Adaptive Optics Phoropters

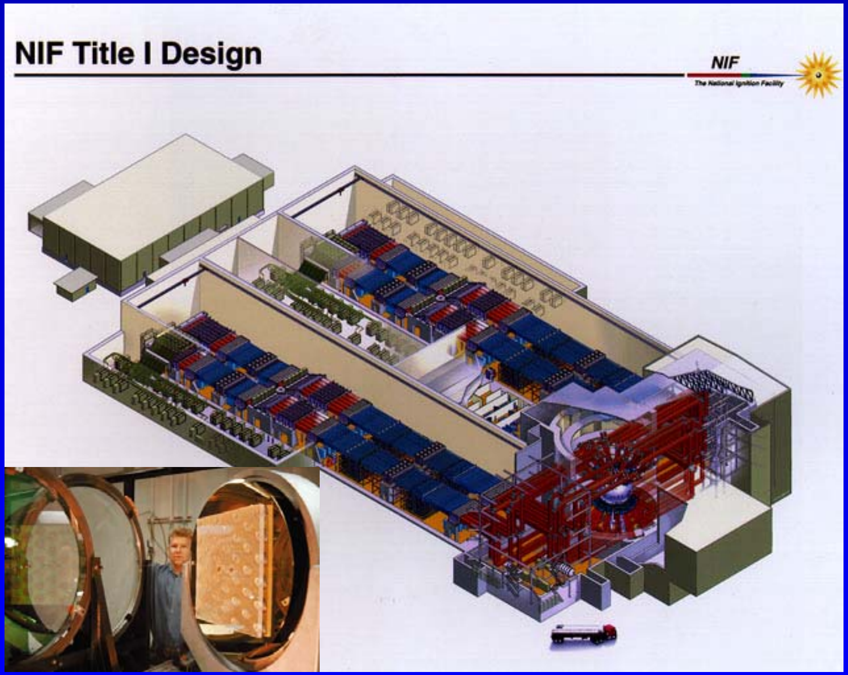
Scot S. Olivier

Adaptive Optics Group Leader
Physics and Advanced Technologies
Lawrence Livermore National Laboratory

Associate Director
NSF Center for Adaptive Optics

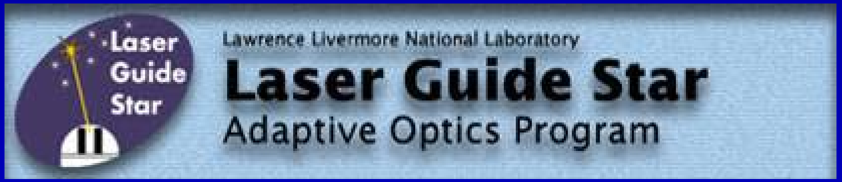
Adaptive optics are a key enabling technology for LLNL projects in laser beam control and imaging

Wavefront control capabilities are crucial for many LLNL projects involving high power lasers

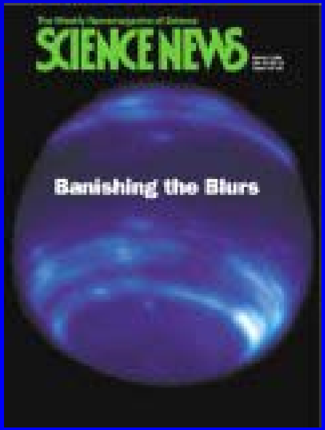


NIF requires AO on all 192 beams

- Enables accurate focusing of light into the target chamber for nuclear physics experiments



LLNL-built sodium-layer laser guide star AO system at Lick Observatory is world's first

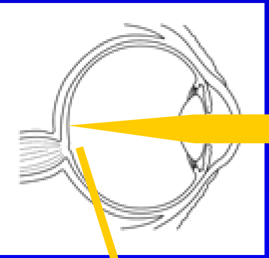


LLNL-built AO system at Keck Observatory is world's most powerful

Center for Adaptive Optics

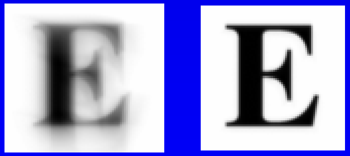
An NSF Science & Technology Center

- Headquarters at UC Santa Cruz
- 11 university nodes
  - 3 primarily vision science (Rochester, Houston, Indiana)
- Over 25 partner institutions (research, education, gov., industry)
- Combines research and development in three science and technology areas:



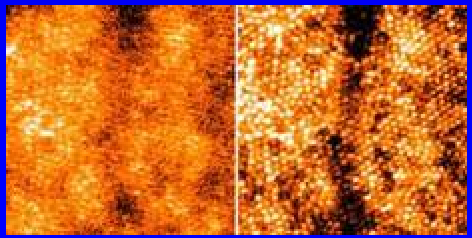
Visual acuity and retinal imaging degraded by aberrations in cornea and lens

Without AO   With AO



Effect of AO aberration correction on the image quality of the 20/20 E

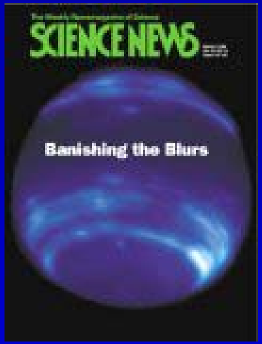
Without AO   With AO



Images of single cells in the living human retina

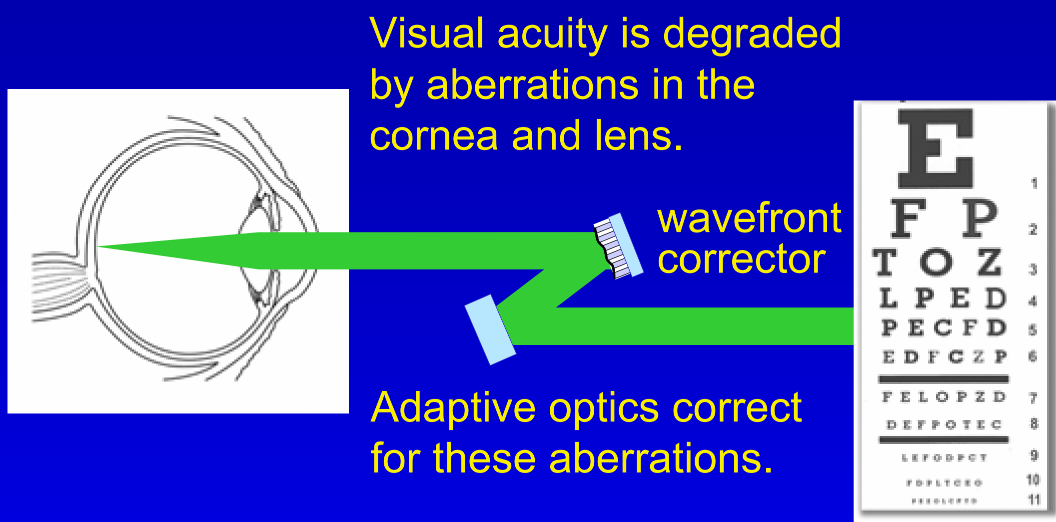
VISION SCIENCE

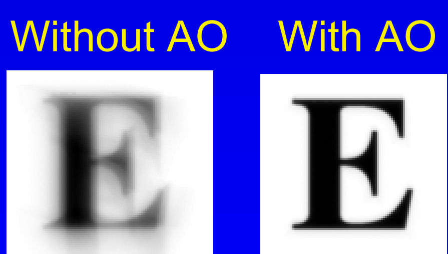
ASTRONOMY



ADVANCED TECHNOLOGY

Adaptive optics can provide unique diagnostic capability to study effects of vision correction





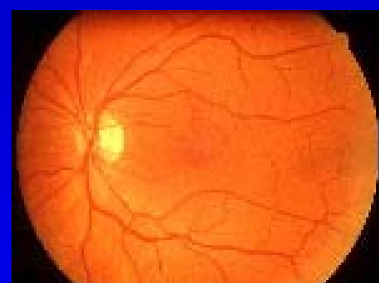
Effect of AO aberration correction on the image quality of the 20/20 E.

