Progress Toward Compact Low-Cost Adaptive Optics Systems

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ACTIVE OPTICAL SYSTEMS

Outline

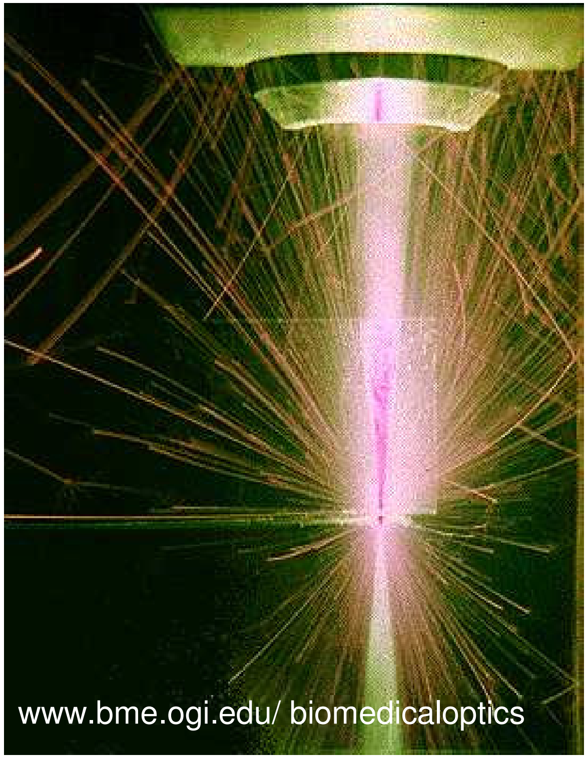
- Introduction & Applications
- Low-Cost Hardware
- Prototype Low-Cost Systems
- Future Developments
- Conclusions

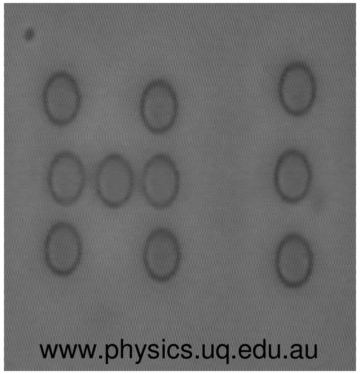
Introduction To
Active Optical Systems, LLC

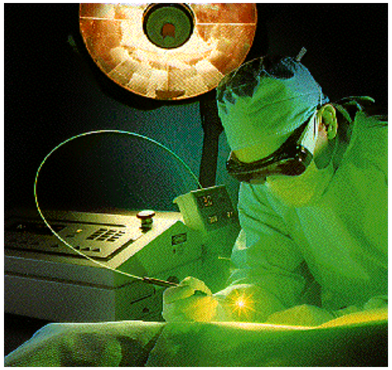
- Founded in 2005 by Justin Mansell and MZA Associates
- GOAL: Commercialize low-cost adaptive optics systems for
  - Imaging and
  - Laser Wavefront Control

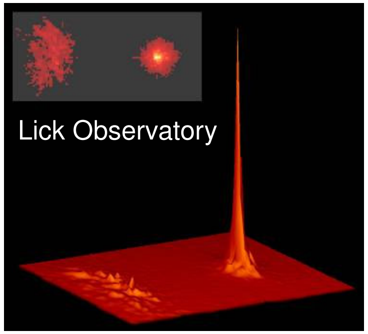
Applications

- Laser Wavefront Control
  - Intensity Profile Shaping
    - Laser Machining
    - Optical Tweezers
    - Medical Applications
  - Atmospheric Aberration Compensation
  - Medical Applications
- Imaging
  - Astronomy
  - Target Inspection
  - Ophthalmology
    - Phoropters









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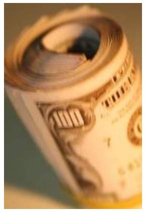
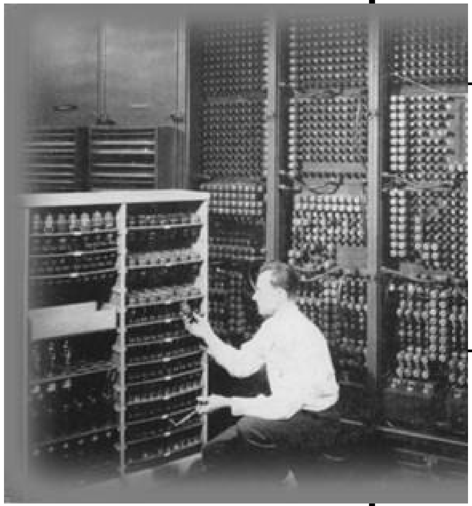
Barriers to Mass Usage





Barrier	Solution
Cost	Implementation via our unique compact low-cost hardware
Complexity	Construction of complete active optical systems
Inertia	AO systems can often relax requirements and increase system functionality

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AOS ACTIVE OPTICAL SYSTEMS

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- Introduction & Applications
- Low-Cost Hardware
  - Deformable Mirrors
  - Drive Electronics
- Prototype Low-Cost Systems
- Future Developments
- Conclusions

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AOS Philosophy on DMs

- Some companies develop AO systems to sell their DMs
  - We develop DMs to sell AO systems
- Our DMs are not the best for all applications
- Our system hardware is flexible
  - Not specific to our DM hardware

Deformable Mirrors

- Design
  - Applications of Annular Actuators
- Influence Functions
- Actuator Throw
- Frequency Response
- Surface Quality
- Comparison to Other Low-Cost DMs

