

**ICNIRP 8<sup>th</sup> INTERNATIONAL NIR WORKSHOP**

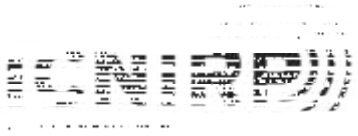
**Cape Town, South Africa, 9-11 May 2016**

# **Biophysical Basis of Optical Radiation Exposure Limits**

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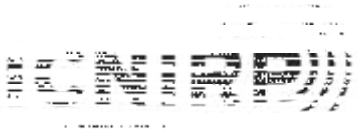
**ICNIRP 8<sup>th</sup> International Radiation Workshop  
Cape Town International Conference Center  
Cape Town, South Africa  
May 9-11, 2016**



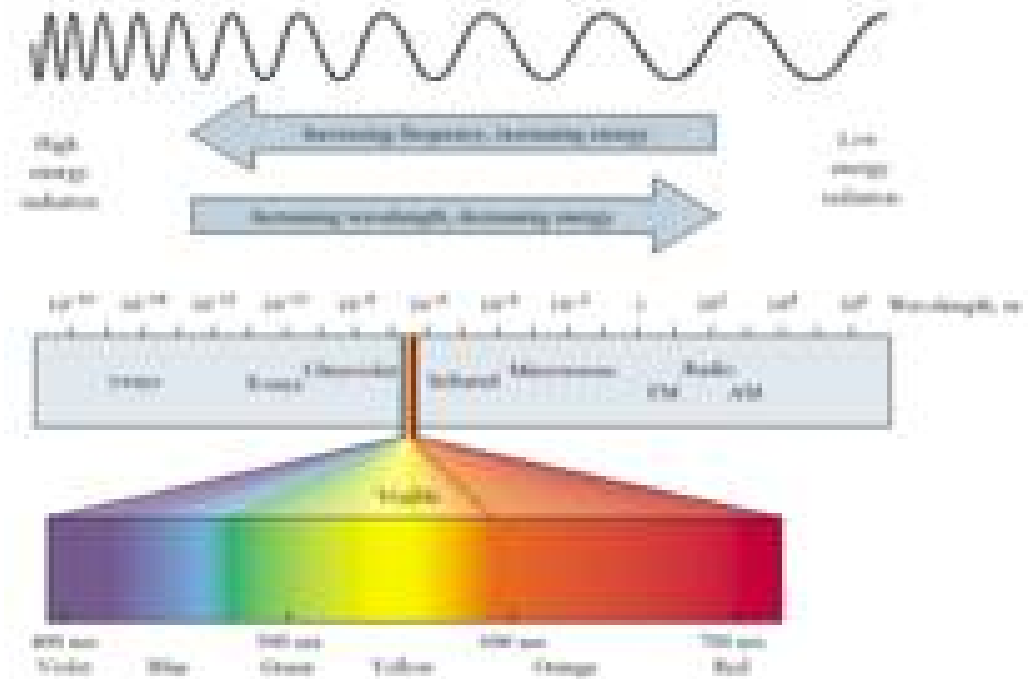
# Biophysical Basis of Optical Radiation Exposure Limits

## Summary: ICNIRP Optical Radiation Exposure Limits

- ICNIRP Radiation Exposure Limit (EL) Guidelines for CIE Optical Radiation Spectral Regions: UVC(100-280 nm), UVB (280-315 nm), UVA(315-400 nm), Visible (400-780 nm), IRA (780-1400 nm), IRB (1.4-3.0 mm), IRC (3 mm- 1000 mm) or 3000 THz – 300 GHZ.
- Latest Optical Radiation Updates: Published in Health Physics Journal in 2013
  - Rationale
  - Important References
  - Laser and Broadband
- Available **free** at the ICNIRP Web Site: <https://www.icnirp.org> under the Publications Tab
- Statements and ICNIRP Blue Books also available.



## Wavelength



### ◆ Absorption

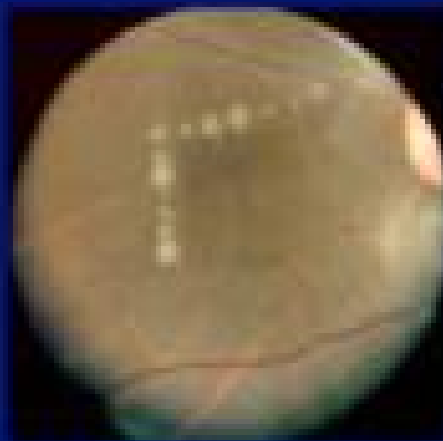
- How effectively light is captured by a target tissue

### ◆ Transmission

- How effectively light penetrates overlying media to reach the target tissue

## Photochemical Effect

- Photochemical lesions are delayed 24 to 48 hours
- Threshold dose in retinal radiant exposure:
  - Constant with exposure duration (reciprocity)
  - Independent of the retinal irradiance diameter
- Small temperature rise



1 hour after exposure



48 hours after exposure

## Thermal Effect

- Generally observable in one hour
- Threshold dose in retinal radiant exposure:
  - Vary as  $t^{2/3}$  where  $t$  is the exposure duration
  - Vary as the diameter of the irradiated area (ms to sec)
- Time-Temperature history

### Photochemical and Thermal

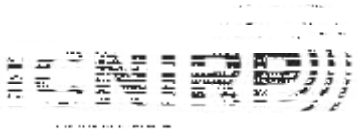
"Marker lesions": 514 nm

100 msec

Lesion array:

440 nm,

100 sec



# Laser Emission Characteristics

- Emission Wavelengths
  - Near ultraviolet to the far infrared
  - Usually highly monochromatic (single wavelength or color)
- Emission Durations
  - Single pulses as short as 10 femtoseconds ( $10^{-14}$  seconds)
  - Continuous wave (CW)
  - Repetitive pulses - Pulse repetition frequencies (single pulse to  $10^8$  pps)
- Beam Divergence
  - Small beam divergence ( 0.1 - 1 milliradian) or “not.”
  - 0.5 mradian divergence - 50 cm beam diameter at 1 km
  - Retinal Hazard Region: retinal irradiance diameter can be 30 micrometers or slightly less
  - Irradiance Diameters (“Spot Size”) – small ( $25 \mu\text{m}$ ) to large



## Dose

Wavelength  
Exposure Duration  
Radiant Exposure  
Irradiance diameter  
Exposure Site  
Pulse Repetition  
Frequency (PRF)

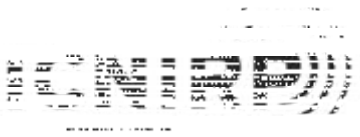
## Response

Ophthalmoscopy  
Angiography  
Pathology  
Electrophysiology  
Visual Function  
Imaging (OCT,SLO)  
Proteomics/Genomics  
Skin: Erythema - Blister

