RAINBOW GLARE

INVESTIGATION OF THE RAINBOW GLARE EFFECT AFTER FS-LASIK

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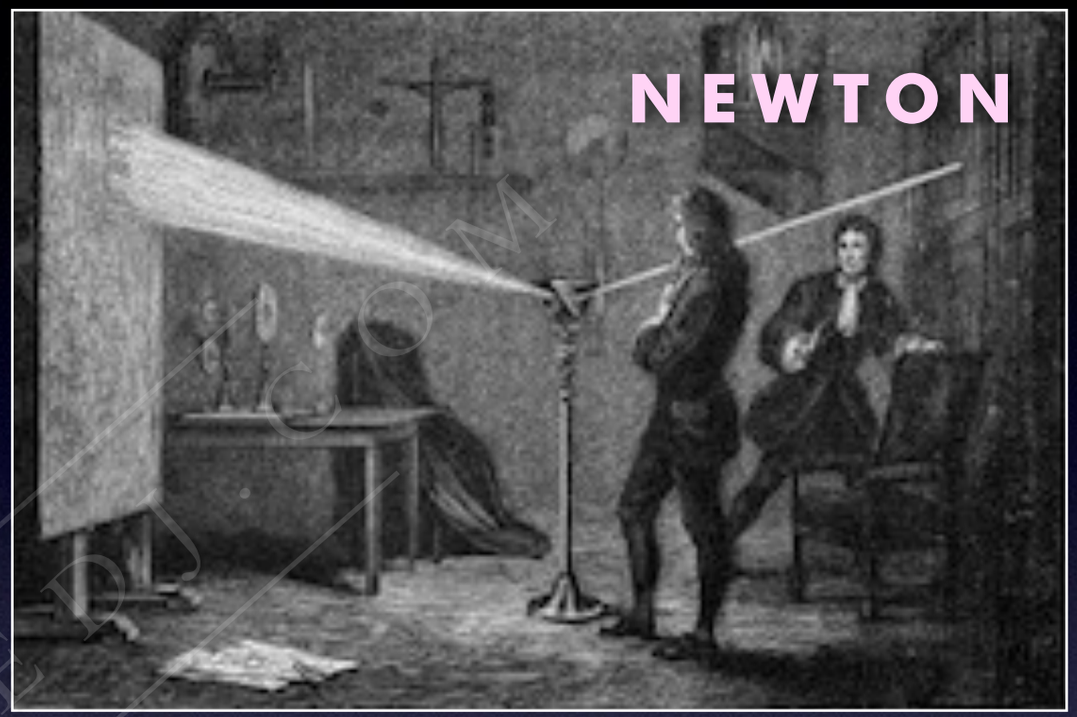
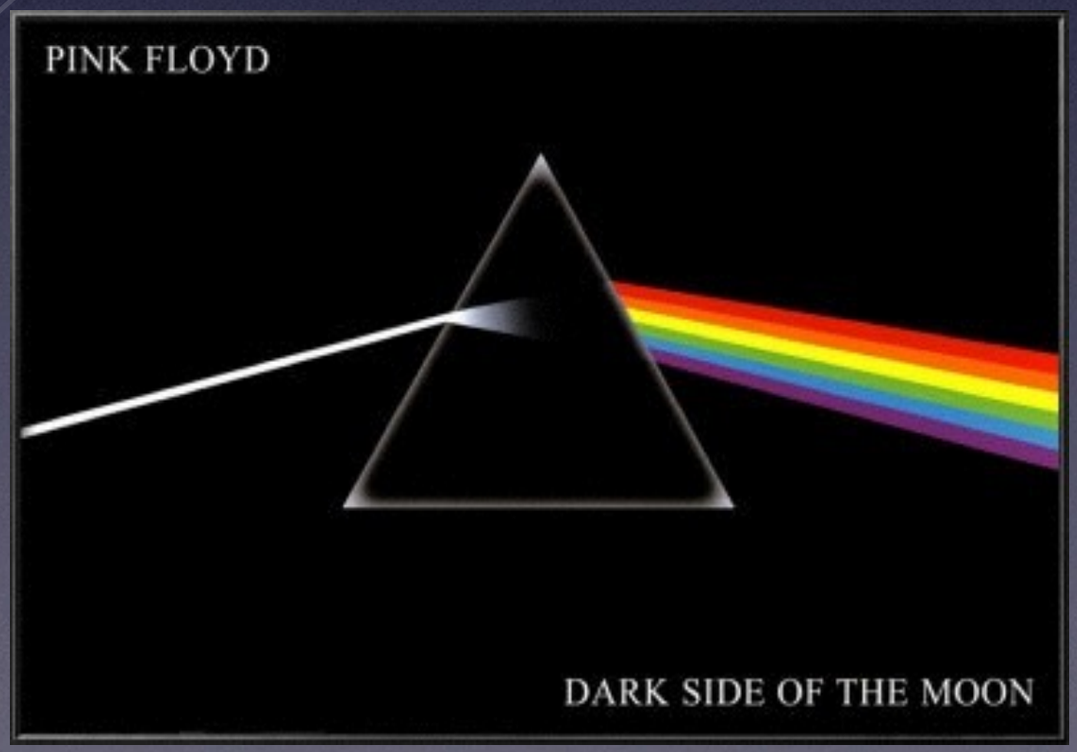
DAMIEN GATINEL
KARSTEN PLAMANN

www.mguedj.com

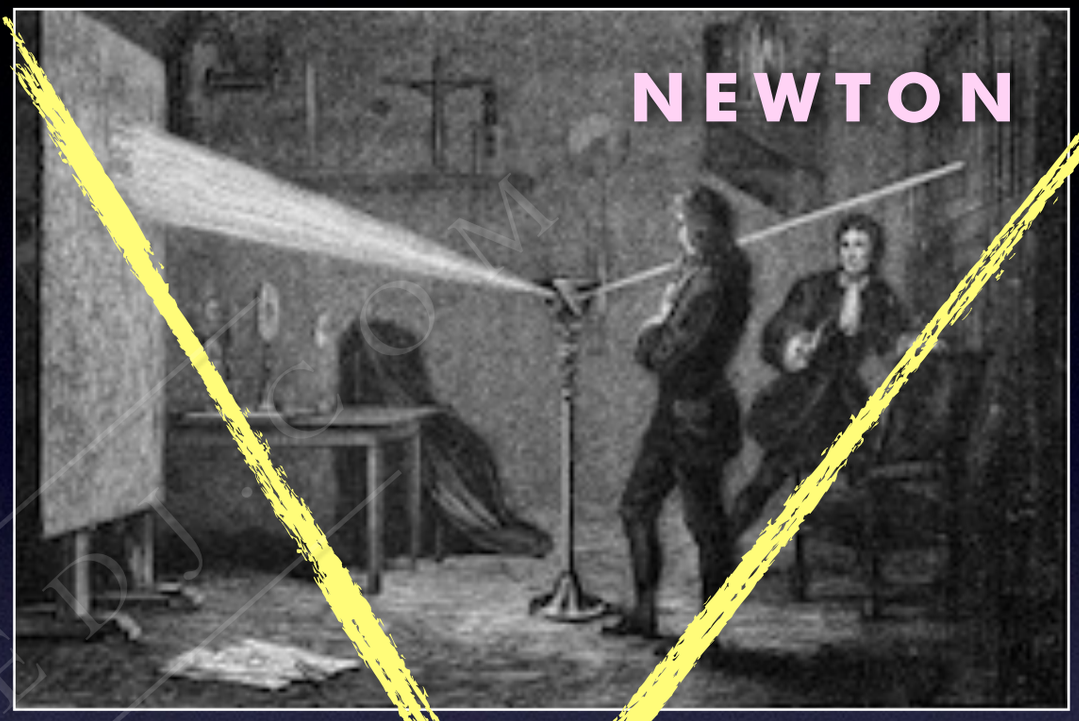
PARTNERSHIPS

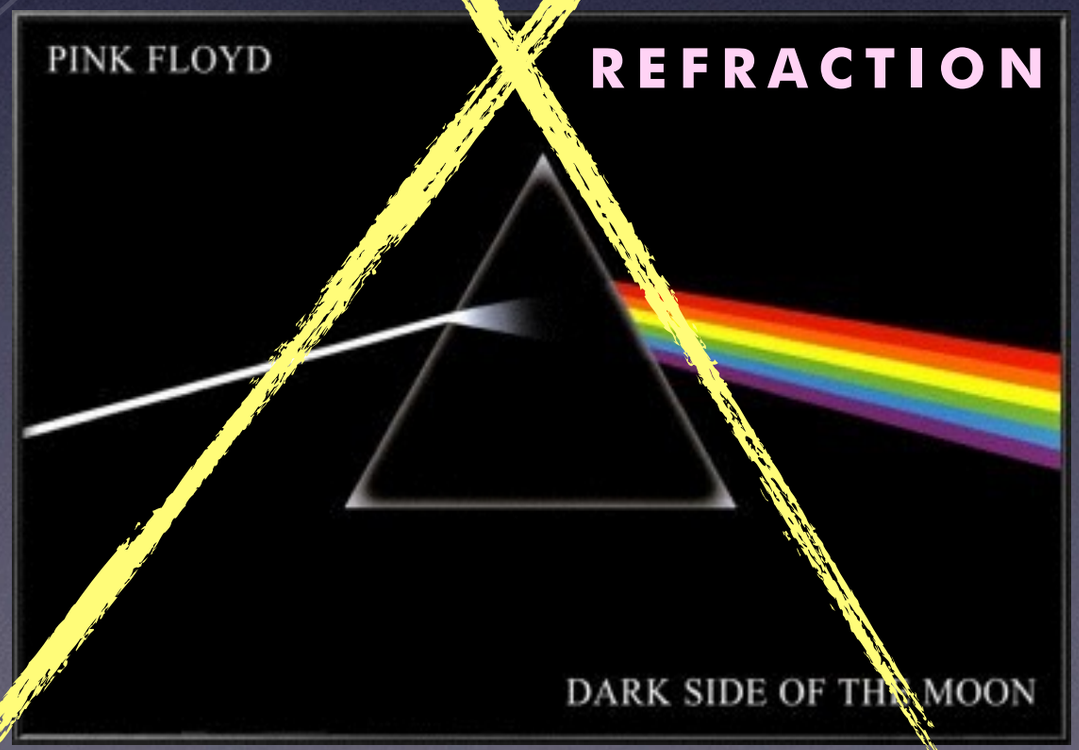
IN RAINBOWS



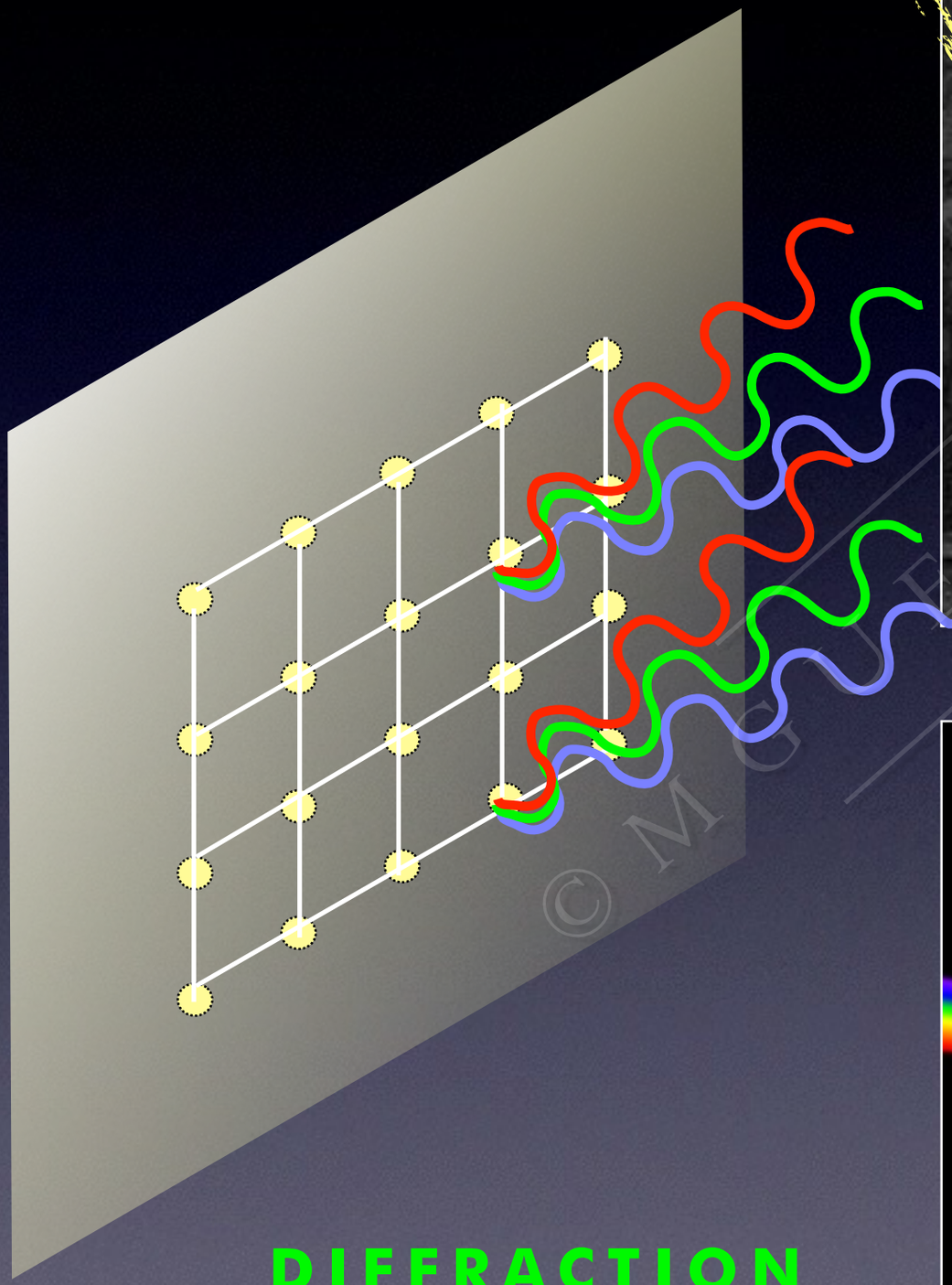


IN RAINBOWS

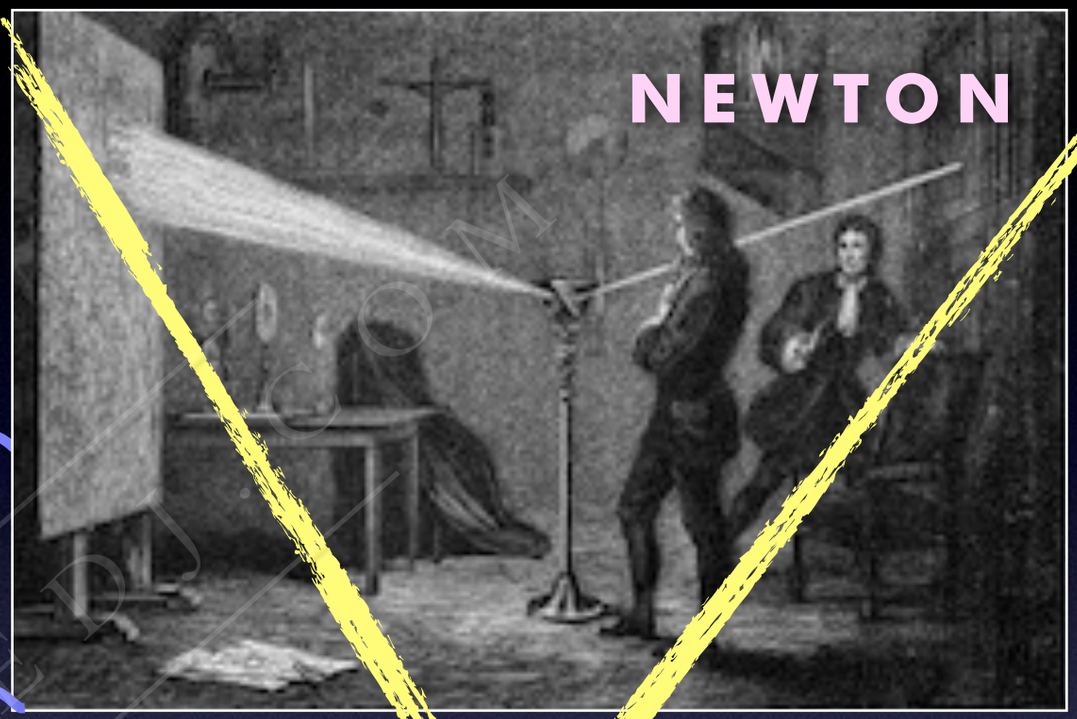


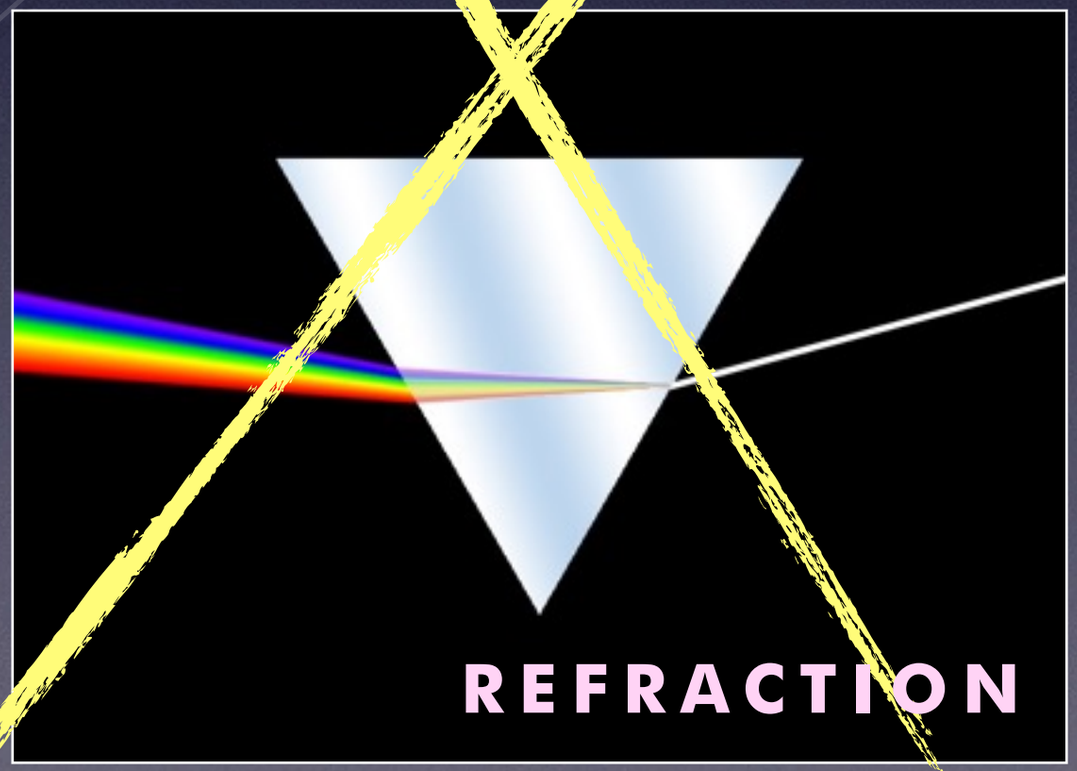


IN RAINBOWS



DIFFRACTION GRATING





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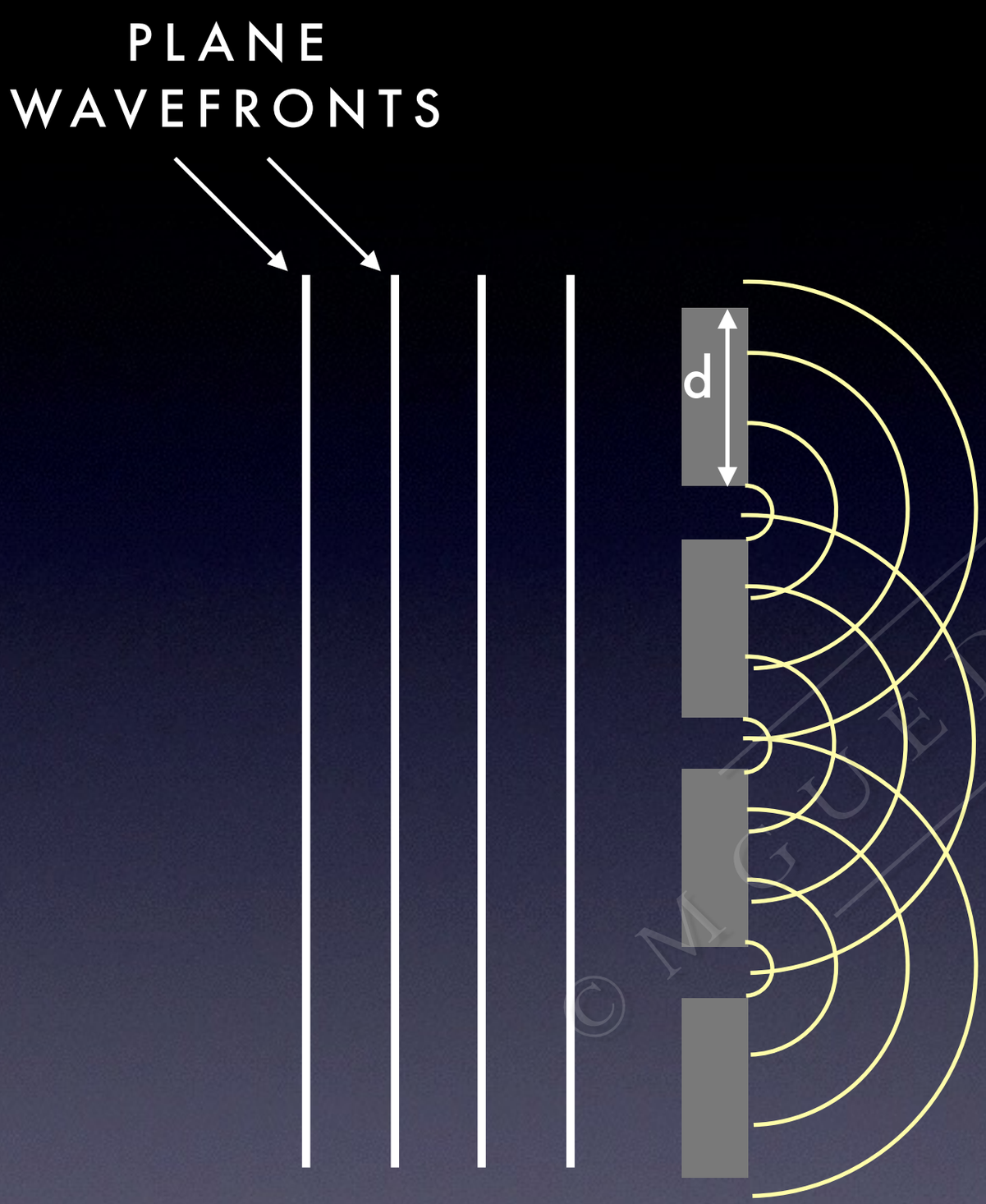
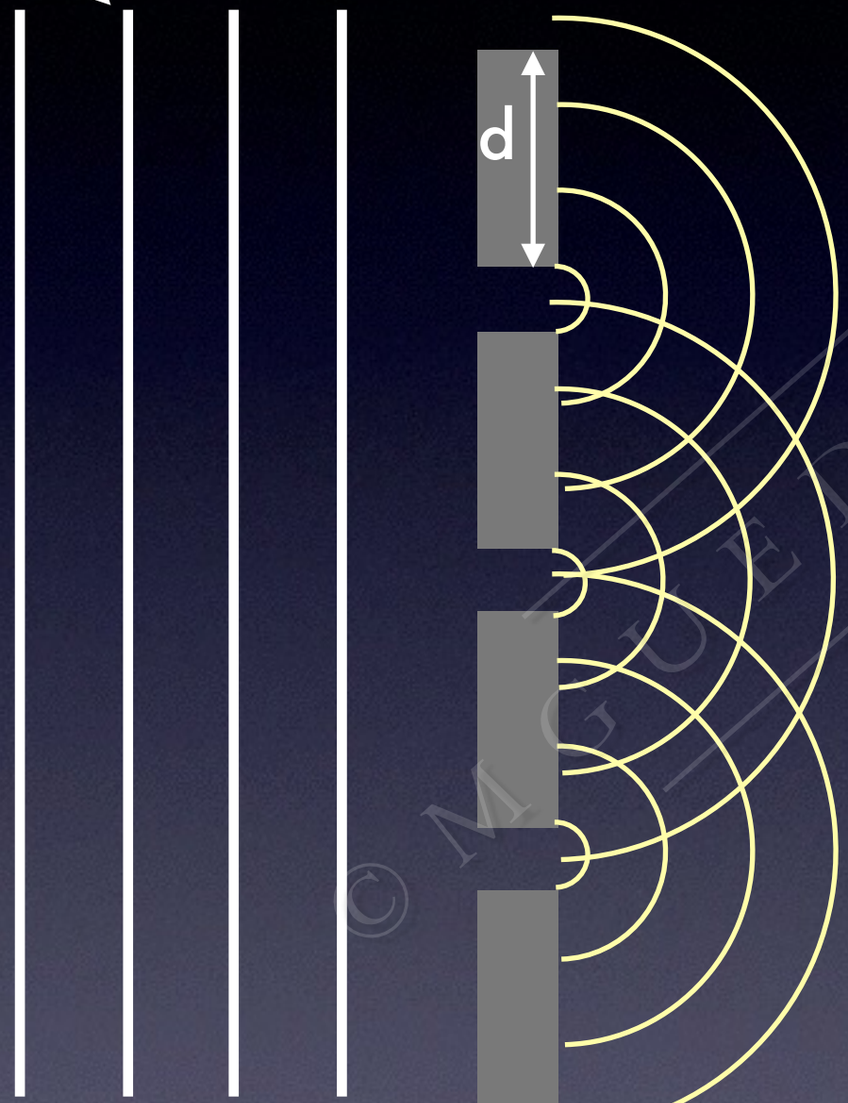
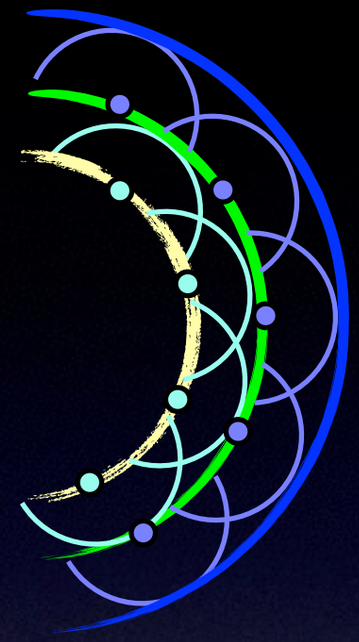