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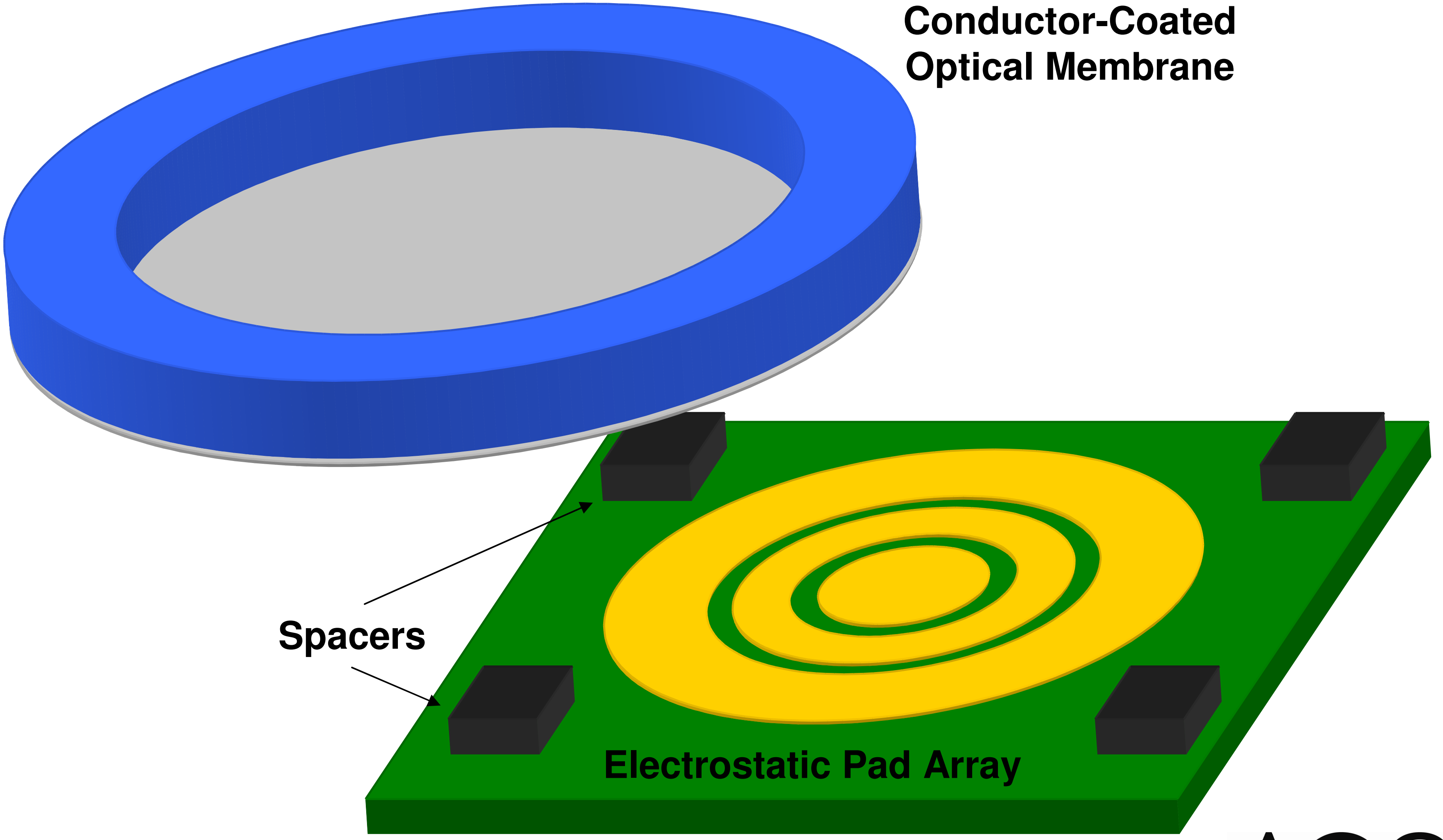
Low-Cost Polymer Deformable Mirrors



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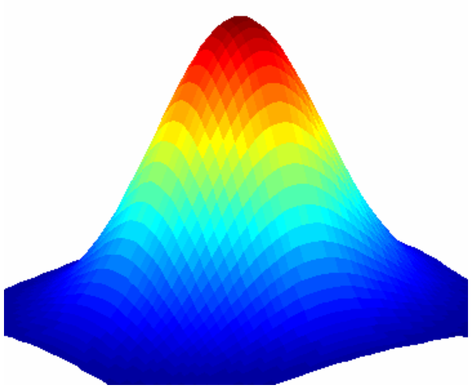
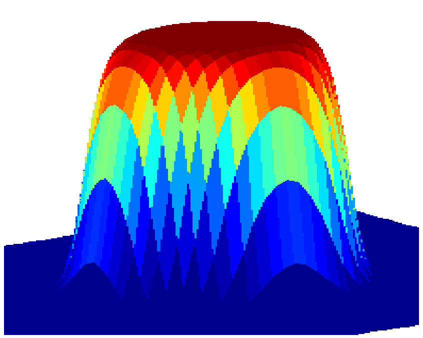
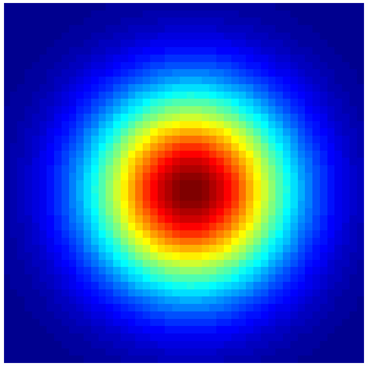
Annular Actuator Applications - Beam Shaping

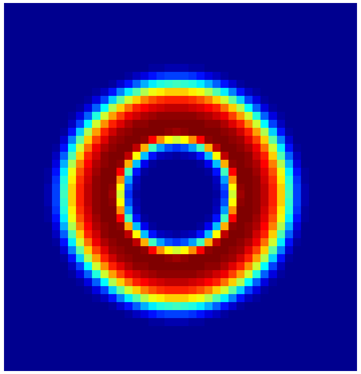
Gaussian to Super-Gaussian





Gaussian to Annulus





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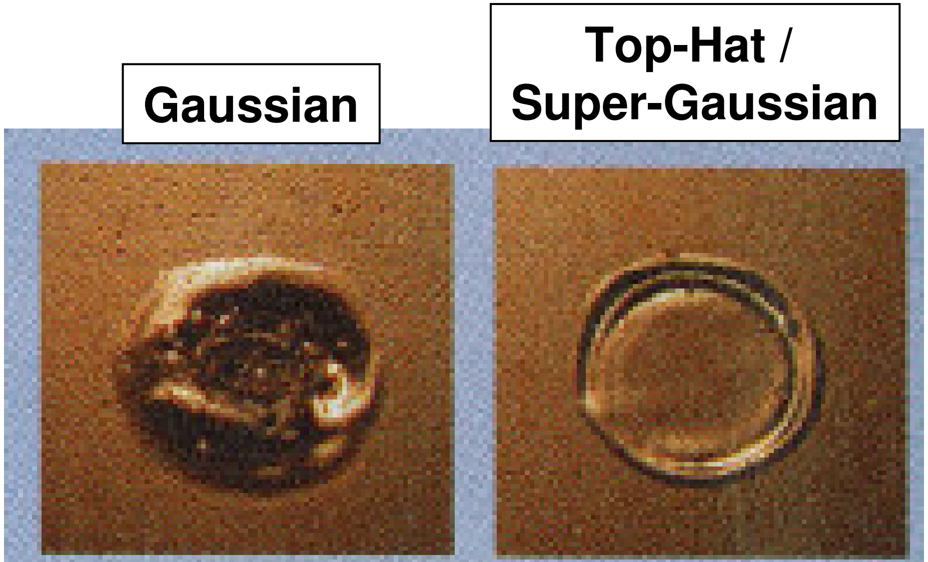
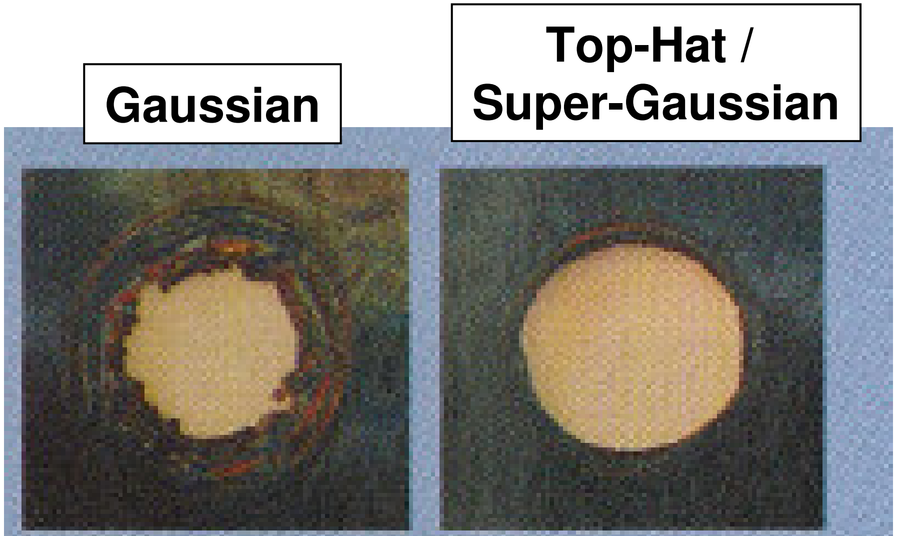
Application: Laser Machining