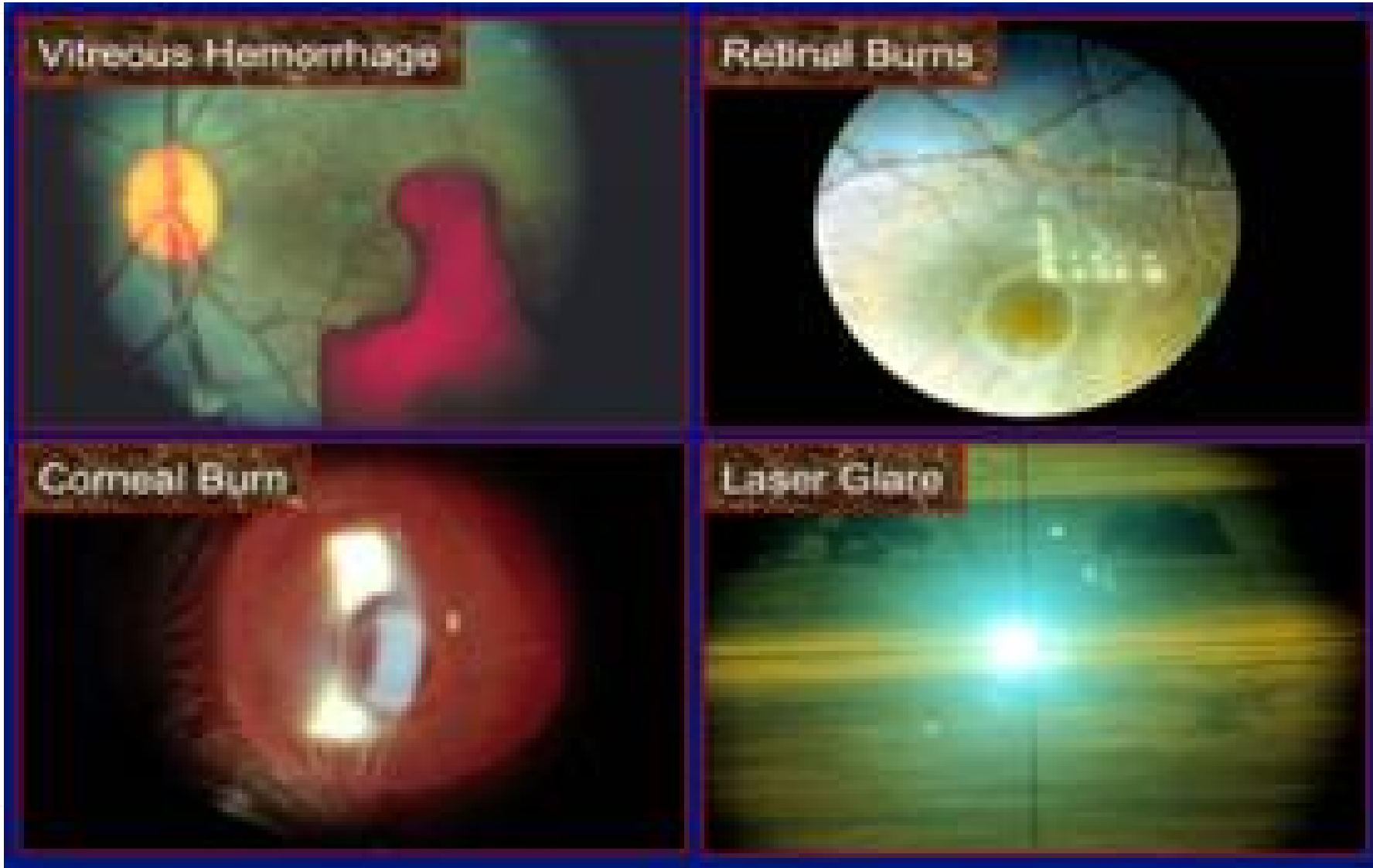
## Models

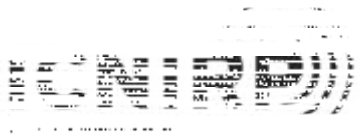
Temperature-Time Histories  
Arrhenius analysis  
Peak temperature  
Mechanism(s) of injury

Time of Observation (1 hr, 24 hrs, days, years?)



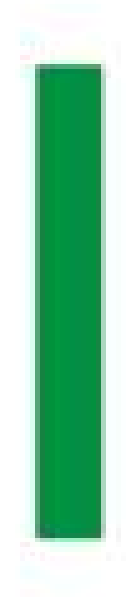
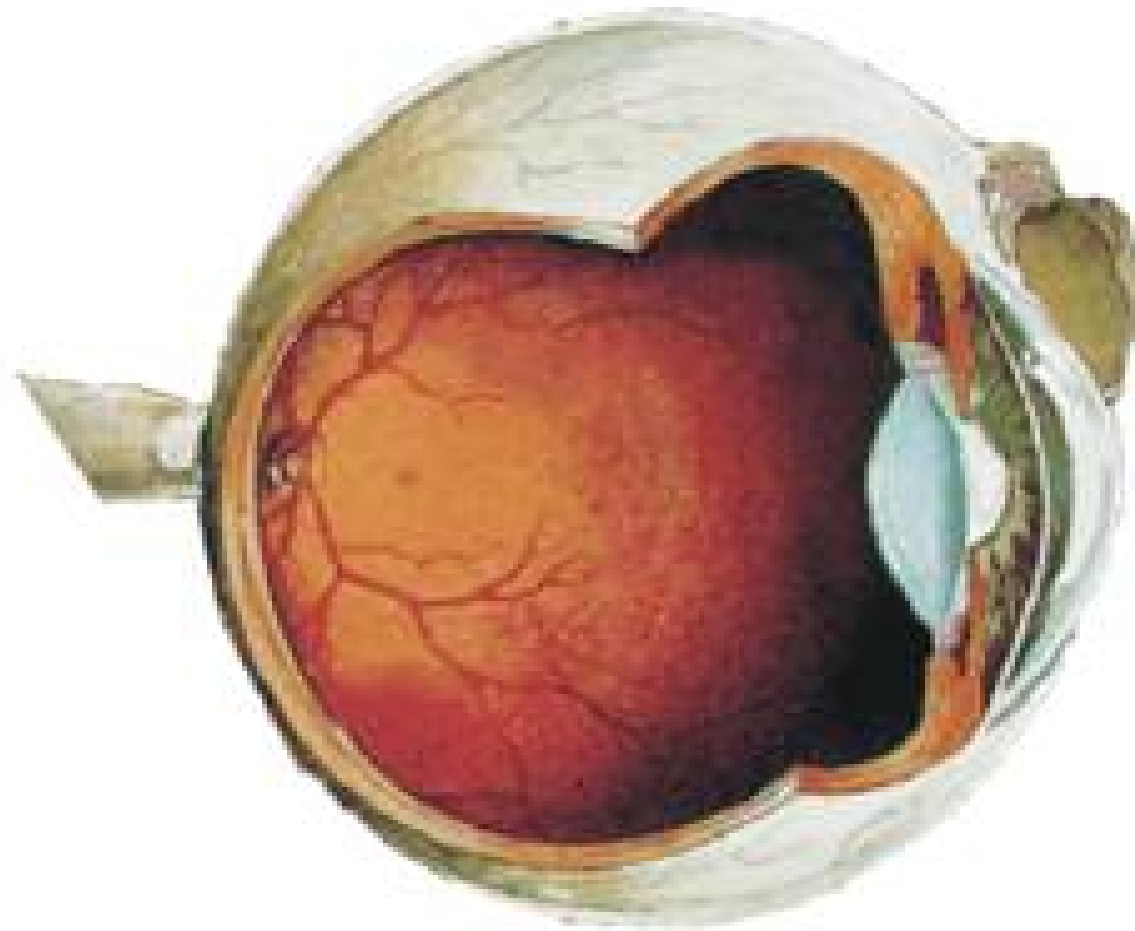
# Ocular Effects



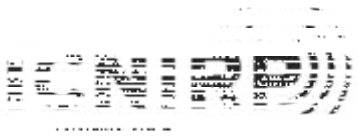


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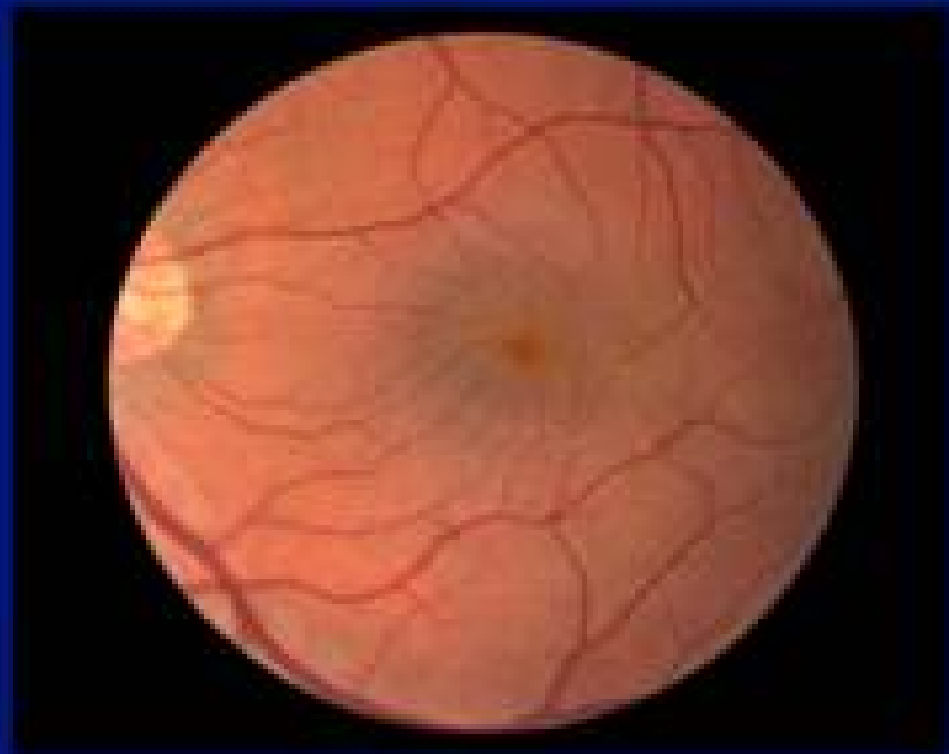




