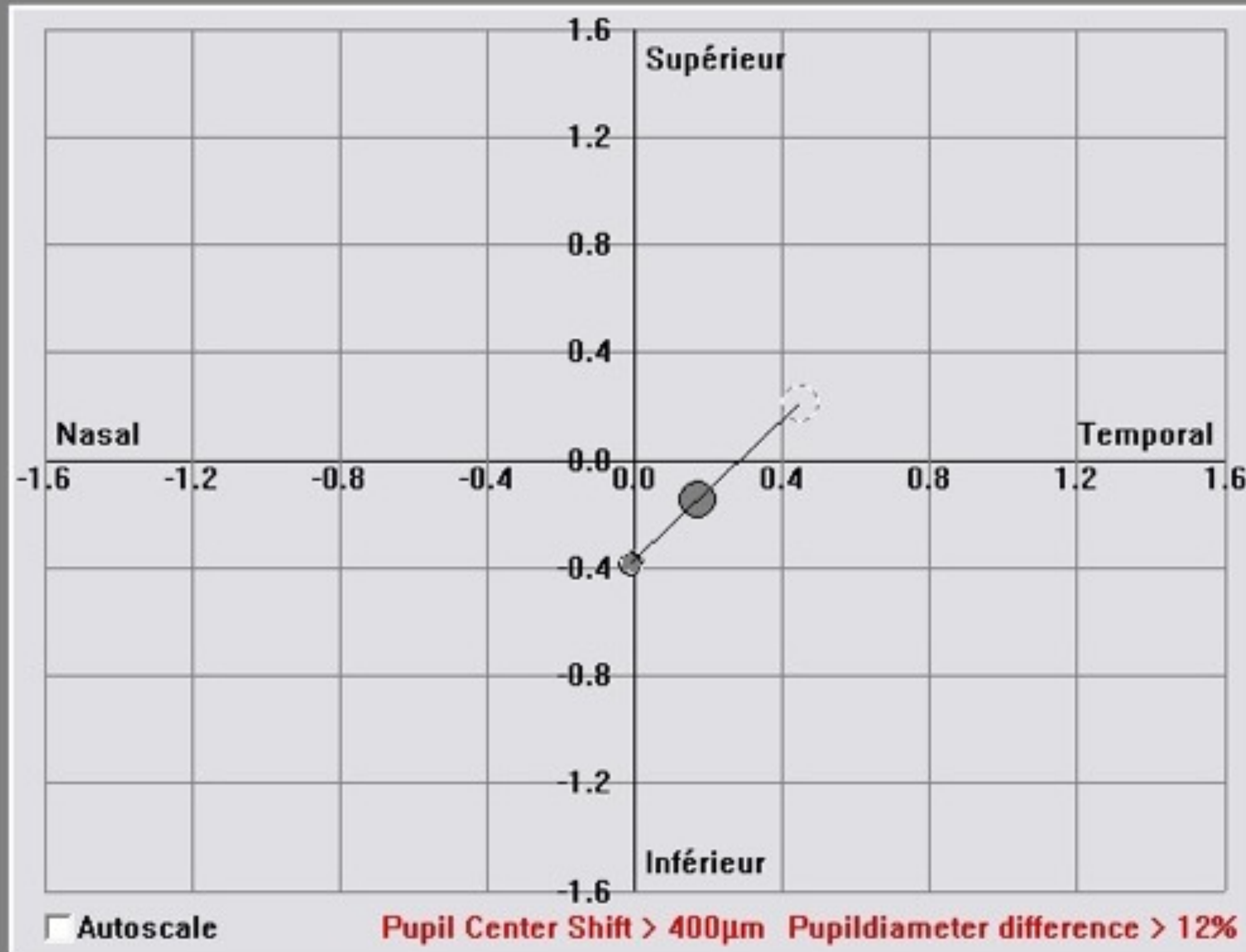
Moy.: 3.92mm

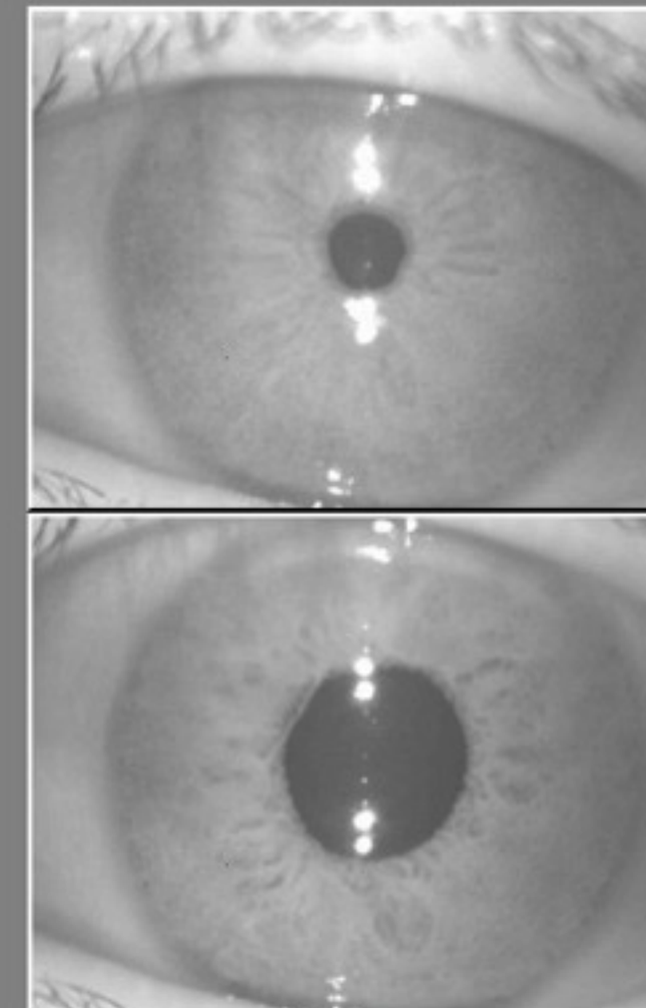
Maximum: 4.19mm

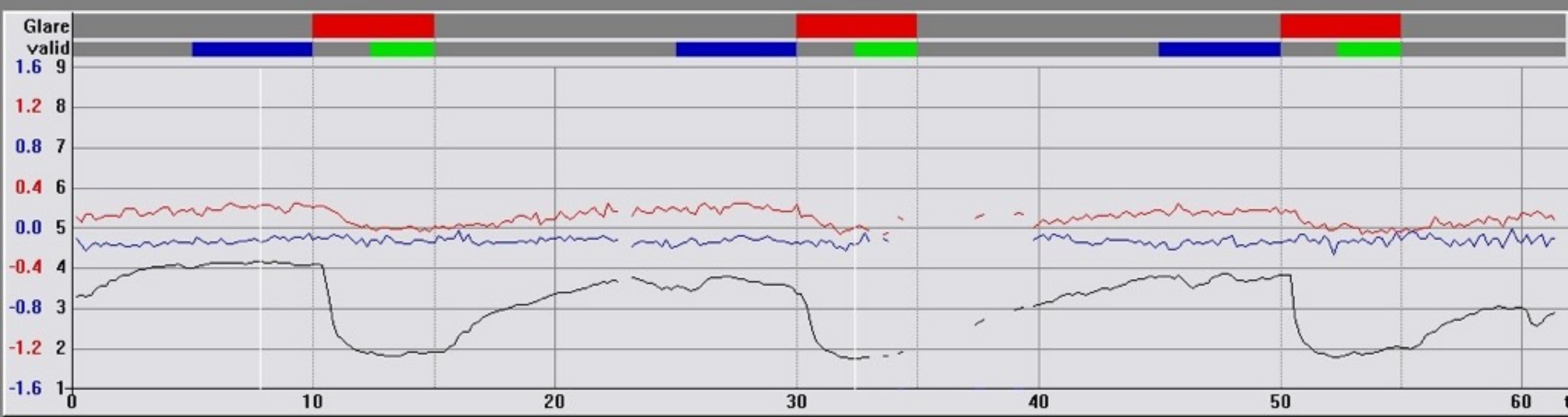
X: 0.17mm

Y: -0.15mm

Dist. to Apex:0.23mm







3. THE PUPILLOMETRY

Mesopic pupil size in a refractive surgery population (13,959 eyes).