- An adaptive optics system can be used to sense and correct aberrations in a subject's eye and allow detailed studies of visual performance under a variety of conditions.

Center for Adaptive Optics Vision Science Theme

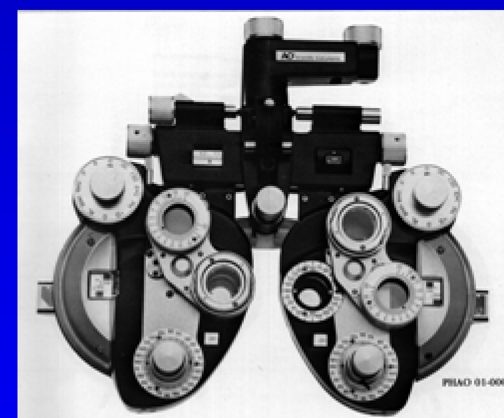
Development of compact clinical ophthalmic instrumentation

- Adaptive optics can be incorporated into fundus cameras to provide ophthalmologists with high-resolution retinal imaging for diagnostic and surgical applications.



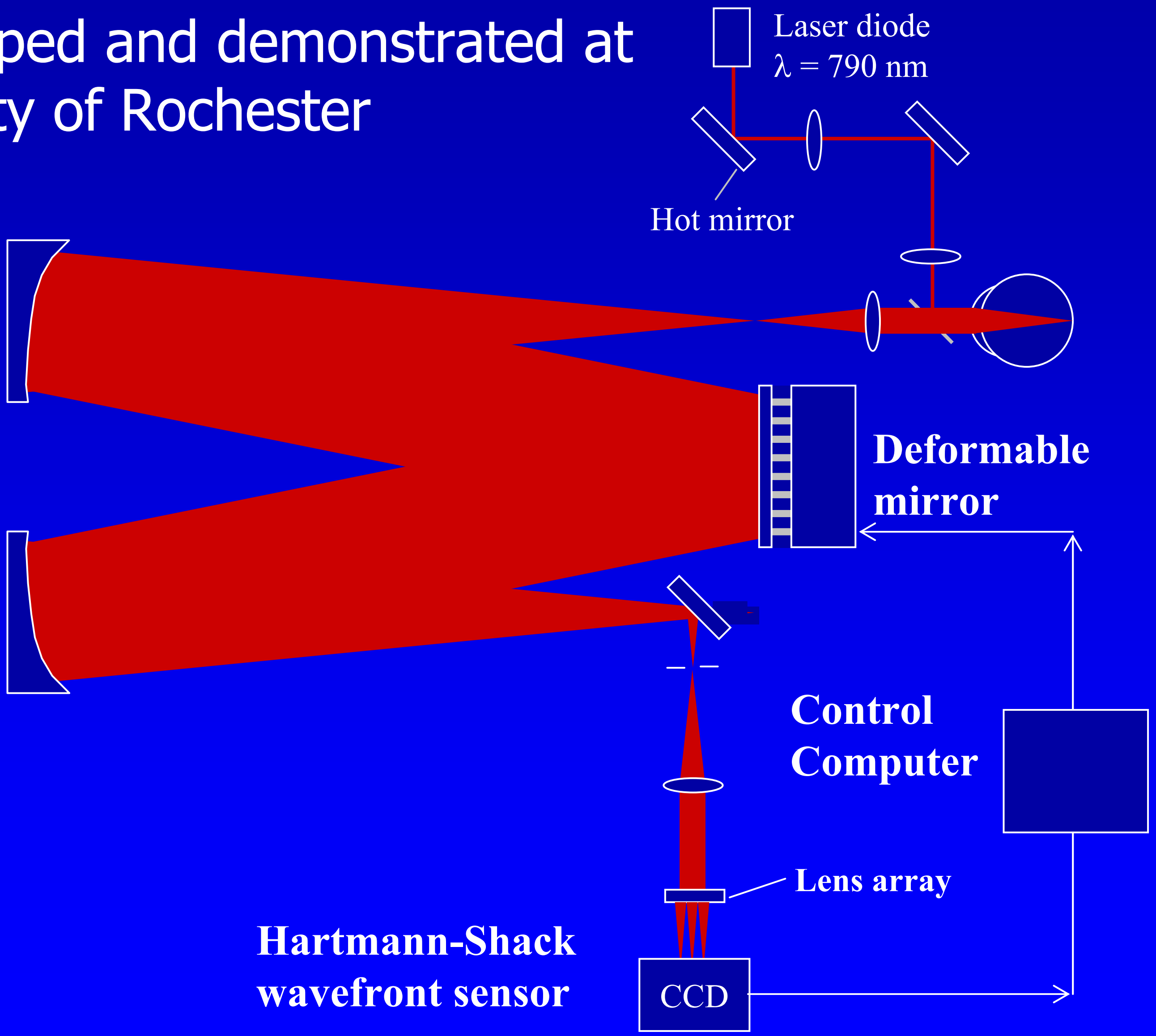
Conventional Fundus Camera and image

Conventional Phoropter



- Adaptive optics can be used to replace the phoropter in order to allow optometrists to assess high-order aberrations in the eye while the patient directly observes the visual benefit of correction.
- Permanent correction of high-order aberrations would then be accomplished with custom laser eye surgery or contact lenses.

Adaptive optics for vision science has been developed and demonstrated at the University of Rochester



Current adaptive optics systems for vision science are large, expensive laboratory instruments

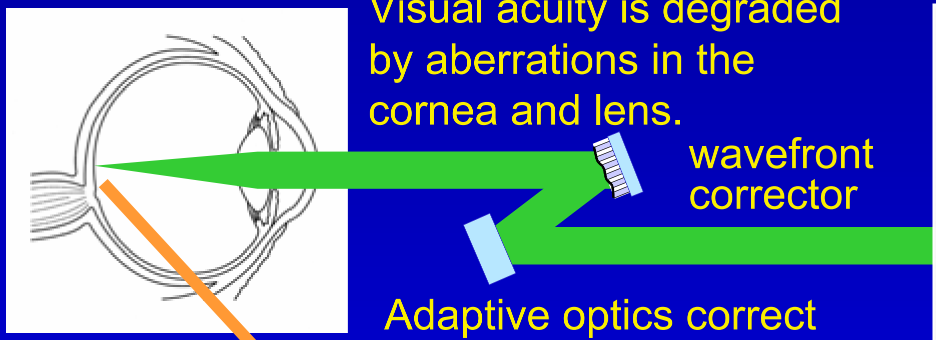
University of Rochester vision science adaptive optics system

Conventional deformable mirror technology, which is both large and expensive, results in a large overall system due to the required magnification of the pupil of the eye to the size of the mirror

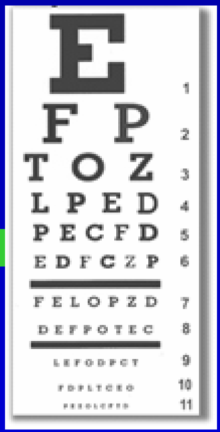
Development of viable clinical ophthalmic adaptive optics instrumentation requires new enabling wavefront corrector technologies that are: *compact, robust and inexpensive*.