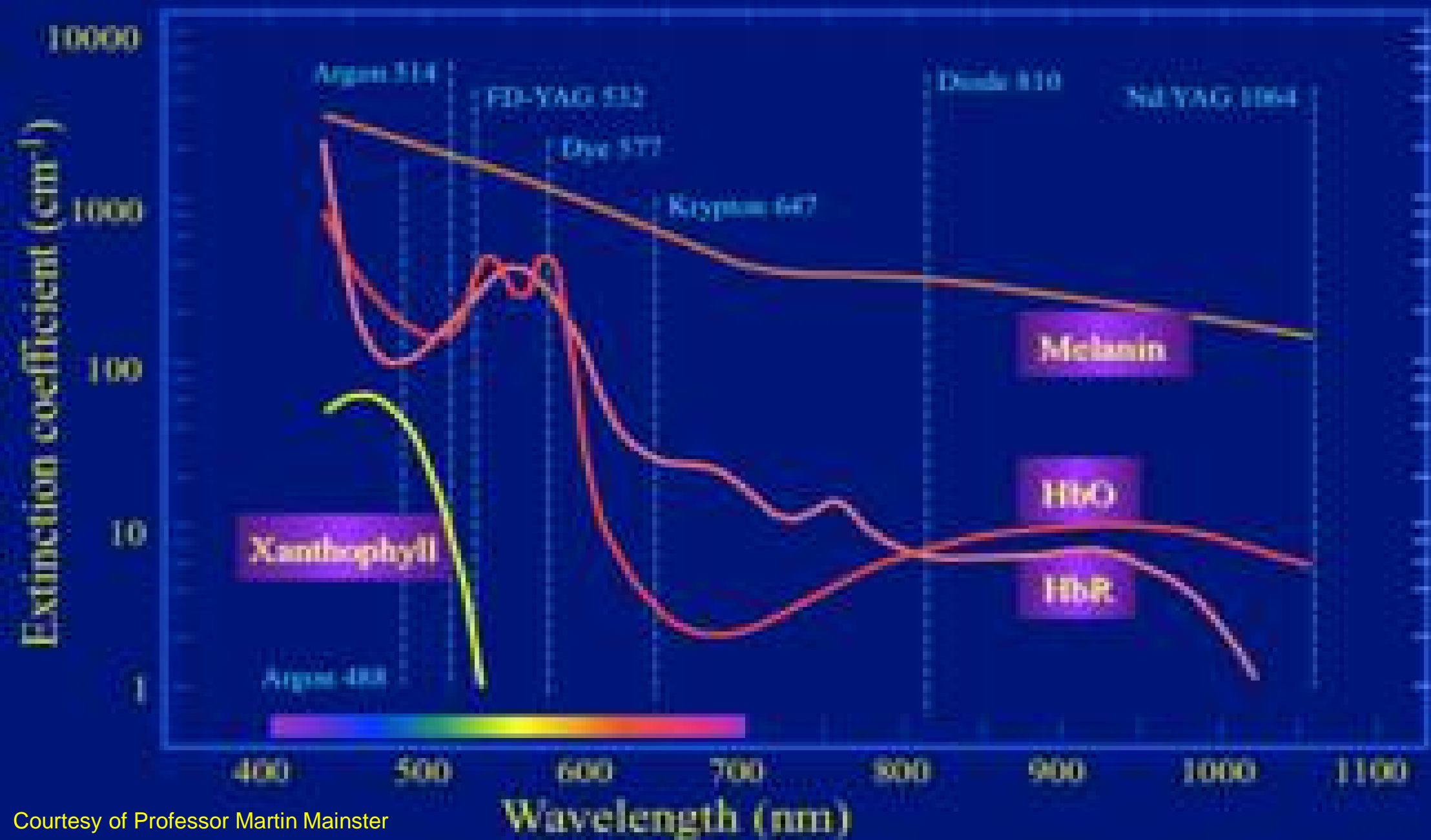


## Factors affecting Laser-Induced Retinal Injury and Laser Dazzle (Glare/Flash)

- Energy/Power through the pupil
- Pupil diameter (dynamic)
- Wavelength
- Exposure duration (on any given retinal site)
- Retinal irradiance diameter (spot size)
- Adaptation state of eye
- Aversion response
  - Eye and head movement
  - Pupillary constriction
  - Source movement
  - Blink



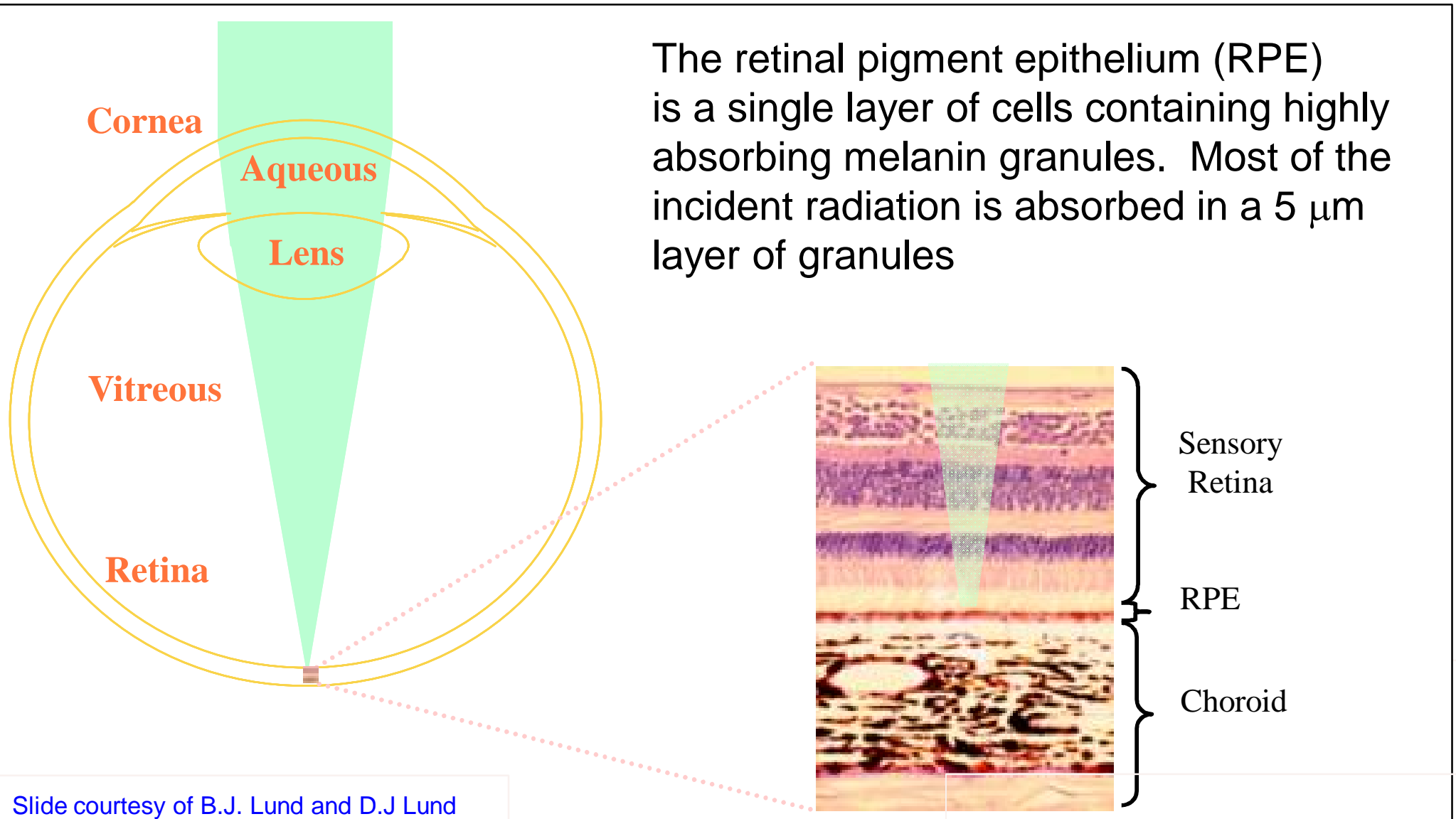
# Extinction coefficient vs. laser wavelength (Mainster, Bursell; Ophthalmology 1986;93:952-8)