- Linke SJ, Baviera J, Katz T. - Optom Vis Sci. 2012 Aug ; 89(8) : 1156-64

Mesopic pupil size = **6.45** ± 0.82 mm (mean age 36.07 years).

5.96 ± 0.8 mm in **hyperopic** astigmatism,

6.36 ± 0.83 mm in **high** astigmatism,

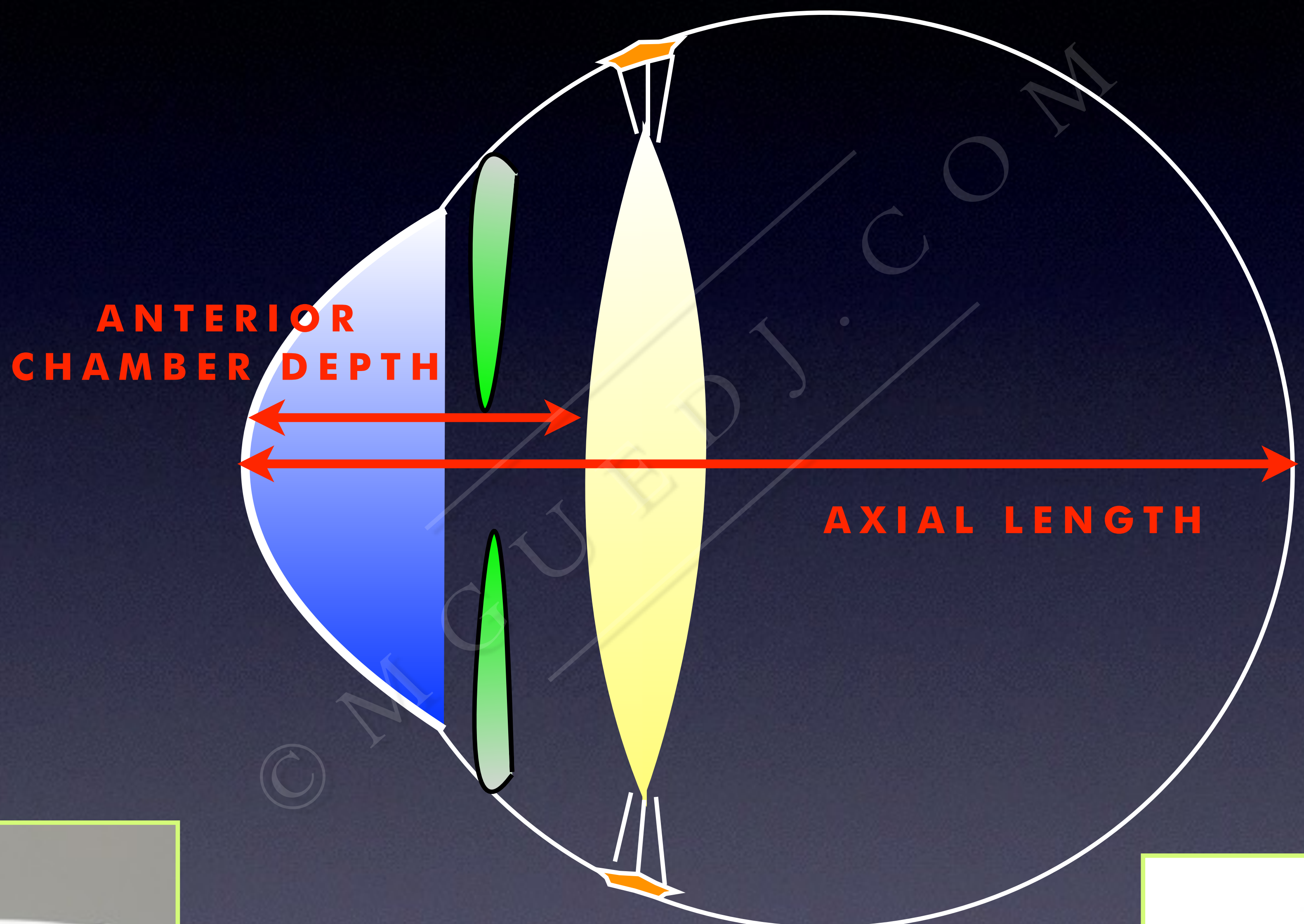
6.51 ± 0.8 mm in **myopic** astigmatism.