New adaptive optics to compensate for aberrations in the human eye could revolutionize ophthalmology

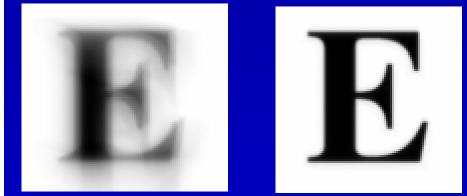
Visual acuity is degraded by aberrations in the cornea and lens.



Adaptive optics correct for these aberrations.

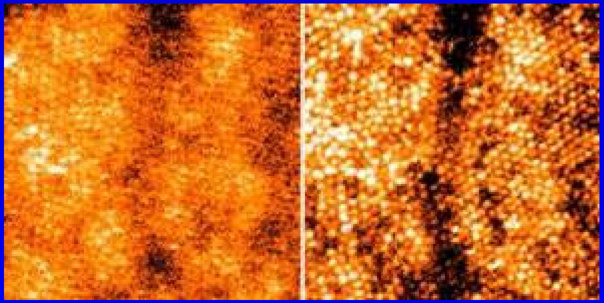


Without AO With AO



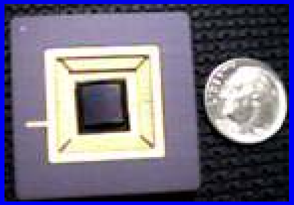
Effect of AO aberration correction on the image quality of the 20/20 E

Without AO With AO

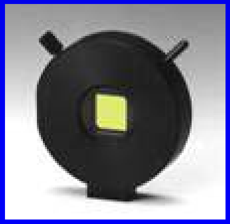


Images of single cells in the living human retina

LLNL is leading a national effort to use new adaptive optics technologies to develop prototype high-resolution clinical ophthalmic imaging systems.



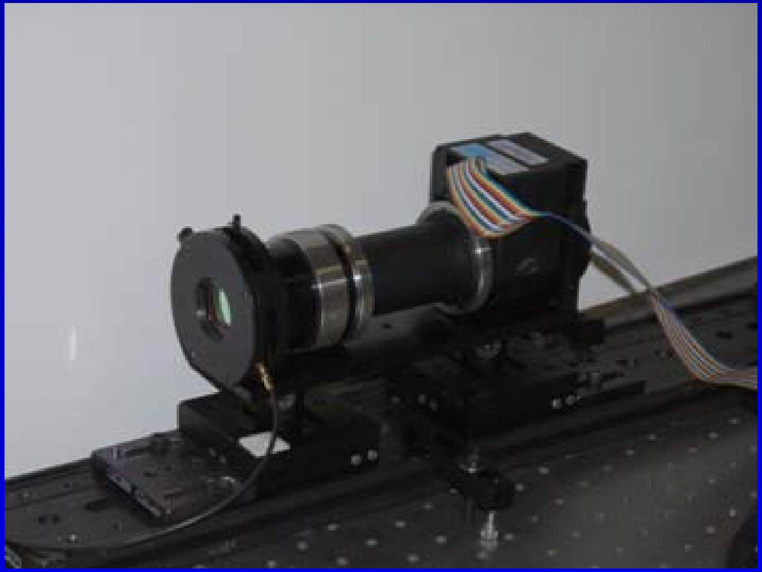
MEMS deformable mirror



liquid crystal spatial light modulator

- These systems will aid in the diagnosis and treatment of diseases causing blindness and the development of new techniques for vision correction in the general population
- Partners include Sandia National Lab, U Rochester, USC, UC Davis, UC Berkeley, US Army Aeromedical Research Lab, Bausch & Lomb, and Wavefront Sciences

High-resolution liquid crystal spatial light modulator is commercially available from Hamamatsu



Advantages

- Compact – 2 cm clear aperture
- Low cost – > $30k
- Ease of use – driven as a display
- High resolution correction (480x480)
  - 200 times higher than largest DM

Acknowledgement:
Project Team

LLNL

Scot Olivier – AO Group leader

Instrument Development

Charles Thompson – Electronics Engineer, project leader
Scott Wilks – Physicist, project scientist
Robert Sawvel – LEOT, optics, mechanics
Dennis Silva – EE TA, software, electronics
Brian Bauman – Optical Engineer, optical design

Instrument Integration, Test and Deployment

Don Gavel – Electronics Engineer, project leader
Abdul Awwal – Optical Scientist, project scientist
Robert Sawvel – LEOT, optics, mechanics
Dennis Silva – EE TA, software, electronics
Brian Bauman – Optical Engineer, optical I&T

UC Davis

Prof. John Werner - Senior Ophthalmology Professor
Thomas Barnes - Senior Optometrist
Joe Hardy – post-graduate researcher

University of Rochester

Prof. David Williams - Director, Center for Visual Sciences
Nathan Doble – post-graduate researcher

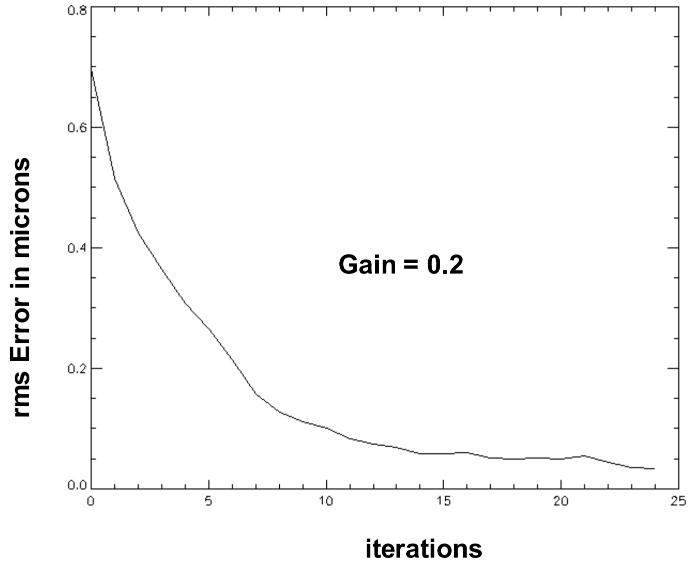
Adaptive optics phoropter using liquid crystal spatial light modulator

Developed at LLNL for use at the UC Davis Medical Center

- Adaptive Phoropter: correcting high-order aberration using Adaptive Optics
- Determine ultimate limits of visual acuity
- Relationship between normal aging, retinal disease and visual performance through psycho-physical testing

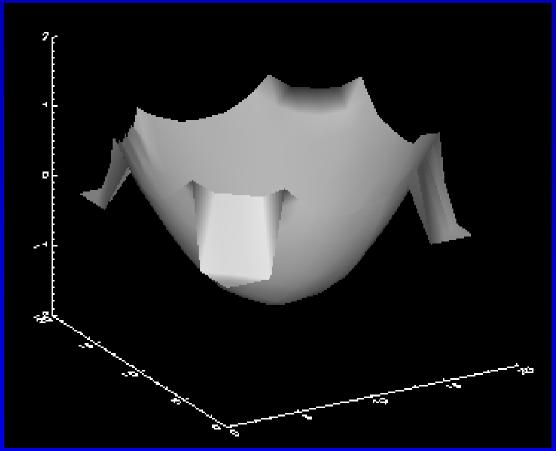
Complete view of adaptive optics phoropter at UC Davis using liquid crystal spatial light modulator