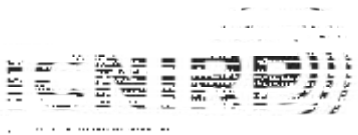




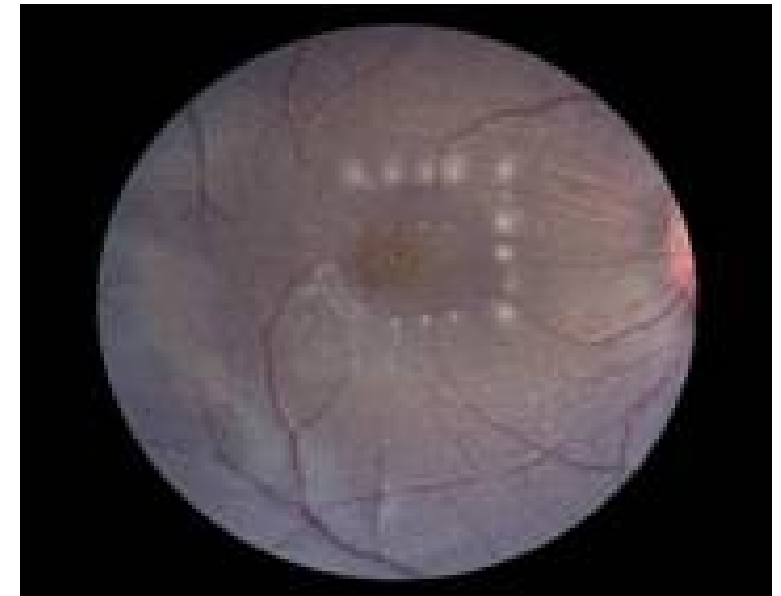
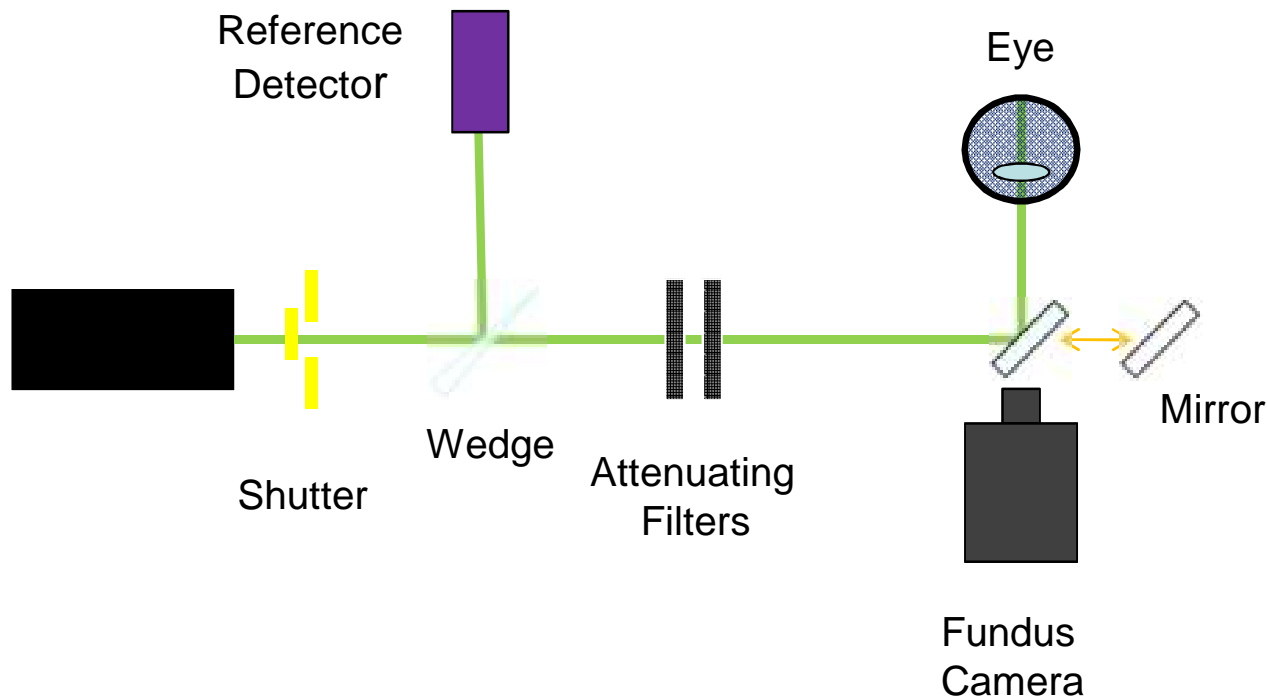
# Collimated Laser Beam Focused onto Retina

The retinal pigment epithelium (RPE) is a single layer of cells containing highly absorbing melanin granules. Most of the incident radiation is absorbed in a 5  $\mu\text{m}$  layer of granules

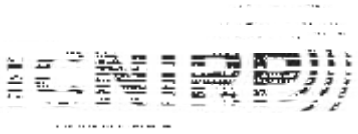




## Measuring Retinal Injury Threshold

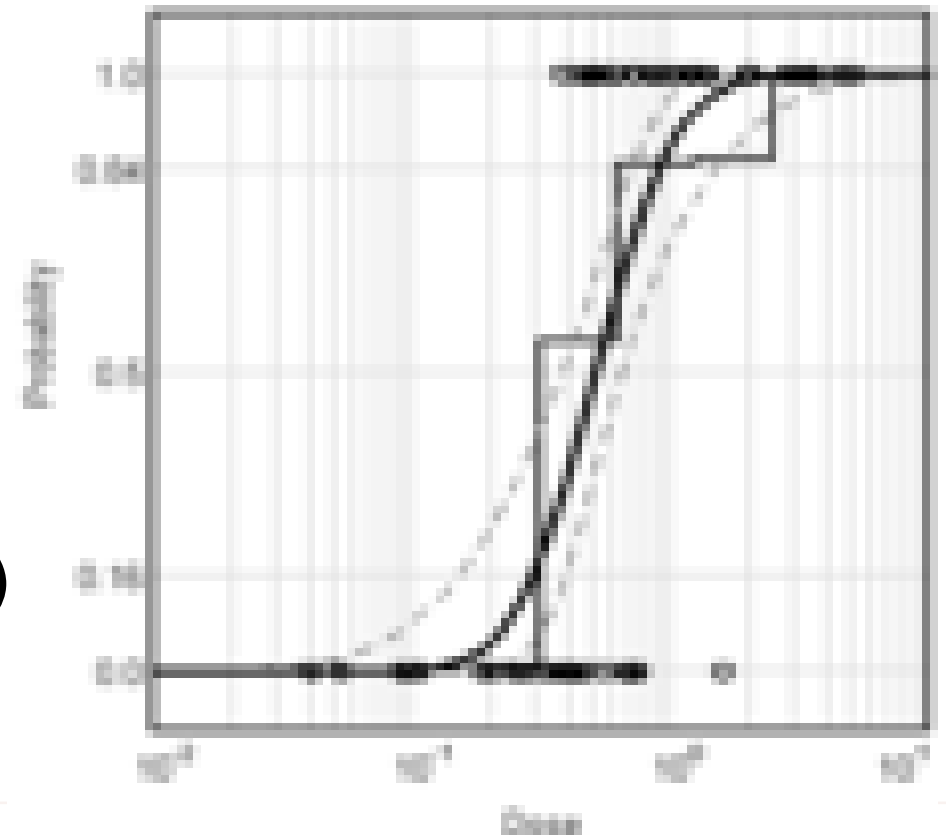


- NHP eye
  - Surgical level anesthesia
  - Retrobulbar block
- Marker lesions define grid
- Dose varied site-to-site
- Evaluate at 1 hr, 24 hrs
  - Fundus Photography
  - Direct Ophthalmoscope
- Response = Any detectable change