CO_2 laser on black delrin. Gaussian beam (left), flat-top beam (right).



A laser with a round flat-top uniform intensity beam (right) drills a much cleaner hole in magnetic tape than one with a Gaussian beam (left).

Taken from *Laser Focus World* (2006)

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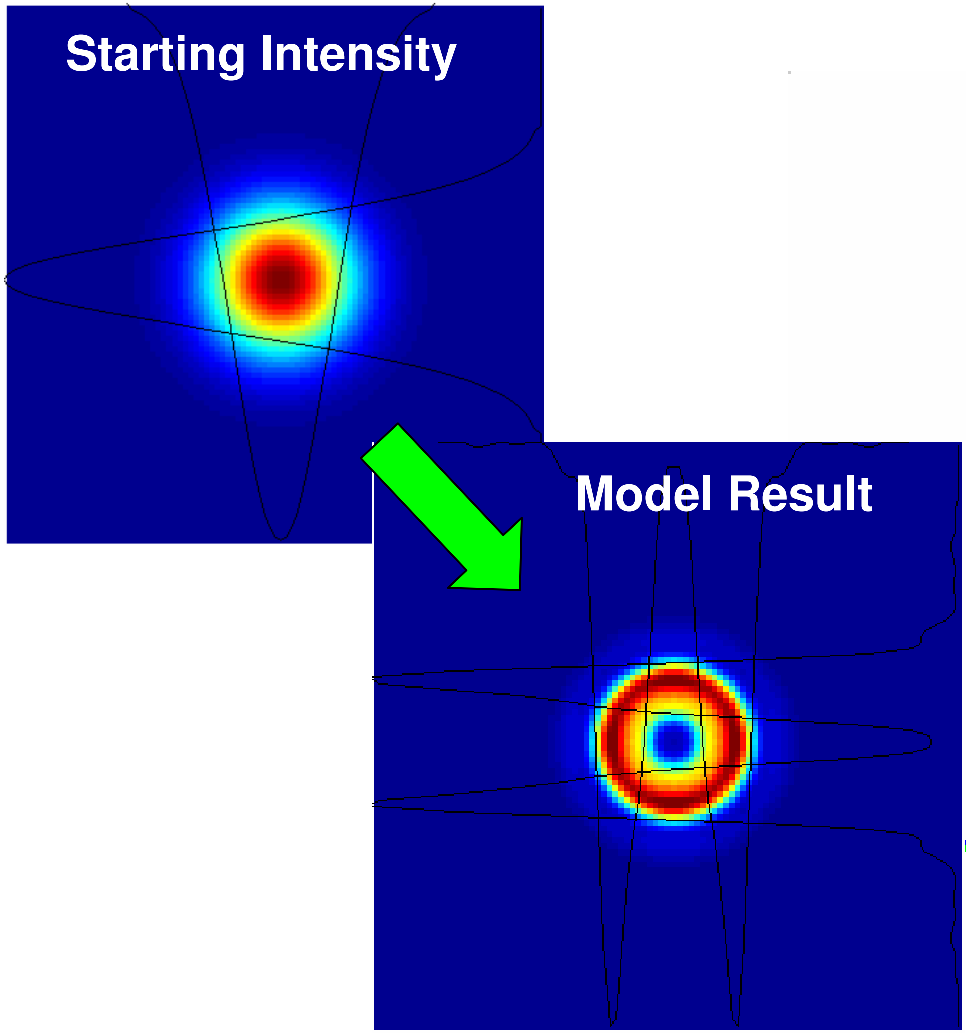
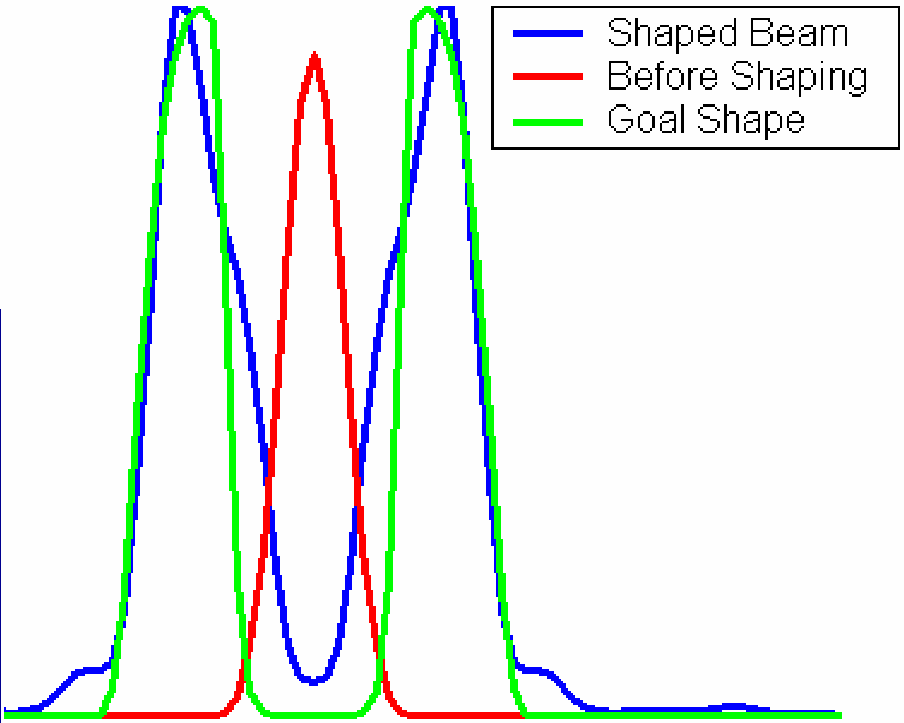
Modeling Beam Shaping - Gaussian to Annulus