Closed Loop: External aberration

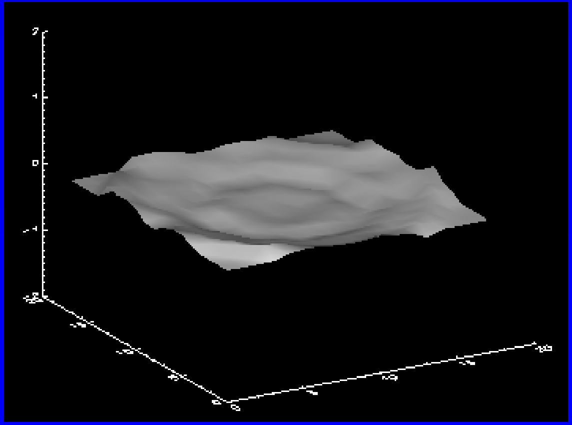


Convergence of the .25 D lens to 0.05 microns

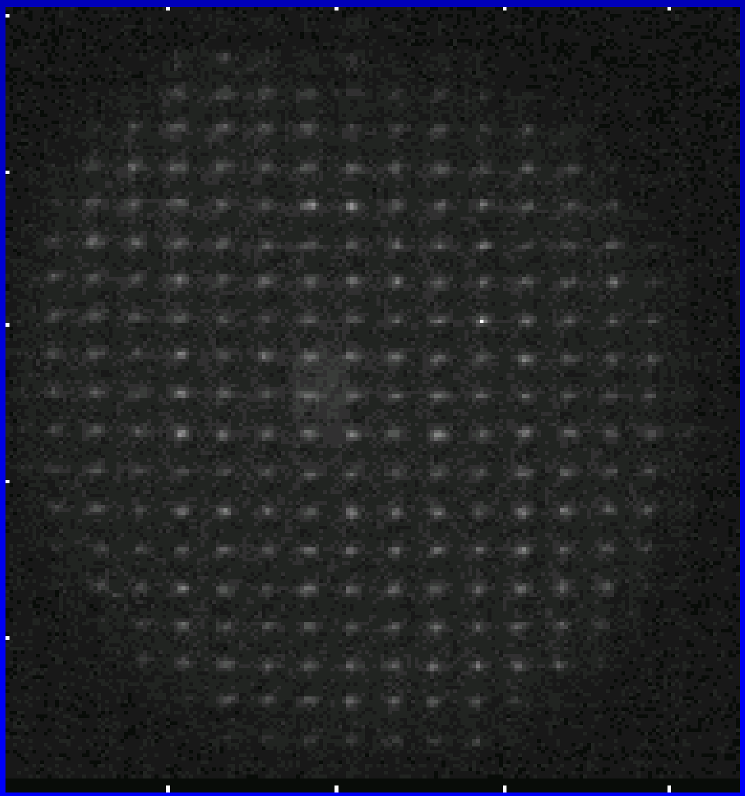
1st iteration



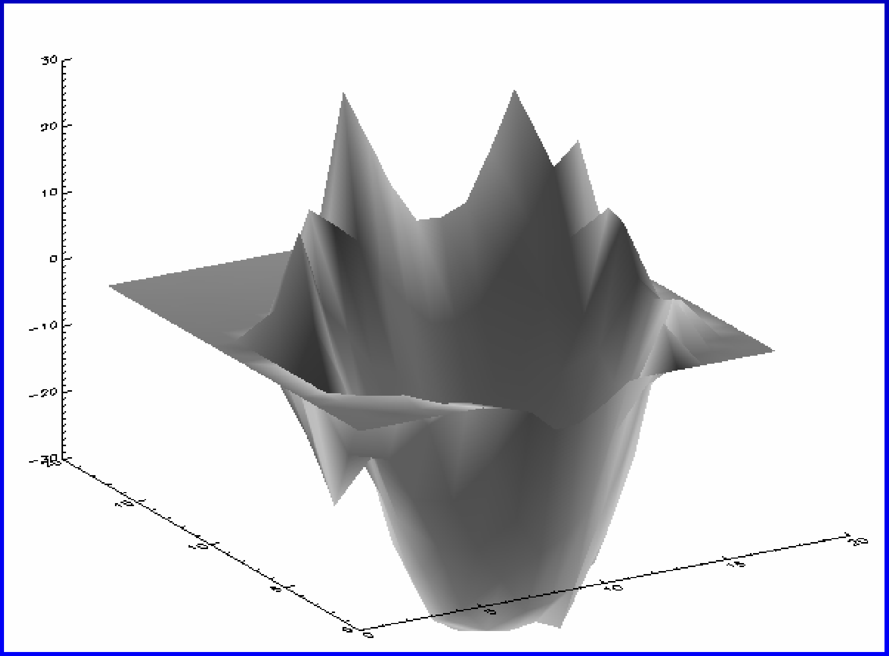
9th iteration



Human Eye Data



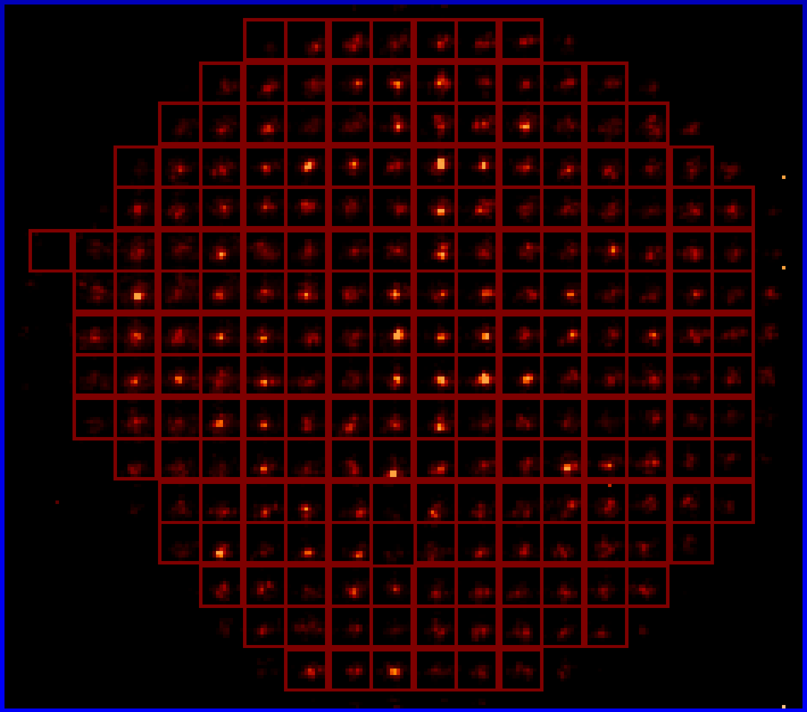
Wavefront Sensor Image



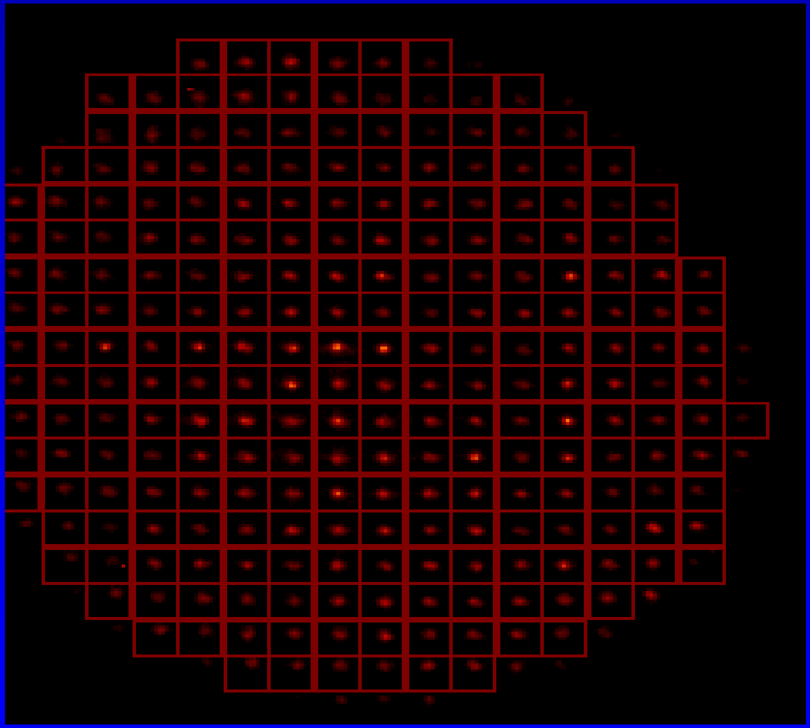
Reconstructed wavefront

Human Eye Wavefront Data

Laser diode



Super luminescent diode



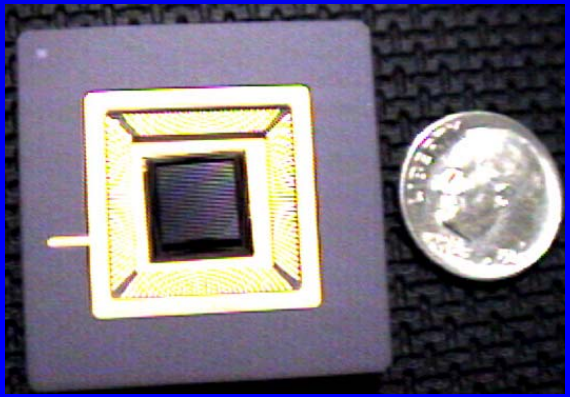
Measurement accuracy: 163 nm

Measurement accuracy: 95 nm

New optical MEMS technology could lead to a revolution in adaptive optics

Current adaptive optics systems are **large and expensive** due to available wavefront corrector technology