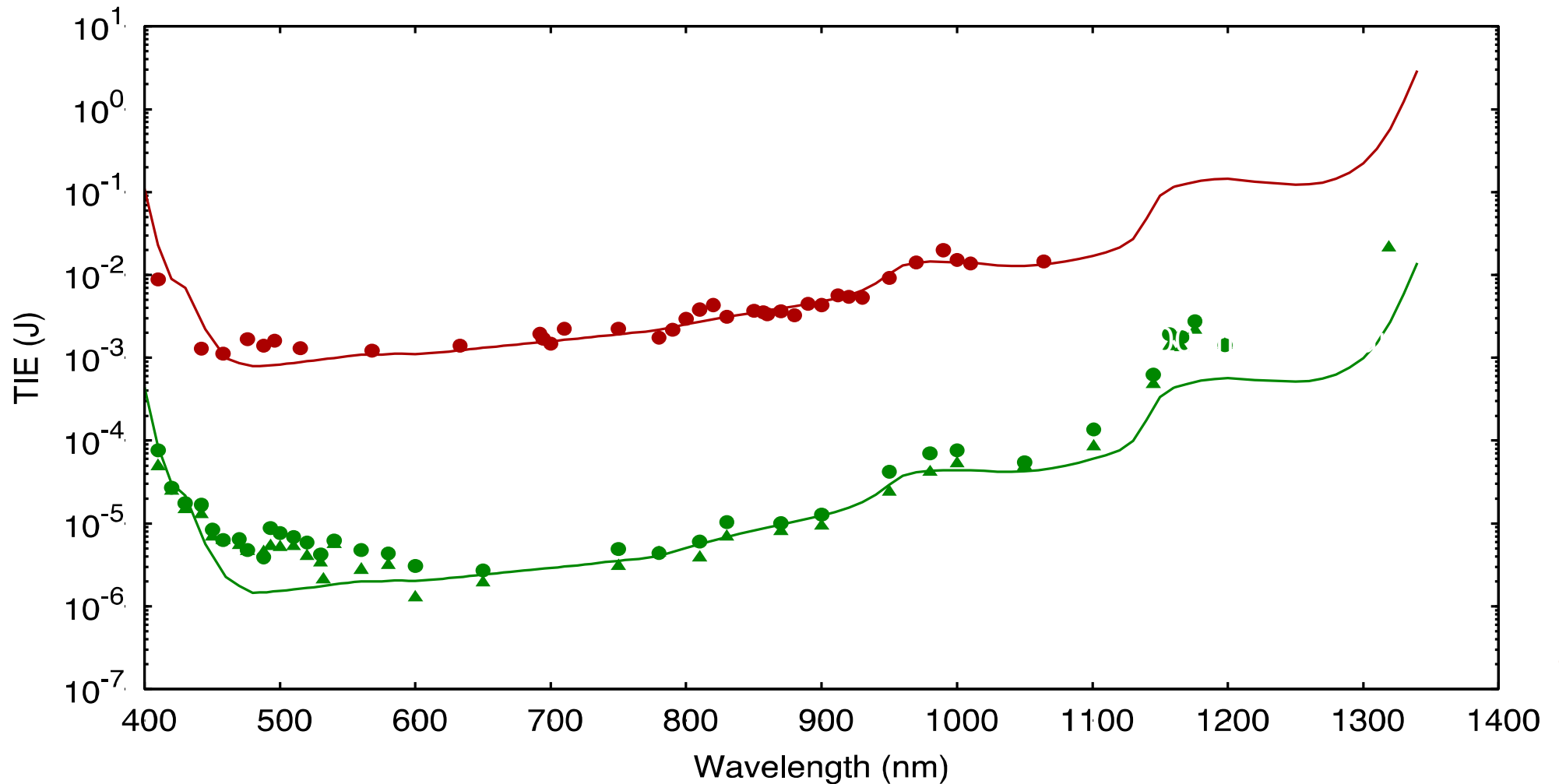
# Measuring Retinal Injury Threshold

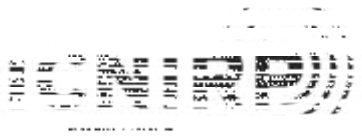
- Probit Analysis
  - Log-normal distribution
- Threshold =  $ED_{50}$ 
  - Dose  $\rightarrow$  50% probability of producing retinal response
  - Reported as irradiance, radiant exposure, or pulse energy (TIE) incident to cornea
  - Also report 95% CL



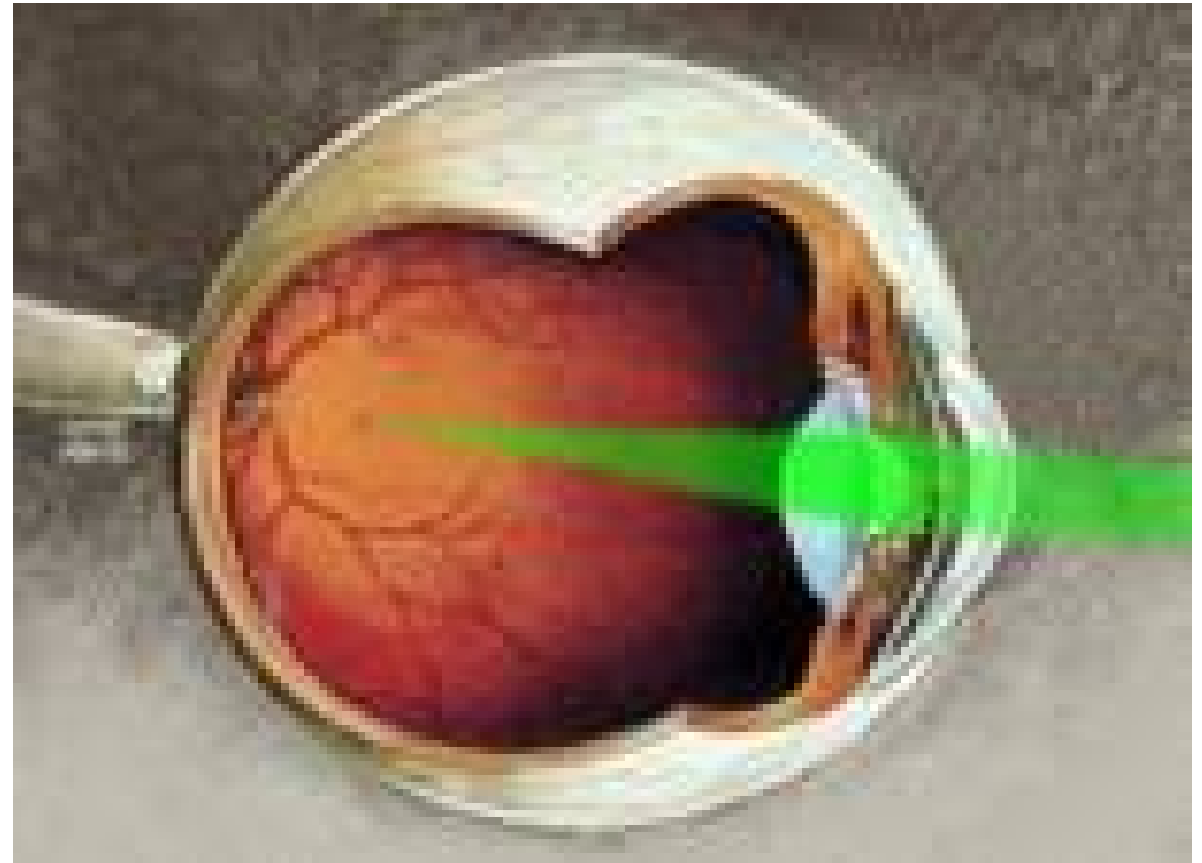
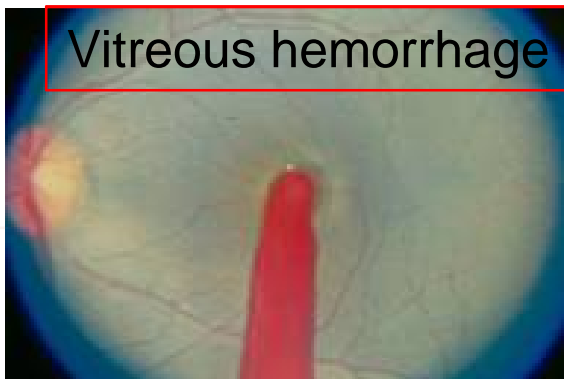
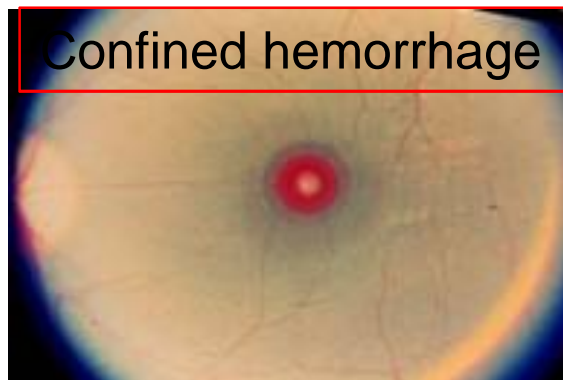


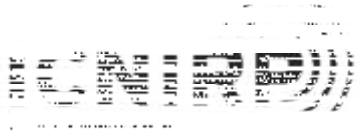
# Wavelength Dependence of ED<sub>50</sub> Data