5 Annular Actuators

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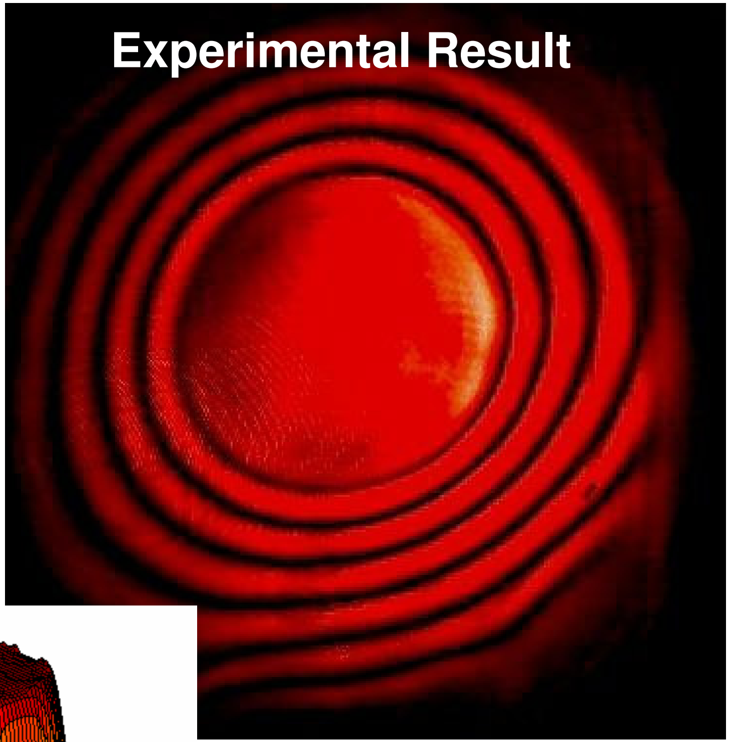
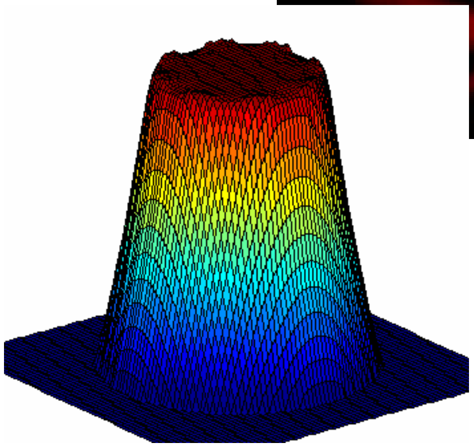
Annular Actuators - Piston

- Phase Locking
- Scanning Fabry-Perot
  - Spectrometer
- Curvature Sensing Actuator





Modeling Result

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Polymer Deformable Mirror

Business Card

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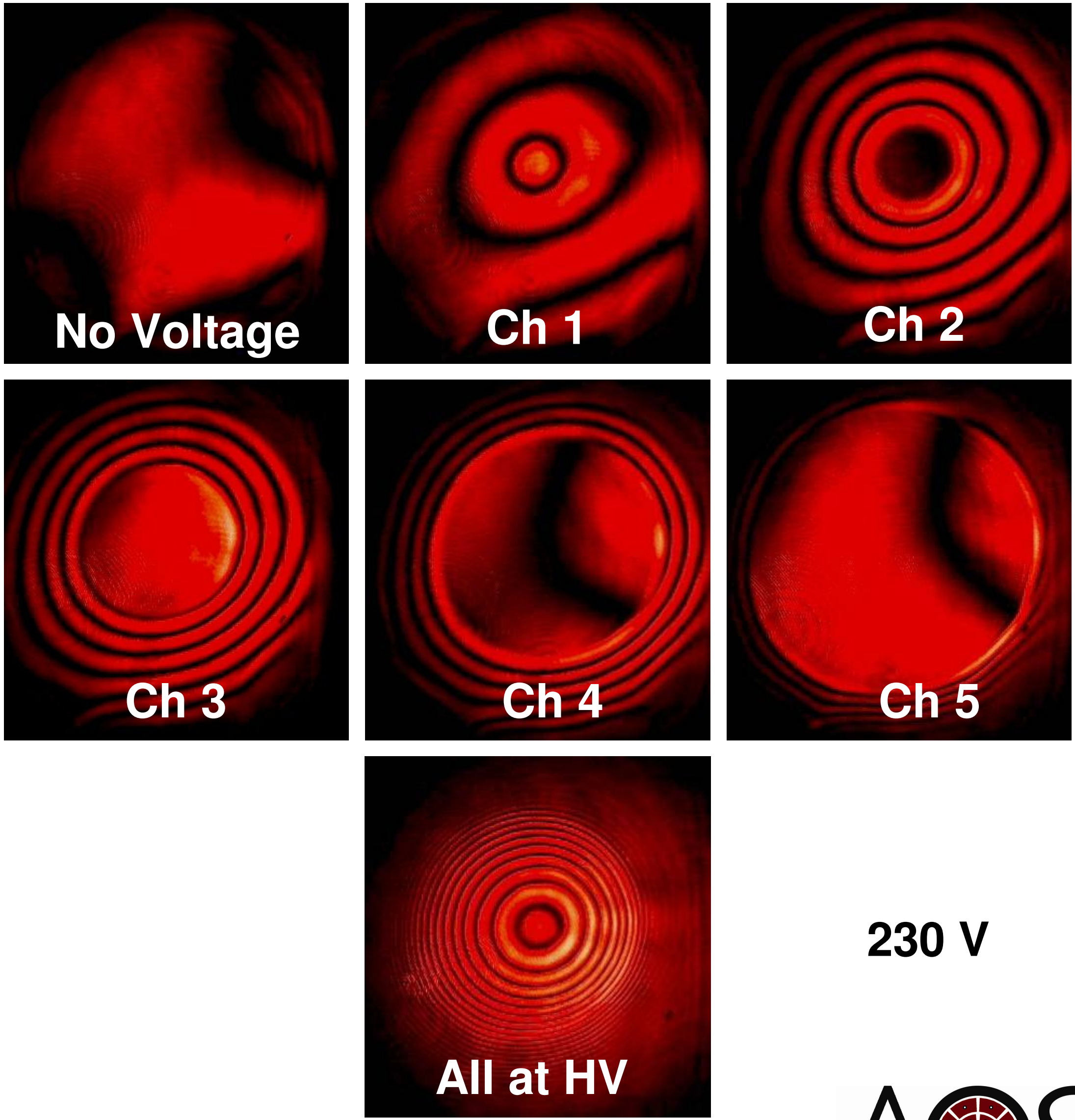
Influence Functions