DIFFRACTION GRATING

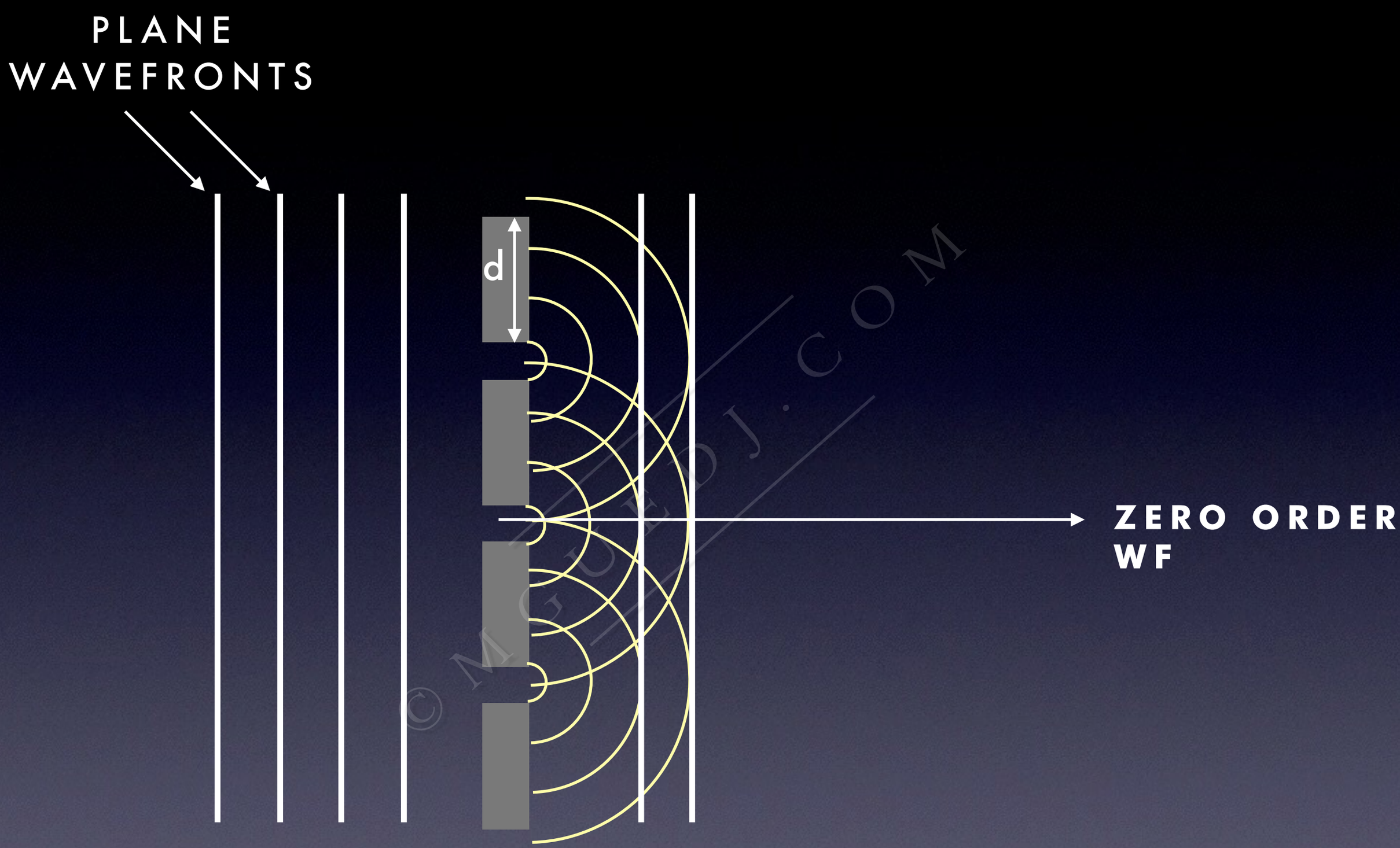
HUYGENS-FRESNEL POSTULATE

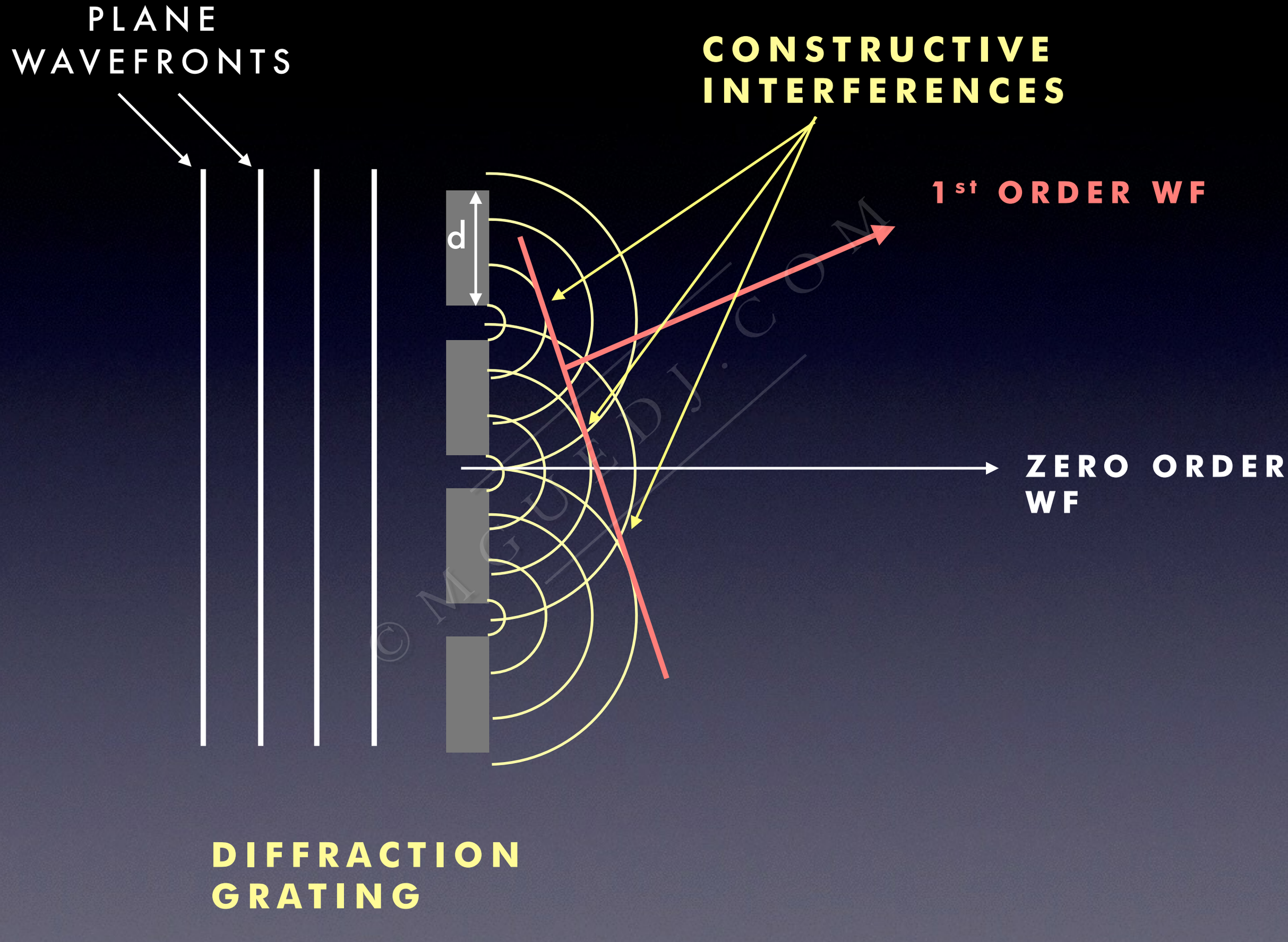
PLANE
WAVEFRONTS

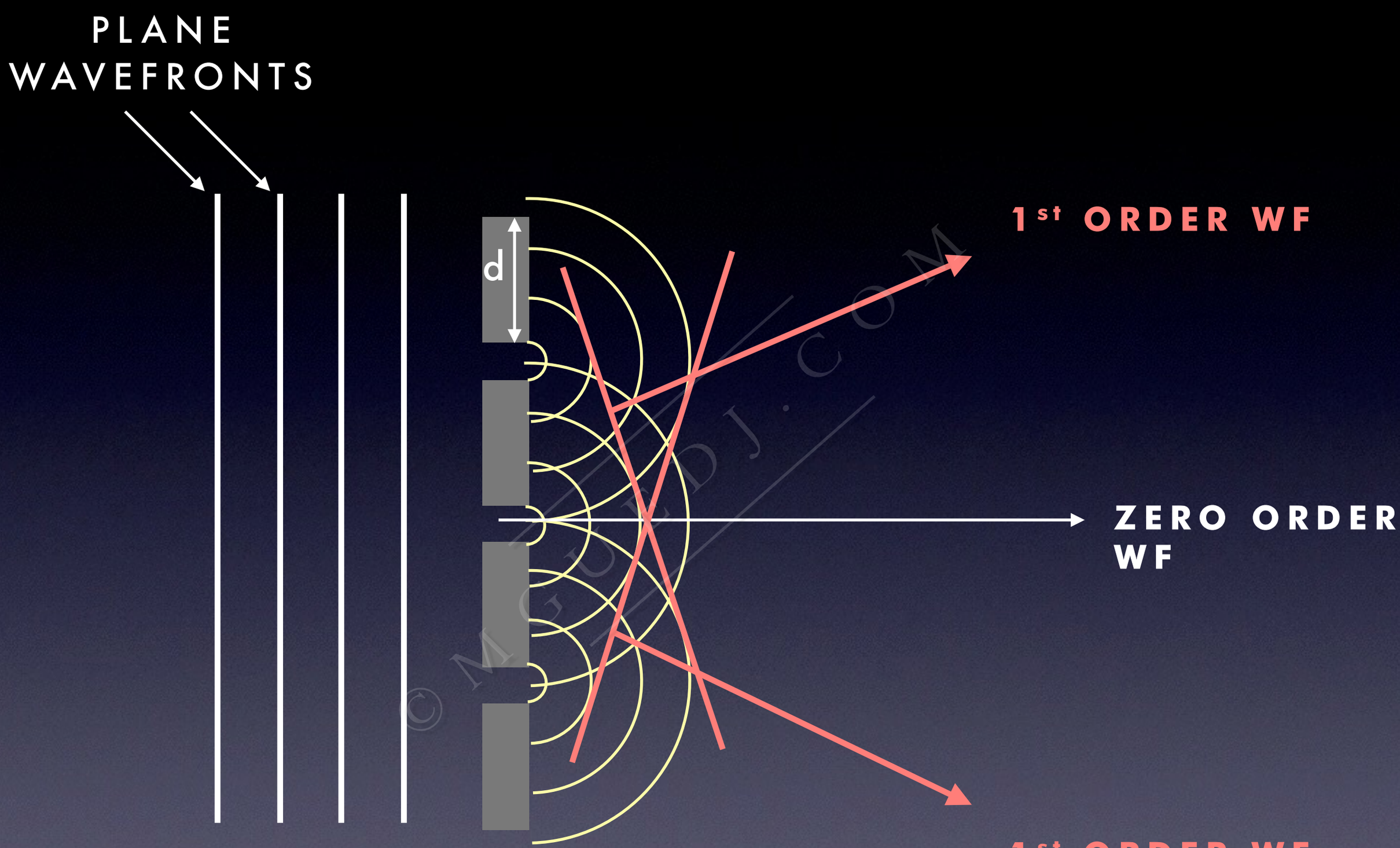




DIFFRACTION GRATING

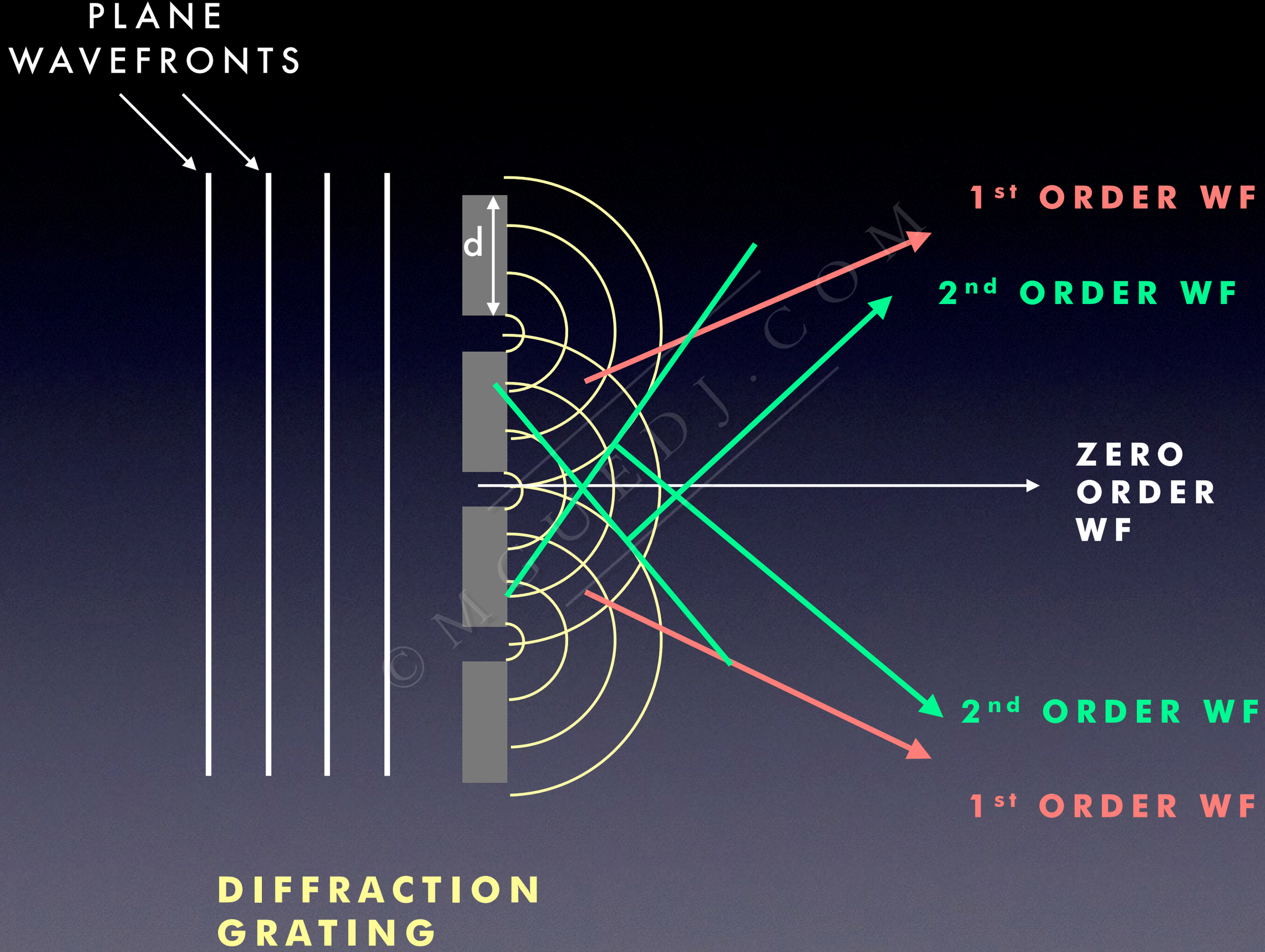

PLANE
WAVEFRONTS
d
ZERO ORDER
WF
DIFFRACTION
GRATING

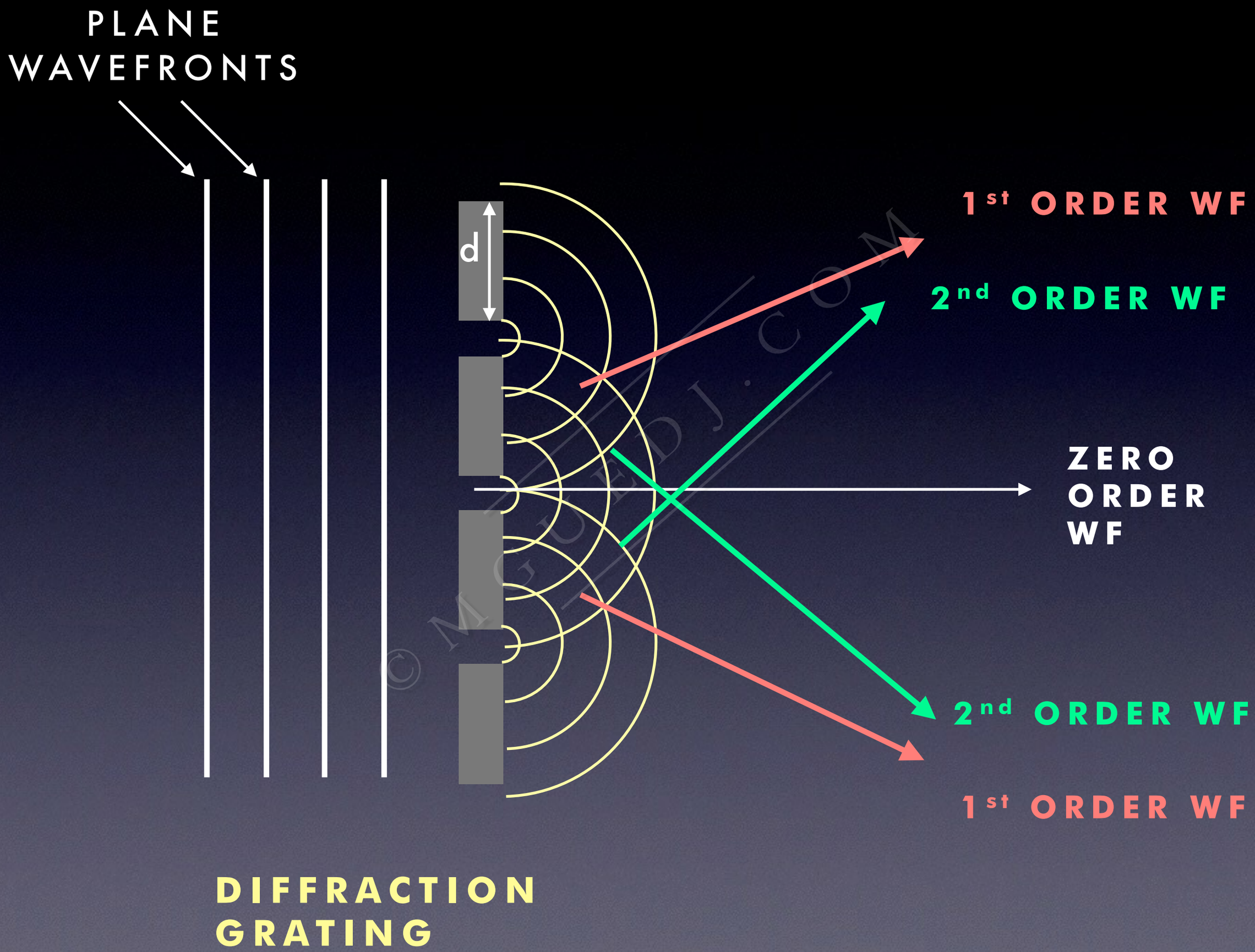

PLANE
WAVEFRONTS
CONSTRUCTIVE
INTERFERENCES
1st ORDER WF
d
ZERO ORDER
WF
DIFFRACTION
GRATING



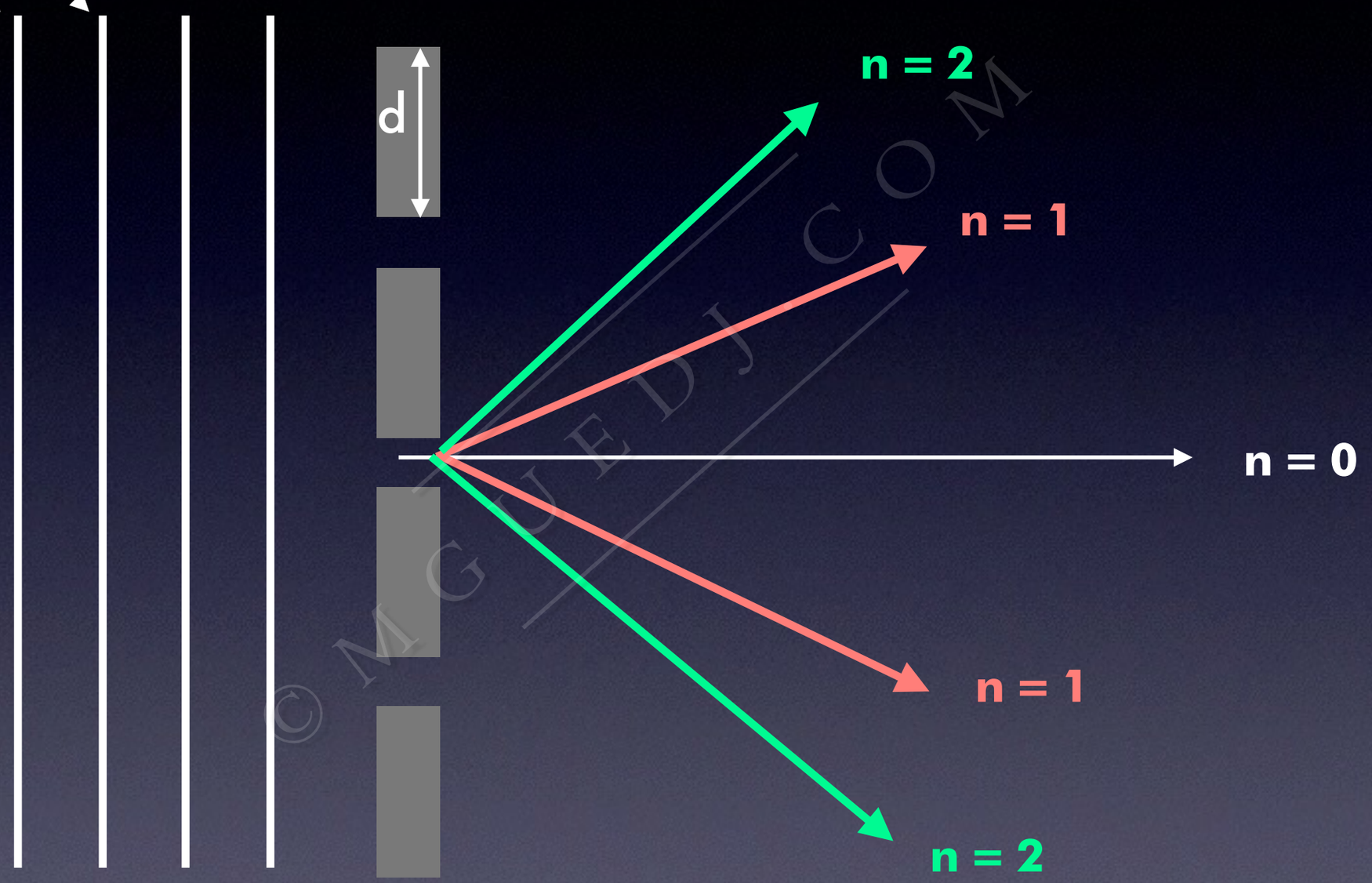
DIFFRACTION GRATING

PRODUCTION OF DISCRETE MAXIMA AT SPECIFIC ANGLES

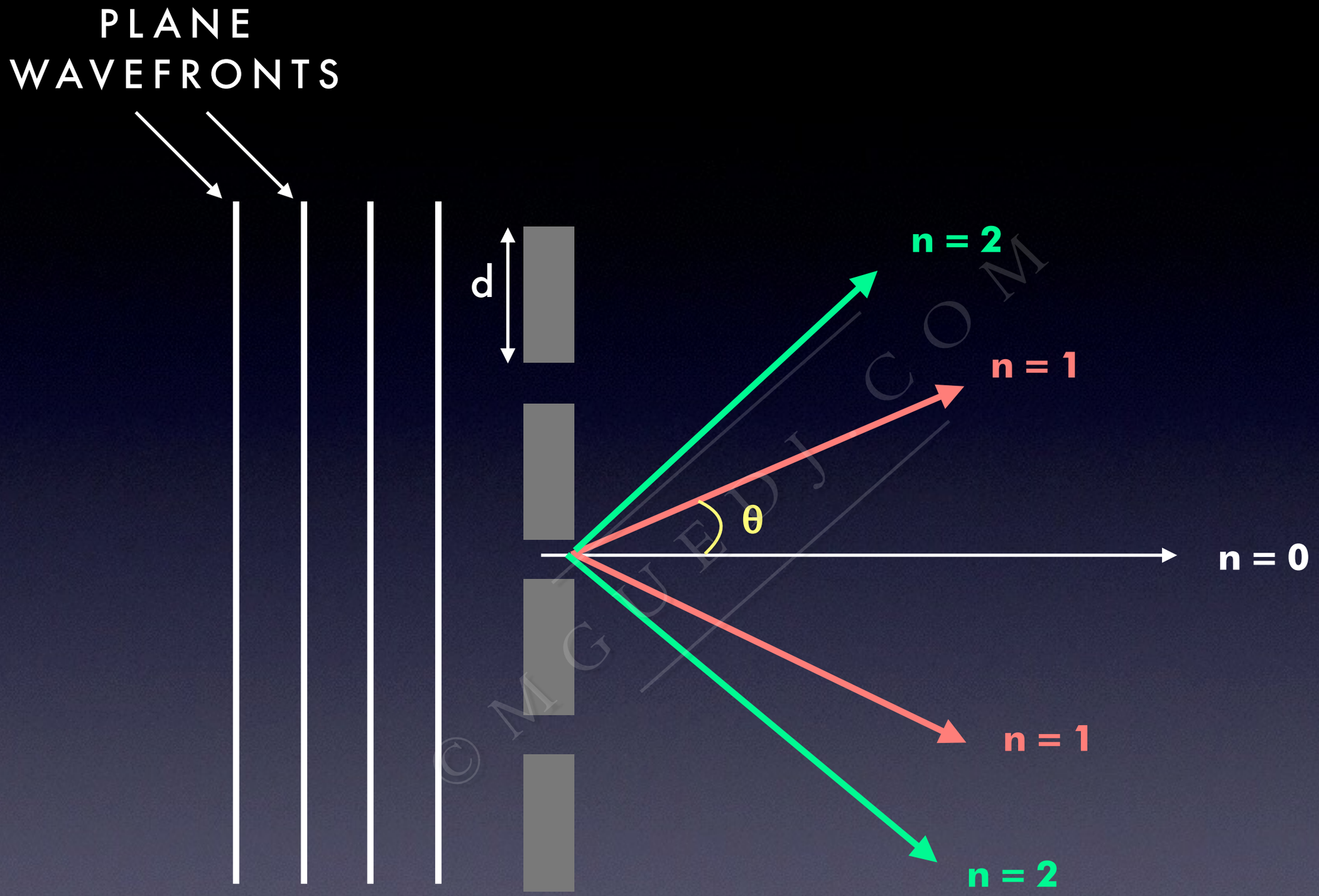

PLANE
WAVEFRONTS
d
1st ORDER WF
2nd ORDER WF
ZERO
ORDER
WF
2nd ORDER WF
1st ORDER WF
DIFFRACTION
GRATING


PLANE
WAVEFRONTS
d
1st ORDER WF
2nd ORDER WF
ZERO
ORDER
WF
2nd ORDER WF
1st ORDER WF
DIFFRACTION
GRATING

PLANE
WAVEFRONTS

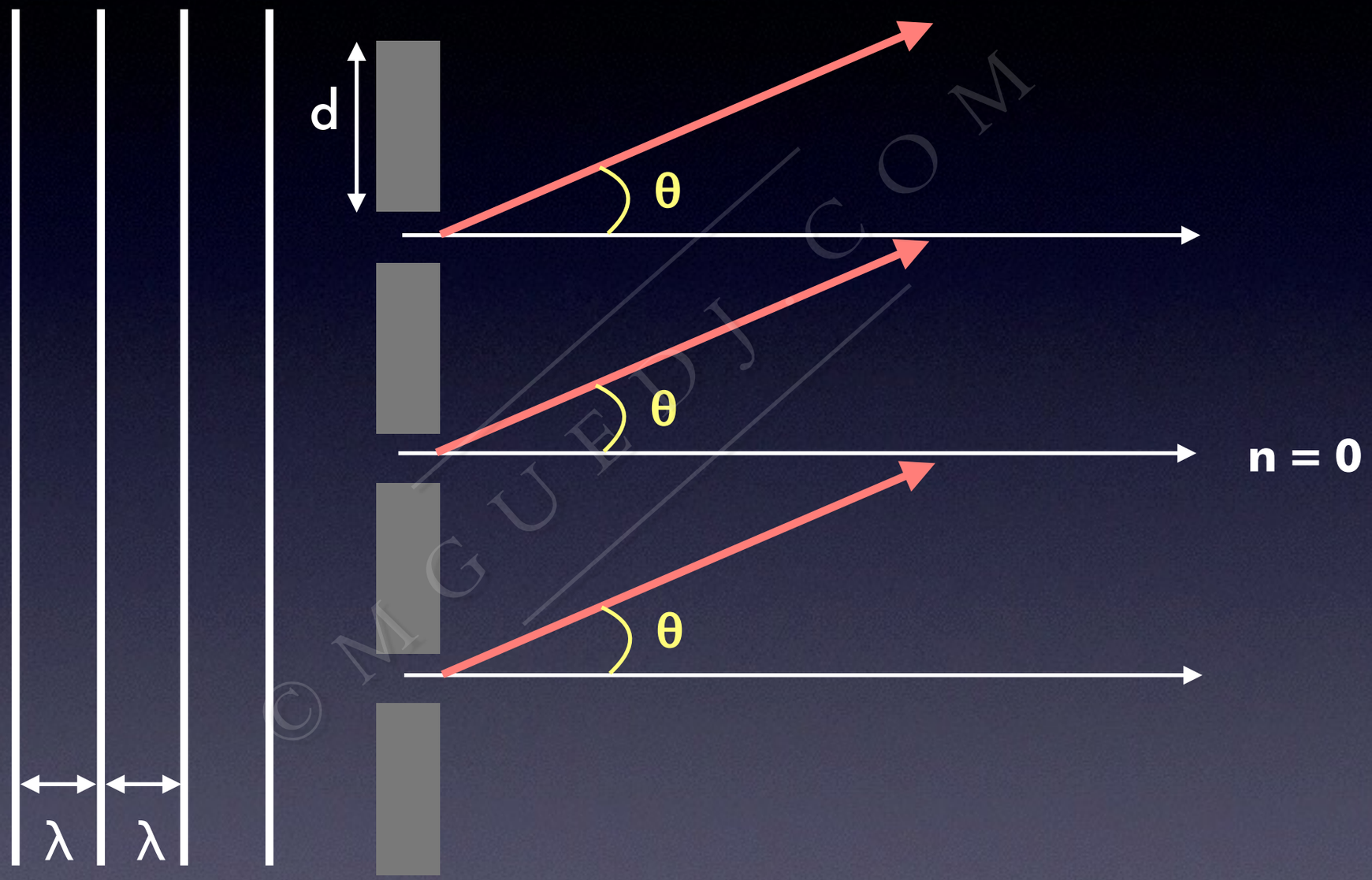


DIFFRACTION
GRATING



GRATING EQUATION :

$$d \sin \theta = n \lambda$$

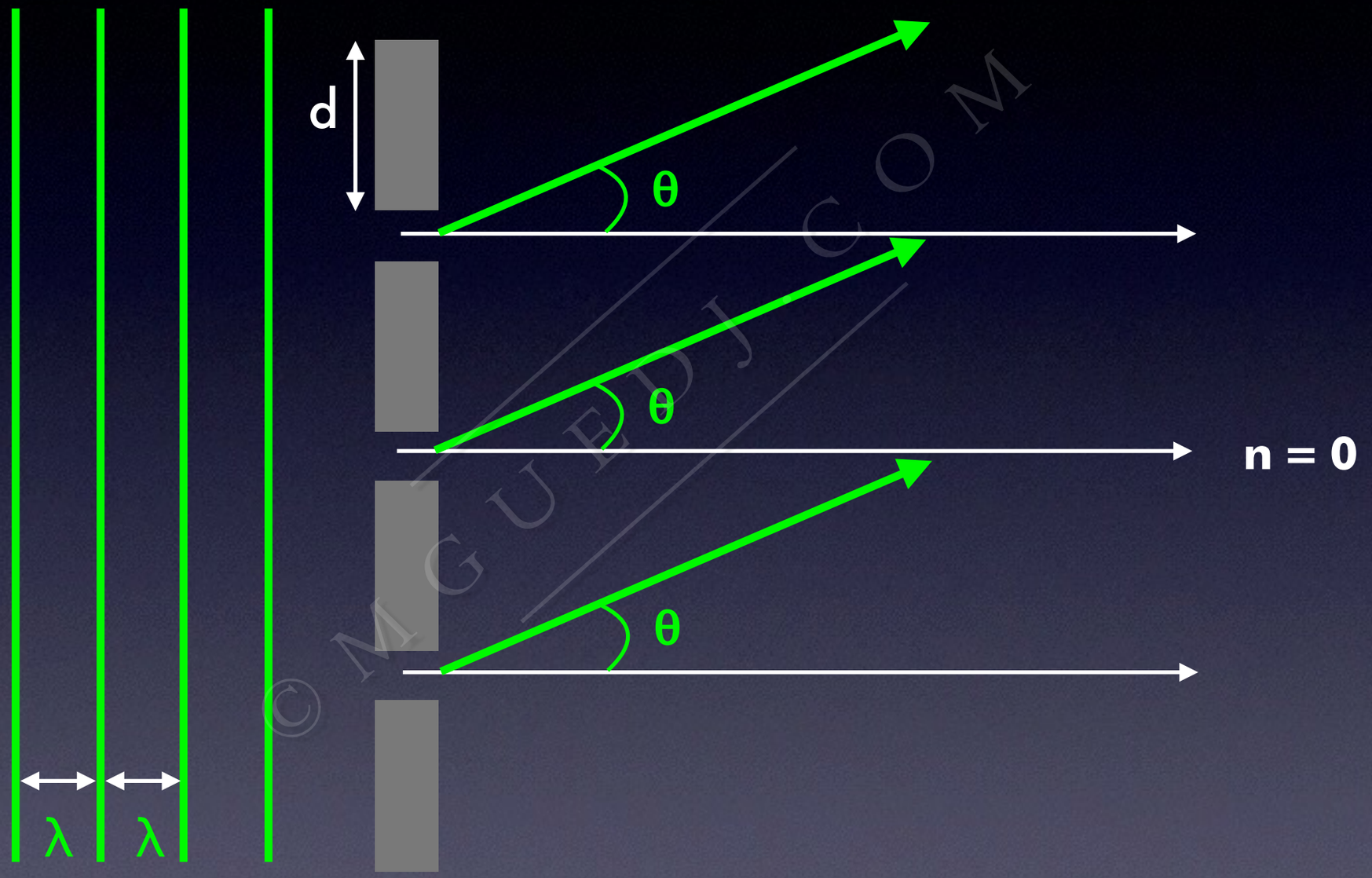


GRATING EQUATION :