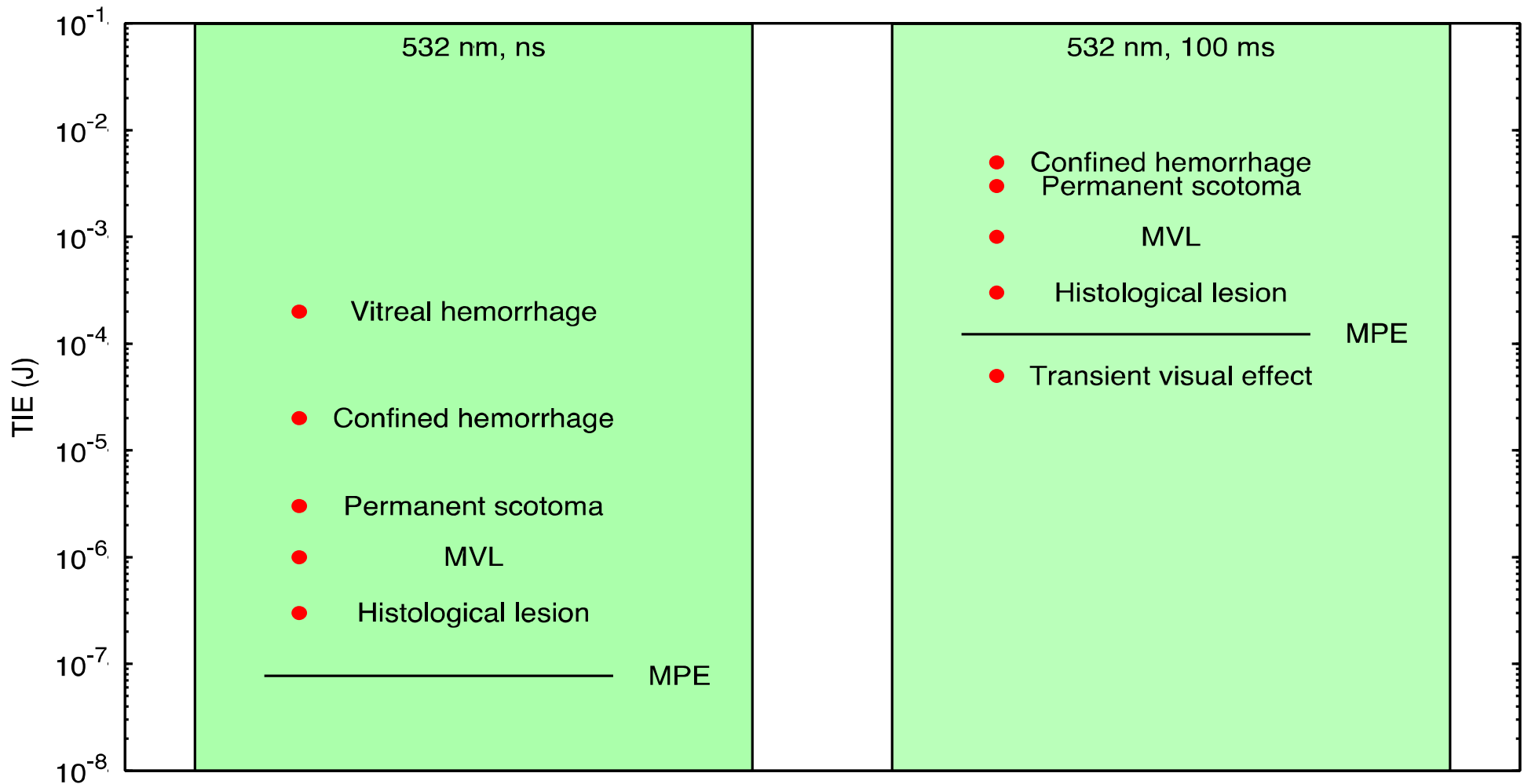


# Laser Bioeffects and Dose

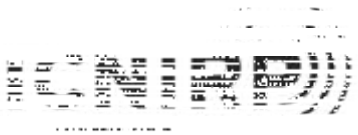




# Retinal Effect vs. Dose



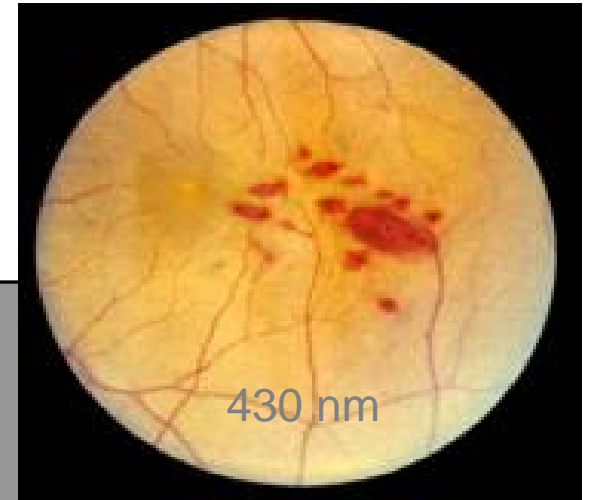
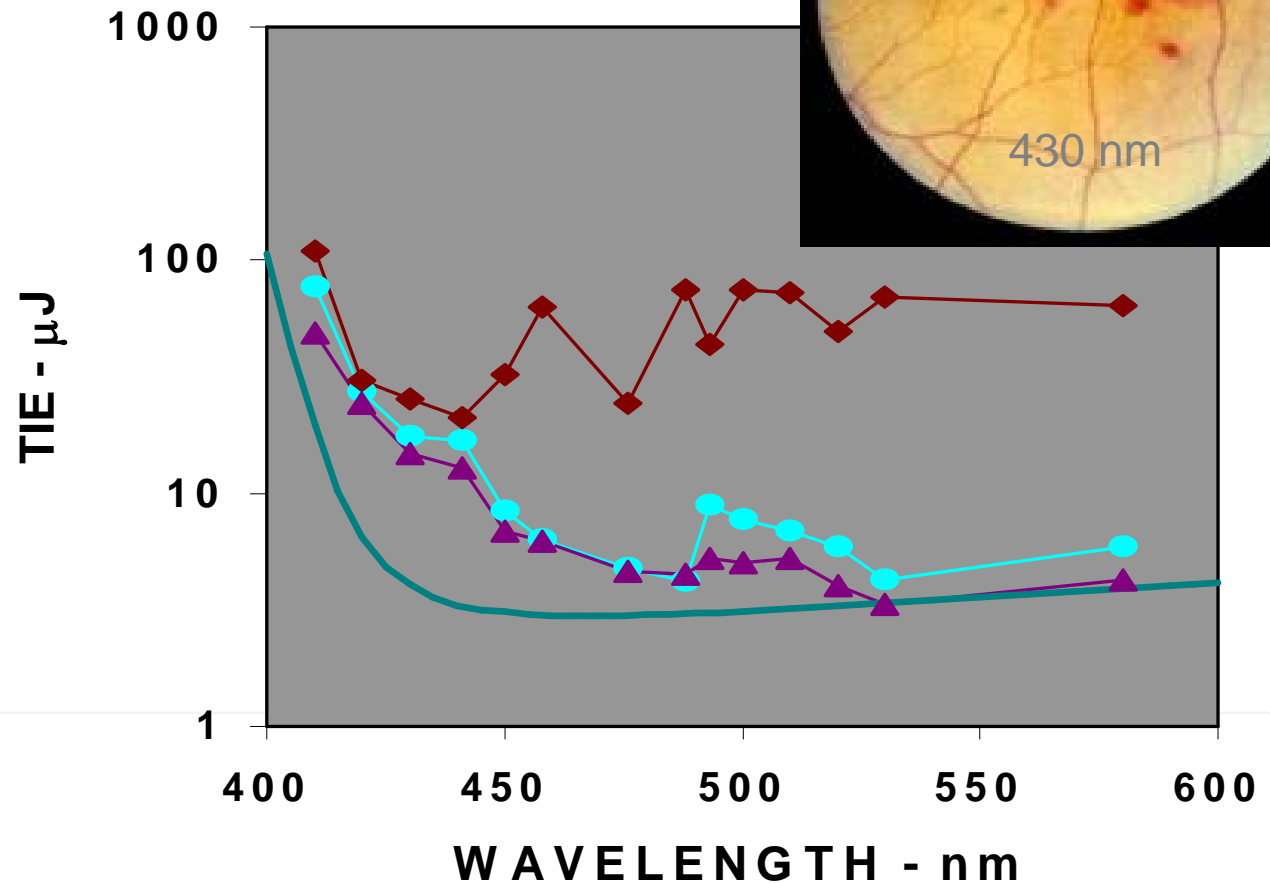


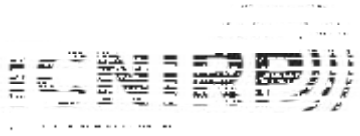


# Laser-Induced Retinal Hemorrhage Thresholds Compared to the Minimum Visible Lesion Thresholds

$\lambda$	ED <sub>50</sub> - $\mu\text{J}$		Hemor.
	1Hr	24Hr	
410	77	49	110
420	27	24	31
430	18	15	27
442	17	13	21
450	8.4	6.9	32
458	6.3	6.2	63
476	4.8	4.6	28
488	4.2	4.5	75
493	8.9	5.3	43
500	7.8	5.0	74
510	6.9	5.3	72
520	5.9	4.0	50
530	4.2	3.3	70
580	5.9	4.2	63