Daytime variations in pupil size under photopic conditions.

Kobashi H, Kamiya K, Ishikawa H, Shimizu K. - Optom Vis Sci. 2012 Feb;89(2):197-202.

Photopic pupil size = **3.08 to 3.91 mm** (mean age 27.3 years)

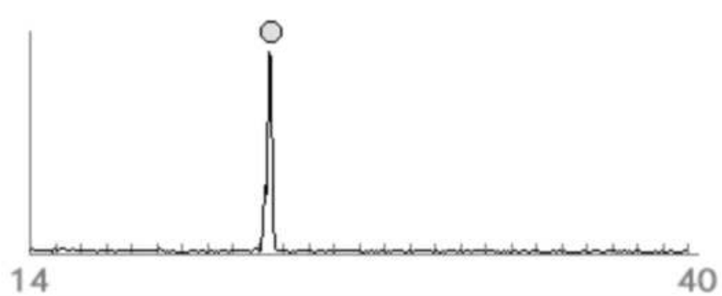
4. THE OPTICAL BIOMETER

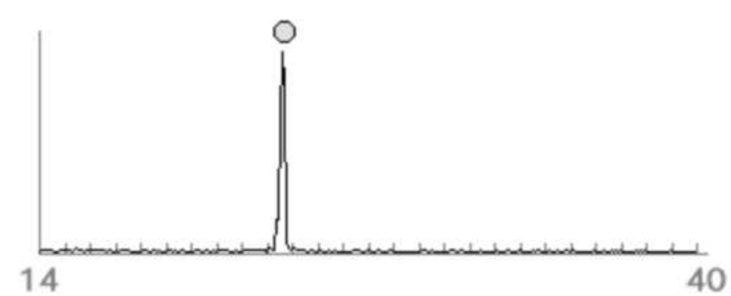


Exam Date: 12/NOV/2013 16:01
Operator: MIKAEL GUEDJ

Right — AL — Left

Right: Eye Type: Phakic				Left: Eye Type: Phakic			
AL	SNR	AL	SNR	AL	SNR	AL	SNR
23.44 mm	18.5			23.59 mm	15.5		
23.42 mm	17.5			23.60 mm	18.0		
23.44 mm	16.5			23.53 mm	16.8		
23.45 mm	14.4			23.52 mm	17.7		
23.44 mm	16.2			23.60 mm	19.2		
Addition:		23.44 mm	22.1	Addition:		23.60 mm	22.6