- The standard wavefront corrector is a deformable mirror consisting of a thin glass plate with a set of ceramic actuators glued to the back
- Typical conventional deformable mirror costs are **$1,000 per actuator**



- **Small low-cost** deformable mirrors can now be fabricated with MEMS techniques for **~$1 per actuator**

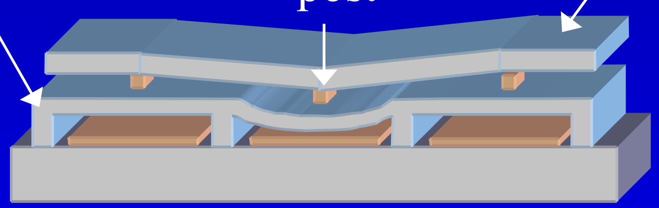
Boston University Continuous MEMS SLM

<u>Fabrication</u>:
Silicon micromachining (structural silicon and sacrificial oxide)

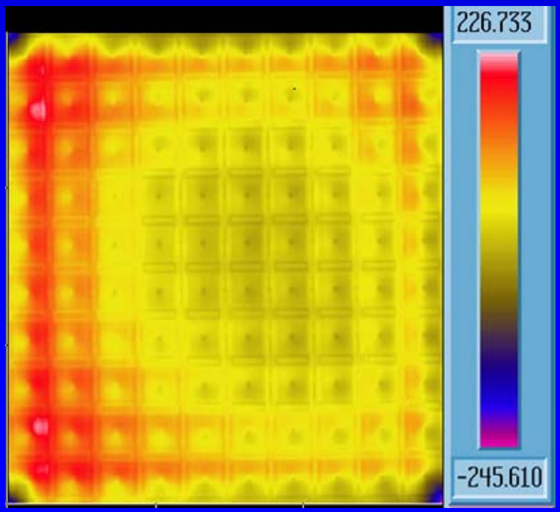
<u>Actuation</u>:
Electrostatic parallel plates, individual addressing of identical actuators in an array

<u>Configuration</u>:
140 actuators (12 x 12 w/o corners), square grid, 300 µm spacing