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Electrostatic Snap-Down

$$F_e = \frac{\varepsilon A V^2}{(d-\Delta)^2} \;\&\; F_m = k\Delta$$

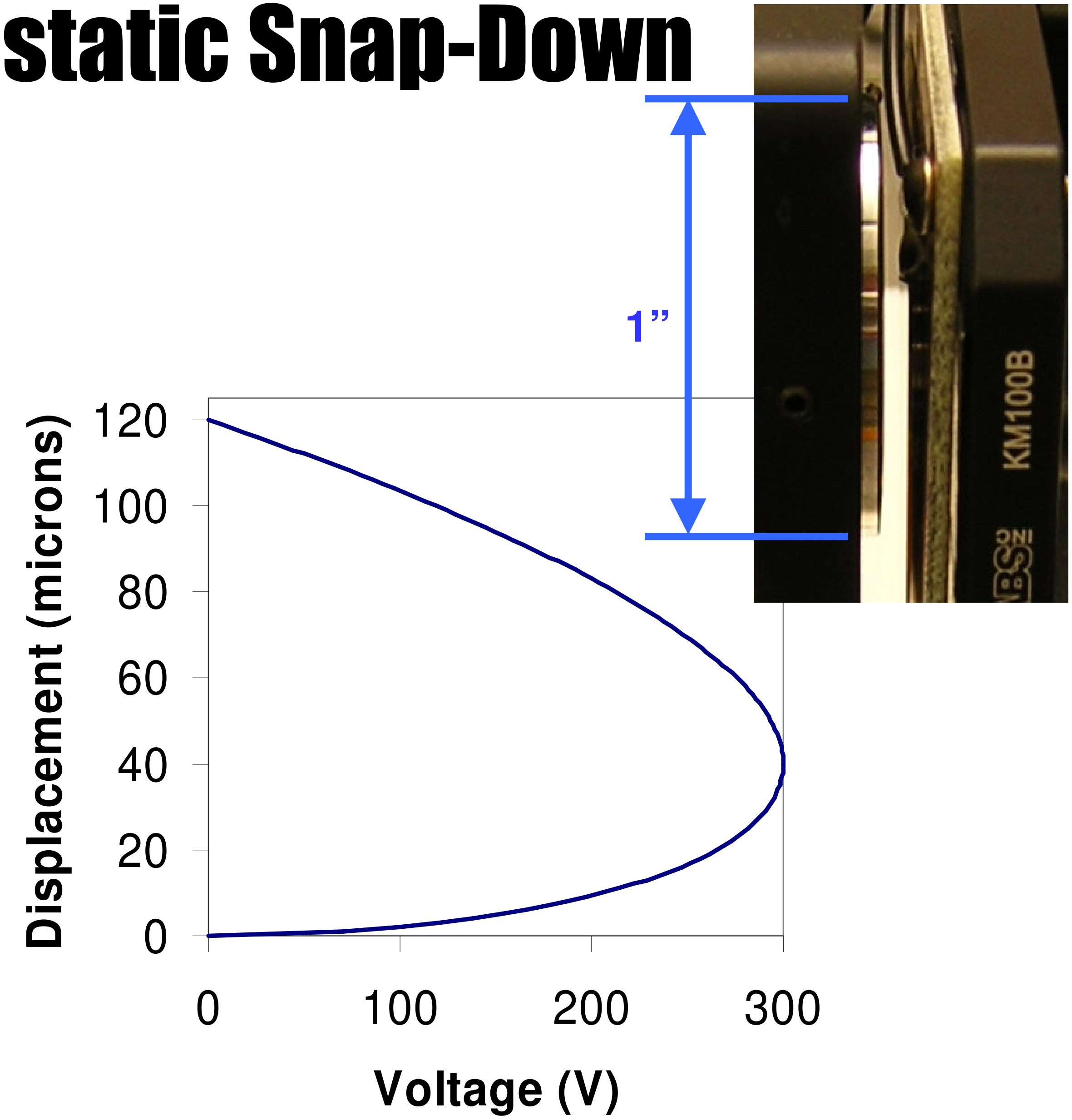
$$V = \sqrt{\frac{k\Delta(d-\Delta)^2}{\varepsilon A}}$$

ε = Permittivity

A = Area

k = Mechanical Spring Constant

Δ = Displacement



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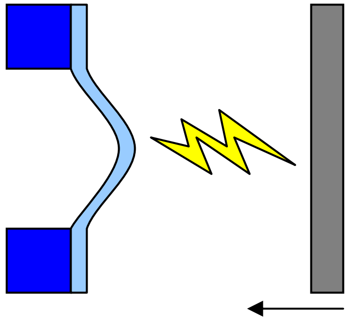
Dynamic Range

- Electrostatic snap-down limits range
  - Electrostatic force exceeds mechanical force
- Achieved ~1m focal length
  - ~40µm over 25mm aperture with 330V
- Mirror did not rupture!

Experimental Setup Cross-Section



Backplane moves toward membrane until snap-down

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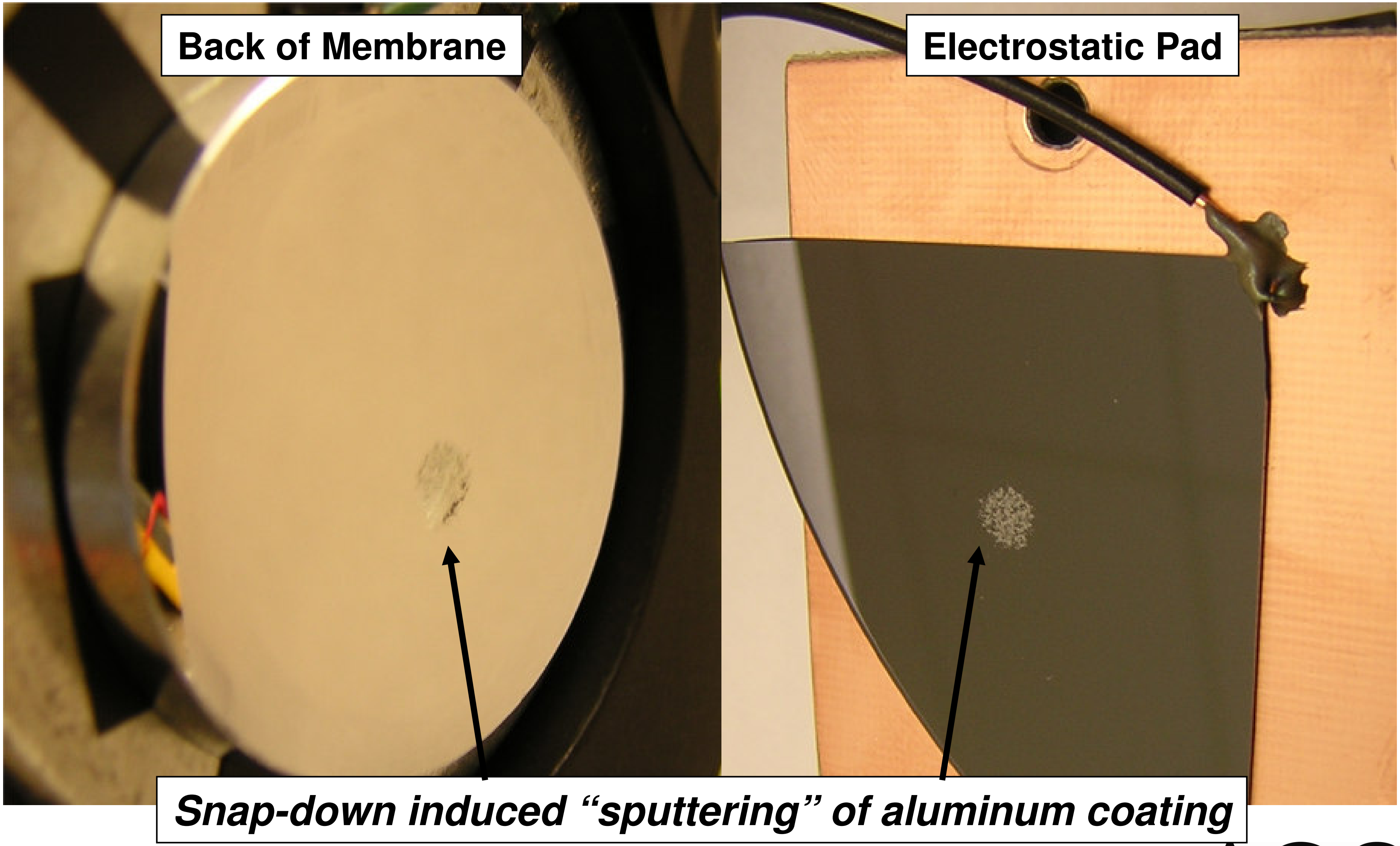
Snap-Down Results