Exposure Duration: 3.5 ns

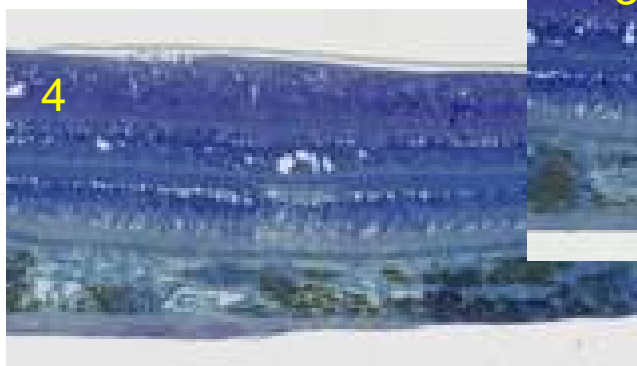
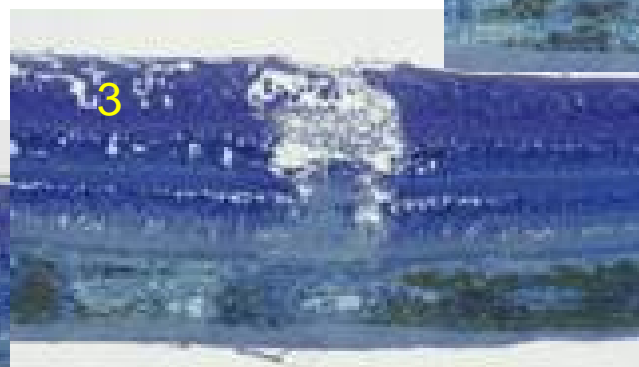
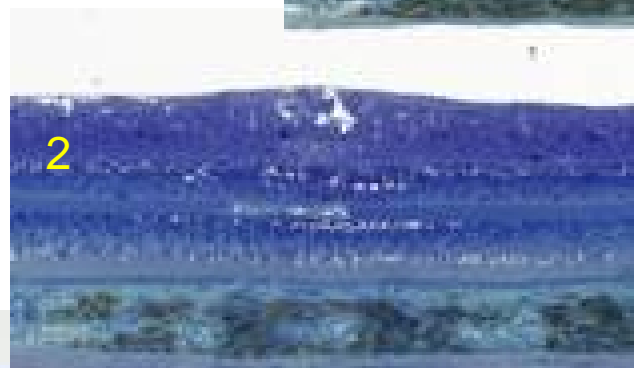
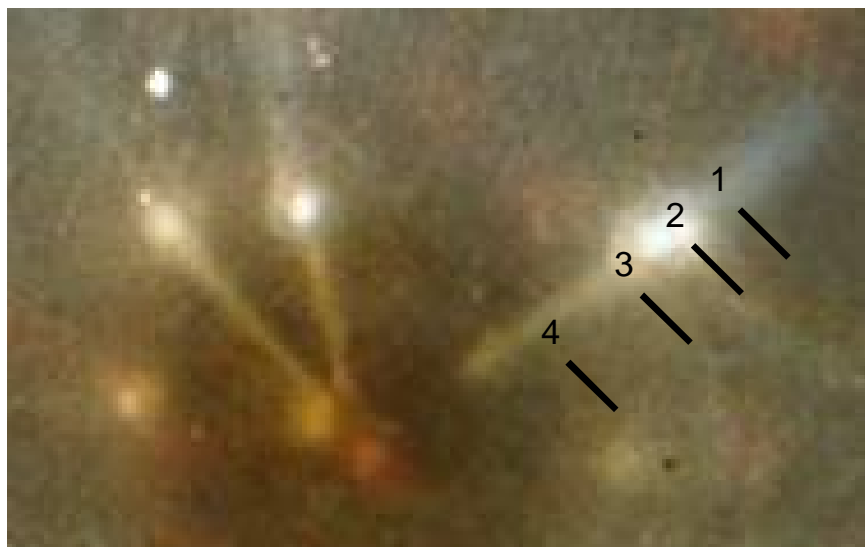




Corneal Lesions at 1.3  $\mu\text{m}$

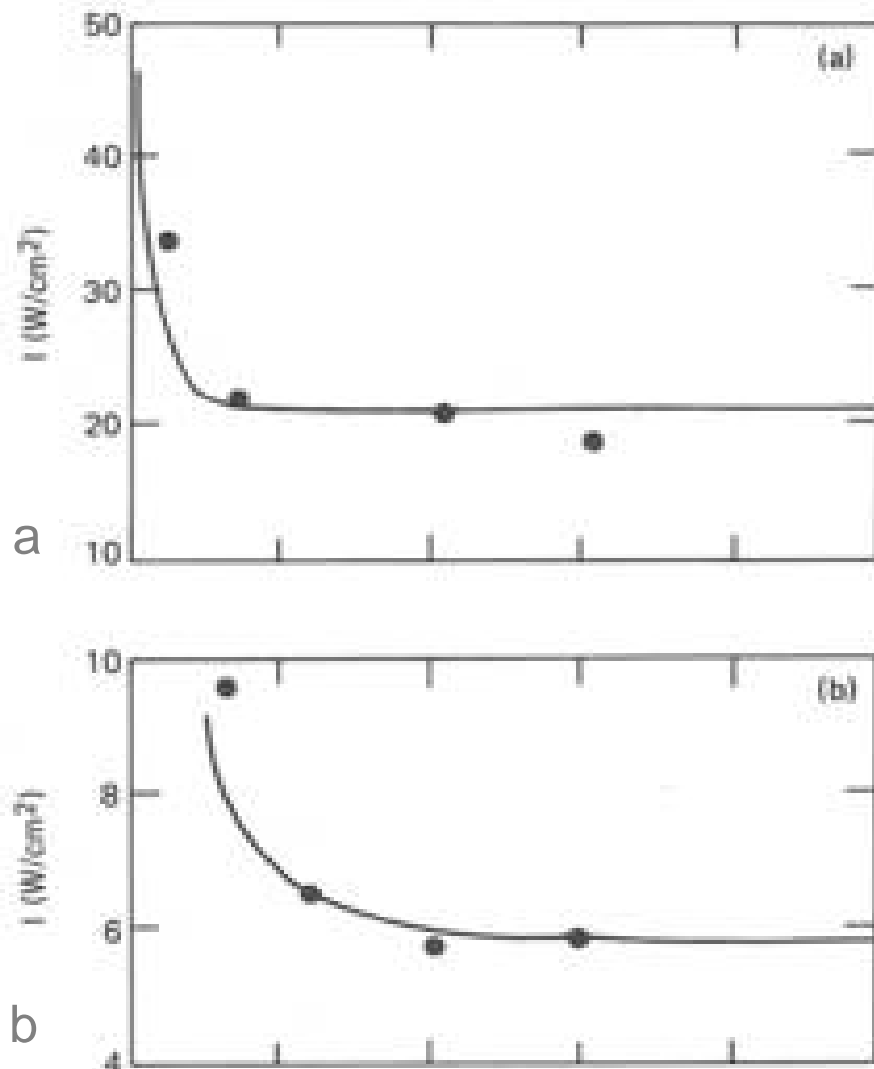


# Optical Radiation Effects a 1315 nm

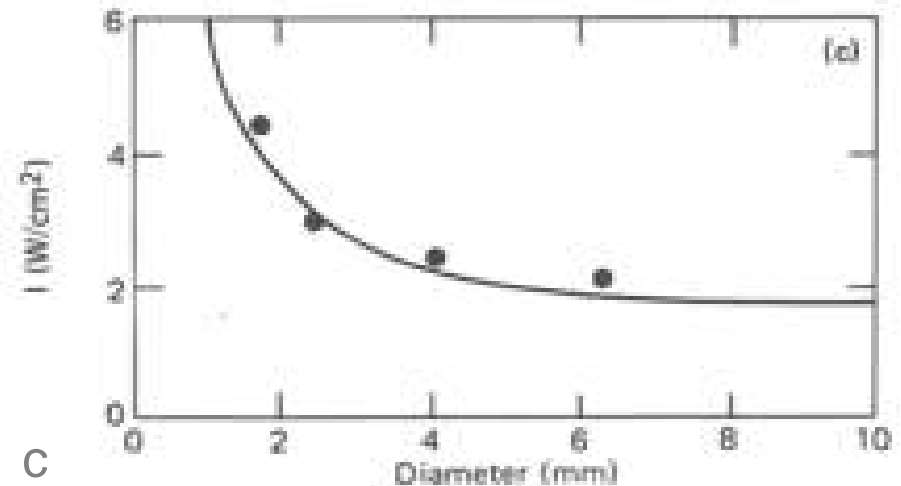




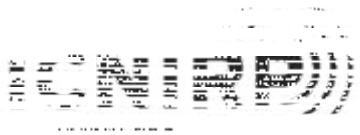
## Corneal Thresholds Dependence on Irradiance Diameter



**CO2 laser radiation at 10.6 μm.  
Bargeron et al., Health Physics  
1989**



**Figure 27** The data points are the experimental peak irradiances required to produce threshold damage as a function of beam diameter. The exposure durations were (a) 0.1 s, (b) 1.0 s, and (c) 10.0 s. The curves are the calculated peak irradiances needed to produce a fixed temperature rise,  $\Delta T_c$ , at a point on the beam axis 10 μm deep into the epithelium.  $\Delta T_c = 41^\circ\text{C}$  in (a),  $39^\circ\text{C}$  in (b), and  $36^\circ\text{C}$  in (c).