<u>Surface Quality</u>:
50 (30) nm rms

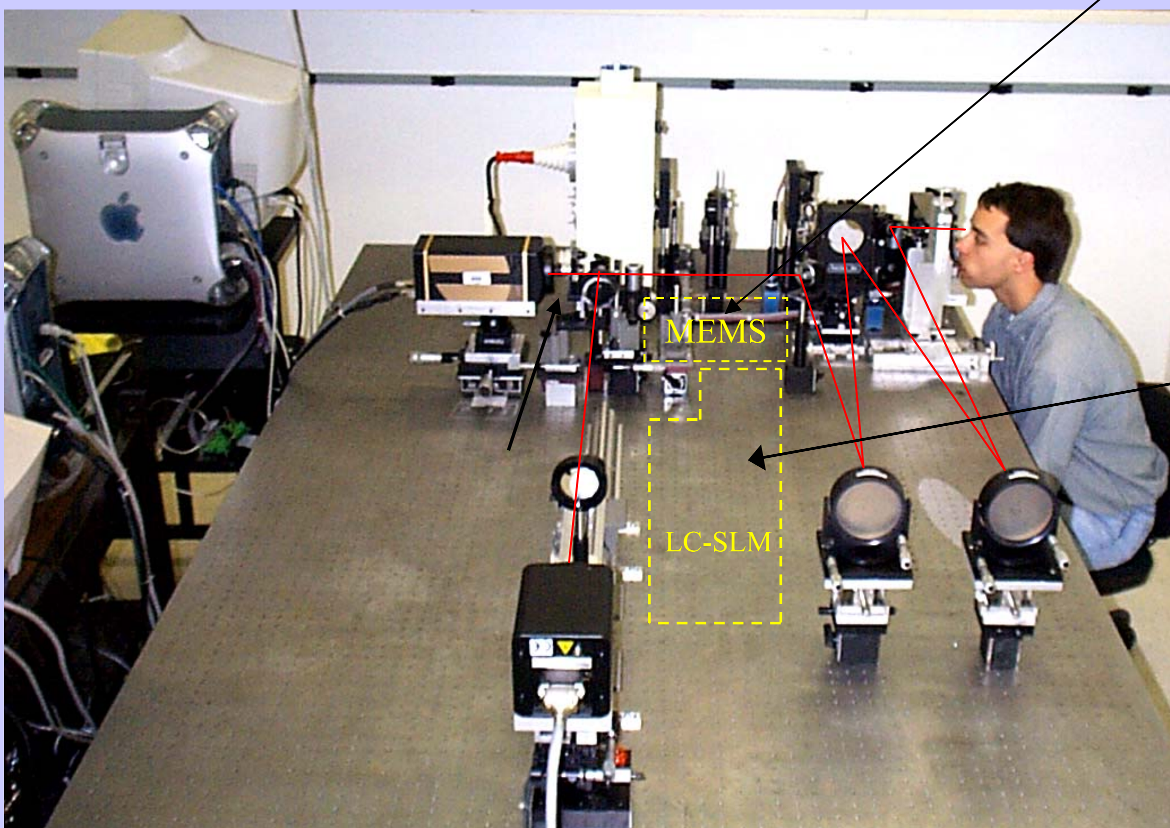


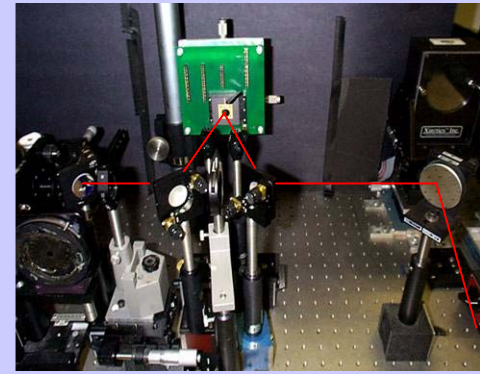
Continuous mirror

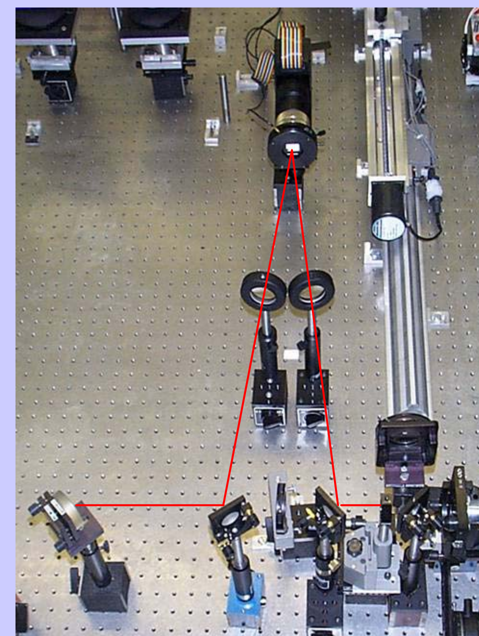


Mirror surface map

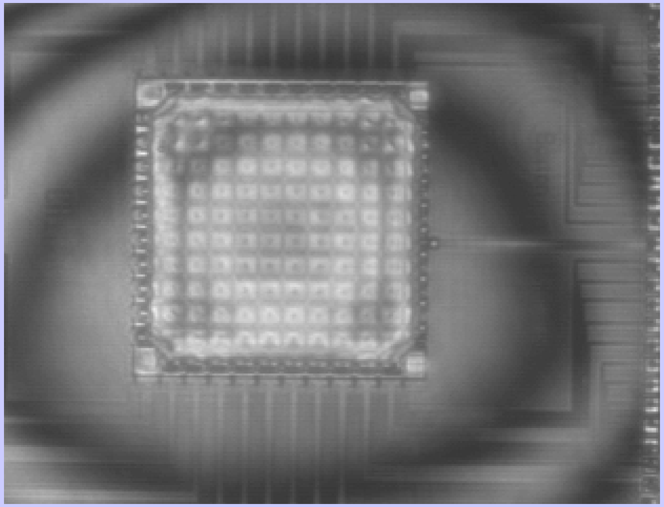
The Rochester AO Testbed







The Mirror and Driver Boards



Zygo Interferogram

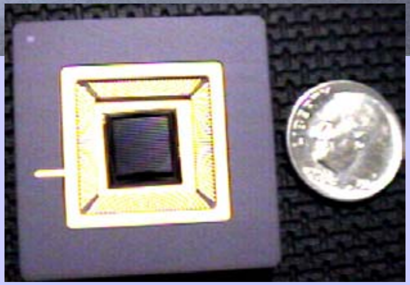
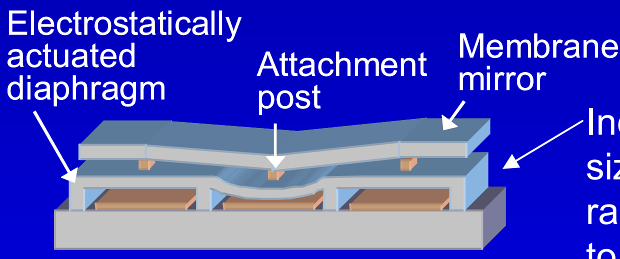


Photo: Paul Bierden, BMC

New MEMS deformable mirrors will have improved characteristics – CfAO goal of 10 micron motion

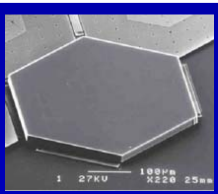
Boston Micromachines Corporation (BMC)

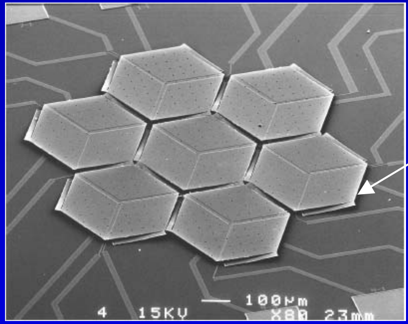


Continuous mirror

Increased gap size will increase range of motion to 4-8 microns

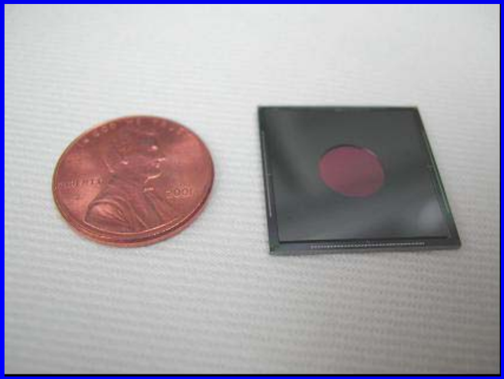
Iris AO, Inc.





Self assembly technique allows large gap sizes – 6 micron motion demonstrated – designs for 12-20 microns

Lucent Technologies
Bell Labs Innovations

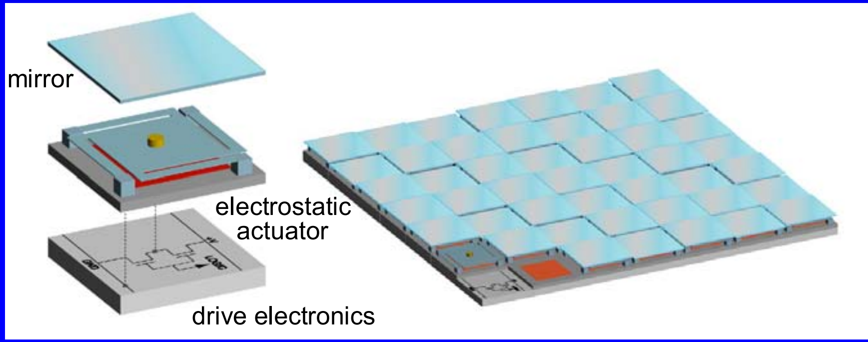


Low-stress membrane allows larger gaps for a given voltage – 4 micron motion demonstrated – designs for 10 microns

DARPA

CCIT

Incorporation of MEMS deformable mirrors with drive electronics will significantly reduce size and cost, improve functionality



