Adaptive Optics and the Eye- Laser Safety Implications

Sandia, July 2008

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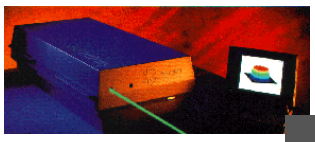
Smaller, Cheaper, More Energy



Enabling Technology
Diode Pumped Solid State Lasers

Outline

- Introduction- Who we are, what we do
- What are adaptive optics (AO)?
- How are AO used in ocular studies?
  - Retinal Imaging
  - Vision Science
- Laser Safety Implications
- Summary

In-House Laser Bioeffects Team

Government

- Semih Kumru, Ph.D.
- Robert Thomas, Ph.D.
- Nichole Jindra
- Jeffrey Oliver, Ph.D.
- Jeff Wigle, Ph.D.
- Becky Vincelette

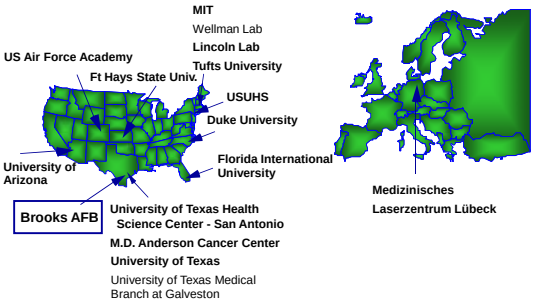
Northrop-Grumman

- Michael Denton, Ph.D.
- Gary Noojin
- Kurt Schuster
- Larry Estlack
- Aurora Shingledecker
- Dave Stolarski
- Michael Foltz
- Harvey Hodnet

Core Competencies

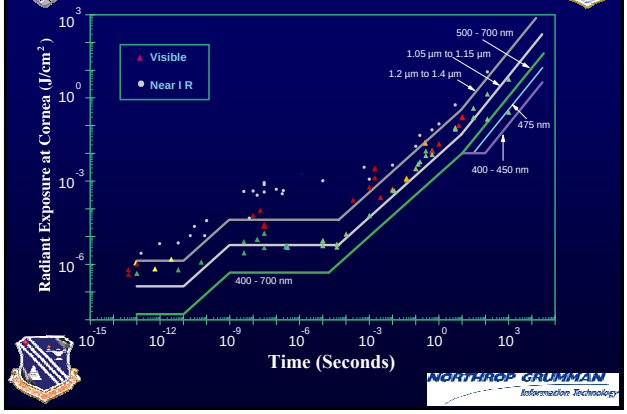
- Technical
  - Laser-Tissue Interaction
    - Photothermal, photomechanical, photochemical, ablation
  - Visibility Threshold Vision Modeling
    - Visual/Neuro- Adaptation
  - Assessment of Laser Exposure on Mission
  - Advanced Modeling (Vision and Bioeffects)
  - Human Factors of Laser-Eye Protection
  - Laser Systems Measurements (Ultrashort and Fielded)
  - Application of Laser Safety Standards to Atypical Situations
- Programmatic
  - Human-Use and Animal-Use Experimentation
  - Laser Range Surveys
  - Early Operational Assessment Process
    - Laboratory - Simulator - Ground – Flight - Acquisition

International Collaboration



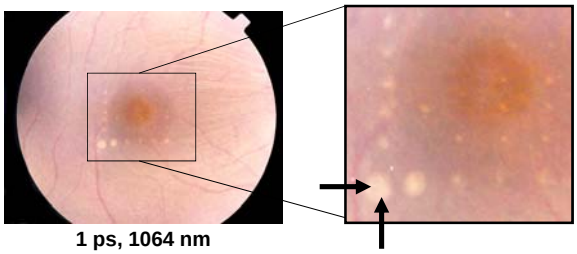
Bold text indicates joint papers published.

Single Pulse MPE and MVL



AF Interest Retinal MVL's

Macular Region with Many Lesions



1 ps, 1064 nm

Row/Column of Marker Lesions

Distribution A

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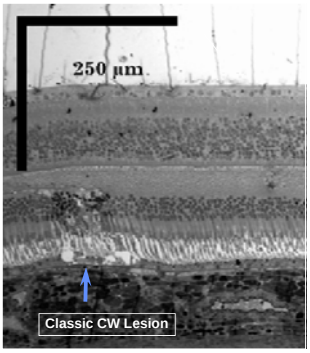
Retinal Histopathology



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Needs for AO for Laser Safety

- Ultrashort or Chronic Exposure Retinal Damage Studies
  - Minimal Retinal Damage
  - Not Extensive Thermal Damage
- Delivery of Diffraction Limited Laser Beam to Create Retinal Damage
  - Previous Studies Estimate (i.e. "Guess") at Retinal Spot Size
  - Correcting High-Order Aberrations in Eye and Delivering Laser Energy- Known Spot Size Will Help Delineate Retinal Damage Mechanism