$$d \sin \theta = n \lambda$$

MONOCHROMATIC LIGHT

$\lambda = 550$ nm

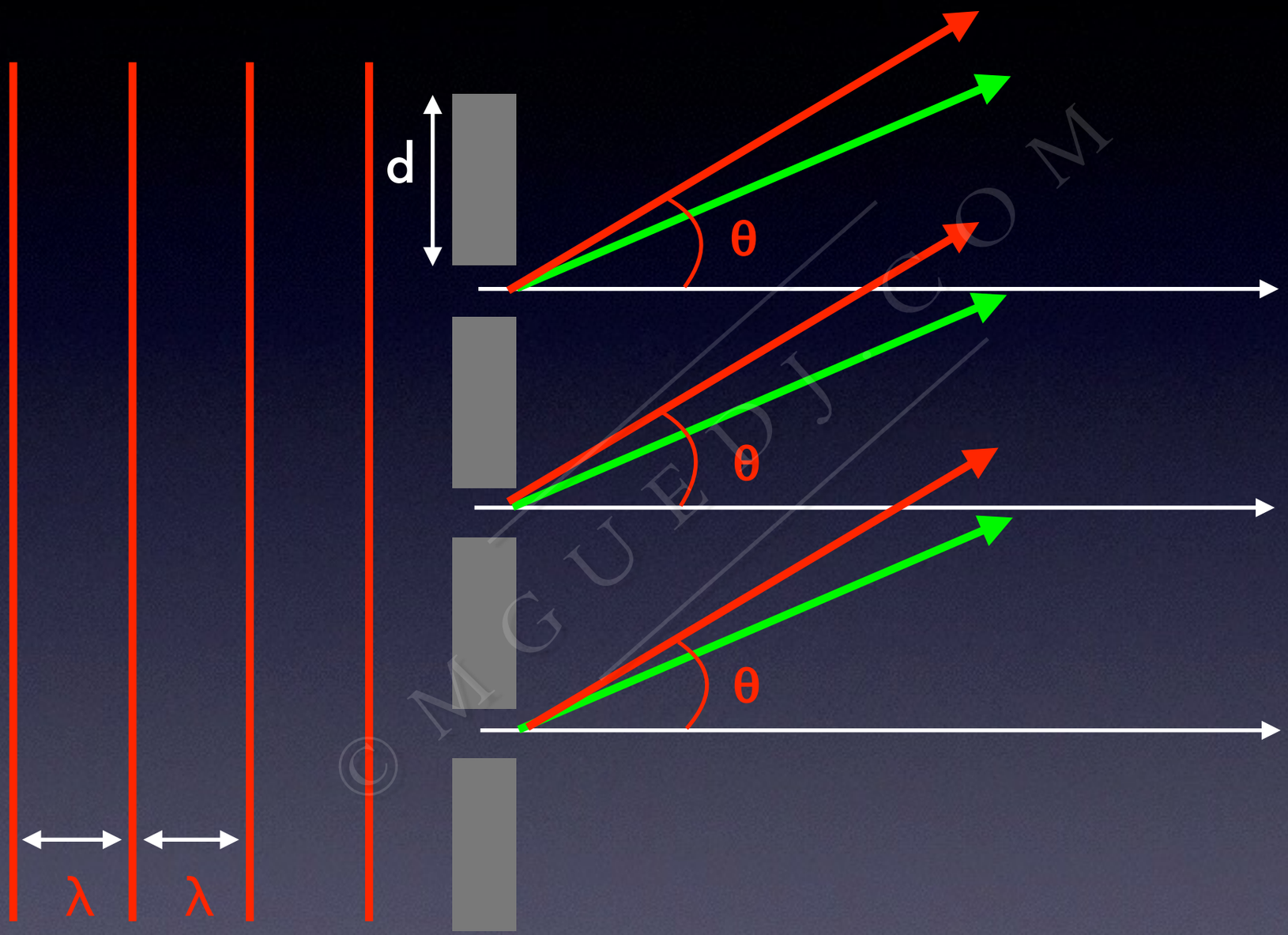


GRATING EQUATION :

$$d \sin \theta = n \lambda$$

MONOCHROMATIC LIGHT

$\lambda = 650$ nm

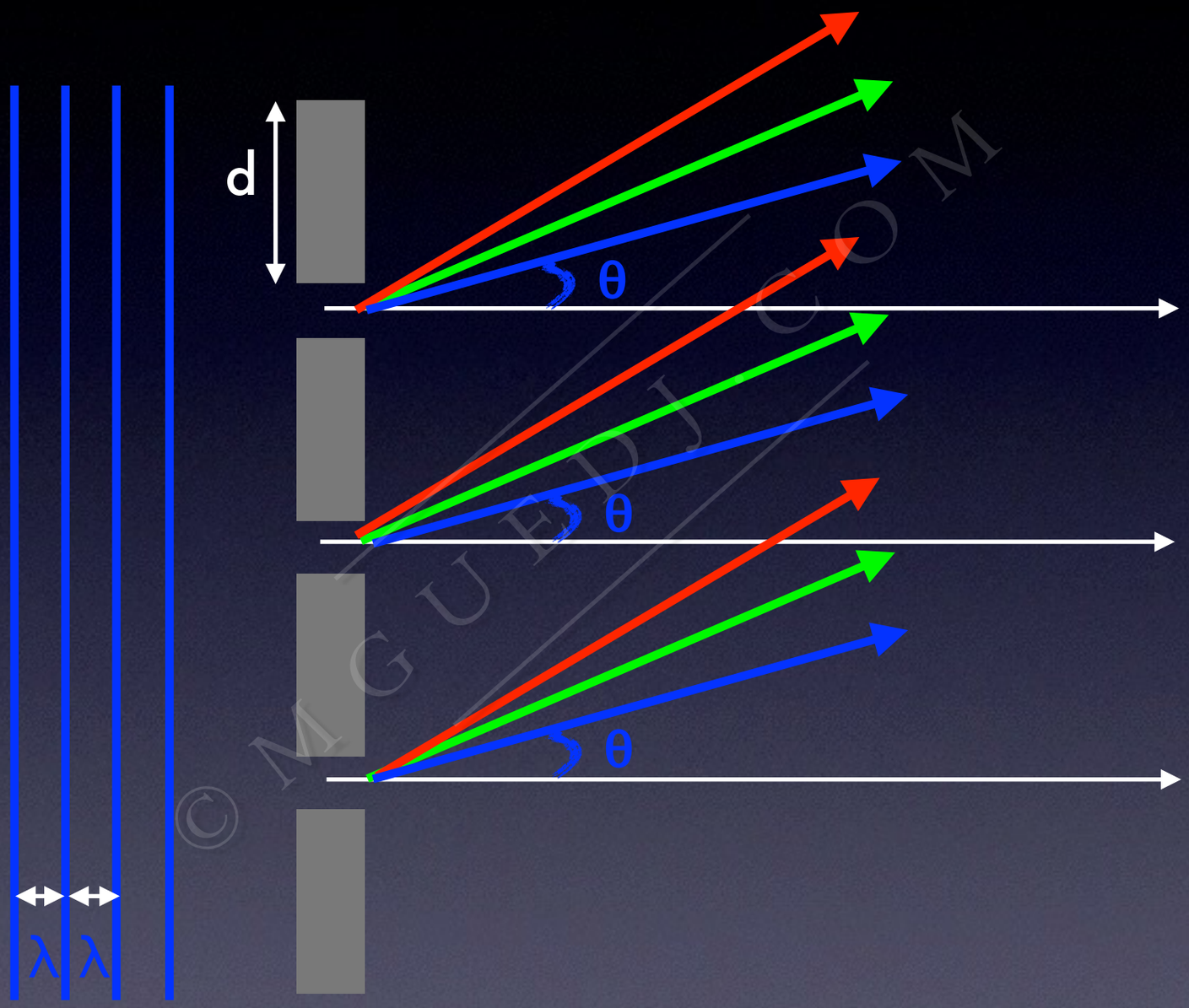


GRATING EQUATION :

$$d \sin \theta = n \lambda$$

MONOCHROMATIC LIGHT

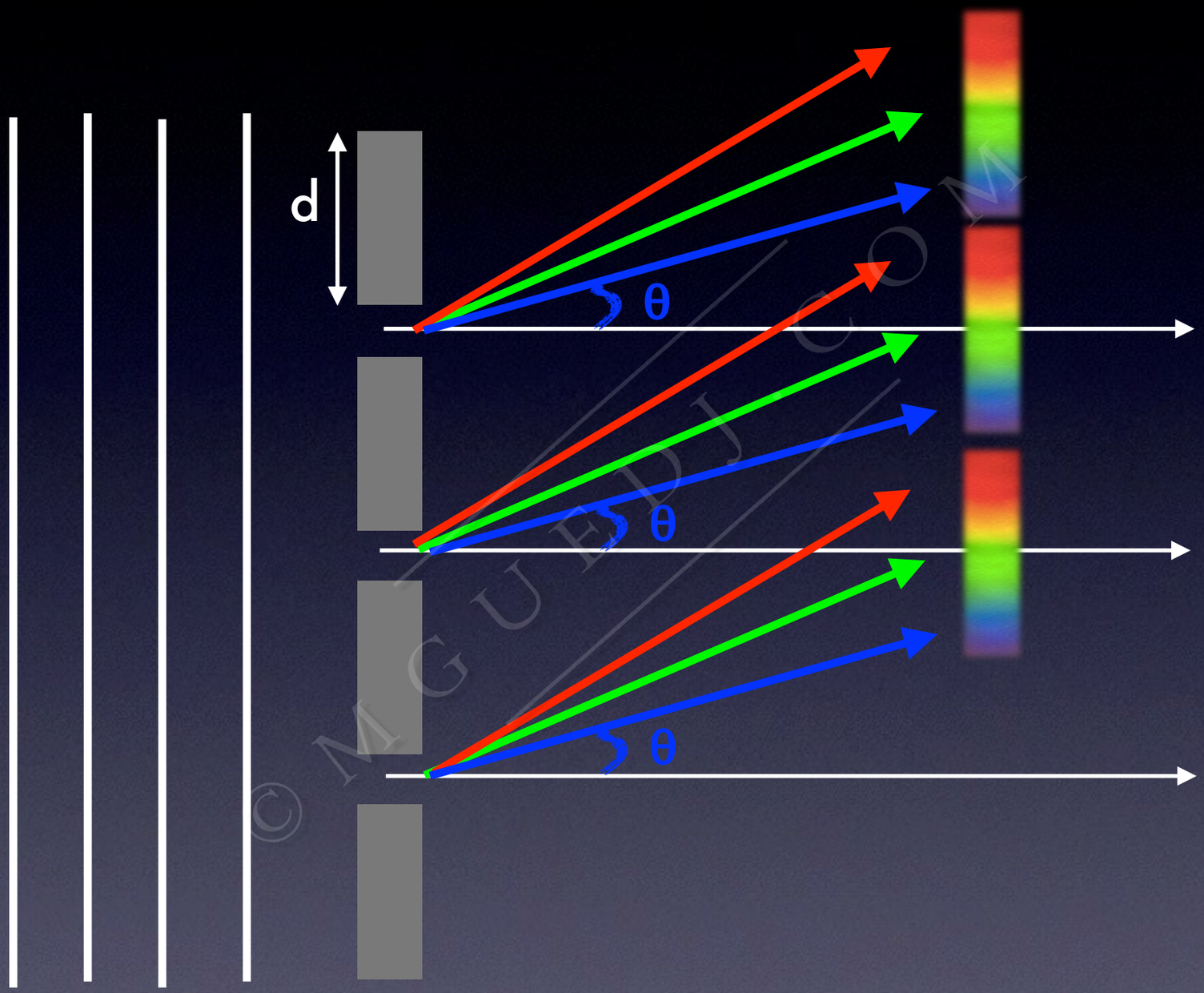
$\lambda = 450$ nm



GRATING EQUATION :

$$d \sin \theta = n \lambda$$

WHITE LIGHT



GRATING EQUATION :

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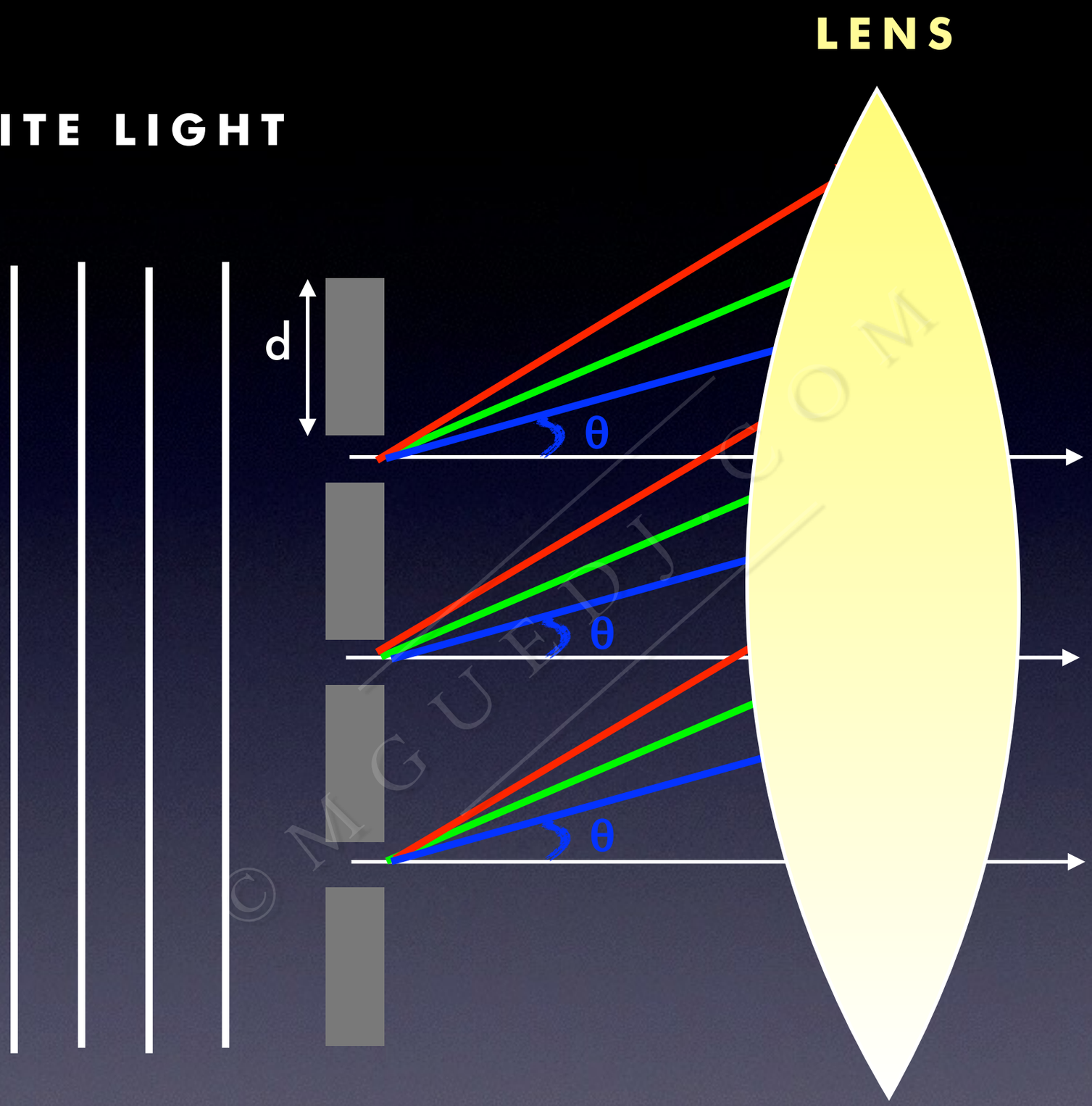
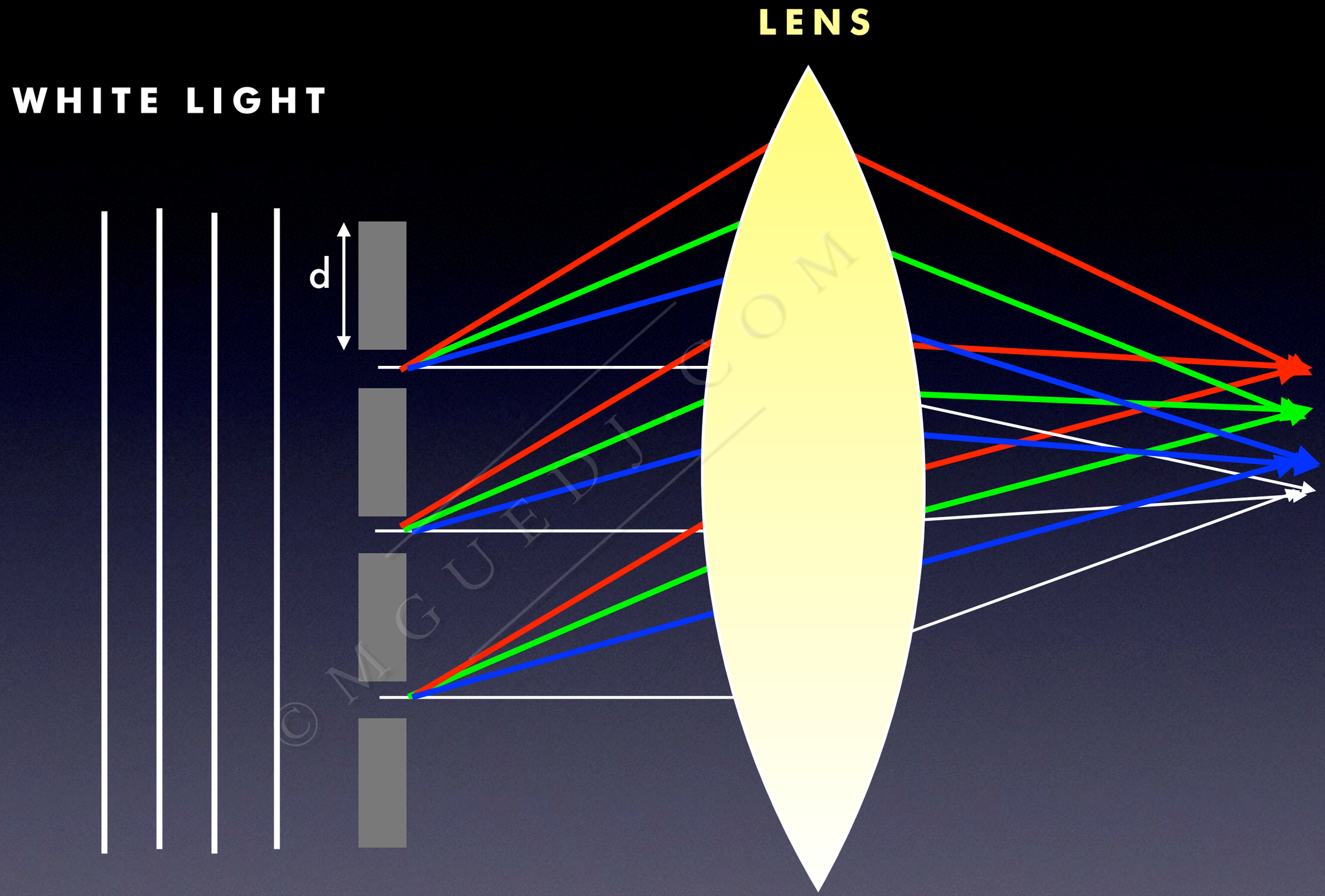
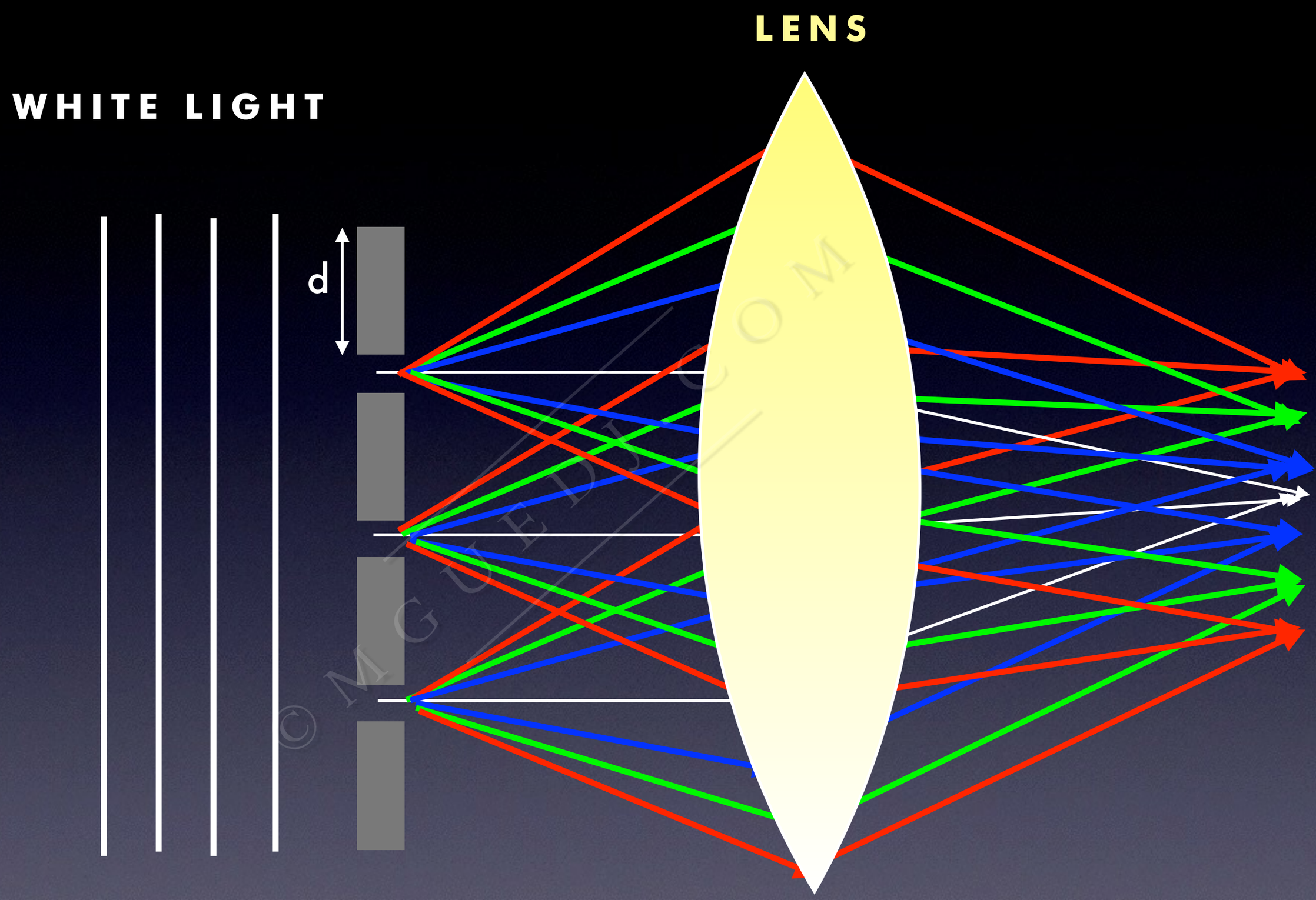
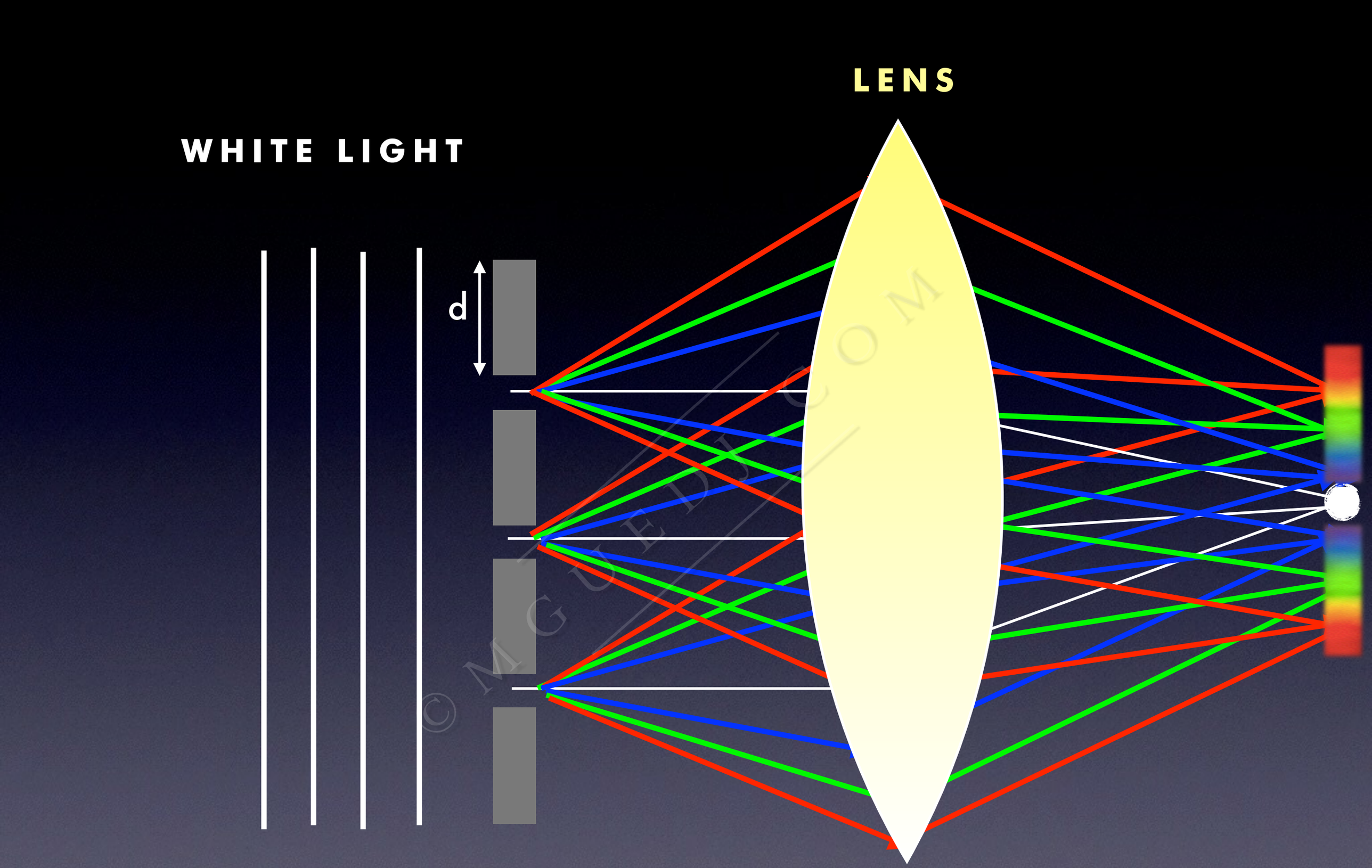

LENS
WHITE LIGHT
d
θ
θ
θ


LENS
WHITE LIGHT
d


WHITE LIGHT
LENS
d


LENS
WHITE LIGHT
d

①

WHAT WAS KNOWN (STATE OF THE ART)

Krueger R - Ophthalmology 2008

Rainbow glare as an optical side effect of IntraLASIK

GROUP 1

399 eyes
(312 patients)

GROUP 2

186 eyes
(97 patients)

older FS

2004-2005
1.3 to 2.6 µJ
9/9 to 11/9 µm

LASIK IntraLase FS 15 kHz

+

4000 Excimer LadarVision

new FS

> 2005
1.3 µJ
10/9 µm

QUESTIONNAIRE

symptoms of glare, halo, starburst, colors & orientation ?

@ postop visit M3 or 📞 call interview

Krueger R - Ophthalmology 2008

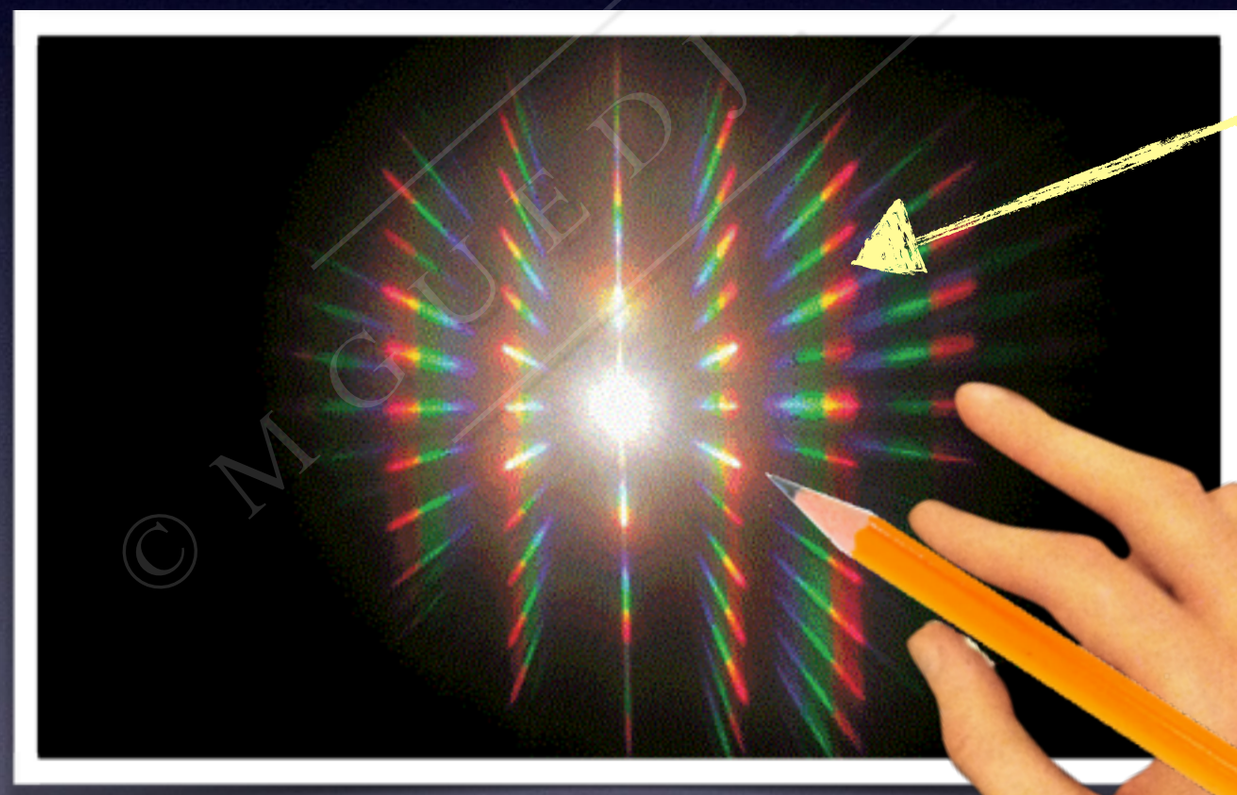
Rainbow glare as an optical side effect of IntraLASIK

+ <u>DRAWING</u>

OF THE PERIPHERAL SPECTRAL PATTERN !

paper @ 55 cm

around a point
white light source



ORIENTATION AND VISUAL ANGLE OF
BLUE
YELLOW
RED

Krueger R - Ophthalmology 2008

Rainbow glare as an optical side effect of IntraLASIK

+ <u>DRAWING</u>

OF THE PERIPHERAL SPECTRAL PATTERN !