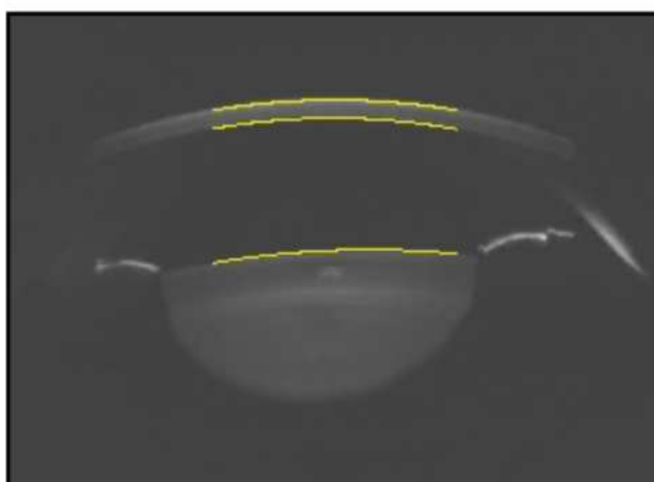




KM

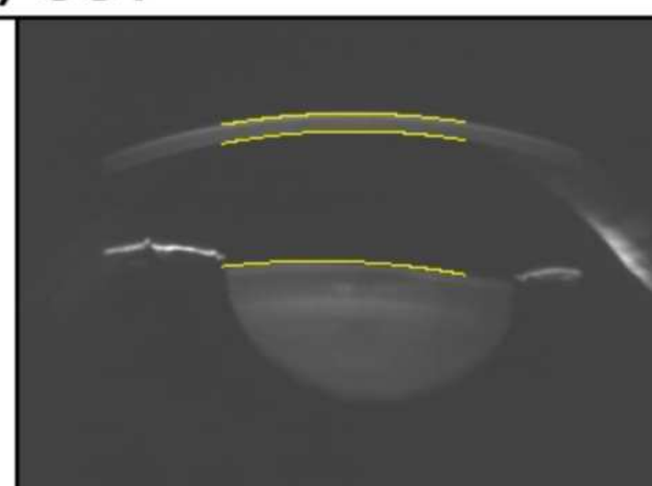
Ref. Index: 1.3375											
KM Mire	K	CYL	K1	K2	Axis	KM Mire	K	CYL	K1	K2	Axis
Φ2.4 mm	44.58 D	- 1.12 D	44.06 D	45.18 D	152 °	Φ2.4 mm	44.23 D	- 0.87 D	43.83 D	44.70 D	5 °
Φ3.3 mm	44.35 D	- 0.99 D	43.89 D	44.88 D	169 °	Φ3.3 mm	44.23 D	- 1.04 D	43.72 D	44.76 D	5 °

ACD/CCT



CCT: 531 µm

ACD: 3.68 mm



CCT: 518 µm

ACD: 3.66 mm

④

DISCUSSION

DISCUSSION

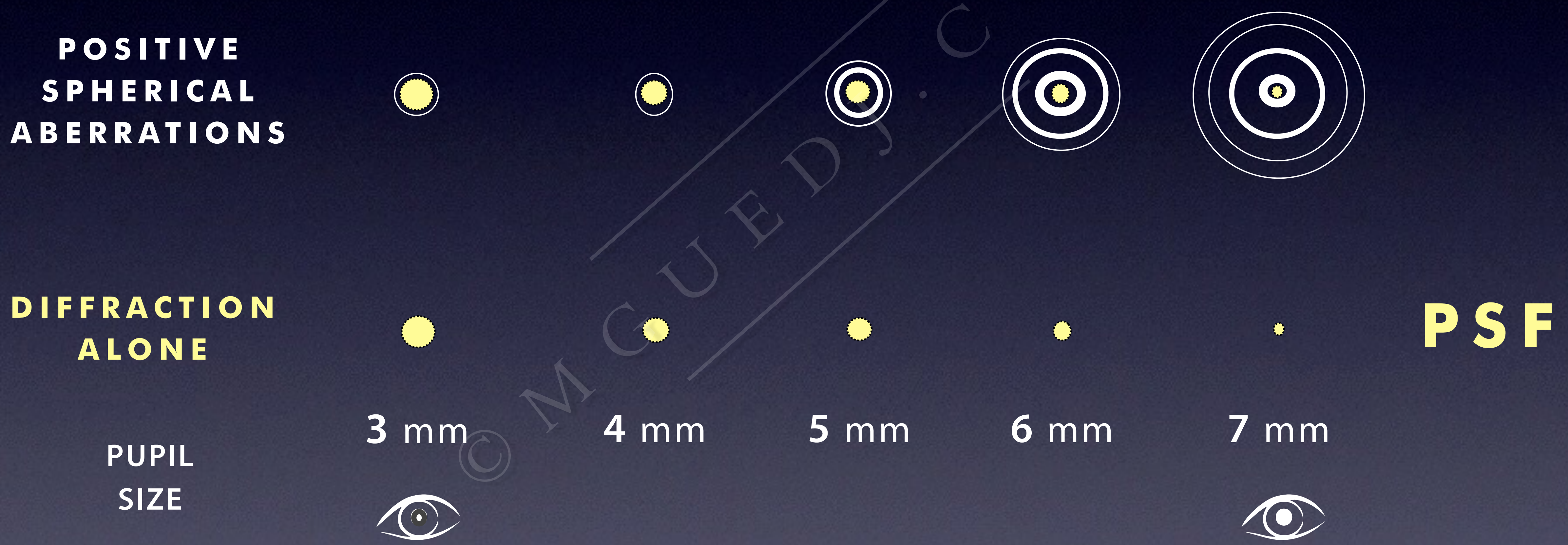
- Performing the clinical (defocus curve) and instrumental examinations (Topolyzer pupillometer, OPD-scan-III, optical biometer) = **complex task**.