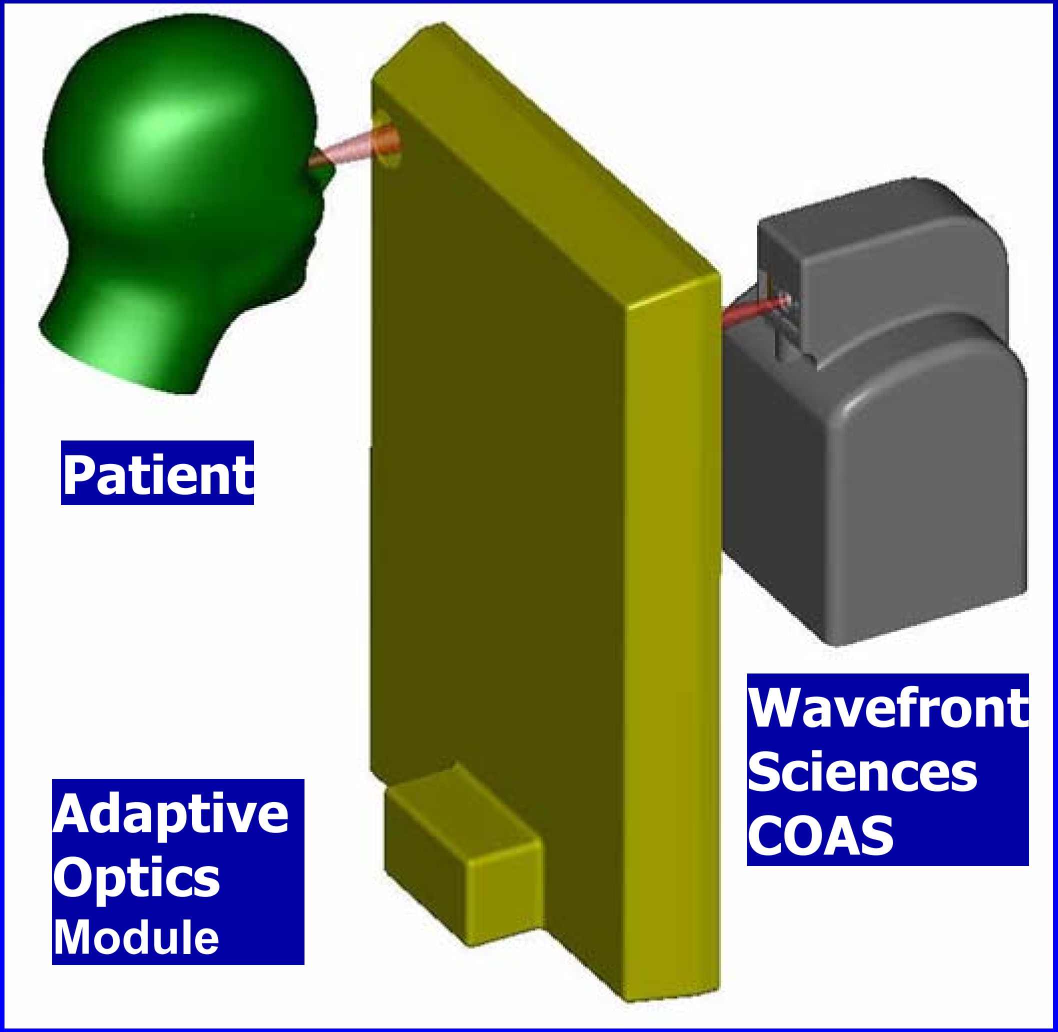
Acknowledgement: Project Team

Scot Olivier : Principle Investigator
Brian Bauman : Optics / Technical Lead
Stephen Eisenbies : Mechanical
Kevin O’Brien : Business Collaboration
Jack Tucker : Tech / Optics
Steve Jones : Software / Project Lead
Don Gavel : Technical Support
Abdul Awwal : Tech. Input, LC SLM comparison

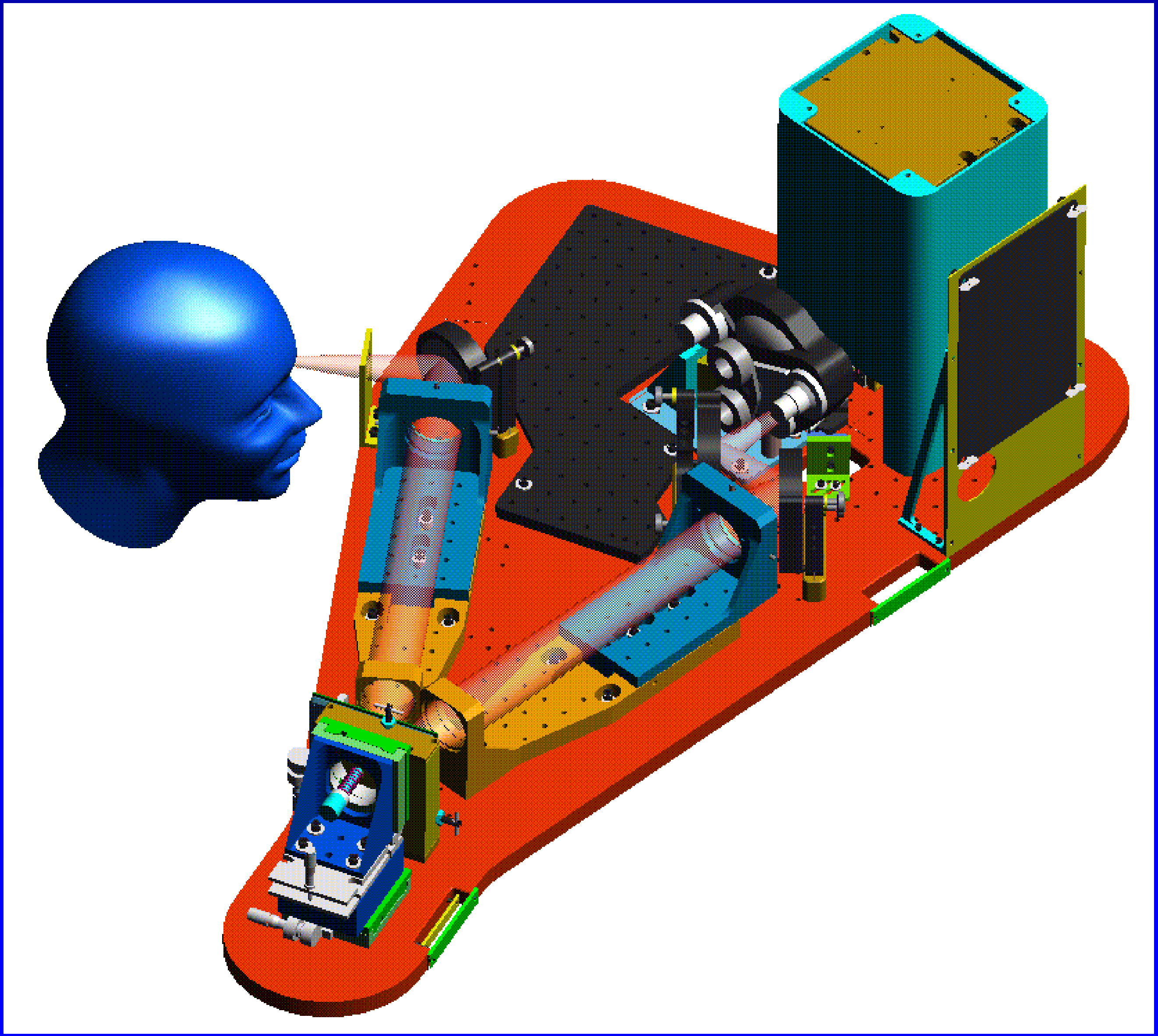
Partners include

- Sandia National Lab,
- U Rochester
- USC,
- UC Davis,
- UC Berkeley,
- US Army Aeromedical Research Lab,
- Bausch & Lomb,
- Wavefront Sciences