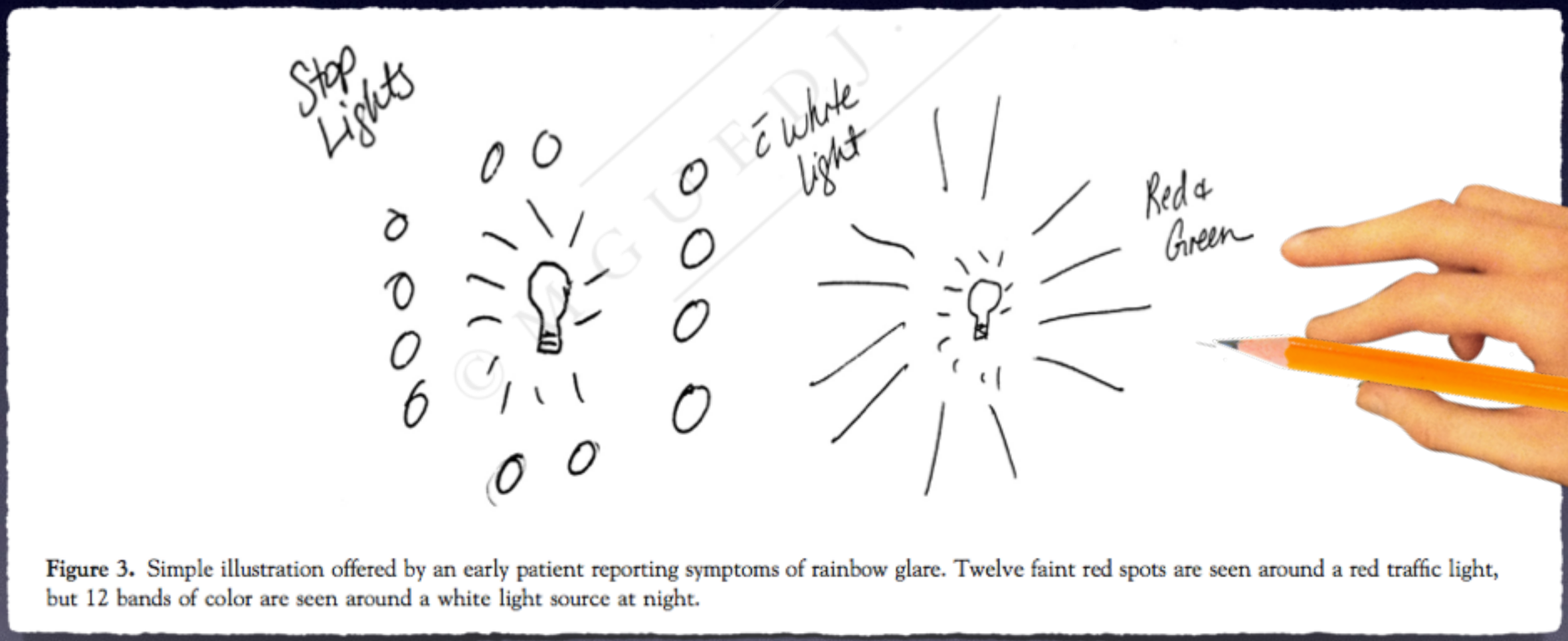


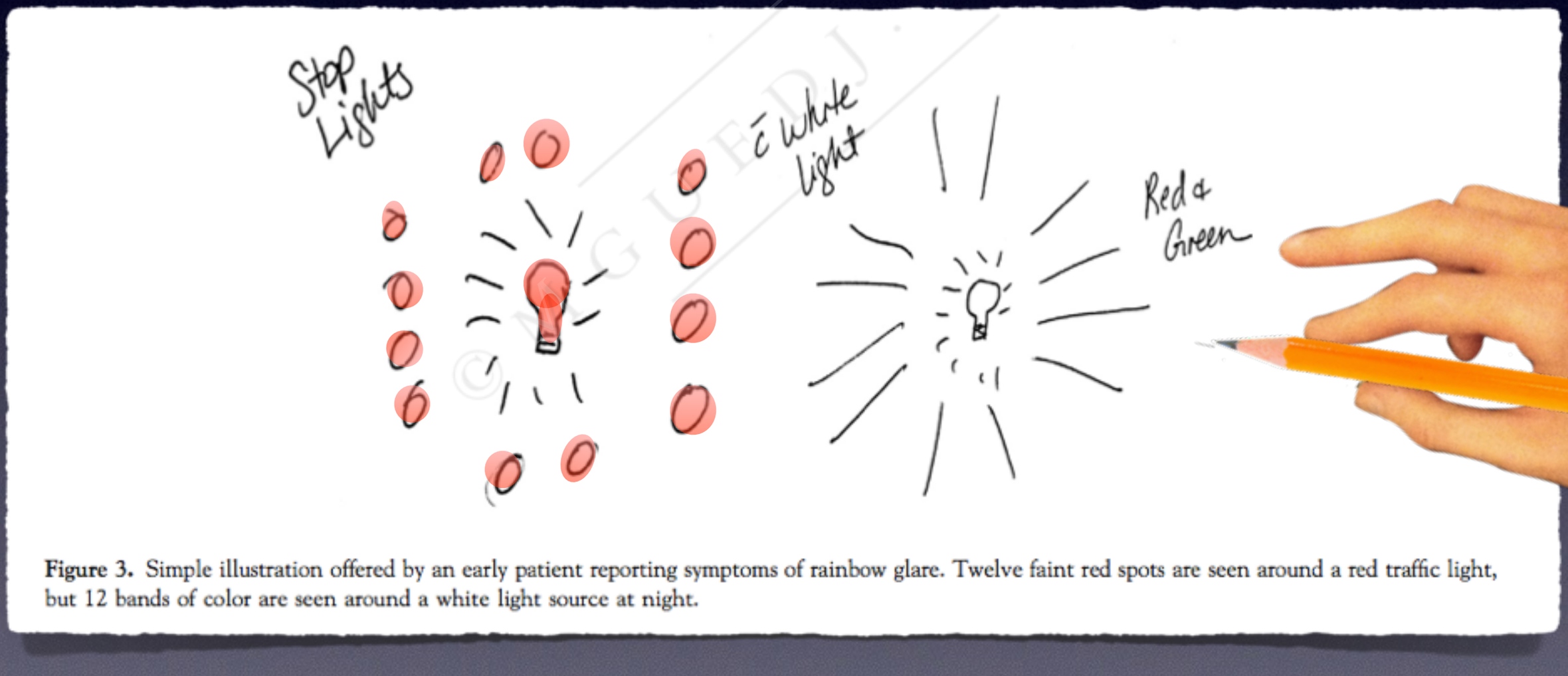
Figure 3. Simple illustration offered by an early patient reporting symptoms of rainbow glare. Twelve faint red spots are seen around a red traffic light, but 12 bands of color are seen around a white light source at night.

Krueger R - Ophthalmology 2008

Rainbow glare as an optical side effect of IntraLASIK

+ <u>DRAWING</u>

OF THE PERIPHERAL SPECTRAL PATTERN !



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Krueger R - Ophthalmology 2008

Rainbow glare as an optical side effect of IntraLASIK

+ <u>DRAWING</u>

OF THE PERIPHERAL SPECTRAL PATTERN !

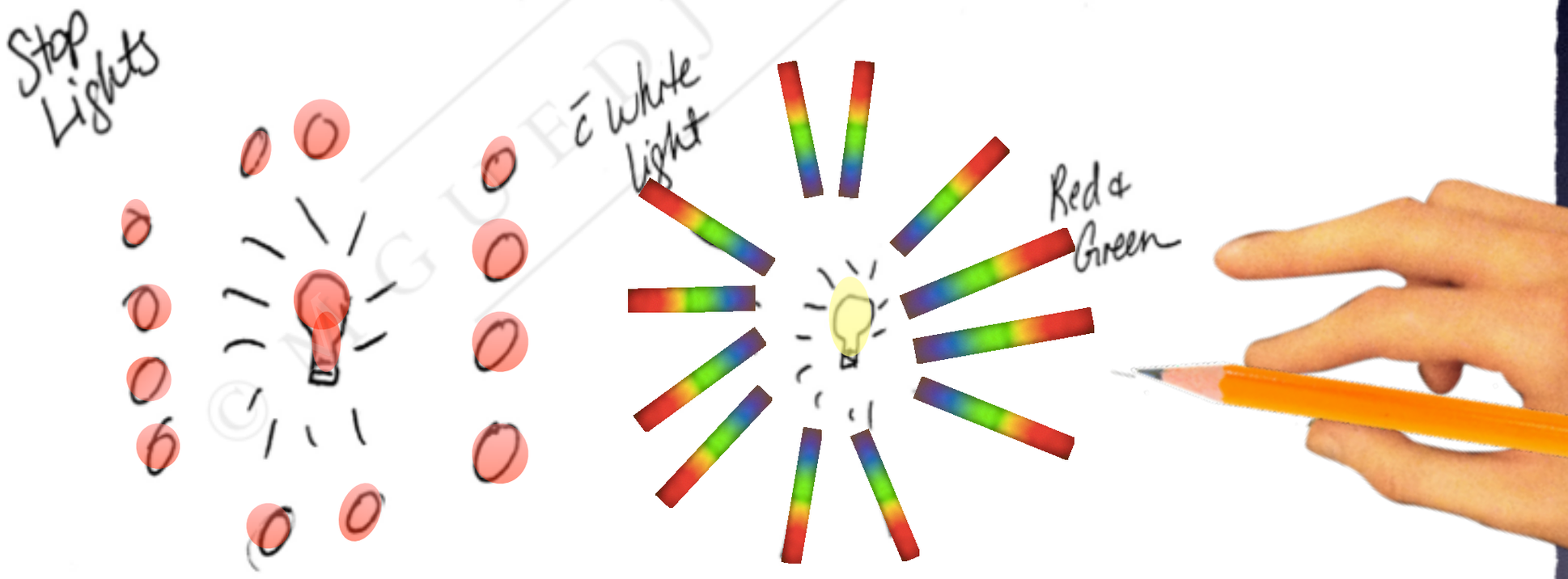

Figure 3. Simple illustration offered by an early patient reporting symptoms of rainbow glare. Twelve faint red spots are seen around a red traffic light, but 12 bands of color are seen around a white light source at night.

Krueger R - Ophthalmology 2008

Rainbow glare as an optical side effect of IntraLASIK

GROUP 1

399 eyes
(312 patients)

GROUP 2

186 eyes
(97 patients)

LASIK IntraLase FS 15 kHz

older FS

2004-2005
1.3 to 2.6 µJ
9/9 to 11/9 µm

new FS

> 2005
1.3 µJ
10/9 µm

37/194 patients
19 %

RAINBOW GLARE

2/86 patients
2.3 %

Krueger R - Ophthalmology 2008

Rainbow glare as an optical side effect of IntraLASIK

GROUP 1

399 eyes
(312 patients)

GROUP 2

186 eyes
(97 patients)

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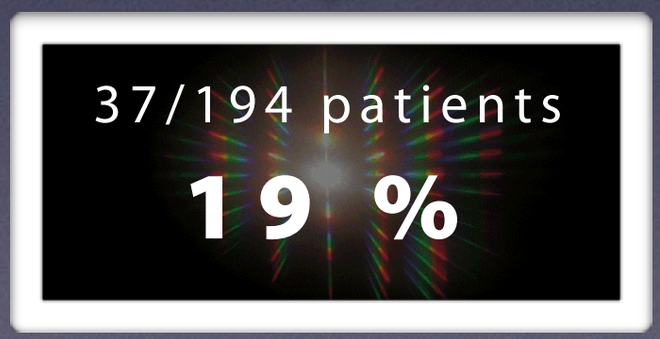
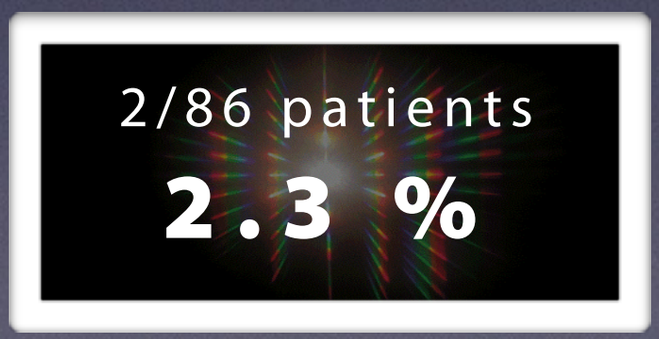




RAINBOW GLARE
OR 9.4
p < 0.001

31.6% HALOS, GLARE, STARBURST 32.1%

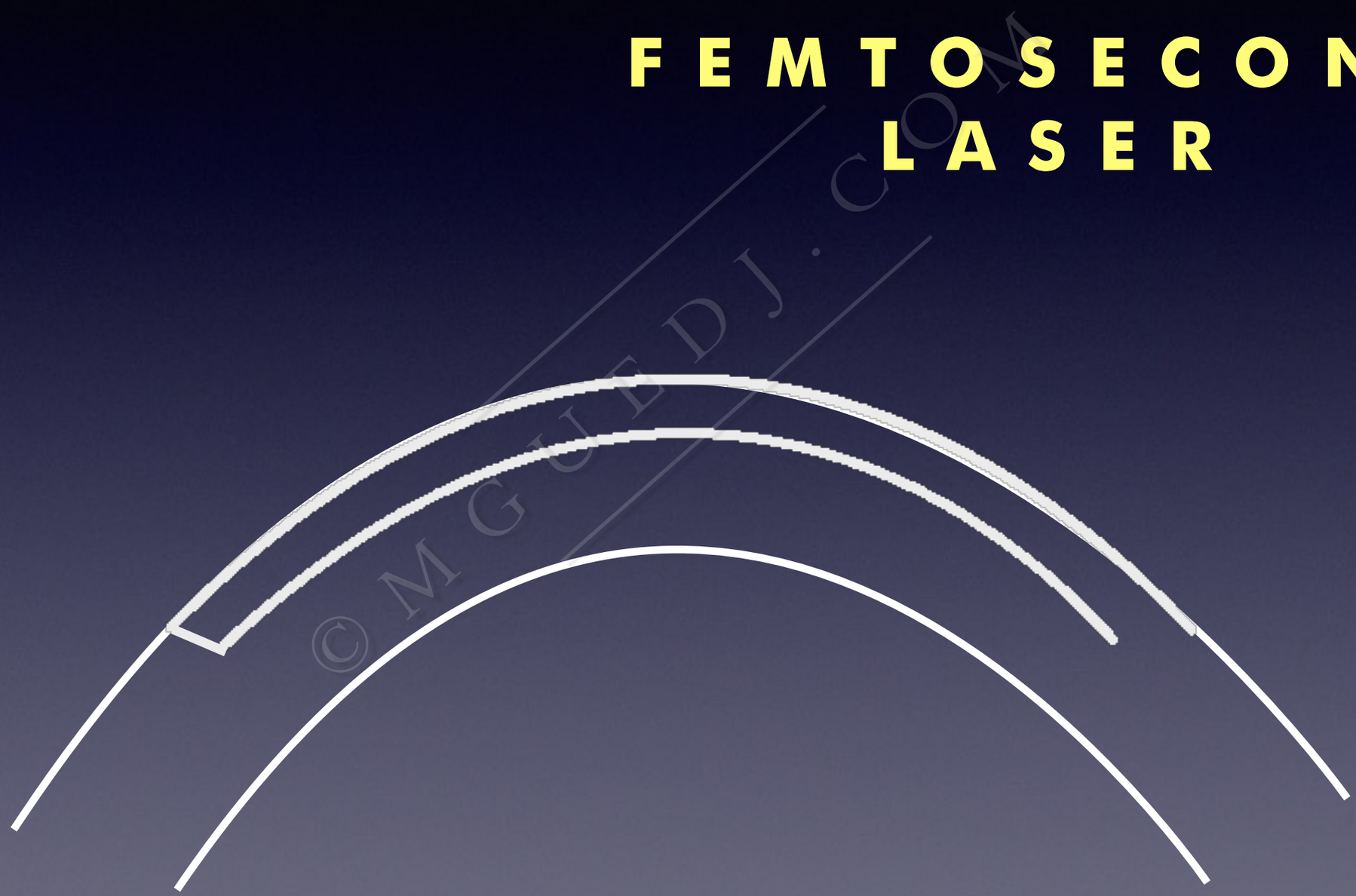
6%

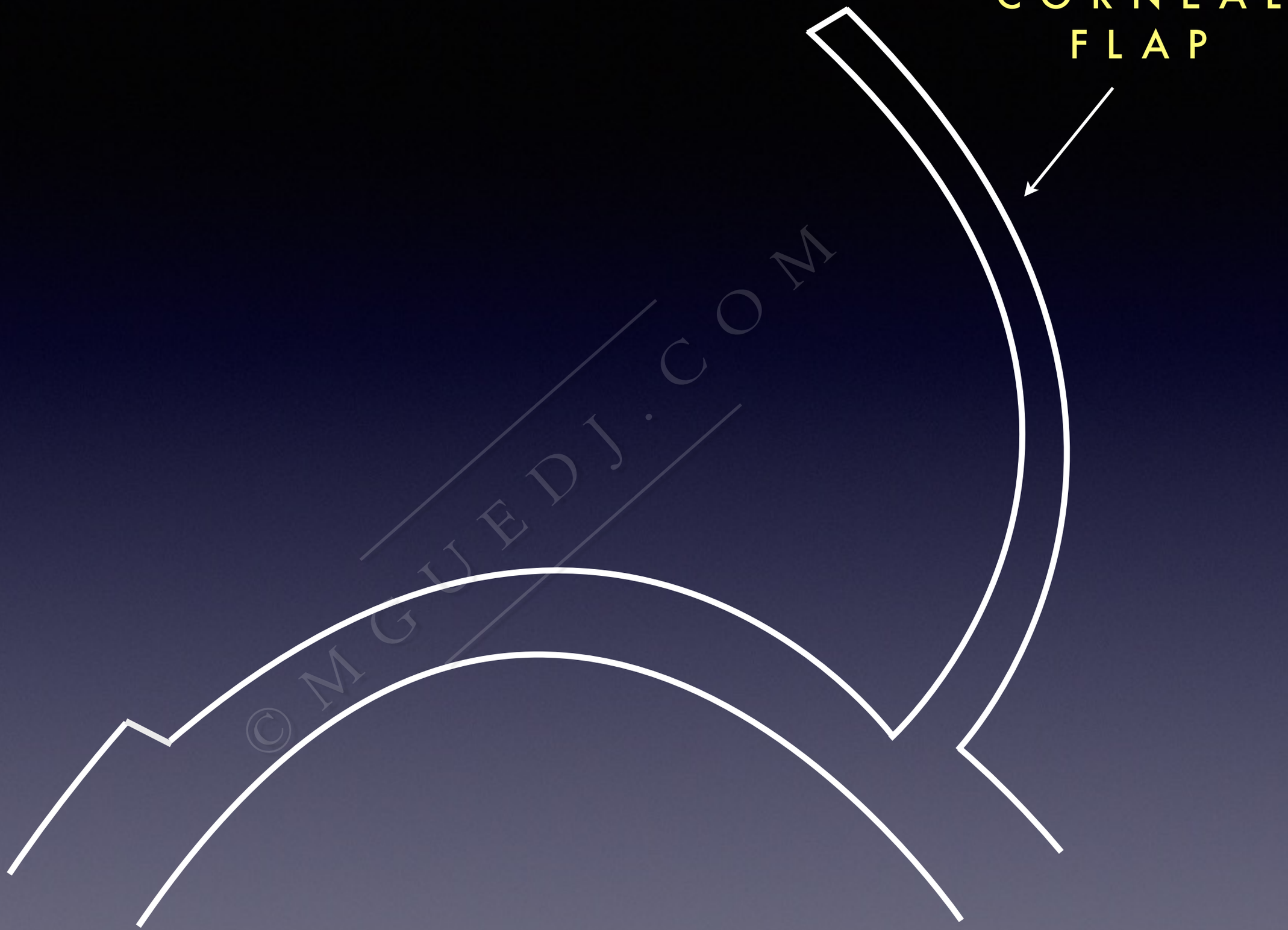
Bamba - Journal of Cataract & Refractive Surgery 2009

Incidence of rainbow glare after LASIK flap creation with a 60 kHz fs laser.

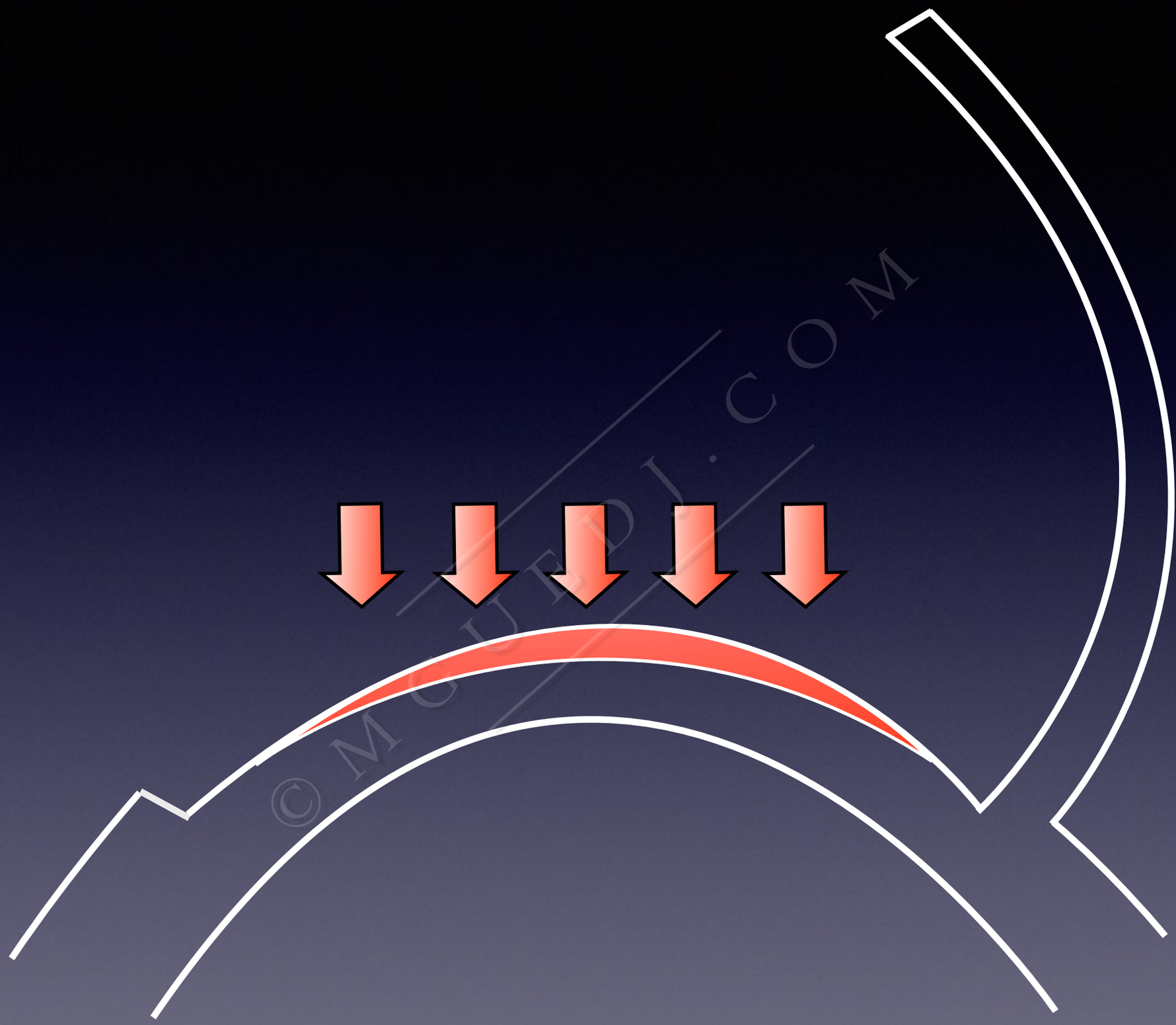
LASER *IN SITU* KERATOMILEUSIS (LASIK) TECHNIQUE