- Launching of an **prospective study** : results and statistics to be completed within the next trimesters

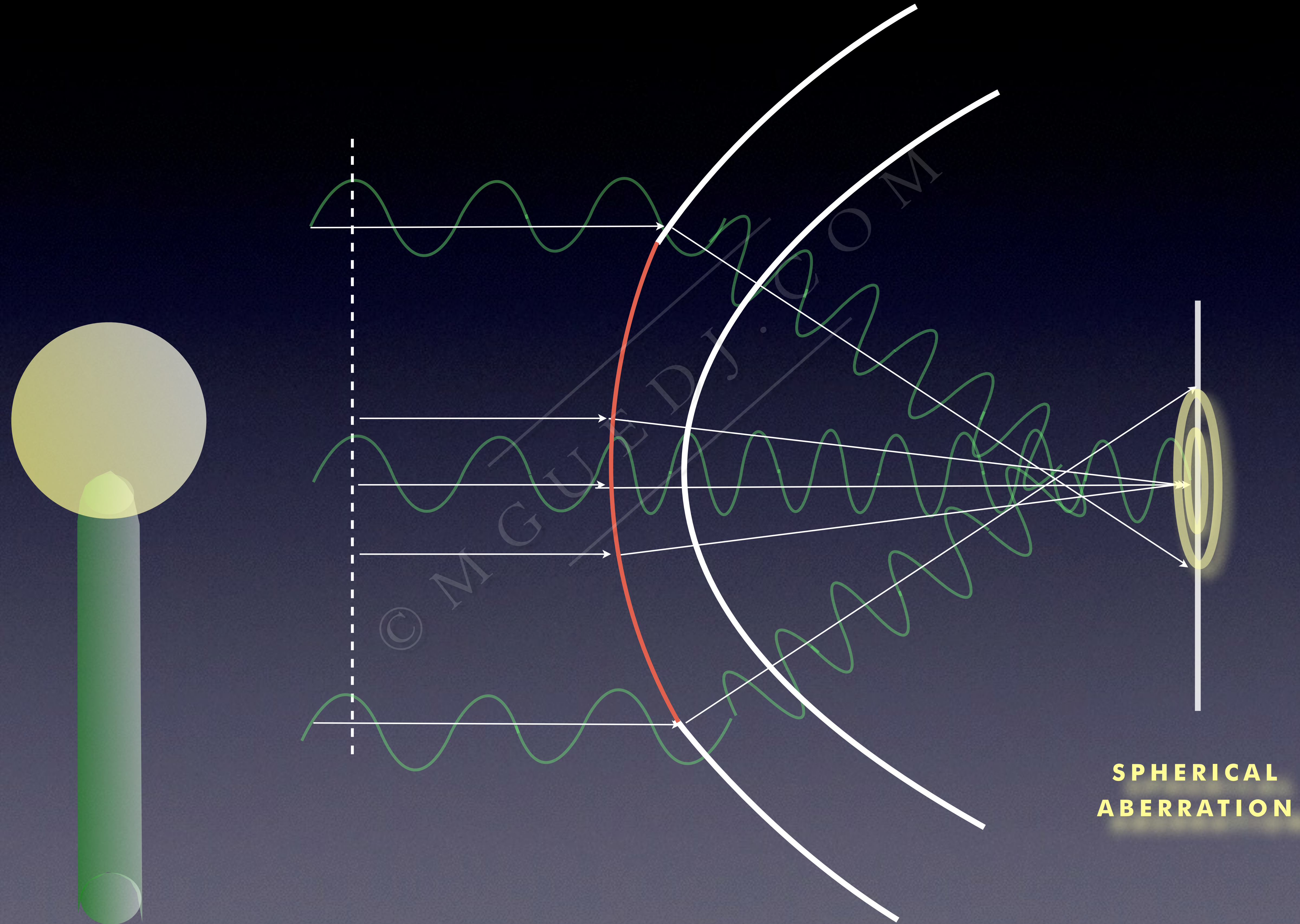
- **Time-consuming** measurements +++

- Medical and scientific activity often mixed in the lab (for better or for worse) : the unit clinical activity often **restricted access** to the measuring equipment for research activities…

Trade-off between positive spherical aberrations and diffraction



LIGHT HALOS



LIGHT HALOS