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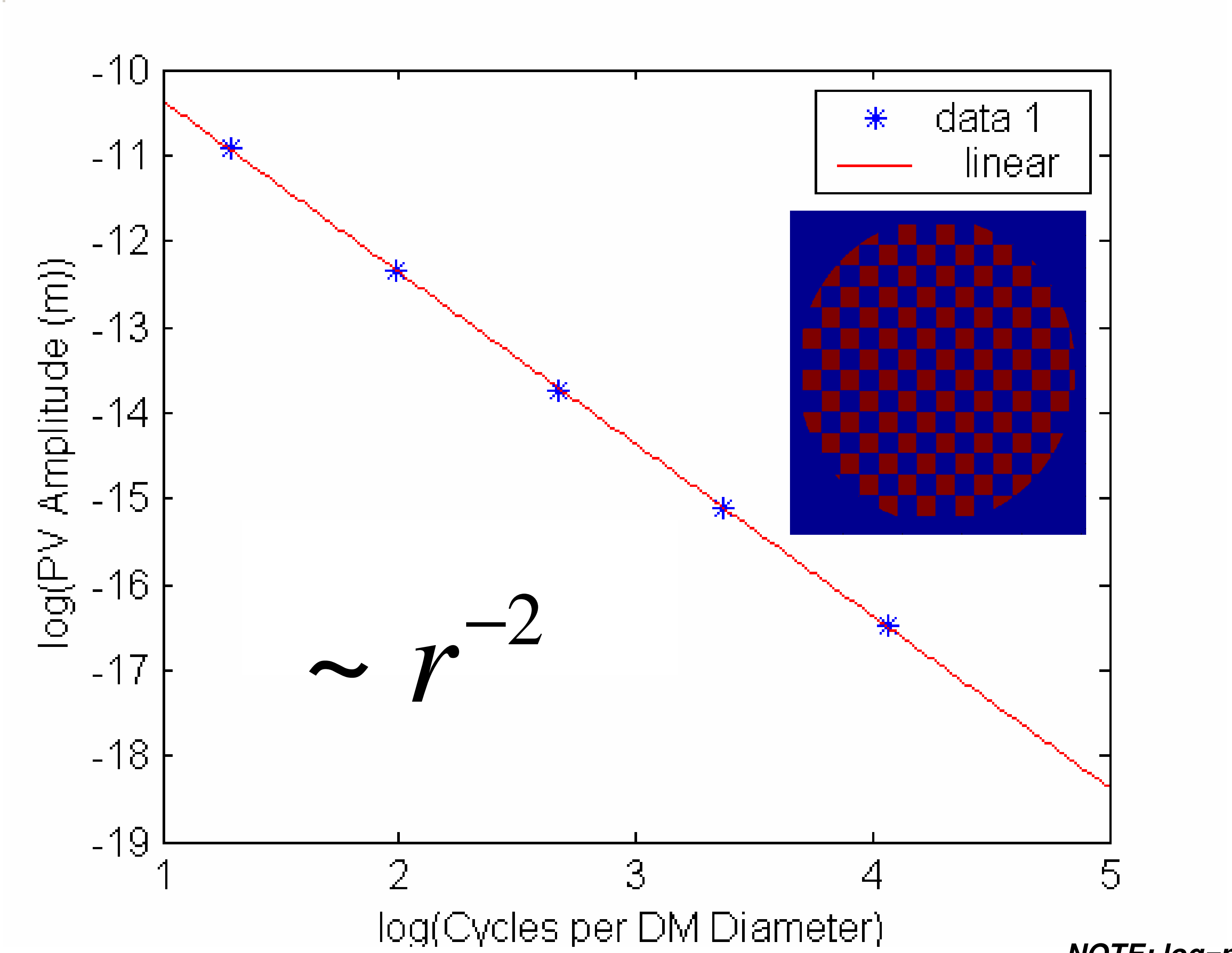
Spatial Frequency Roll-Off