FEMTOSECOND LASER

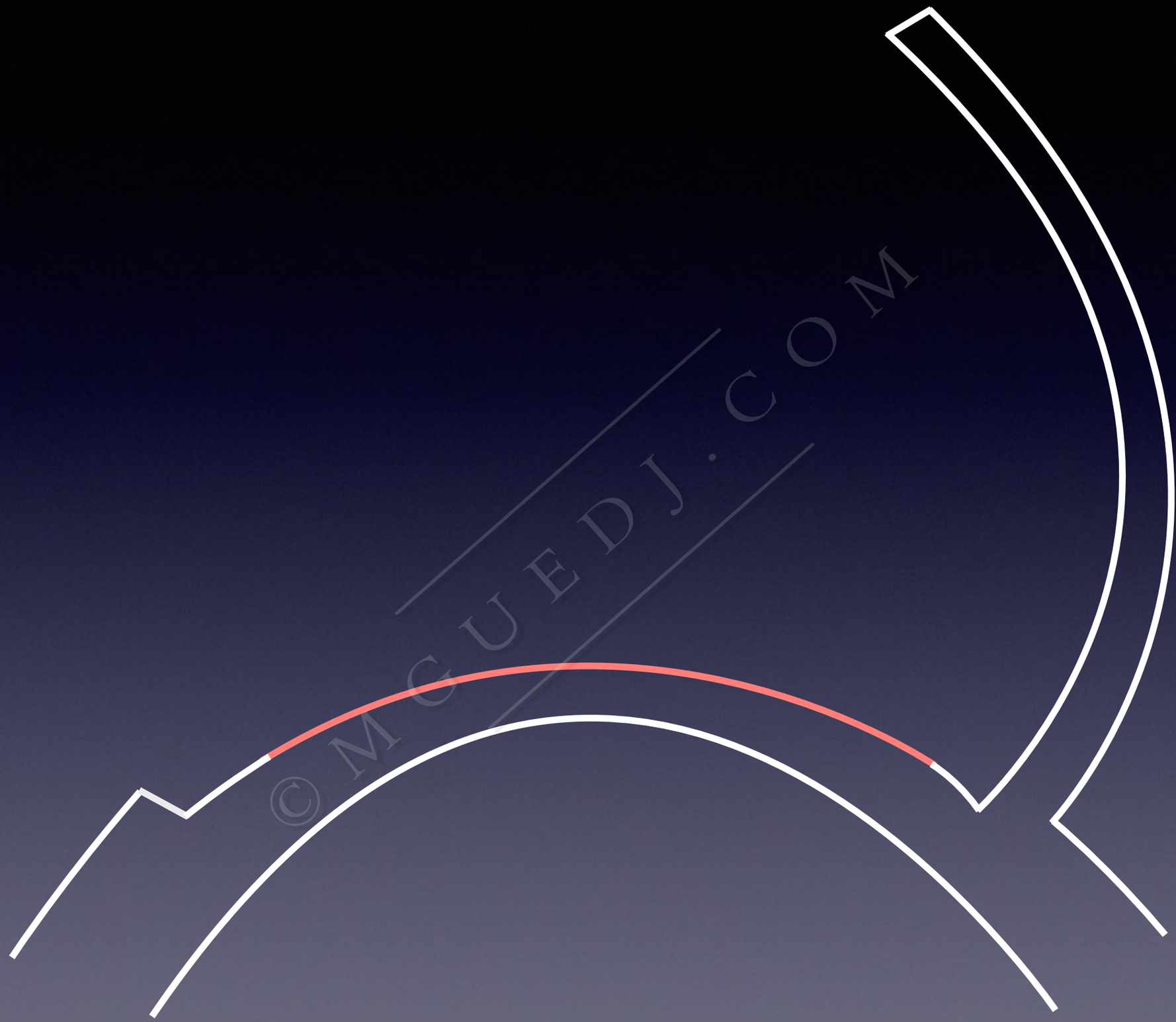


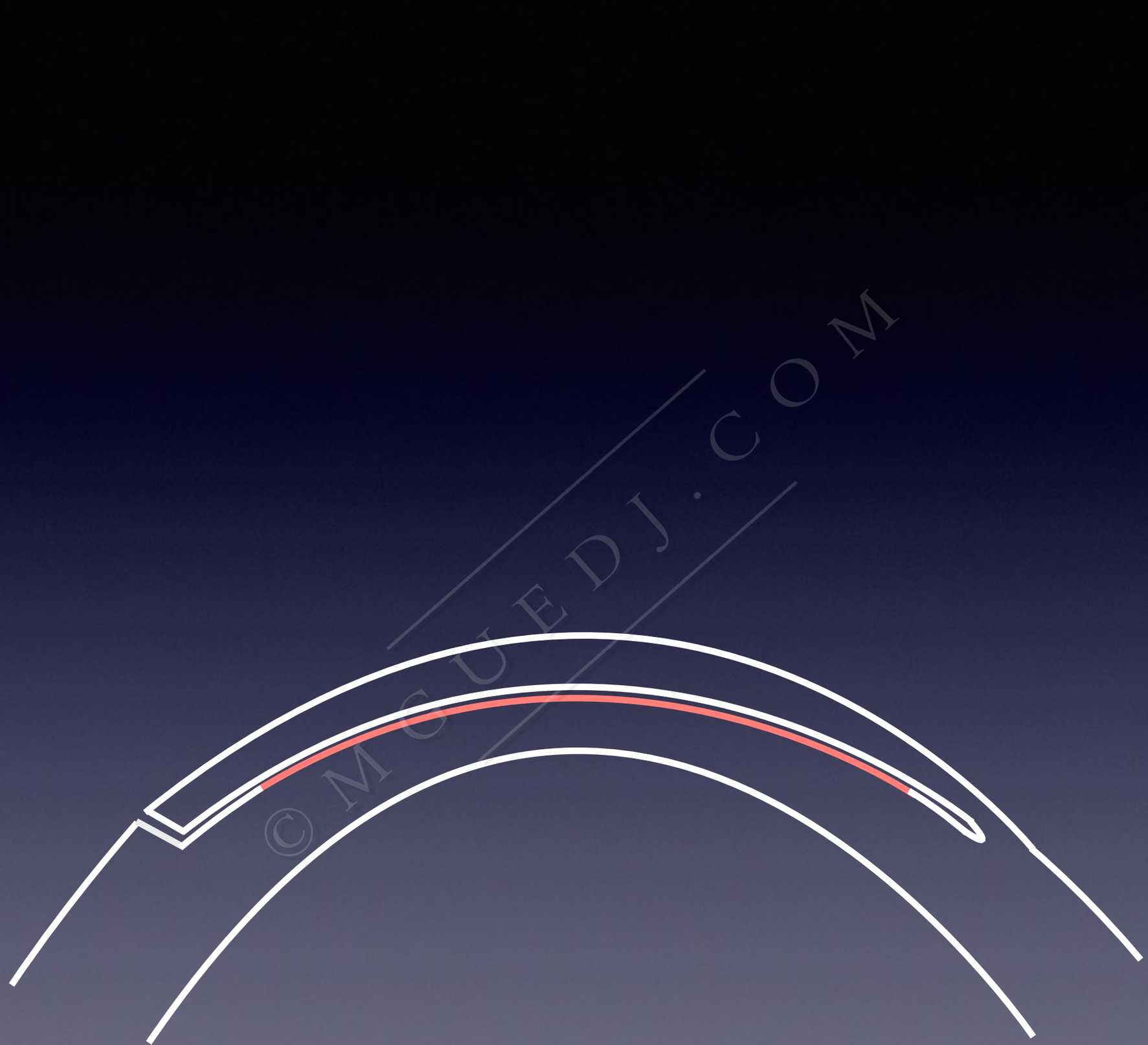


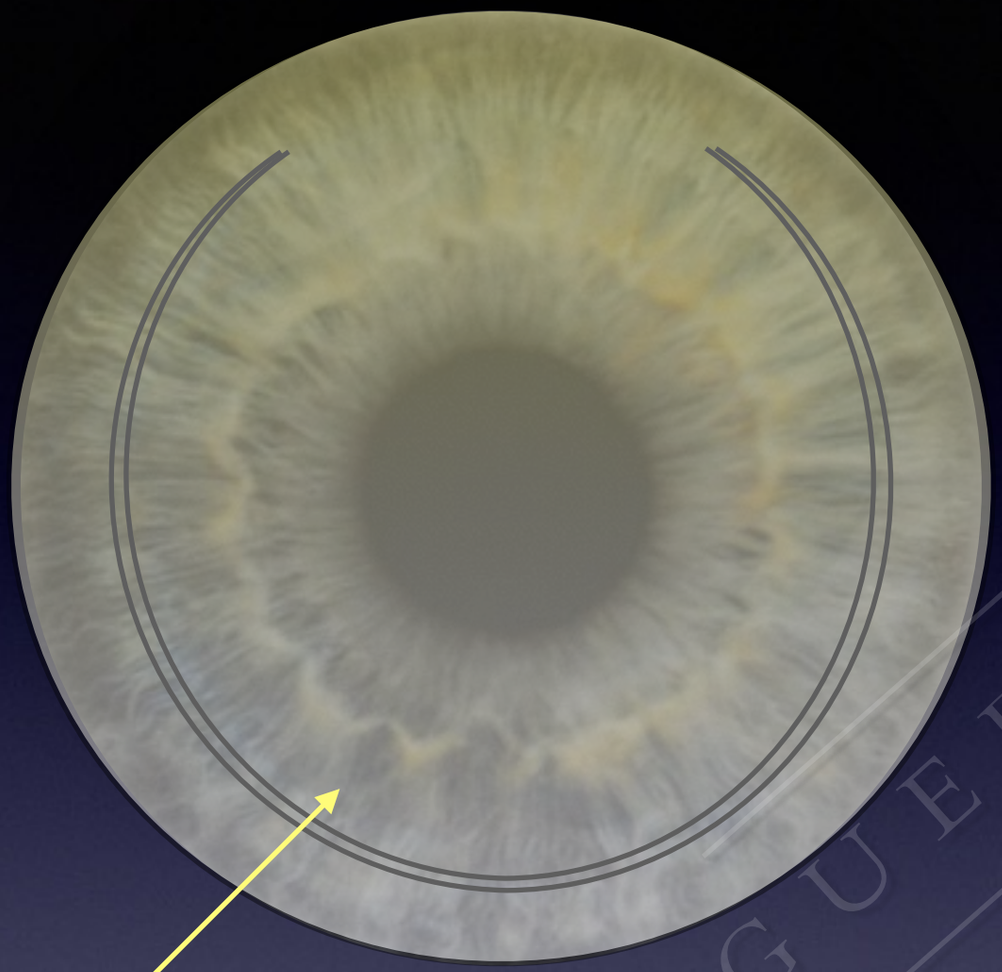
EXCIMER LASER



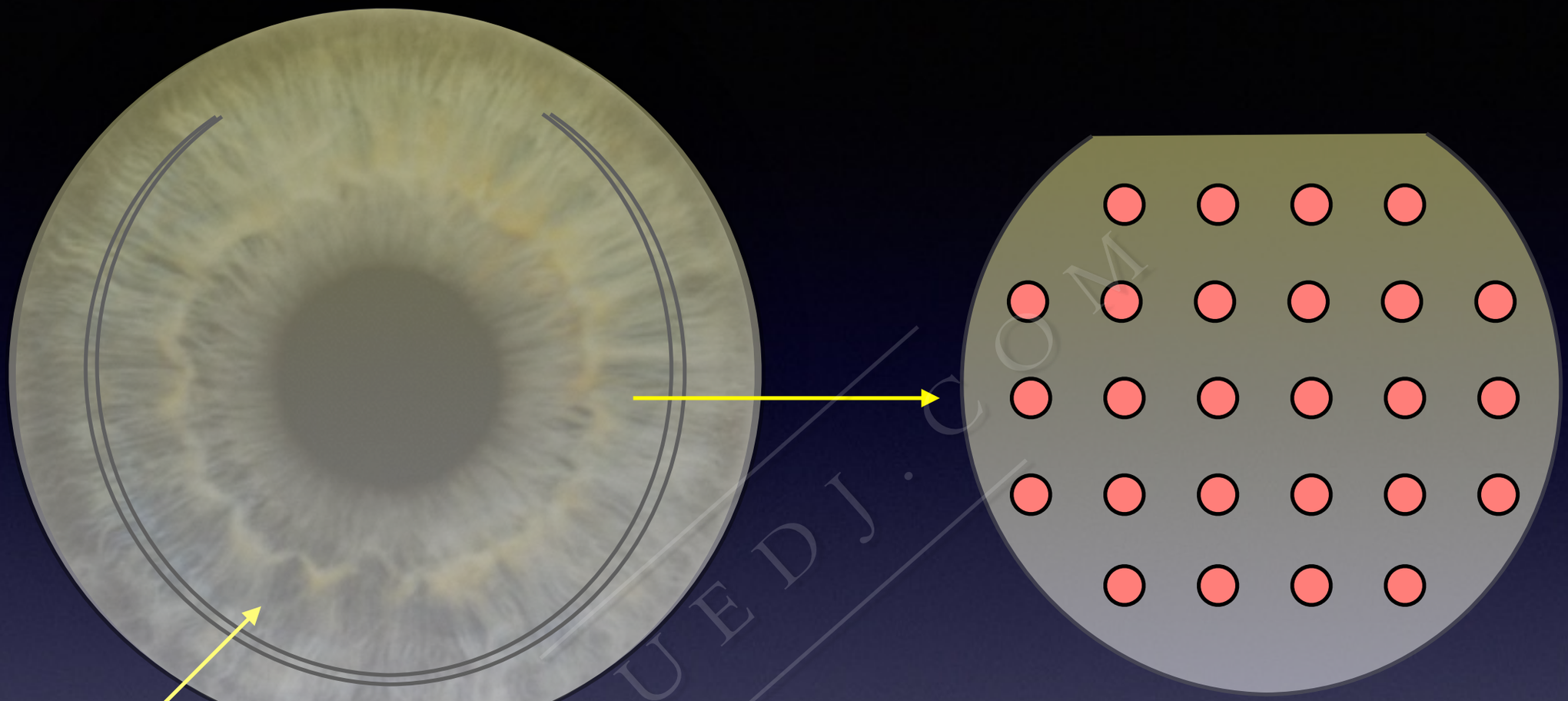
PHOTOABLATION



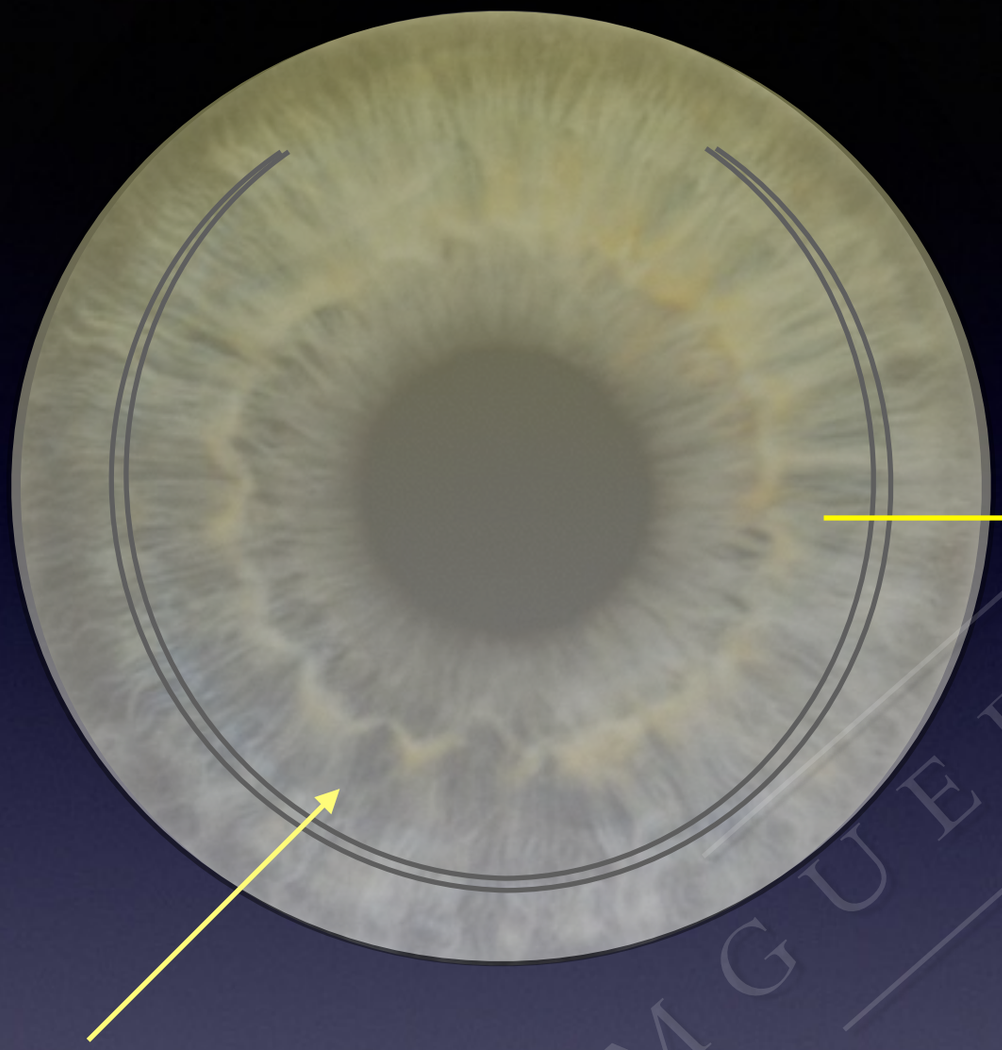




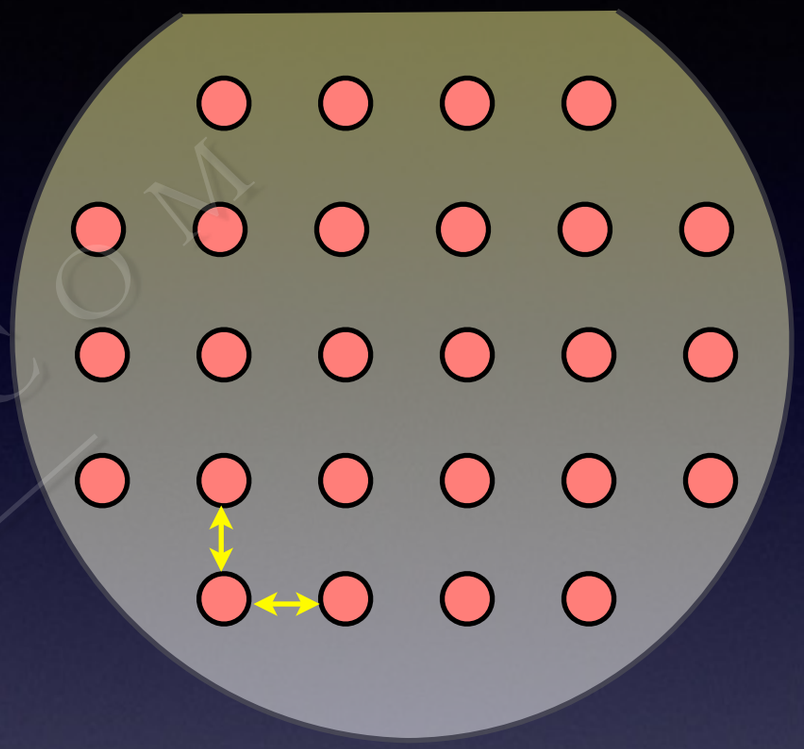
FLAP



FLAP



FLAP

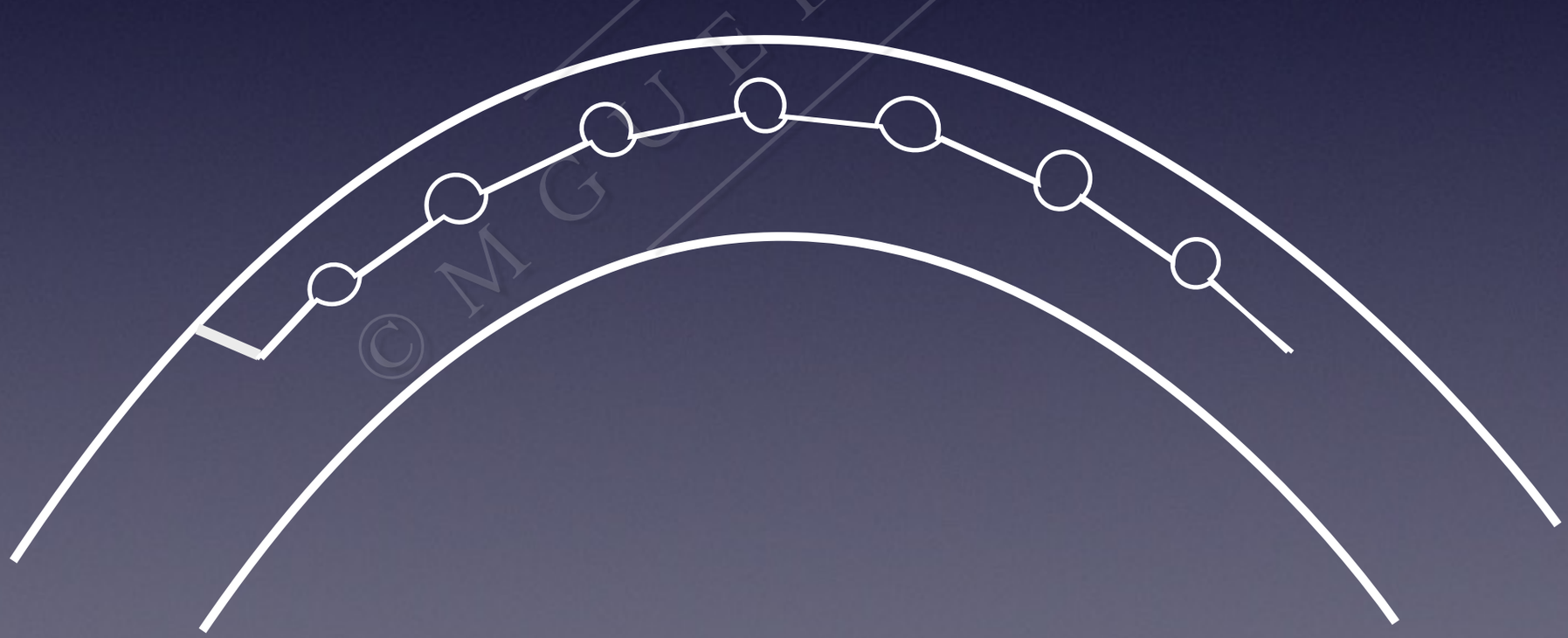


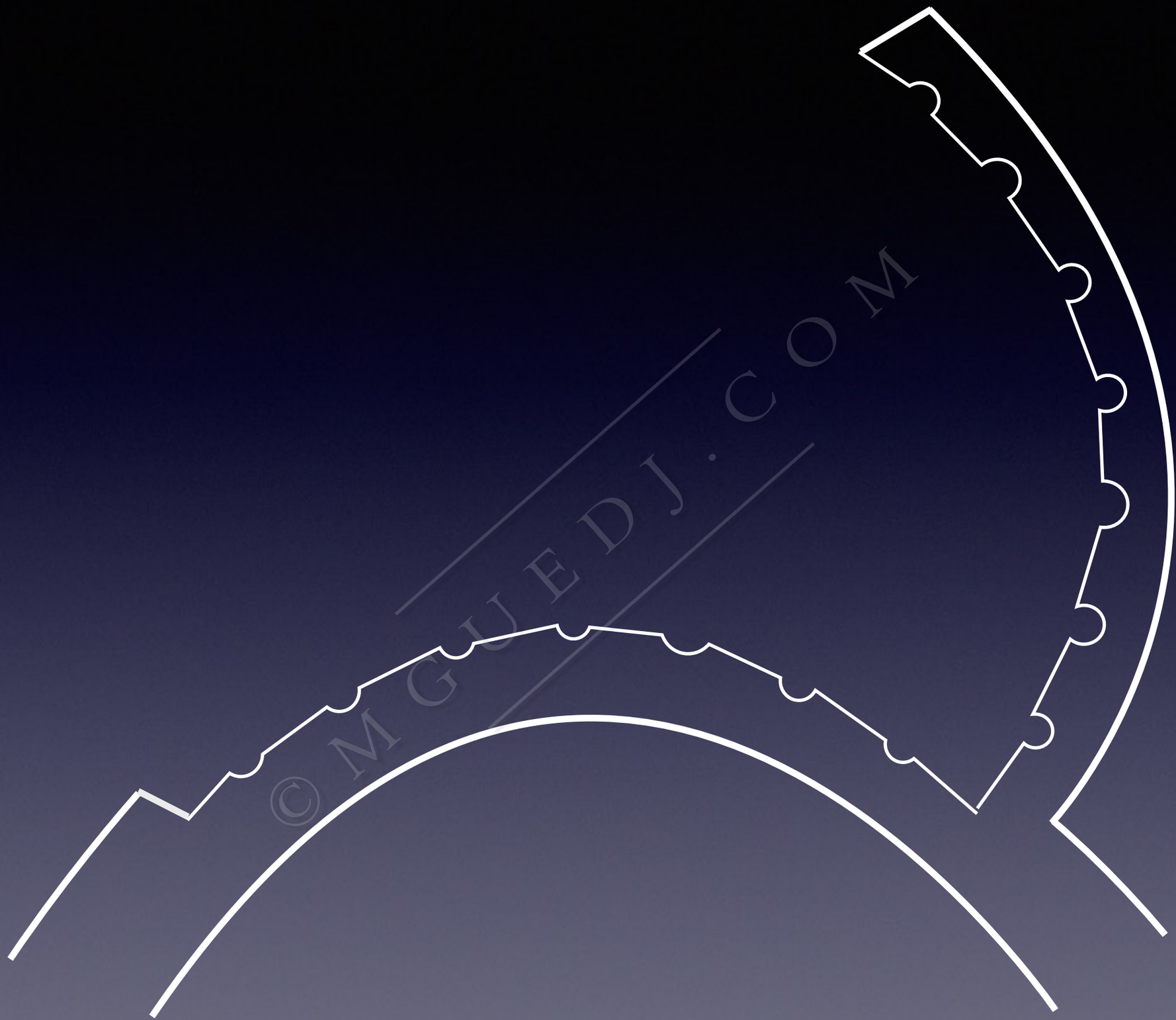
↔ SPOT SEPARATION

↕ LINE SEPARATION

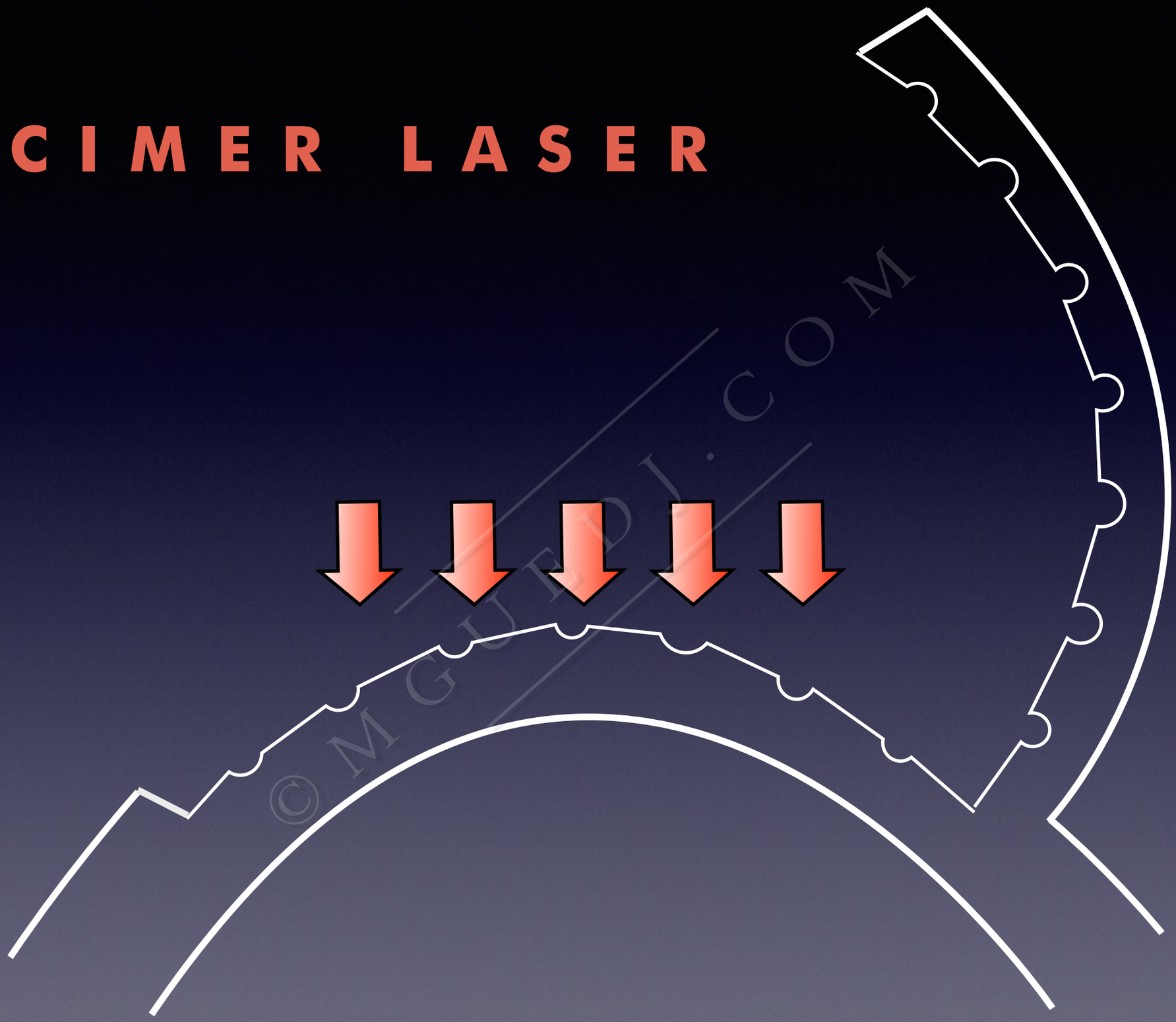
≃ 9.5 µm

FS IMPACTS A DIFFRACTION GRATING



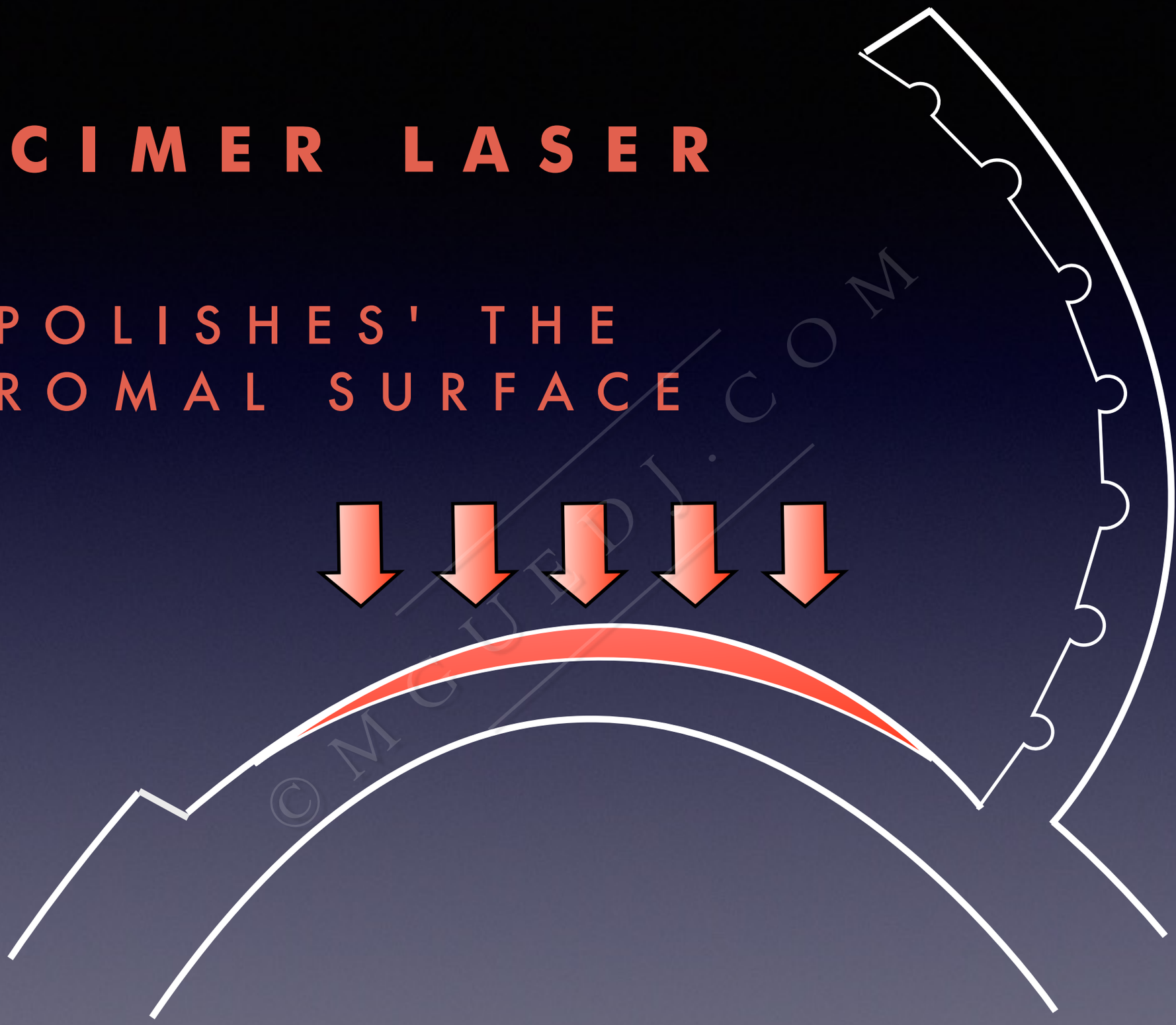


EXCIMER LASER

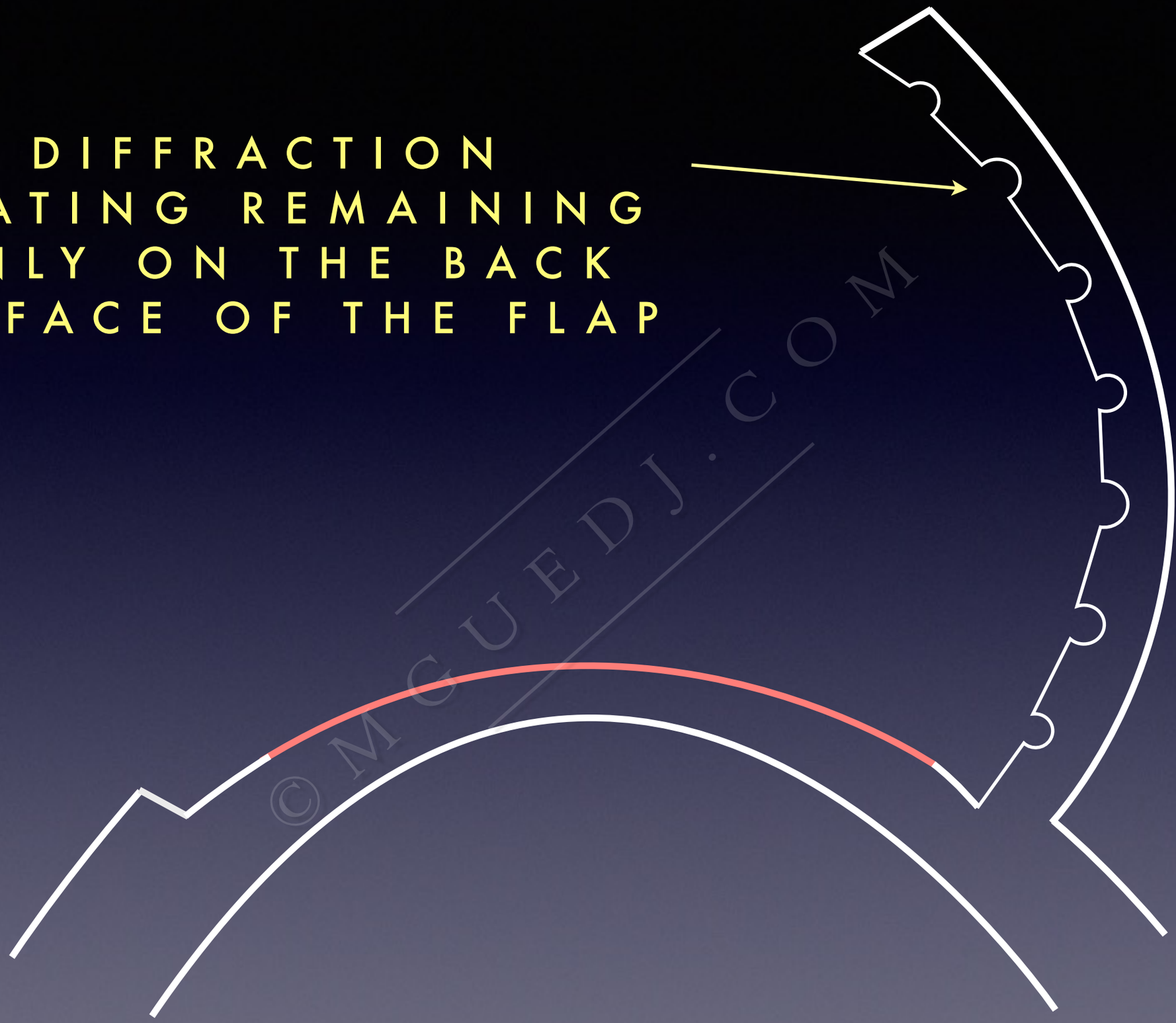


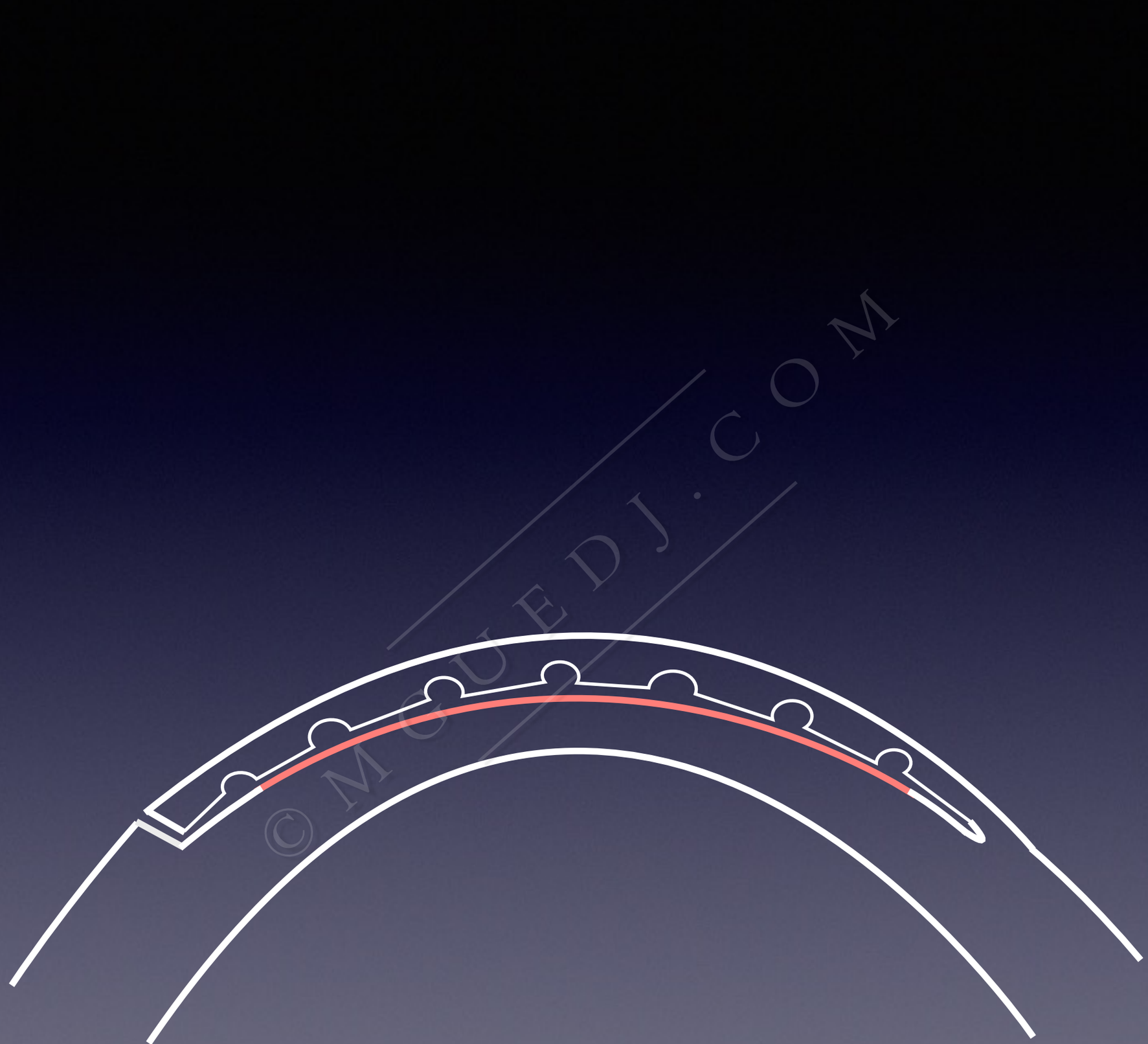
EXCIMER LASER

'POLISHES' THE STROMAL SURFACE

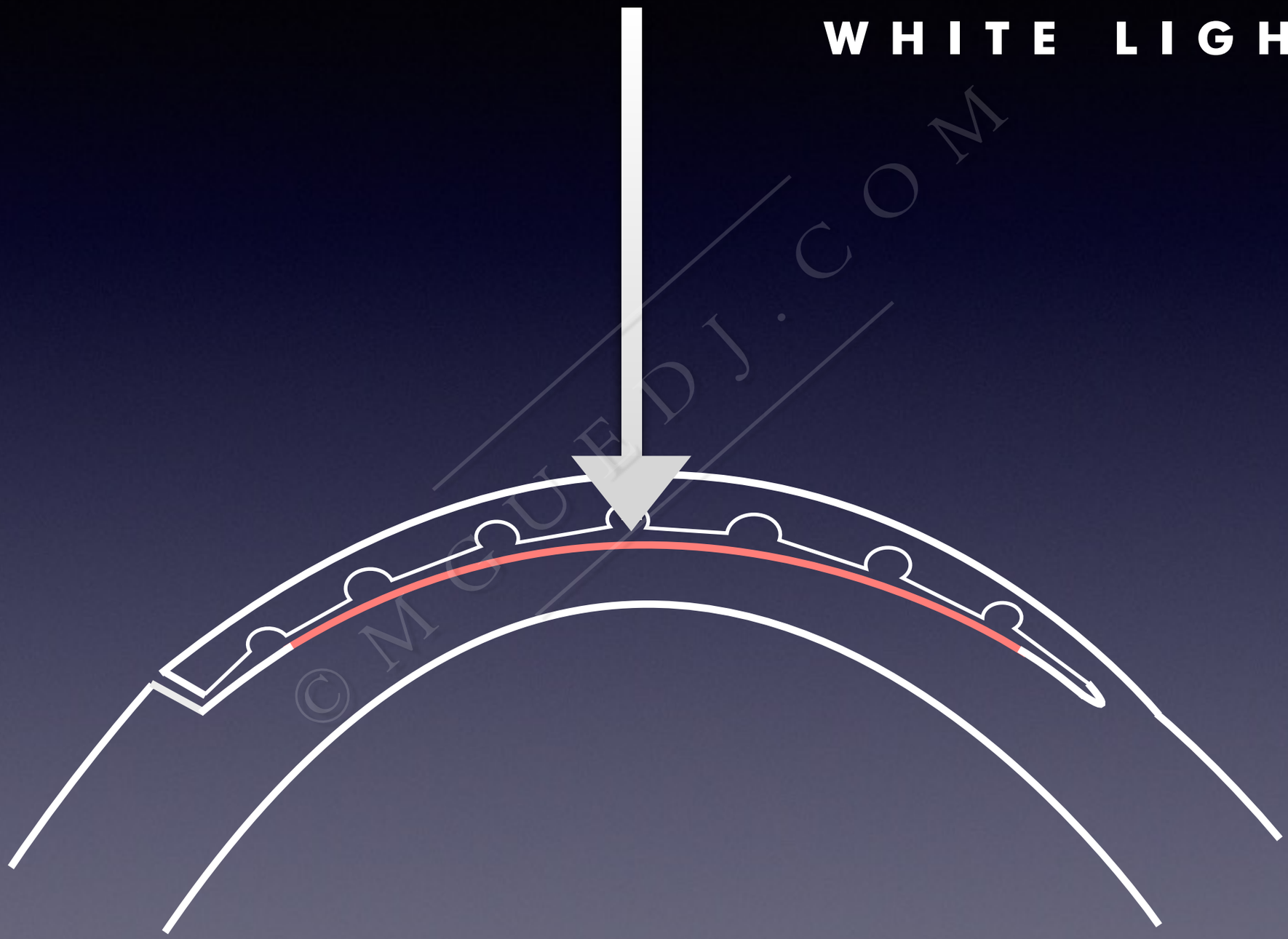


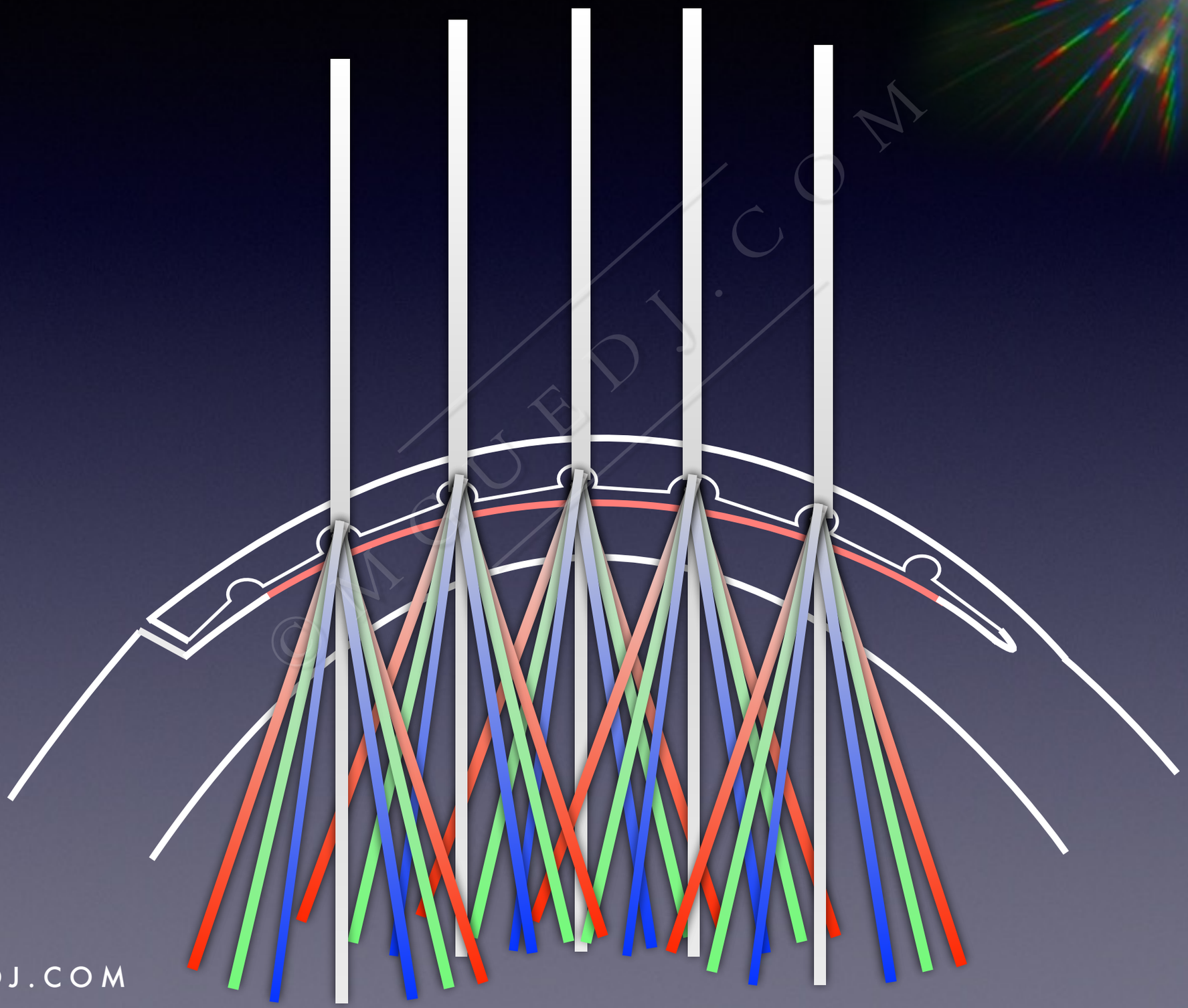
DIFFRACTION GRATING REMAINING ONLY ON THE BACK SURFACE OF THE FLAP





WHITE LIGHT





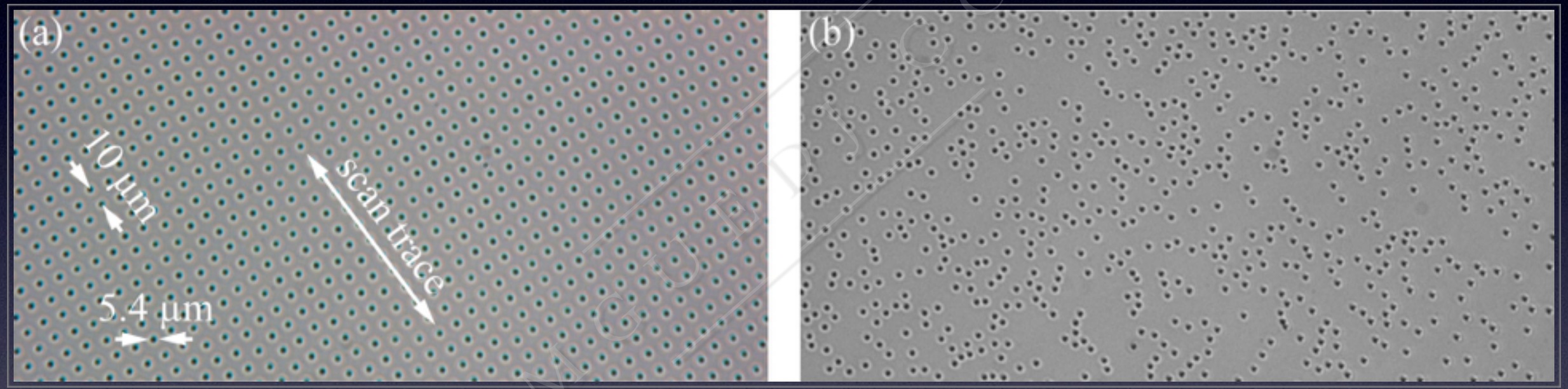
②

AIMS AND QUESTIONS

Can we minimize rainbow glare by randomising the FS-impact pattern ?

Ackermann R - Biomedical Optics Express 2012

Optical side-effects of fs-laser treatment in refractive surgery investigated by means of a model eye