Distribution A

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Eye Anatomy

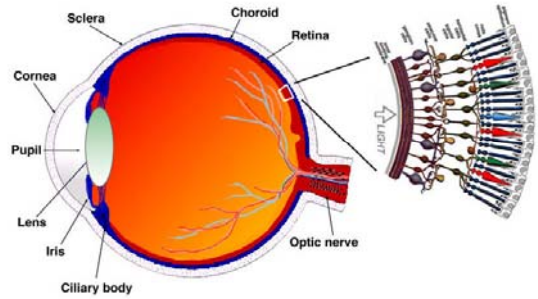
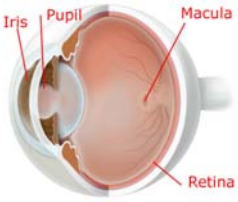


Fig. 1.1. A drawing of a section through the human eye with a schematic enlargement of the retina.

The Ophthalmoscope

http://www.foresightintl.com/Refurbished_Topcon_DigitalHtml



invented in 1850 by the German physiologist Hermann von Helmholtz.

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Ophthalmoscope Images

http://mazur-www.harvard.edu/news/articles/accident.html

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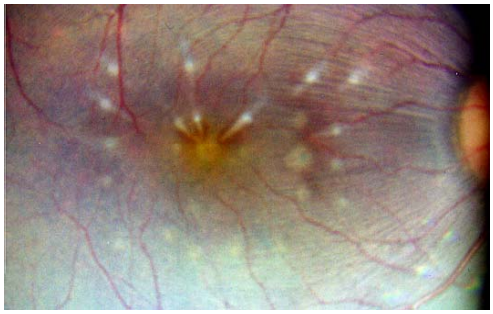
1315 nm Retinal Laser Exposures



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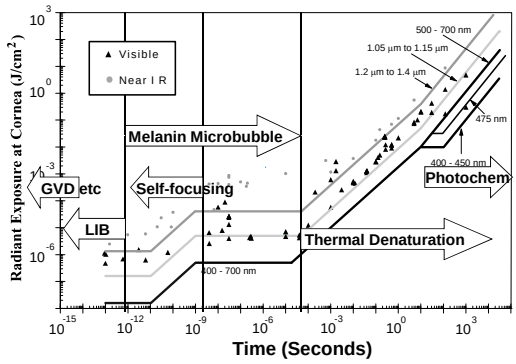
Summary of Damage Mechanisms



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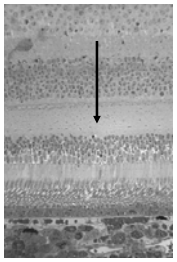
Remaining Problem!!



Macular Lesion <1 hour,
44fs, 810nm, single pulse,
Energy 0.17μJ
Not visible on FA

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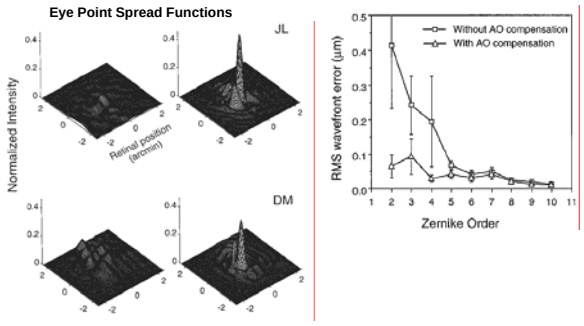
The Impact of Ocular Aberrations



Junzhong Liang, David R. Williams, and Donald T. Miller, Supernormal vision and high-resolution retinal imaging through adaptive optics, J. Opt. Soc. Am. A, Vol. 14 (11), 2884-2892 (1997).

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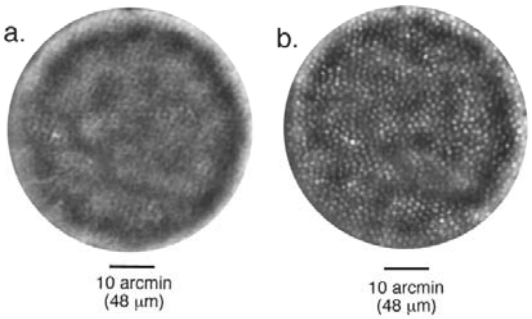
Retinal Imaging with AO



Junzhong Liang, David R. Williams, and Donald T. Miller, Supernormal vision and high-resolution retinal imaging through adaptive optics, J. Opt. Soc. Am. A, Vol. 14 (11), 2884-2892 (1997).

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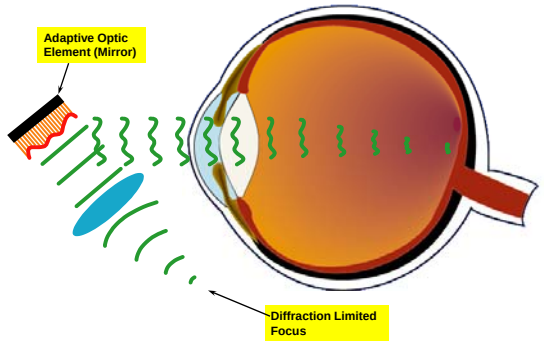
Correcting Ocular Aberrations



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Benefits of Including Adaptive Optics?