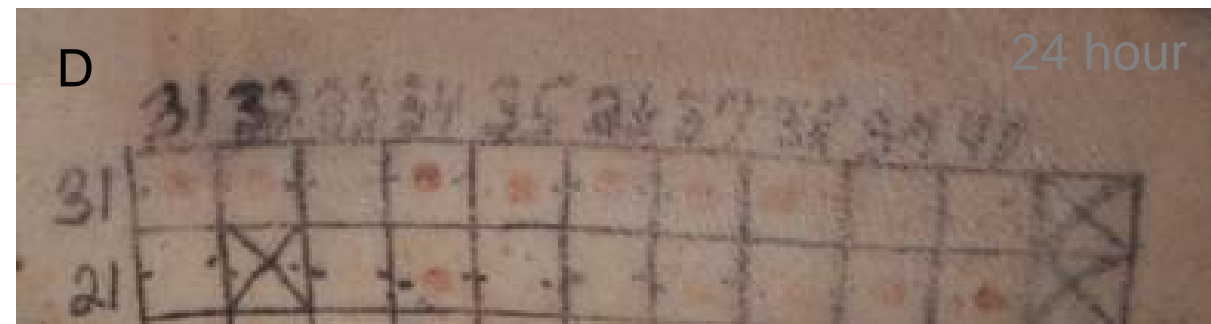
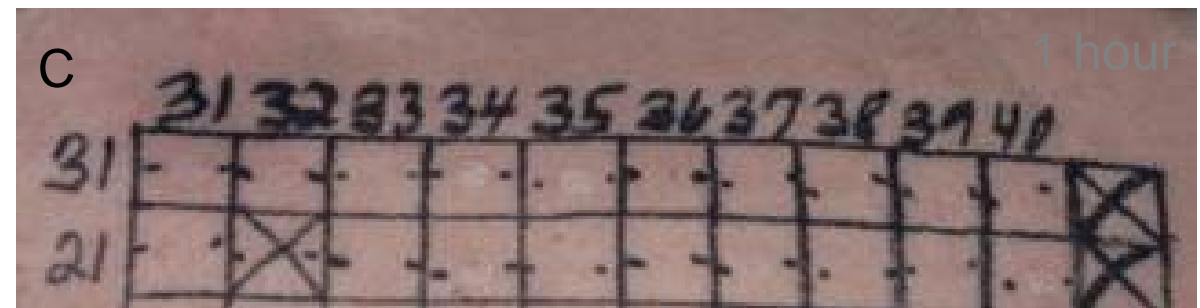
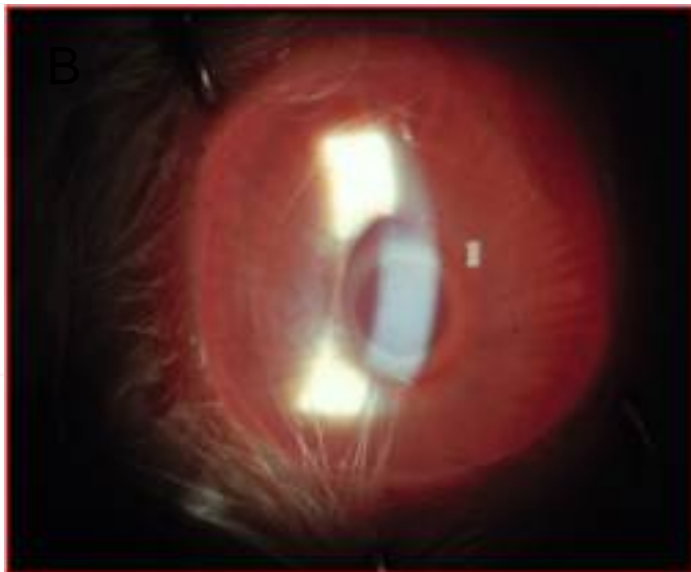
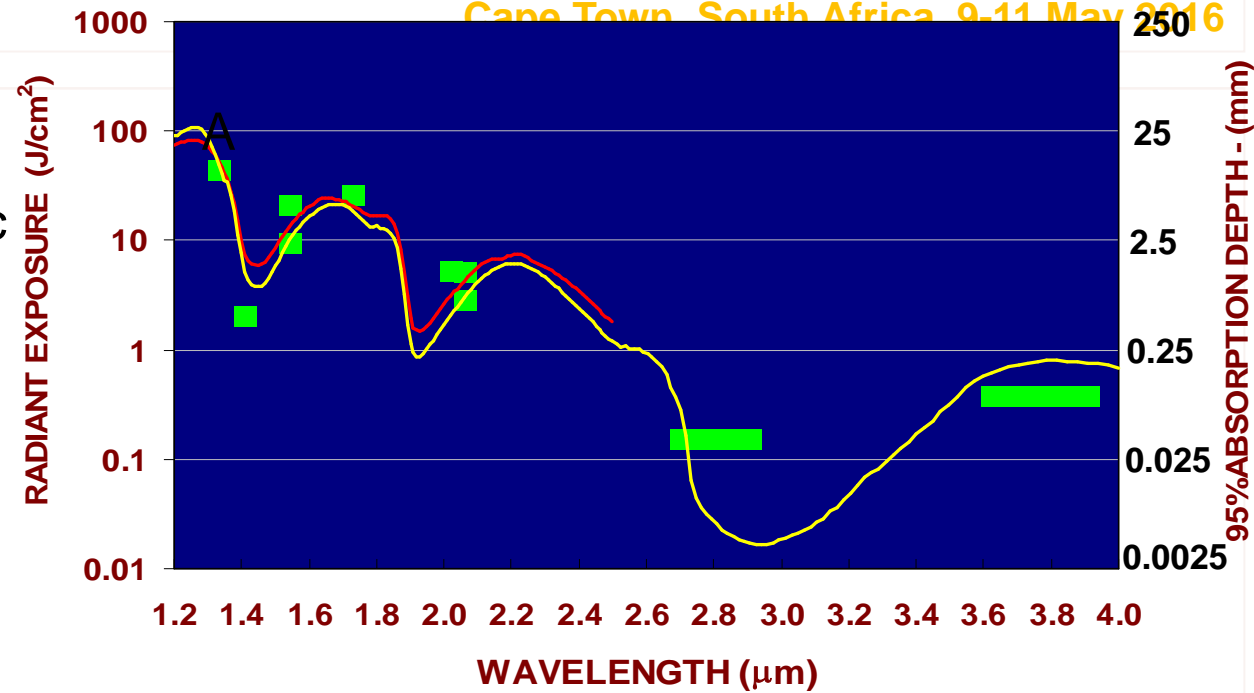


# Infrared Laser Bioeffects

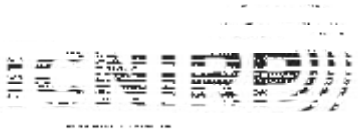
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- A. Corneal injury thresholds for “short” pulses and water absorption
- B. Corneal lesion 10.6  $\mu\text{m}$ , 100 msec
- C. Porcine skin - one hour after exposure at 10.6  $\mu\text{m}$
- D. Porcine skin - 24 hours after exposure 10.6  $\mu\text{m}$







# Summary

- ICNIRP optical radiation guidelines are supported by a robust laser bioeffects data base
  - Animal and Cellular Models
  - Computational Models with understanding of light-tissue interaction mechanisms
  - Some comparisons with human injury thresholds
  - Interaction mechanisms
    - Photochemical
    - Photothermal
    - Microcavitation around melanosomes
  - Dose-Response Relationships
    - Wavelength, Exposure Duration, Irradiance Diameter (Spot size), and Repetitive Pulses,
- Data requirements, issues or “gaps” - identified for the ICNIRP PG