REGULAR 10 µm spacing

RANDOM

Ackermann R - Biomedical Optics Express 2012

Optical side-effects of fs-laser treatment in refractive surgery investigated by means of a model eye

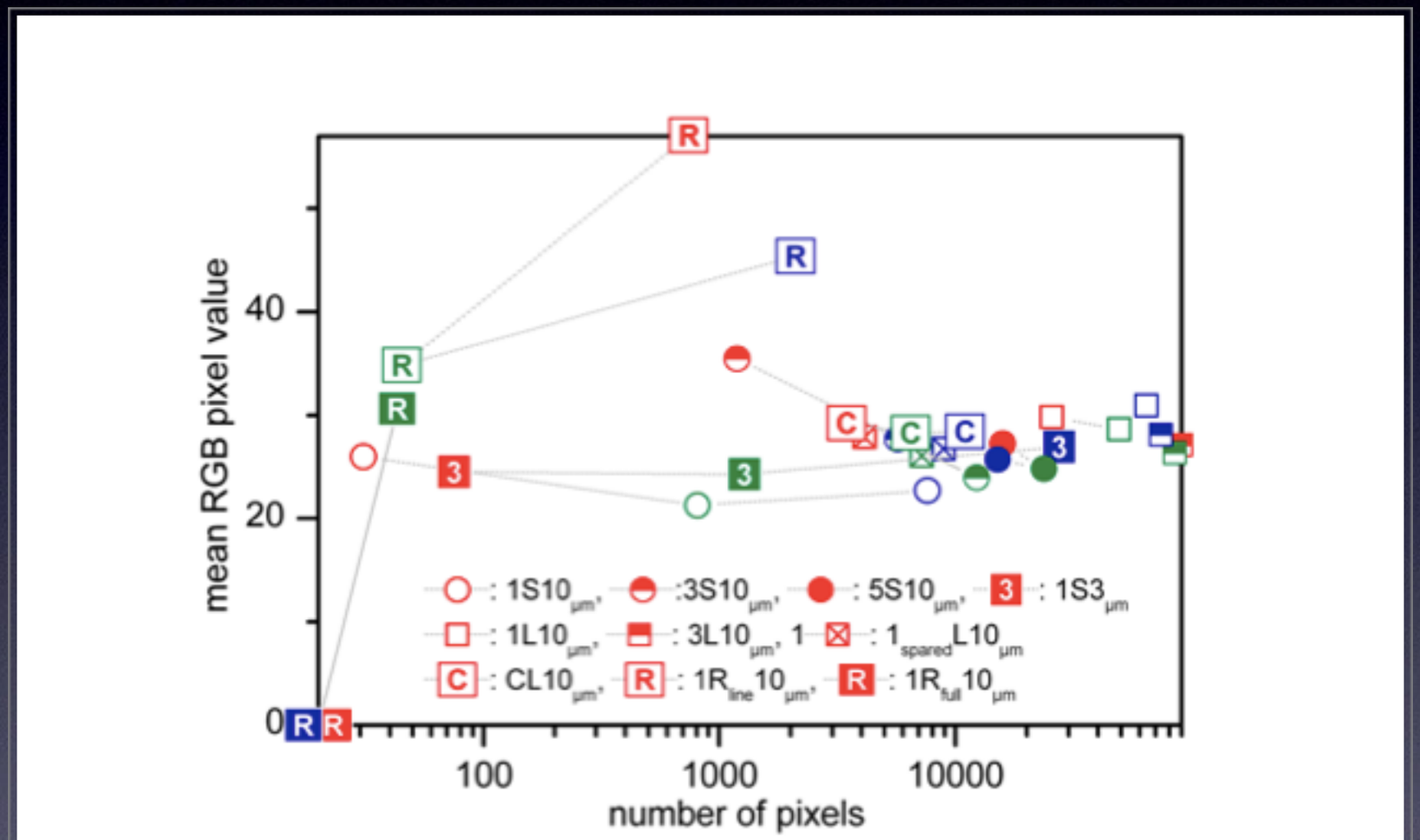
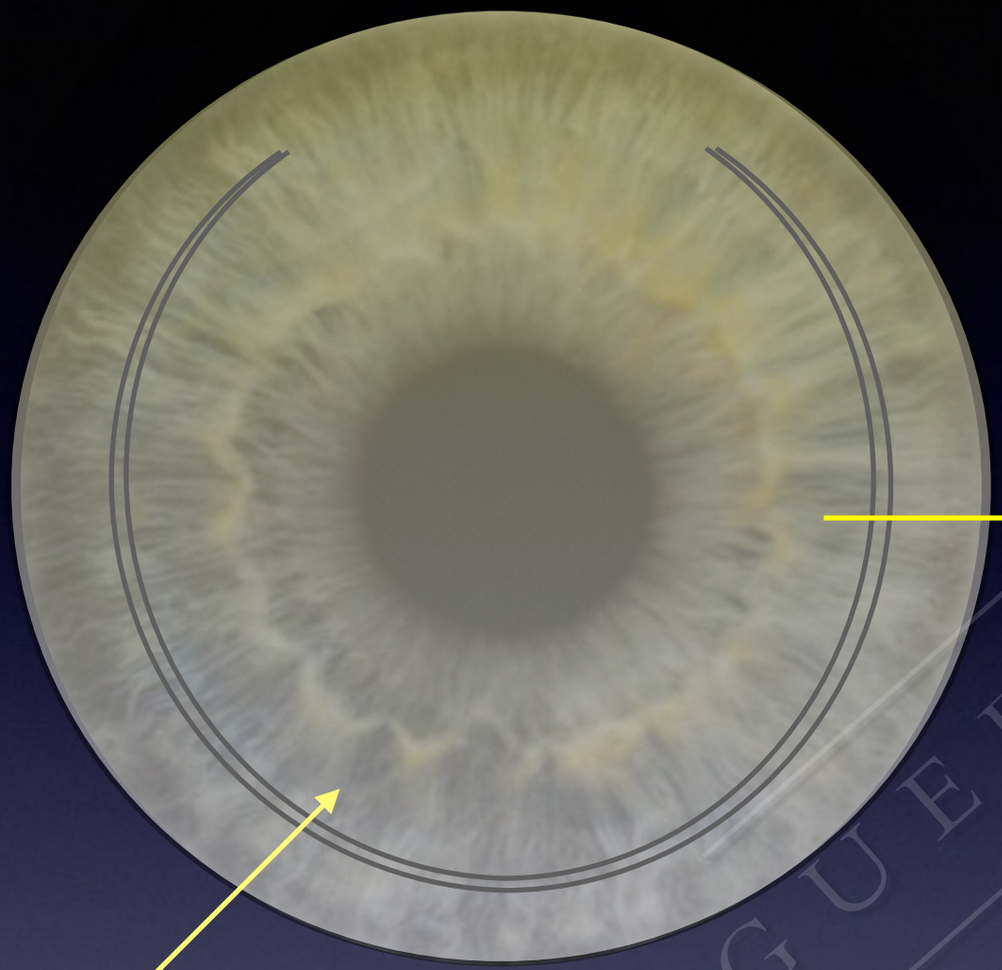


Fig. 3. Number of pixels, for which the intensity of the RGB-channel to be analyzed is 25% higher than the other two channels; the ordinate shows their mean intensity value. Colors indicate the corresponding RGB-channel. For the lens with laser spots at random positions, the number of pixels is exactly zero.

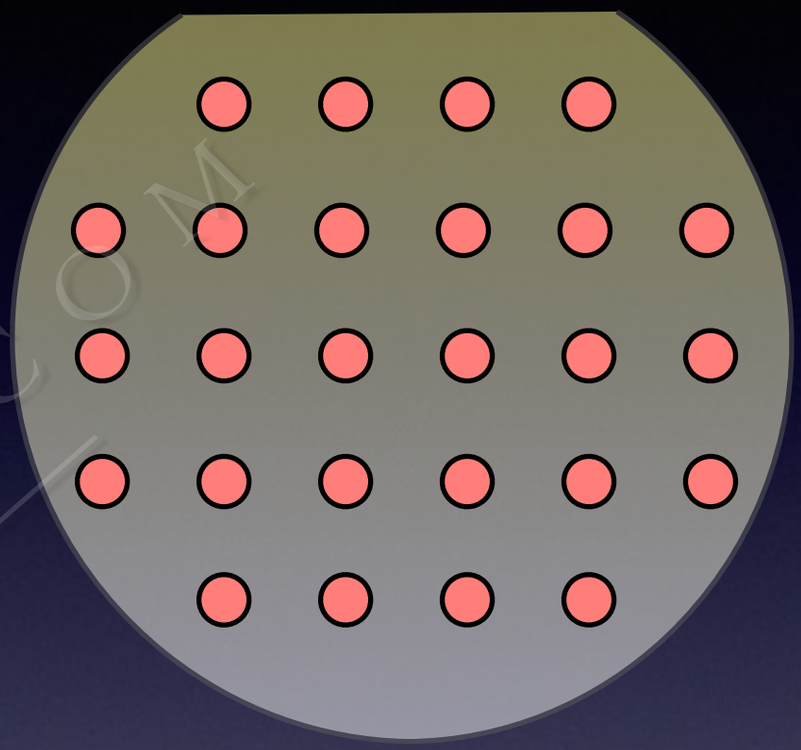
Ackermann R - Biomedical Optics Express 2012

Optical side-effects of fs-laser treatment in refractive surgery investigated by means of a model eye

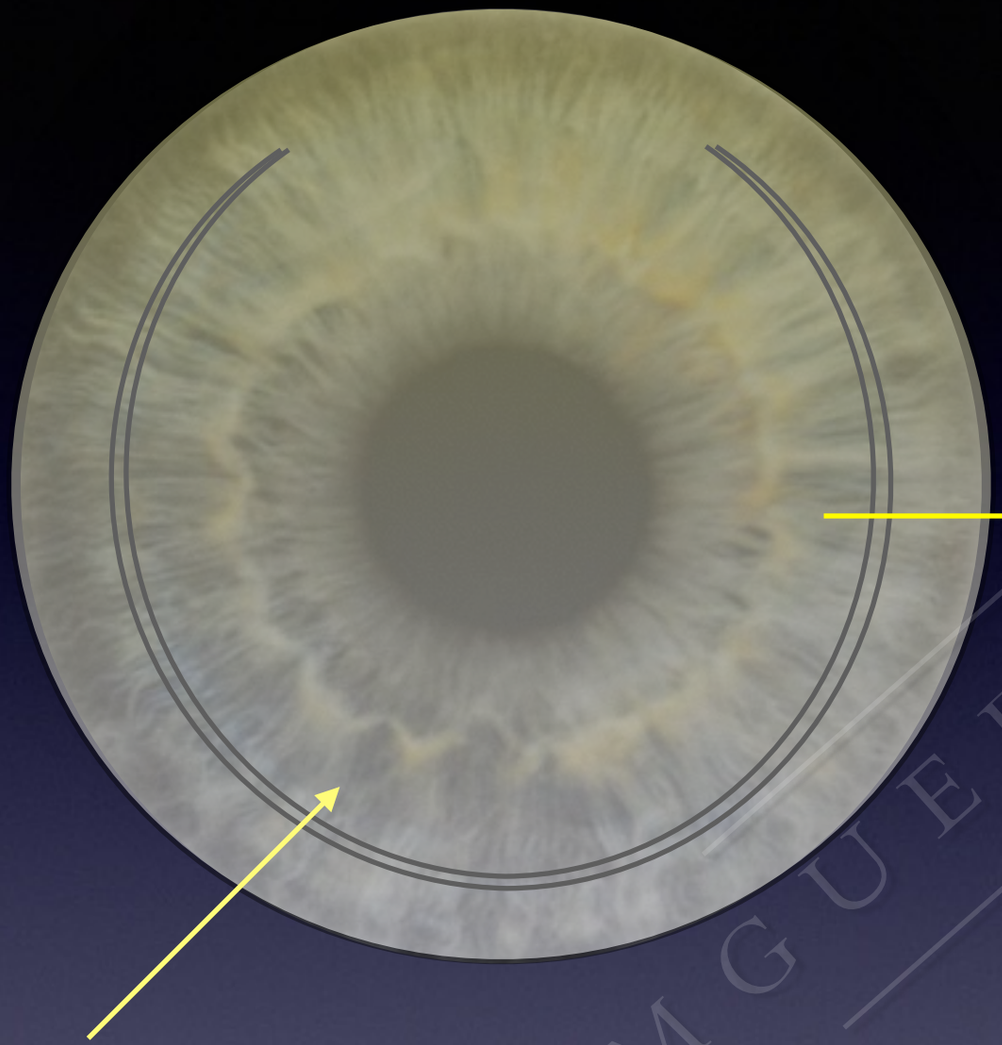
- **RG = dominant optical side effect in fs-refractive surgery.**
- **For corneal treatments, it can be avoided by spot-to-spot distances of ~3 µm.**
- **For fs-laser treatment of the crystalline lens, rainbow glare may nearly entirely be suppressed by a random distribution of the laser spots within the lens.**