For a diffraction-limited system (i.e. one free of aberrations), The angular resolution α is given by:

$$\alpha \approx 1.22\,\lambda / D$$

where λ is the wavelength and D is the aperture diameter.

Example: (λ = 550nm)

Theoretical Limit

D = 10m (Keck telescope), α ≈ 0.013 arc seconds
D = 8mm (dilated pupil), α ≈ 0.3 arc minutes

Practical Result

For Keck, α ≈ 0.5 arc seconds because of turbulence.
For the eye, α ≈ 1 arc minute at best.

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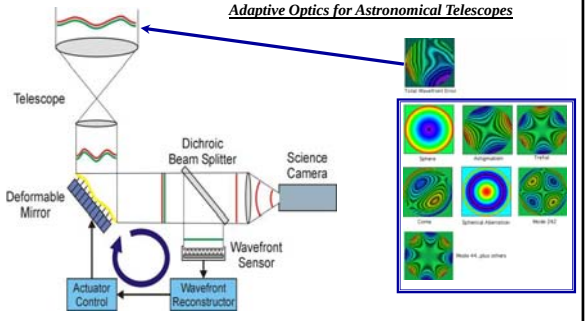
Adaptive Optics

… is the technology for correcting optical wavefront distortions in real time. **John W. Hardy,** ***Adaptive Optics for Astronomical Telescopes***



Distribution A

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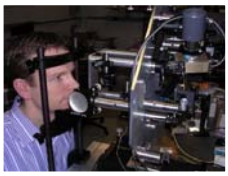
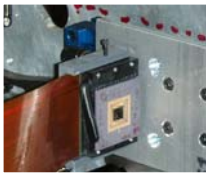
TAOSLO System

Patient interface



Deformable mirror



Distribution A

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High Resolution Imaging

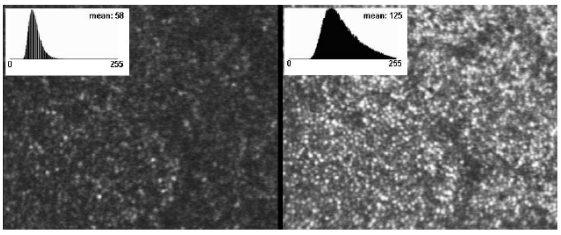

Fig. 2. The two figures show the same area of retina taken with and without aberration correction with AO. In this case, the RMS wavefront error was reduced from 0.55 to 0.10 µm. The insets show the histograms of gray scales in the image.

Austin Roorda, Fernando Romero-Borja,William J. Donnelly III, Hope Queener, Adaptive optics scanning laser ophthalmoscopy, Optics Express Vol. 10, No. 9, 405 (2002).

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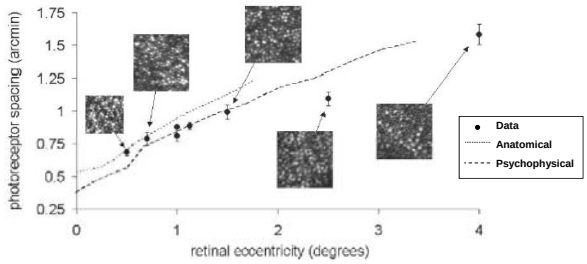
AO in Vision Science



Austin Roorda, Fernando Romero-Borja,William J. Donnelly III, Hope Queener, Thomas J. Hebert, Melanie C.W. Campbell, Adaptive optics scanning laser ophthalmoscopy, OPTICS EXPRESS Vol 10(9), 405-412 (2002).

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Safety Implications of AO Technology

- "The power levels for completely overlapping beams are greater than a factor of 2 below the ANSI laser safety limits."
- **Safety Standard Expressed in terms of Corneal Radiant Exposure - Assumes normal eye (i.e. aberrations reduce laser irradiance on retina from diffraction limited)**
- **Safety Standard (starting in 2000) assumes normal ocular movements- and allows more corneal radiant exposure for CW exposures**

Summary

Ocular Adaptive Optics

- **Adaptive optics have revolutionized placement of diffraction limited light on the retina**
  - **Dramatic improvement in retinal imaging**
  - **Can test the limits of human vision system**
- **Normal process for laser safety evaluation is pushing the limits for any device that:**
  - **Defeats the normal aberrations of an eye**
  - **Tracks the retina and places energy with eye movement corrected**
- **Noted deficiency- Technical Subcommittee 1 (Chair Bruce Stuck) of ANSI Z136 is working this issue**

AF Laser Bioeffects

- **New Laser Technology Requires Evaluation of Safety Standards**
- **New Applications Bring New Safety Considerations**

The DoD continues to lead the world in laser safety research