NOTE: log=natural log

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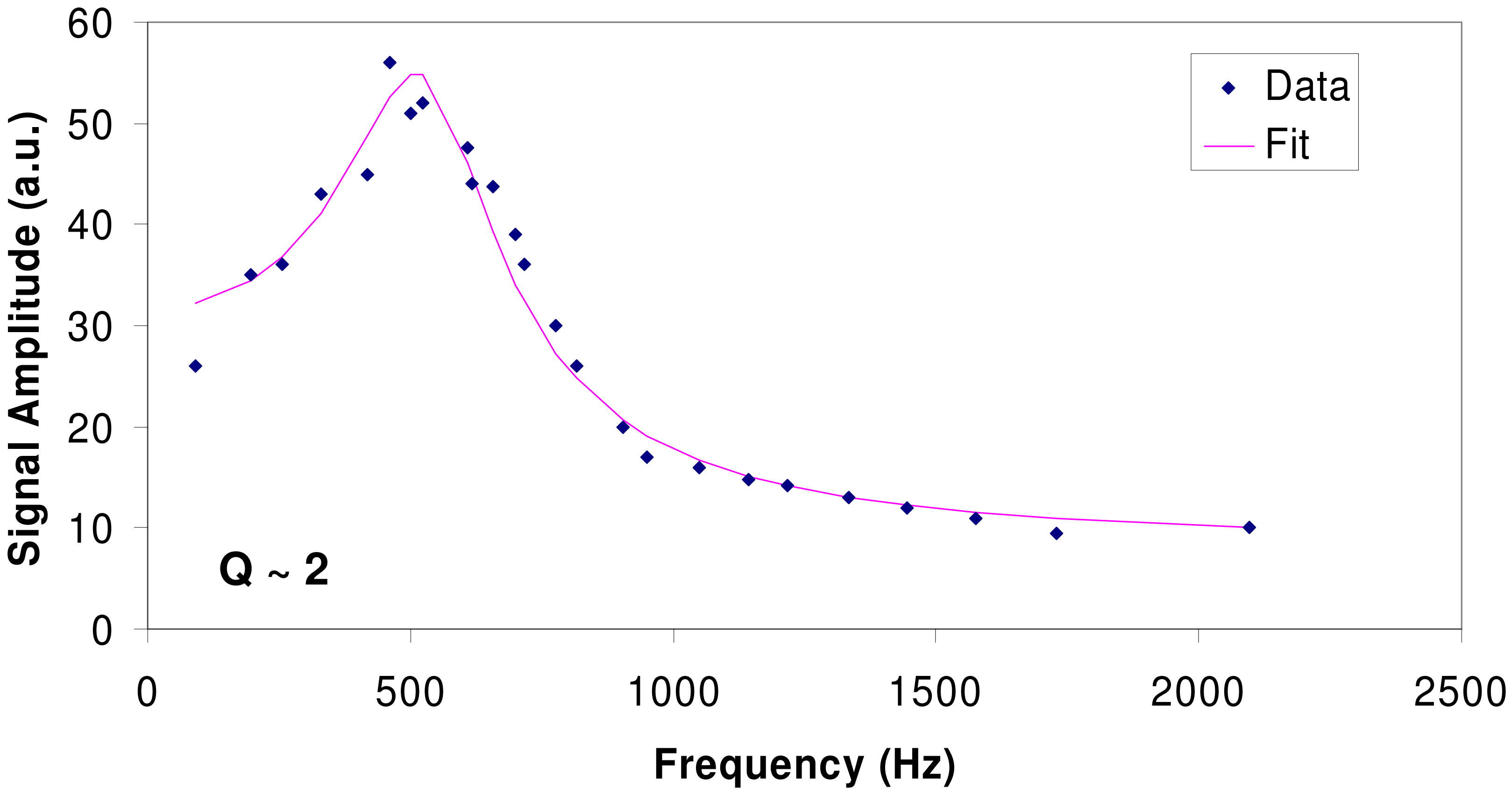
Resonance Frequency



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Pellicle Characteristics

- Wavefront Quality : $\lambda/2$ per inch
  - mostly in an astigmatic term
- Demonstrated high reflectivity coatings
  - Q-Switched damage at 3.3 J/cm^2 (235 MW/cm^2)
- Available in 6” Diameter

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Advantages of Pellicle DMs

- Compared to Bulk MEMS (OKO, Intellite)
  - Reasonable Resonance Frequency
    - D=25mm → 550 Hz (adjustable to > 1 kHz)
  - Lower Static Aberration
  - Scalable to Large (6”+) Diameters
- Compared to Surface MEMS (BU, Iris)
  - Higher Optical Quality
    - Continuous front surface
    - Capable of HR Coatings
- Lower Cost

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Drive Electronics

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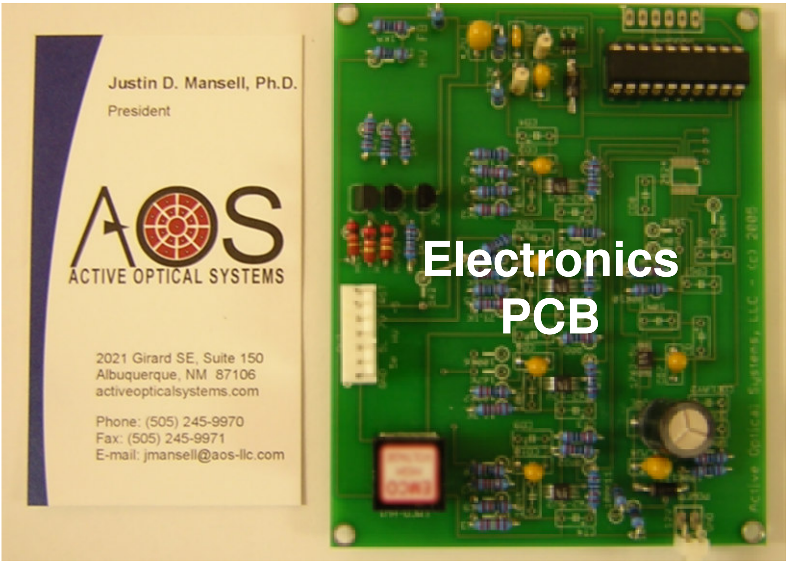
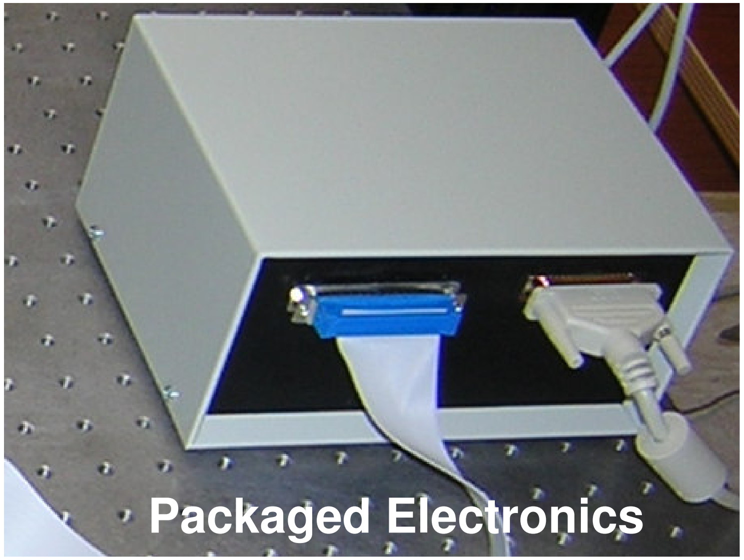
Drive Electronics

- Digital Interface
- 32-Channels
  - Scalable beyond 1024 channels
- Up to 295 V output
- 3.2” x 4” PCB