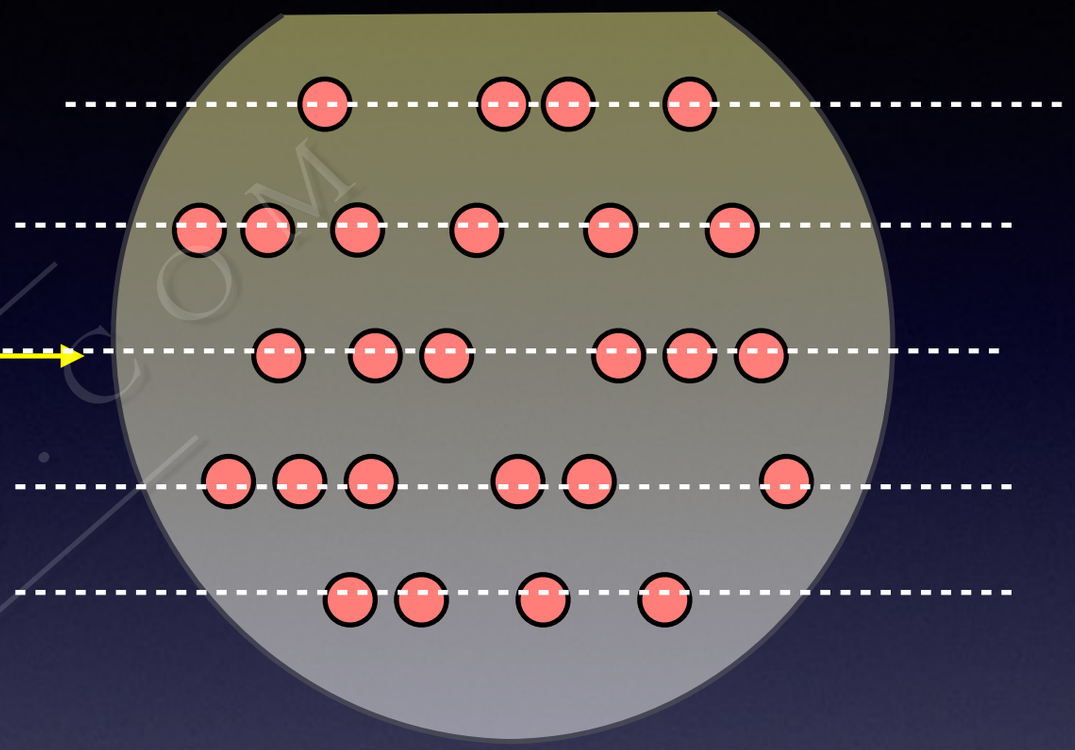
FLAP



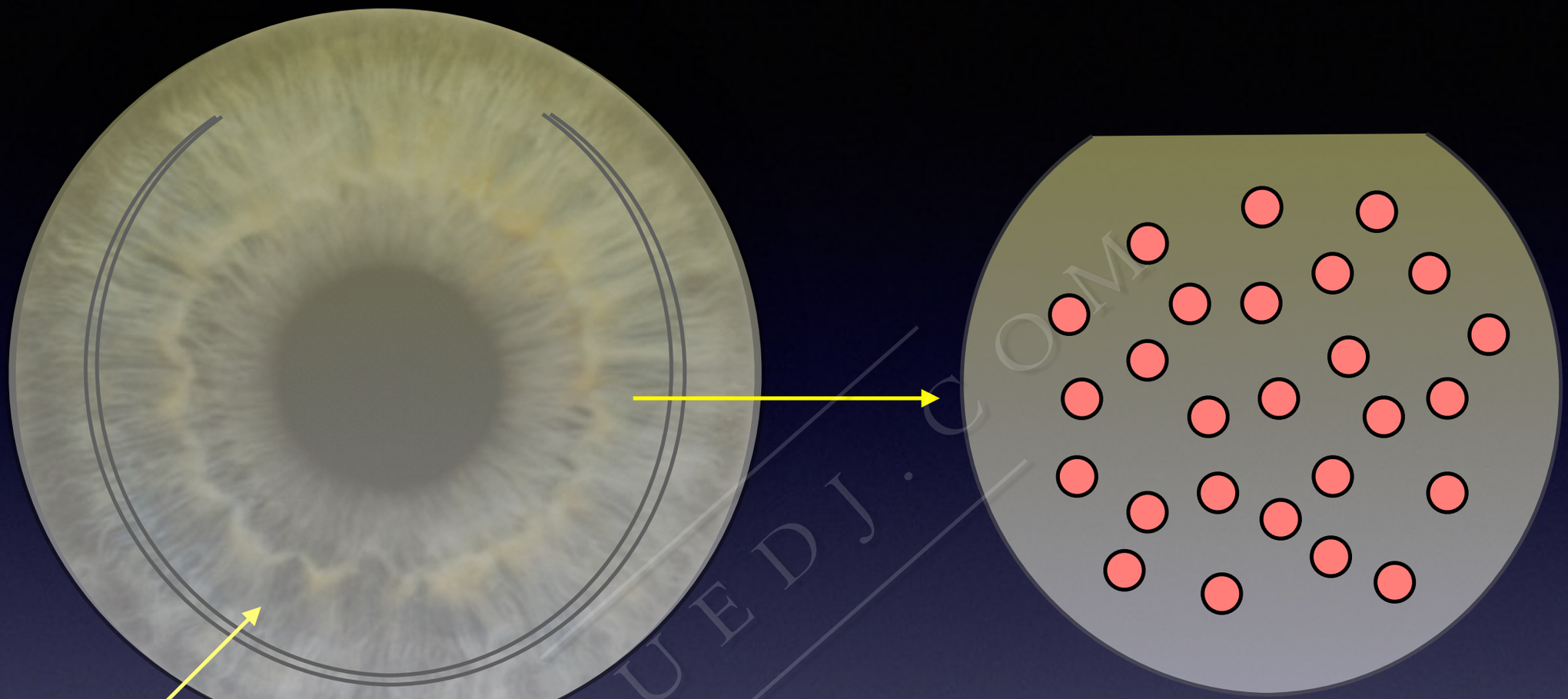
REGULAR LINES



FLAP



RANDOM PER LINE

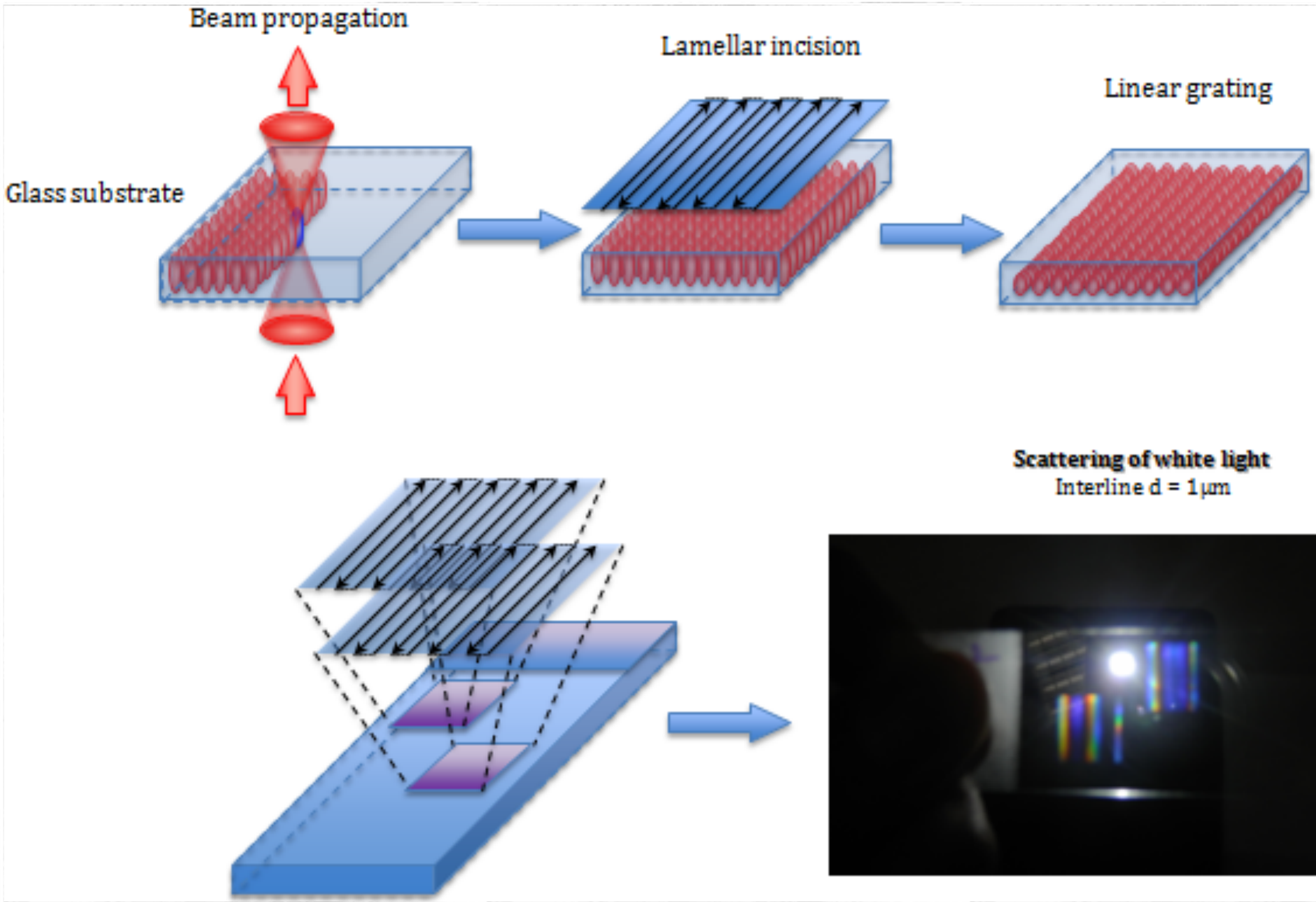


FLAP

FULLY RANDOM

③

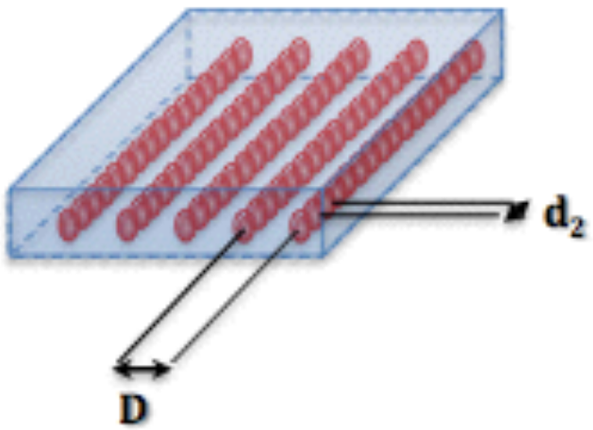
METHODS

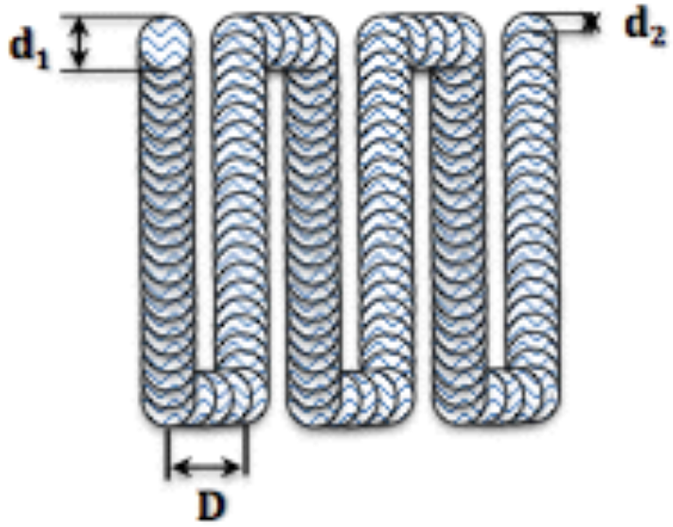


COURTESY OF Z. ESSAIDI

Quantification

Linear grating





✓ Pulses overlapping (~67%)

Distance between pulses:

$$d_2 = \frac{\Delta}{Fr \times T_x}$$

Δ: line length (1cm)
Fr: laser rep. rate (10kHz)
T_x: time per line (1s)

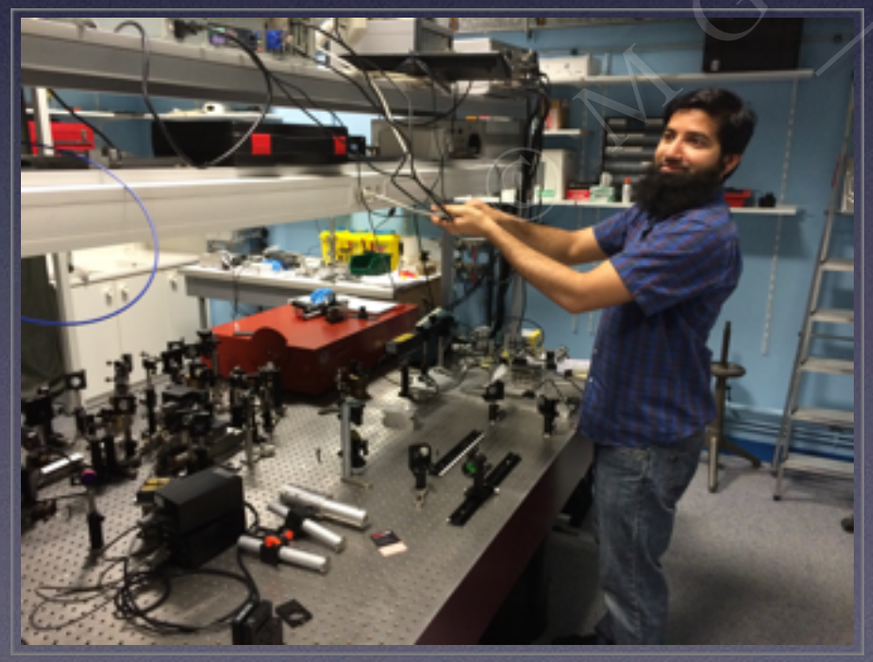
Spot size: $d_1 = \frac{1.22\lambda}{N.A.}$

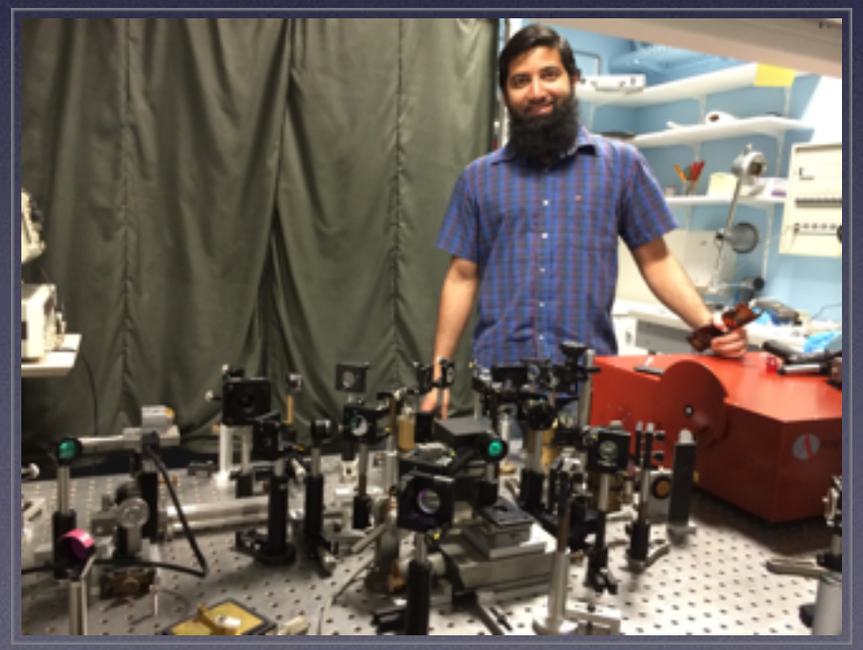
Values:

d_1: 2,79µm
d_2: 1µm
D: variable (1,3,5,7,10,15 µm)

Femtosecond laser

Repetition rate	10 kHz
Pulse duration	780 fs
Wavelength	1030 nm

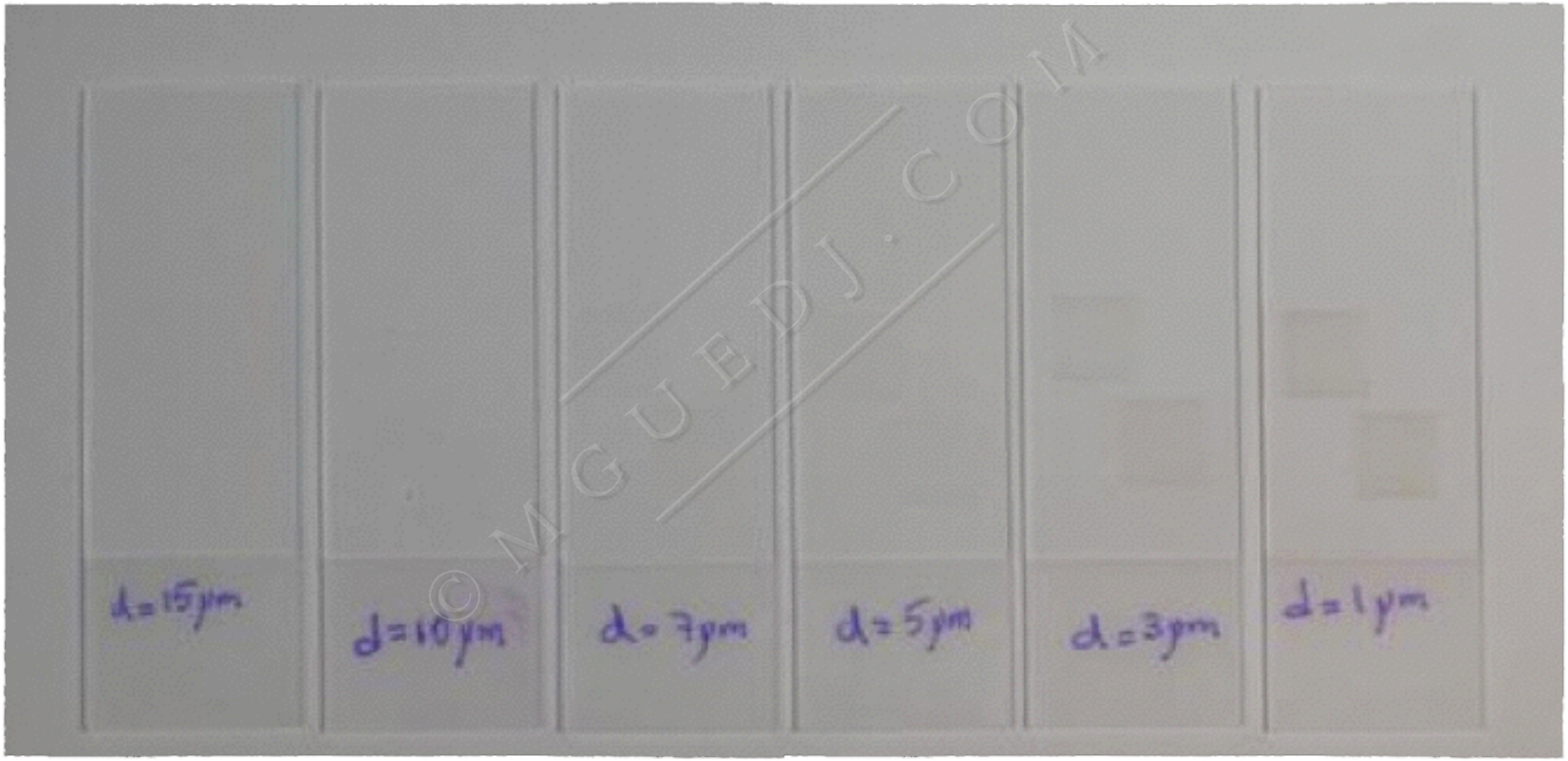




Glass slides & incisions

Glass thickness	1.2 mm
Incision type	lamellar
Incision depth	200 µm
Incision shape	square 1 cm x 1 cm
Line spacing width	1, 3, 5, 7, 10 and 15 µm
Random / line	randomized per line
Random / full	fully randomized