Early design concept for clinical adaptive optics phoropter and using a MEMS deformable mirror



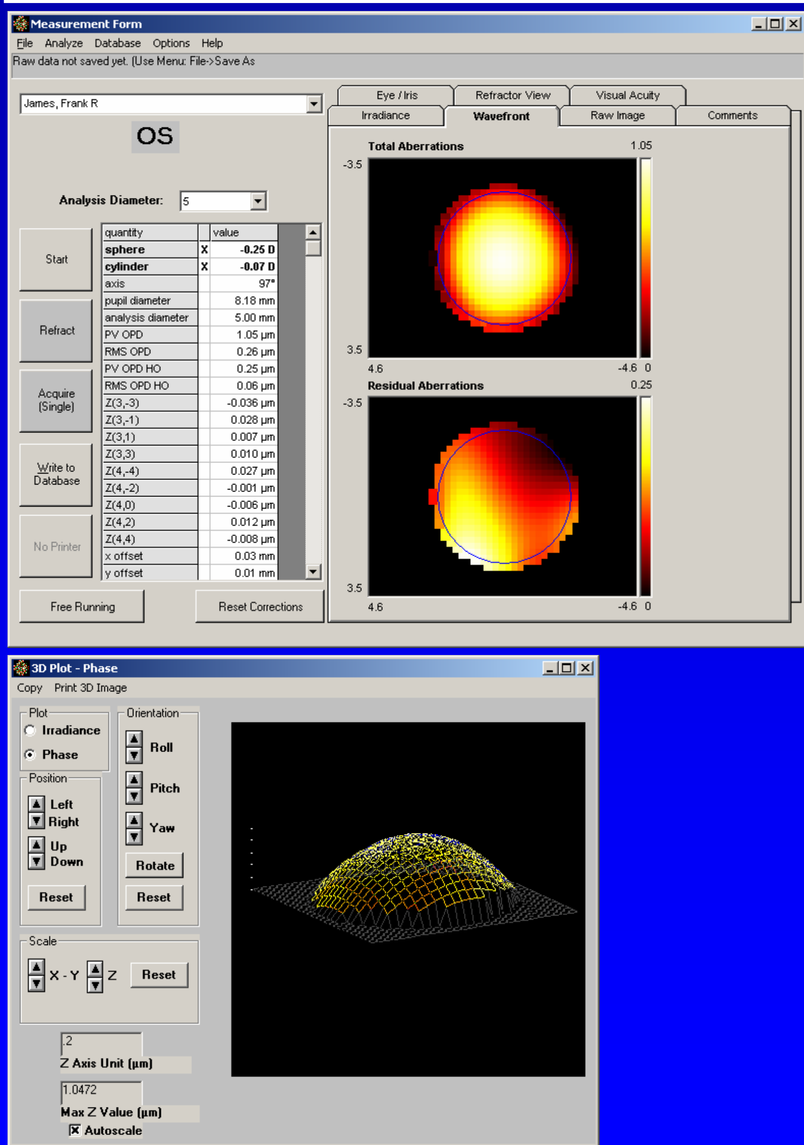
Model of adaptive optics phoropter

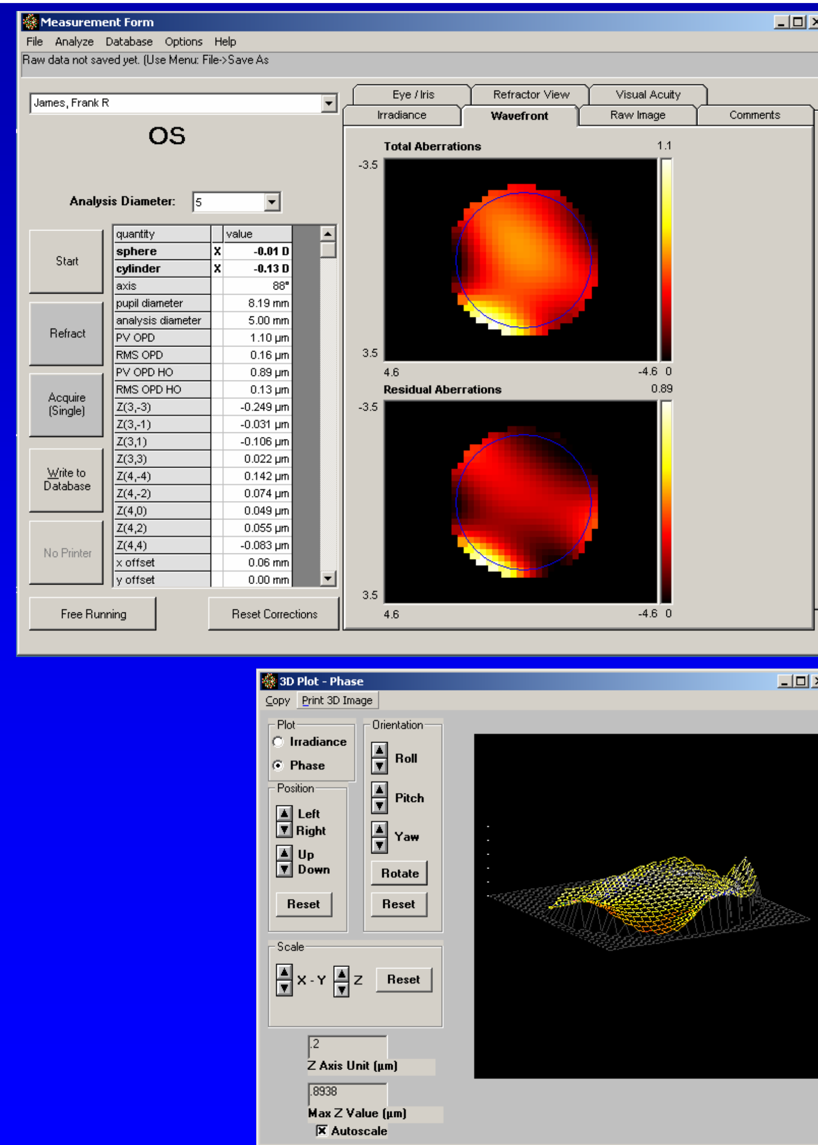


Model of assembled prototype clinical adaptive optics phoropter on movable cart for portability

Complete assembled prototype clinical high-resolution ophthalmic imaging system using MEMS adaptive optics

Initial test data shows correction of 0.25 diopter lens to 0.01 diopter - still has some residual astigmatism





Conclusions

- The High-resolution Ophthalmic Imaging Systems project, sponsored by the DOE Biomedical Engineering Program, has made excellent progress in producing a prototype clinical adaptive phoropter using new MEMS wavefront corrector technology.
- *The first generation of functional prototype adaptive phoropter instrumentation using MEMS deformable mirror technology will be available for clinical testing later this year.*
- *This new instrumentation will provide the ophthalmic community with another tool to facilitate progress on optimization of vision correction procedures.*
- *Tests of this new instrumentation will be facilitated by comparison with two laboratory adaptive optics systems for vision science at the University of Rochester (using a conventional deformable mirror) and UC Davis (using an LC SLM).*
- *Interested industry partners encouraged to attend CfAO Spring Industrial Advisory Board Session, March 21 in San Jose, CA*