GLASS SAMPLES



COURTESY OF Z. ESSAIDI

MACROSCOPE IMAGES 1 µm

COURTESY OF Z. ESSAIDI

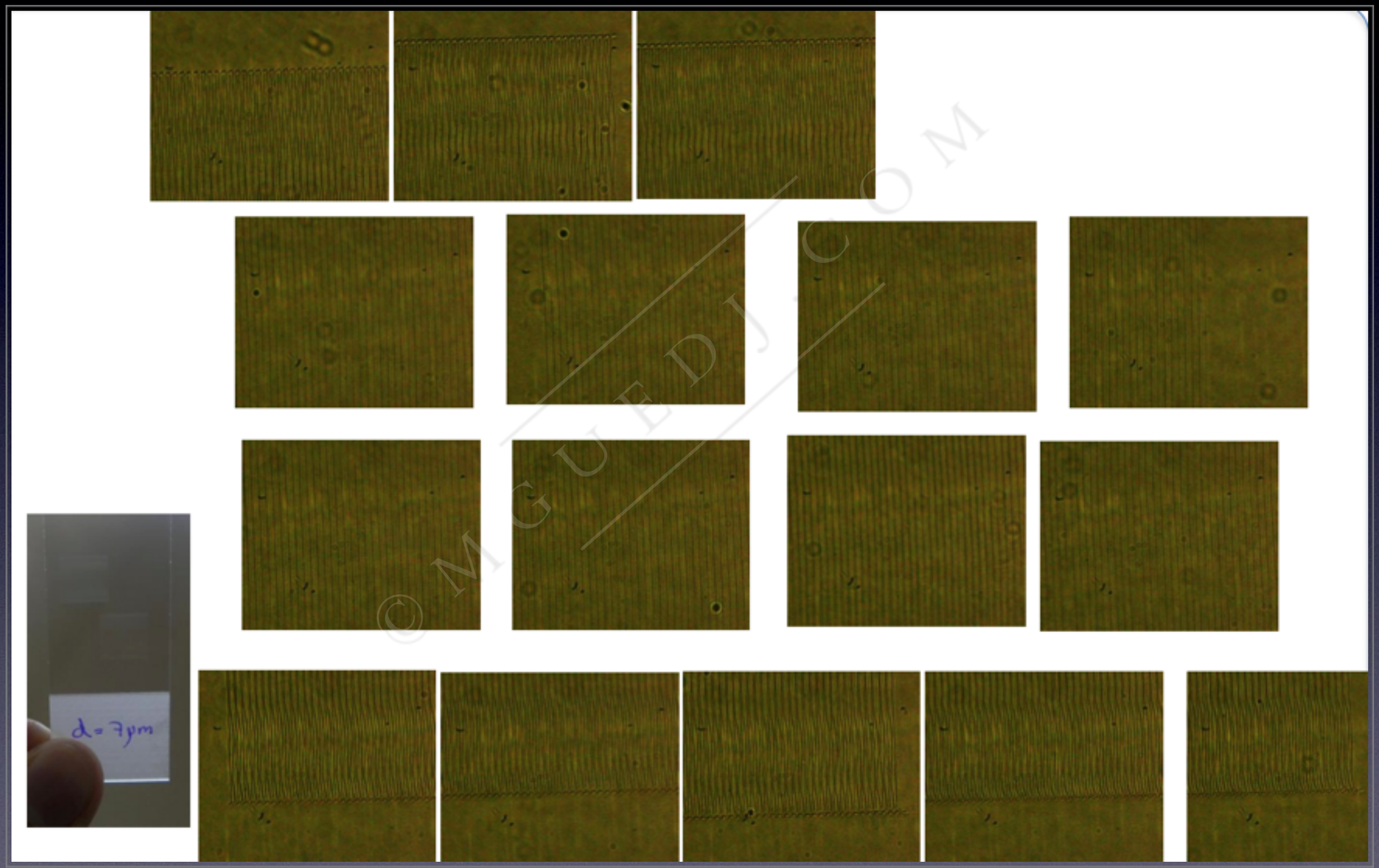
MACROSCOPE IMAGES 3 µm

COURTESY OF Z. ESSAIDI

MACROSCOPE IMAGES 5 µm

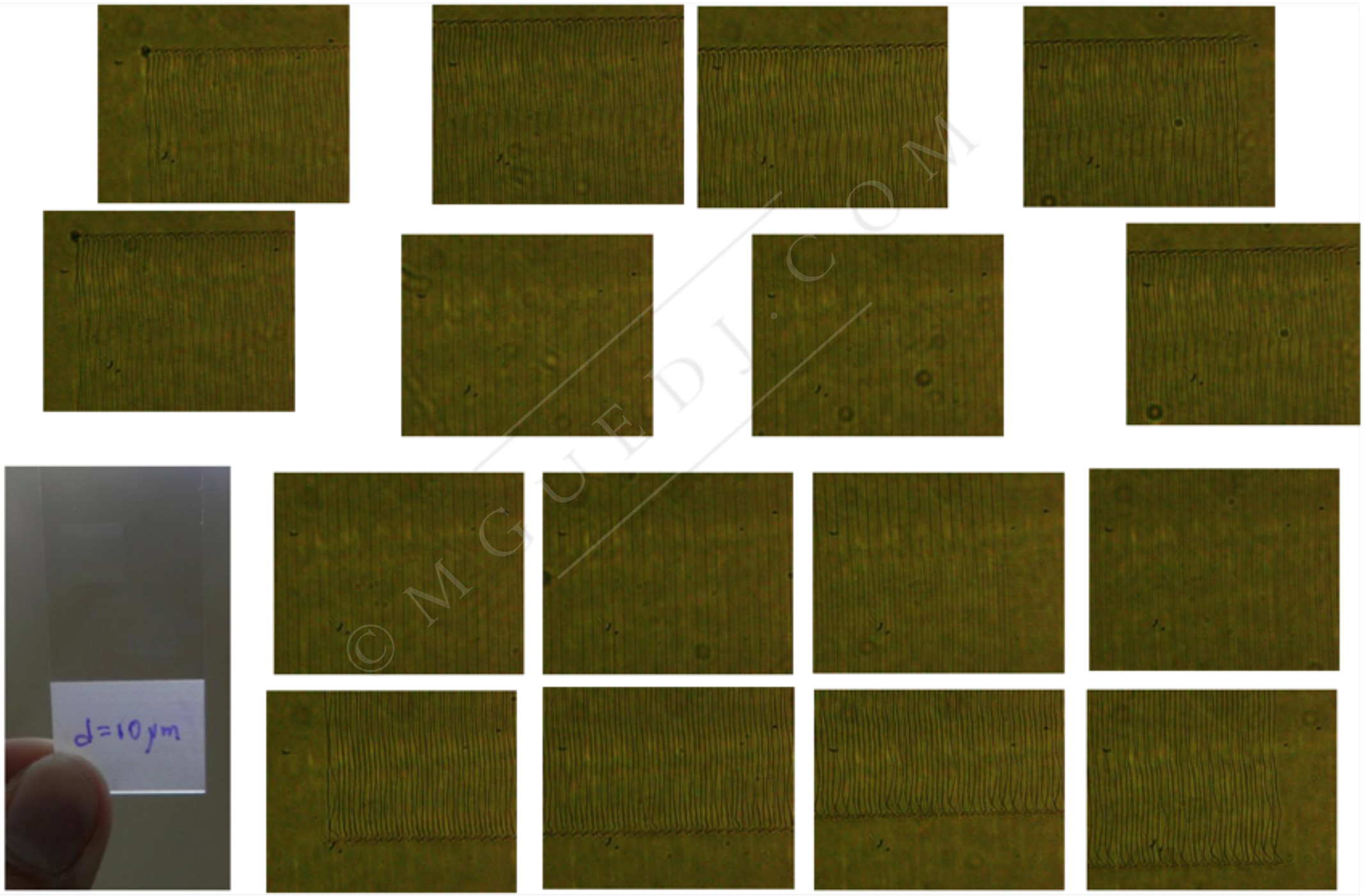
COURTESY OF Z. ESSAIDI

MACROSCOPE IMAGES 7 µm



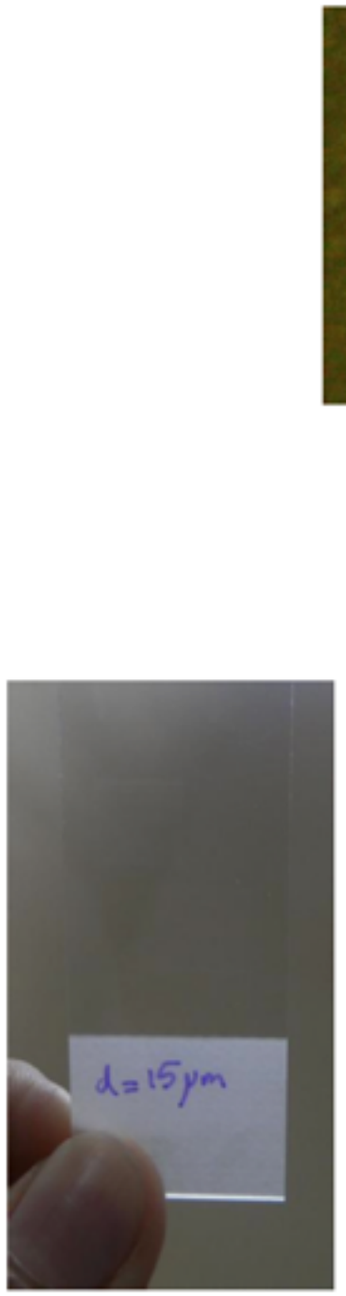
COURTESY OF Z. ESSAIDI

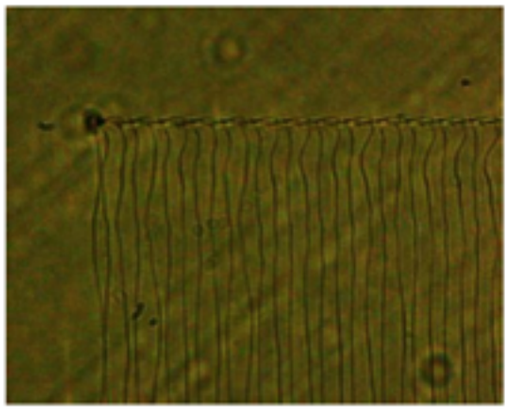
MACROSCOPE IMAGES 10 µm

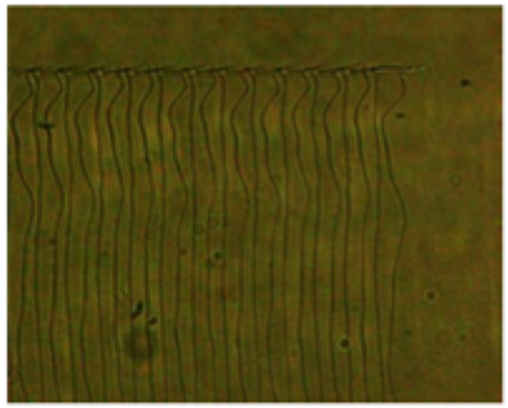


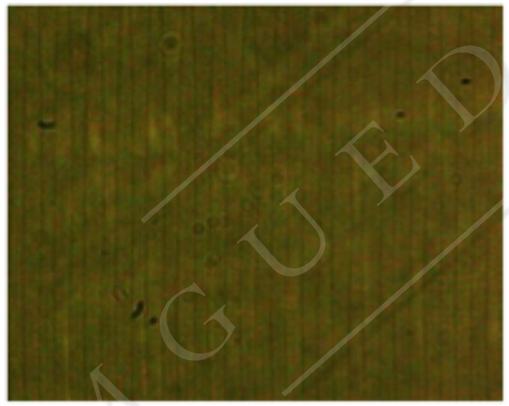
COURTESY OF Z. ESSAIDI

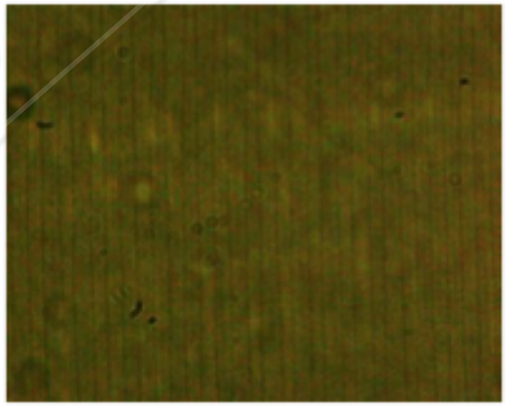
MACROSCOPE IMAGES 15 µm

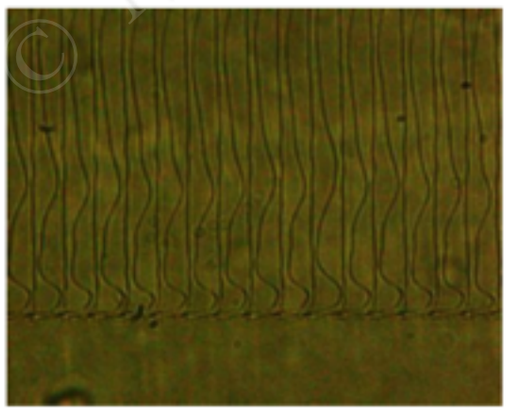


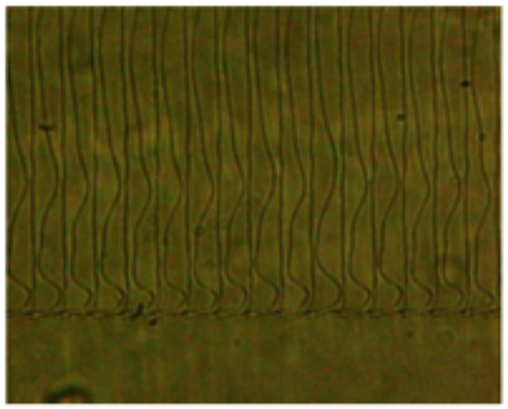


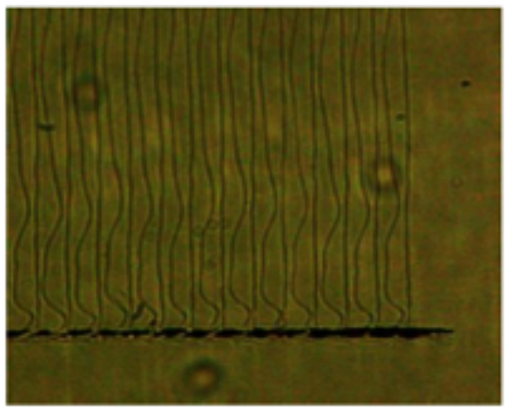












COURTESY OF Z. ESSAIDI

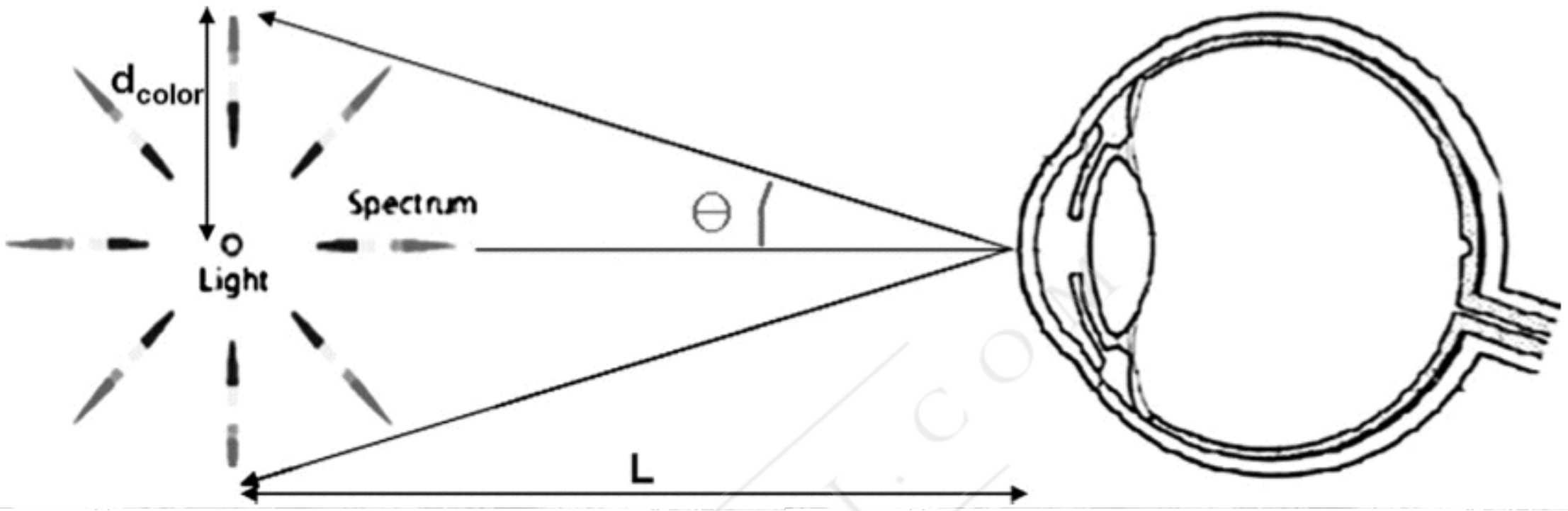
MACROSCOPE IMAGES 15 µm

PERIPHERAL VIBRATIONS

REGULAR LINES

COURTESY OF Z. ESSAIDI

RANDOM SPOTS



Krueger R - Ophthalmology 2008

$$A \sin \theta = m \lambda$$

A = grating constant, depicting the space between 2 spots and between 2 lines

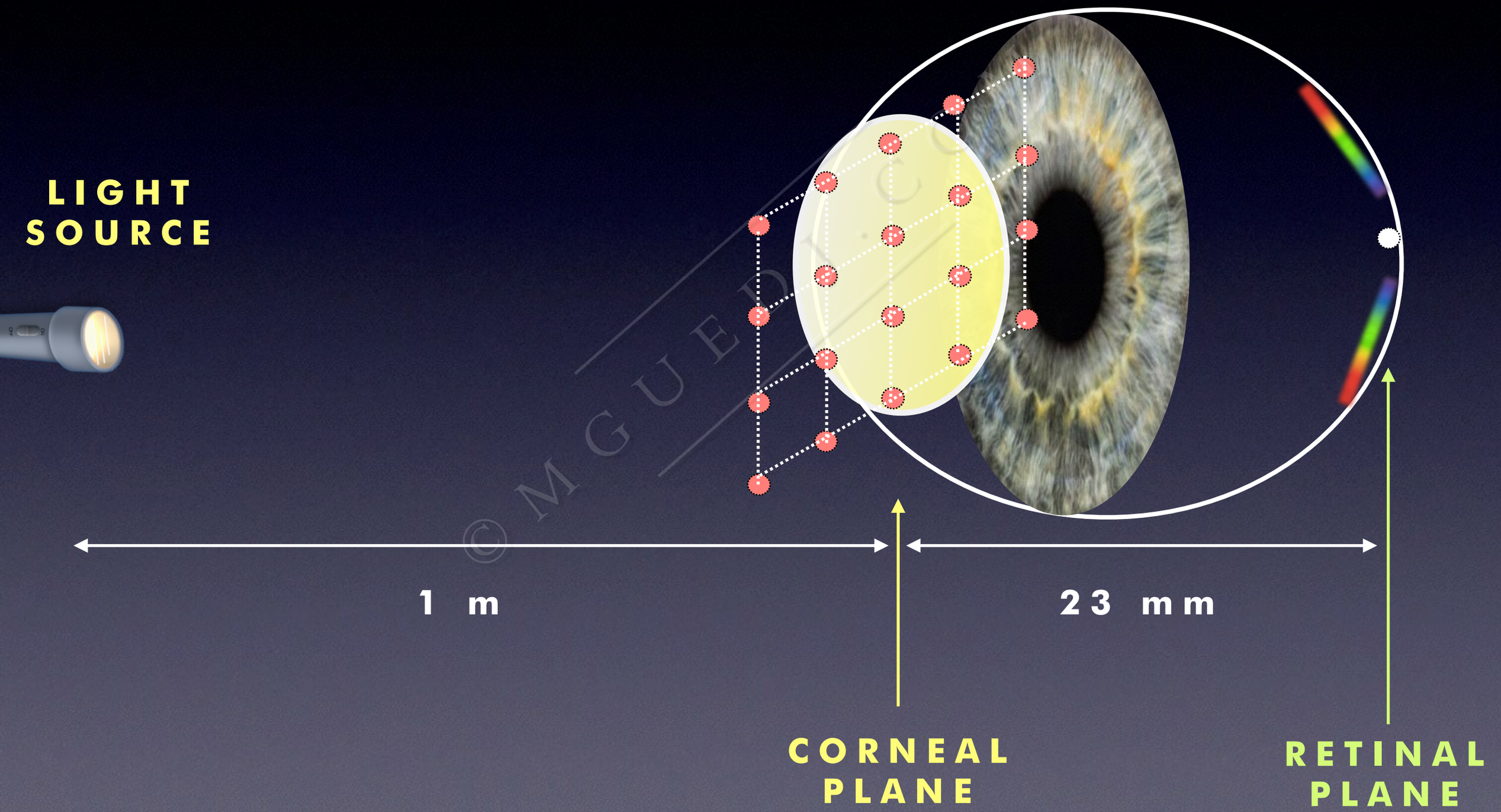
d = color distance from the light source

θ = visual angle of a perceived color ($\sin \theta \simeq \tan \theta = d/L$ for small angles)

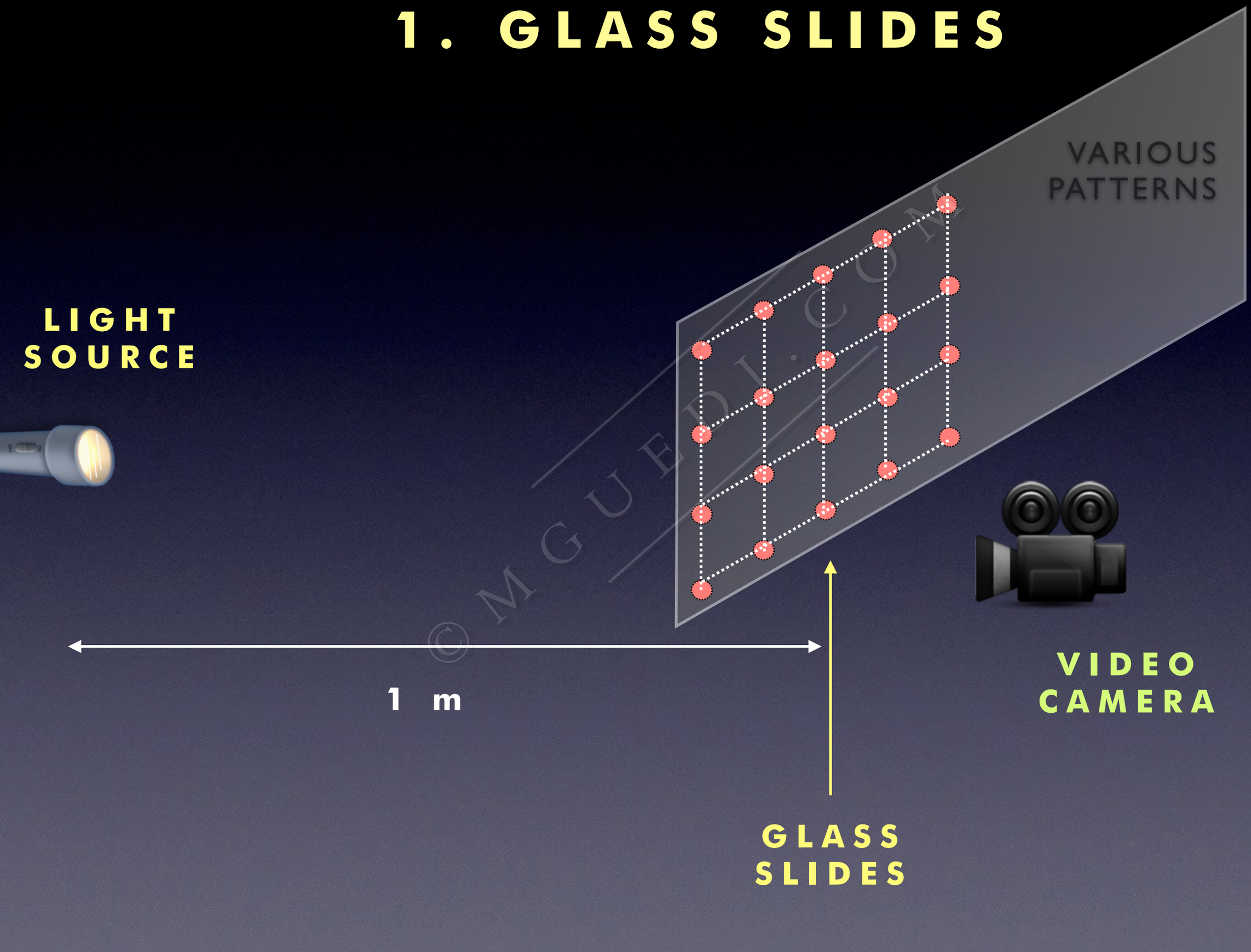
m = diffraction order (for the fundamental order, m = 1)

λ = wavelength for a given color

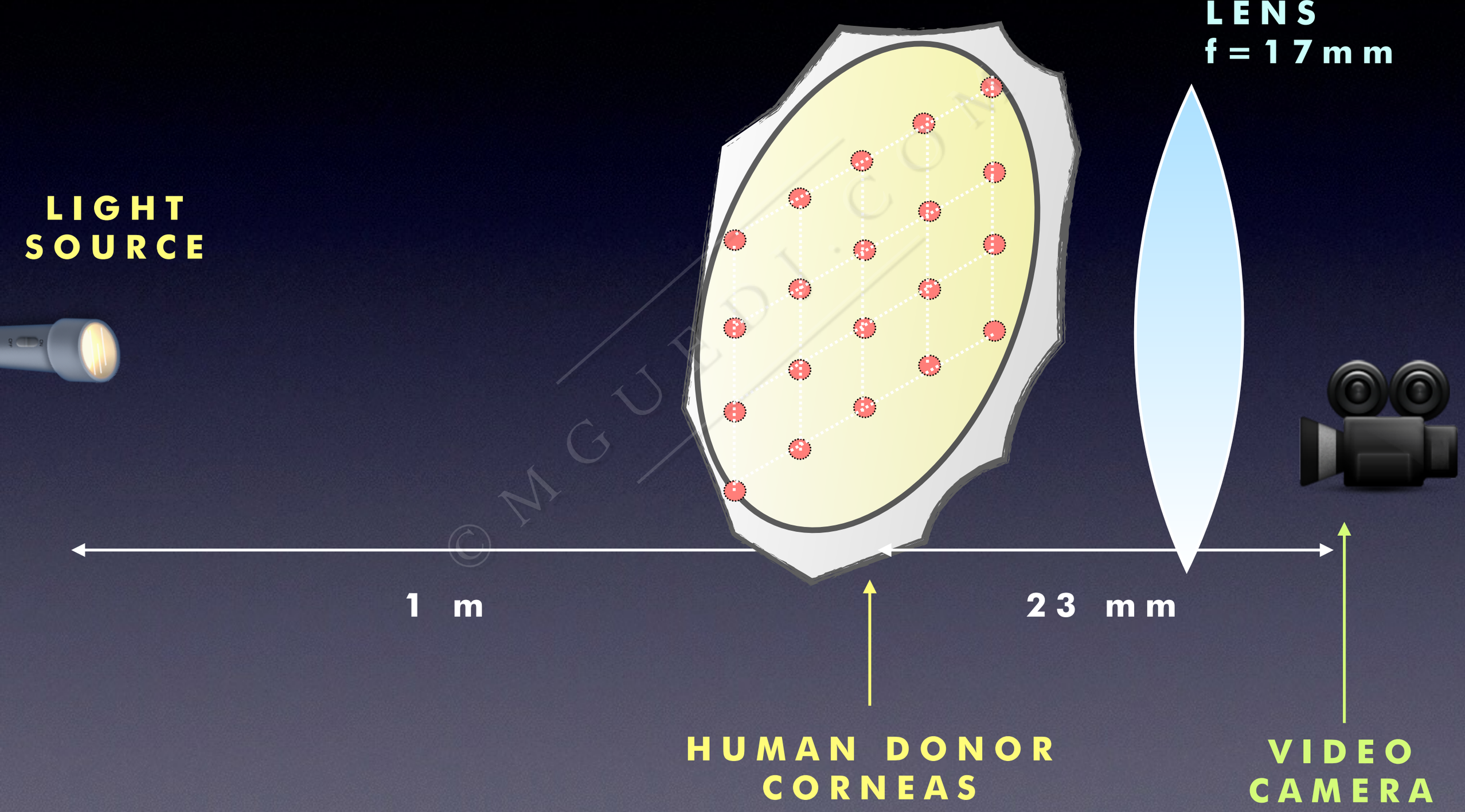
METHODS



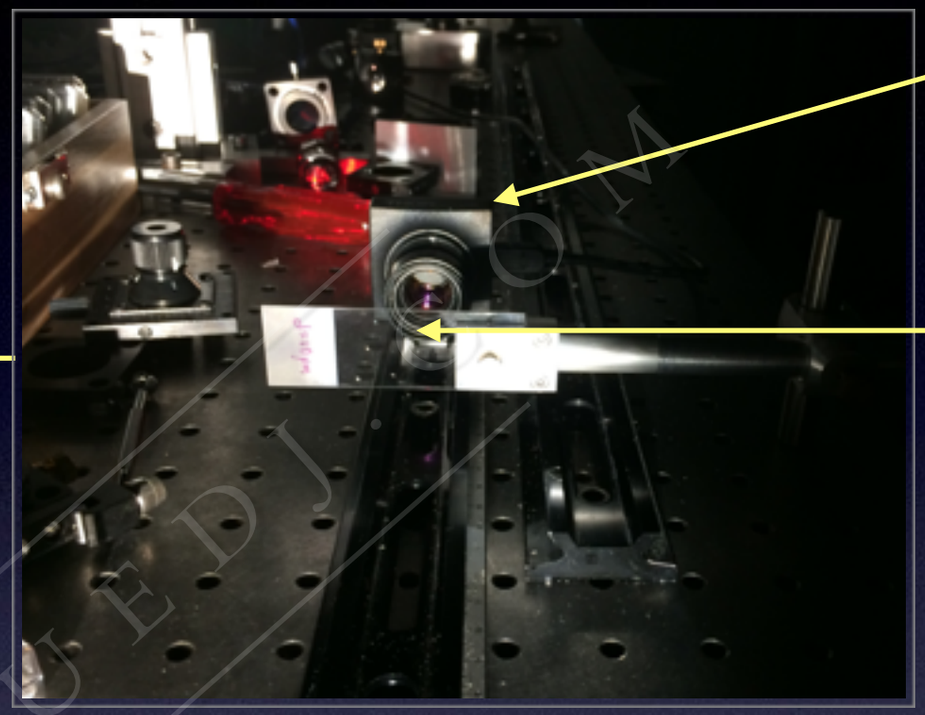
1. GLASS SLIDES



2. HUMAN CORNEAS



METHODS

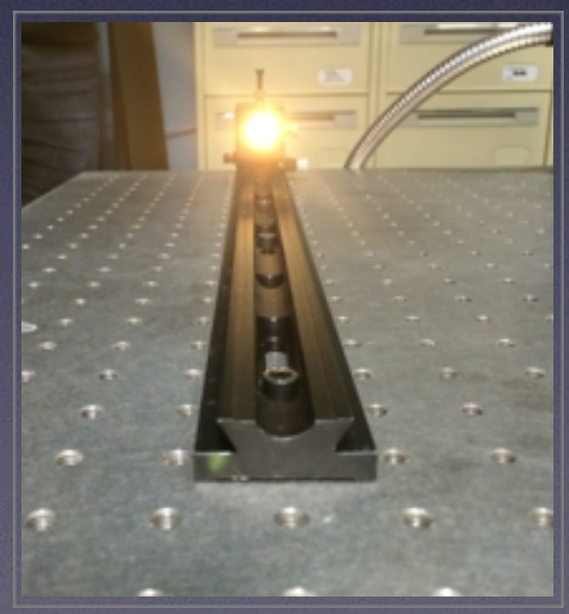


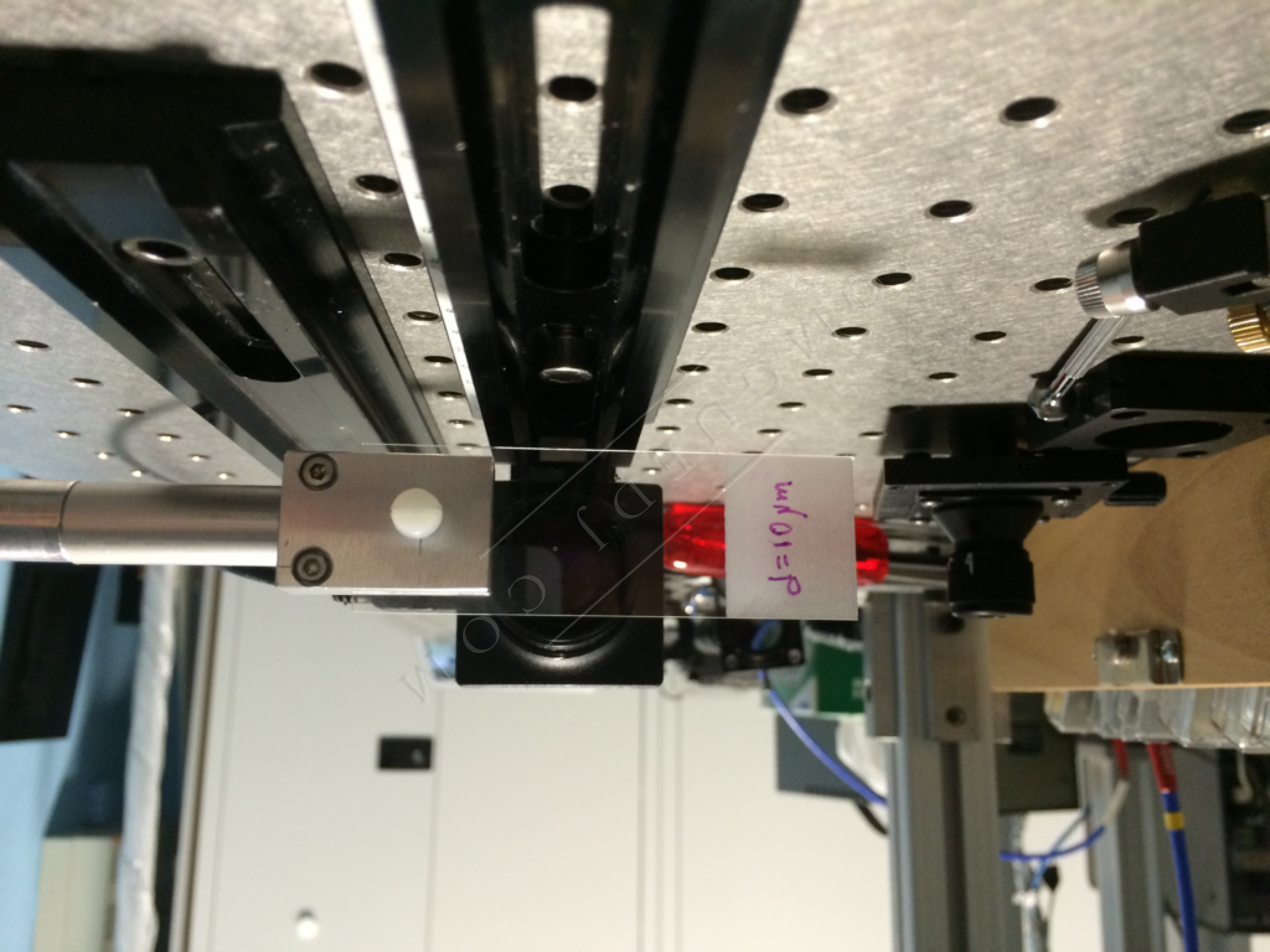
CAMERA

GLASS SLIDE IMPACTED BY FS LASER

SOURCE

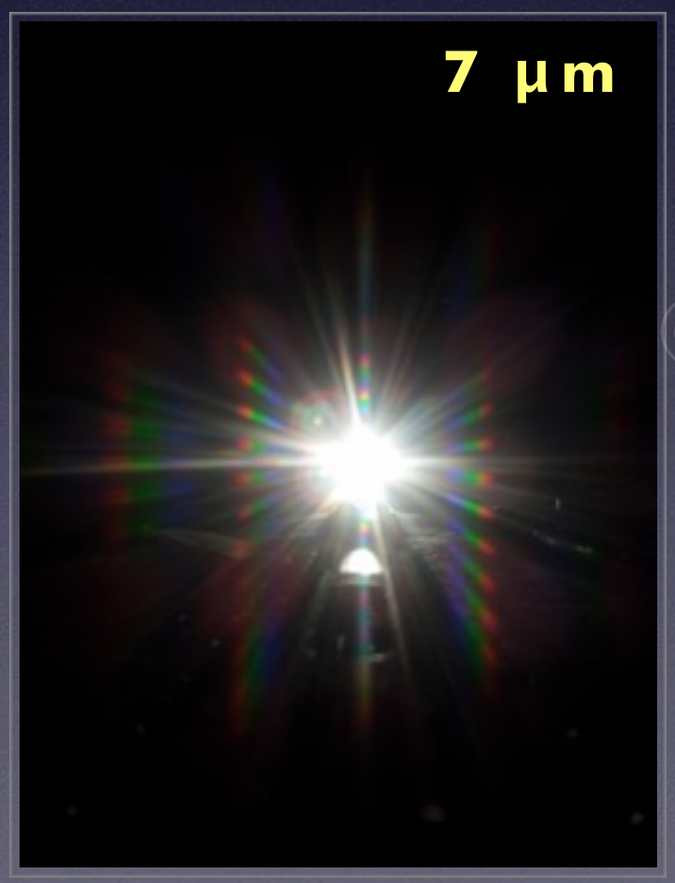
DIASCOPIC ILLUMINATION

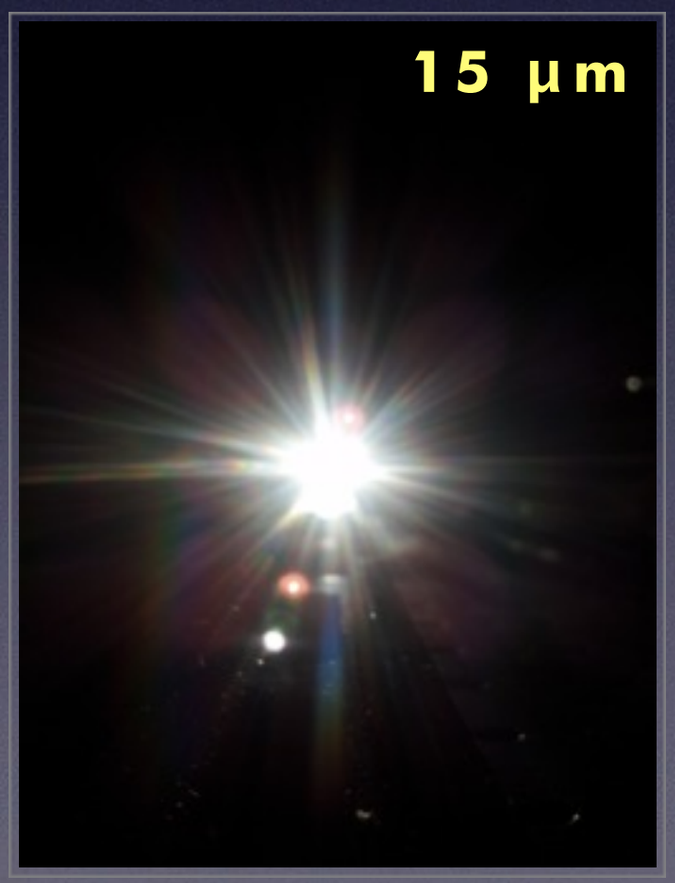



d=10μm

④

PRELIMINARY RESULTS






1 µm
© MGUEDJ.COM

3 µm


5 µm

7 µm


10 µm

15 µm

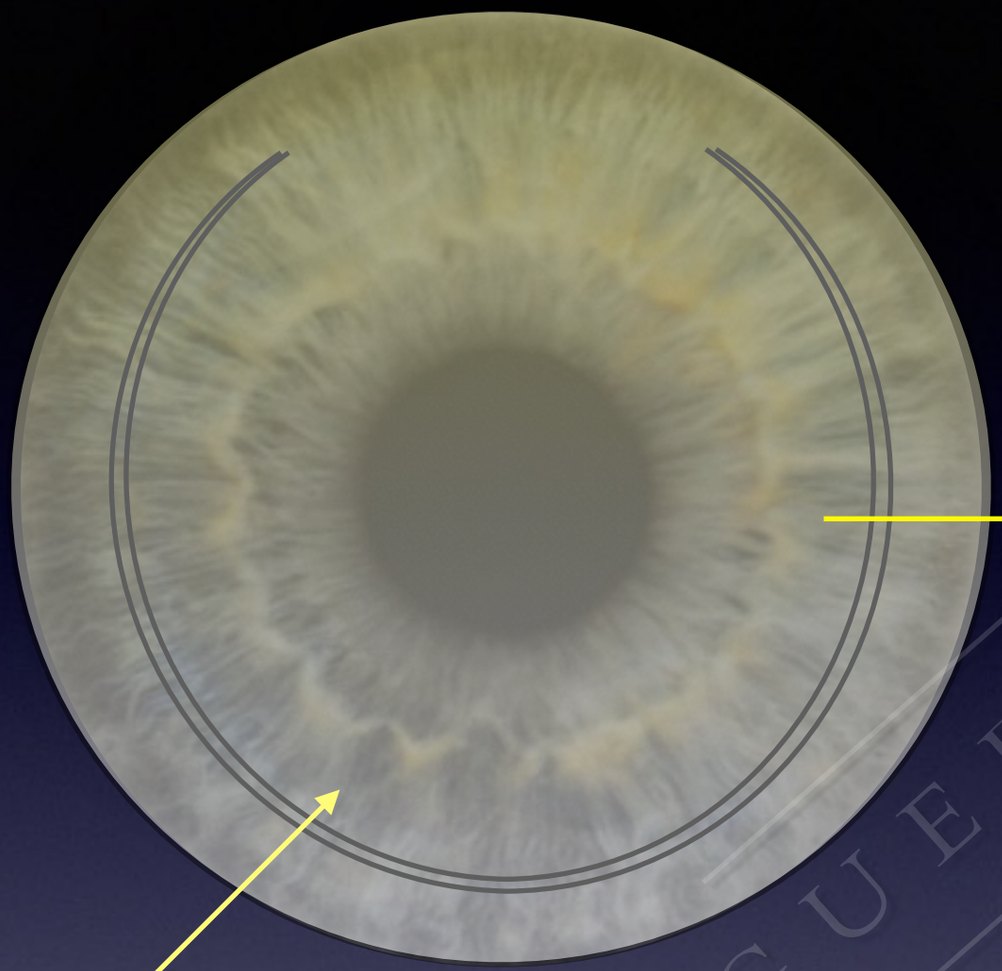
⑤

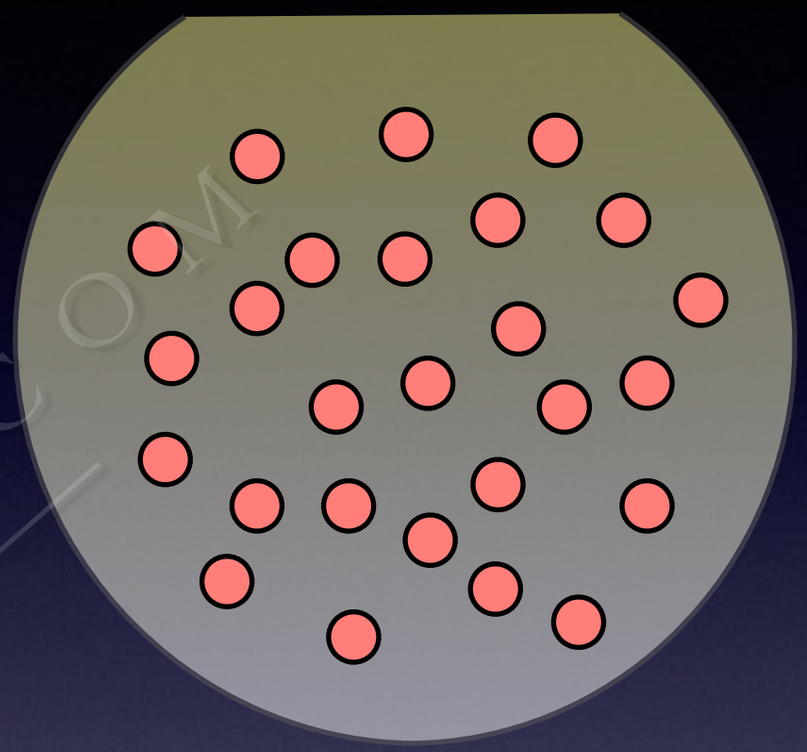
CONCLUSIONS & PERSPECTIVES

① Concentration of diffracted light in periodic orders is reduced by **randomisation of the FS impacts**.

② Spot-to-spot distance of ≃ 3 µm on glass slides ?
(*Ackermann, BOE 2012*)
Rainbow glare not avoided by line spacing < 10 µ

③ However, **light scattering** not assessed here
➪ possible source of discomfort.





FULLY RANDOM

FLAP

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A. HUSSAIN
F. ALAHYANE