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- Introduction & Applications
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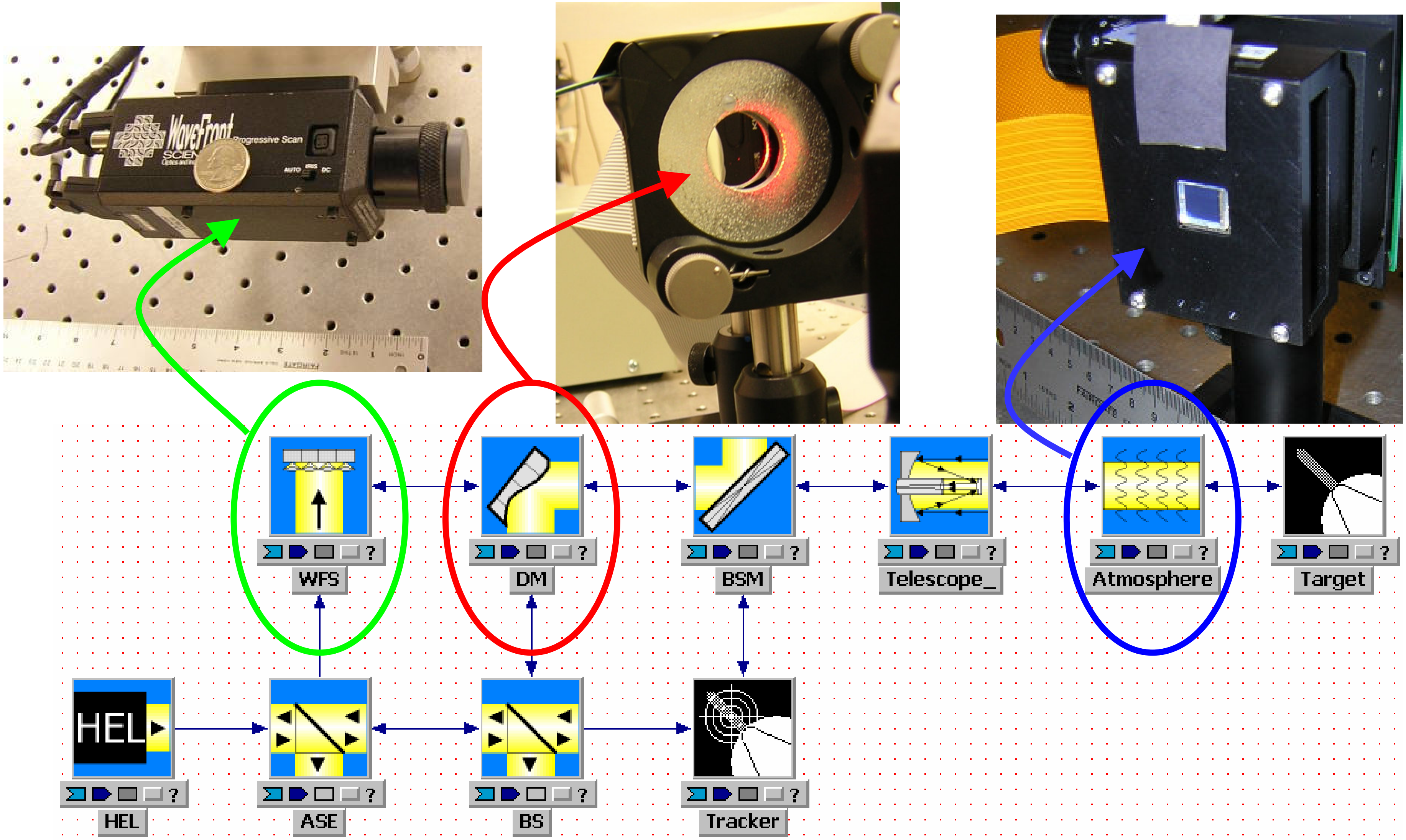
- Prototype Low-Cost Systems
  - Introduction to “WaveTrain Lab”
  - Strehl Optimization via SPGD and GESA
- Future Developments
- Conclusions

Introduction to WaveTrain Lab



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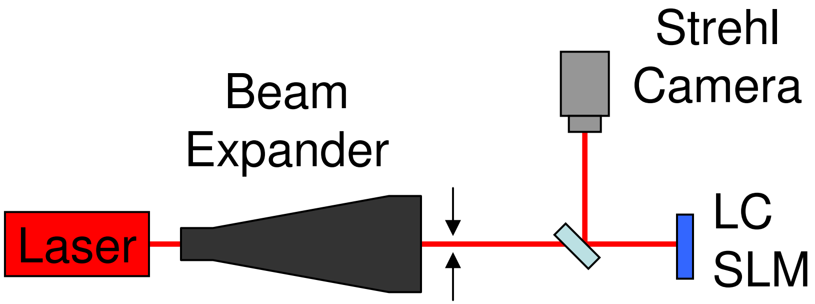
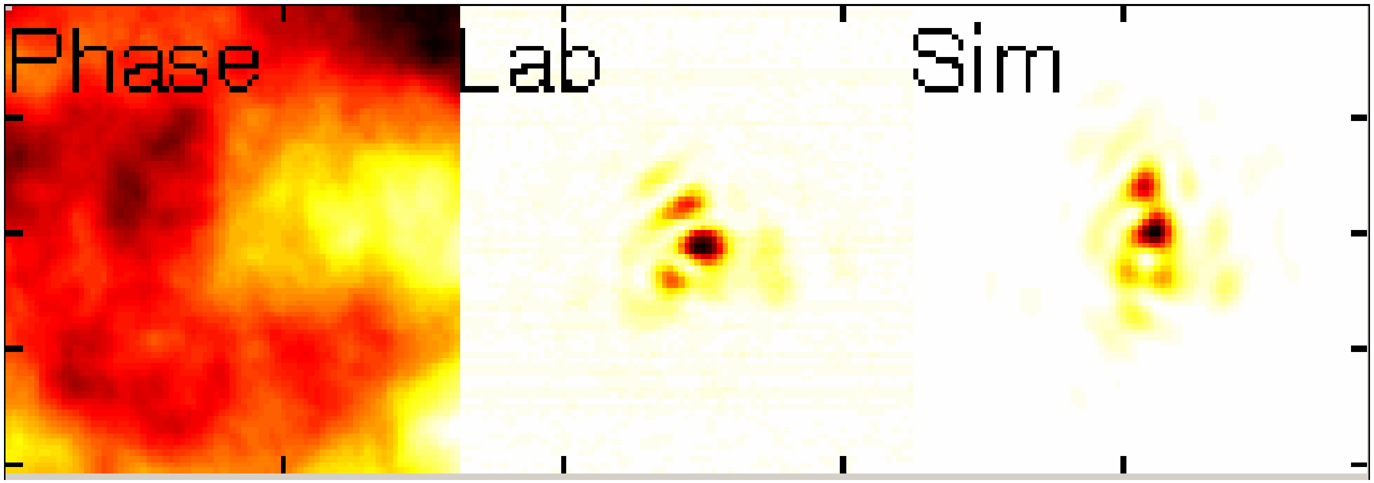
Demonstration of WaveTrain Lab

- WaveTrain Lab has components that interface directly to hardware
- Allows simulation and experimentation in parallel





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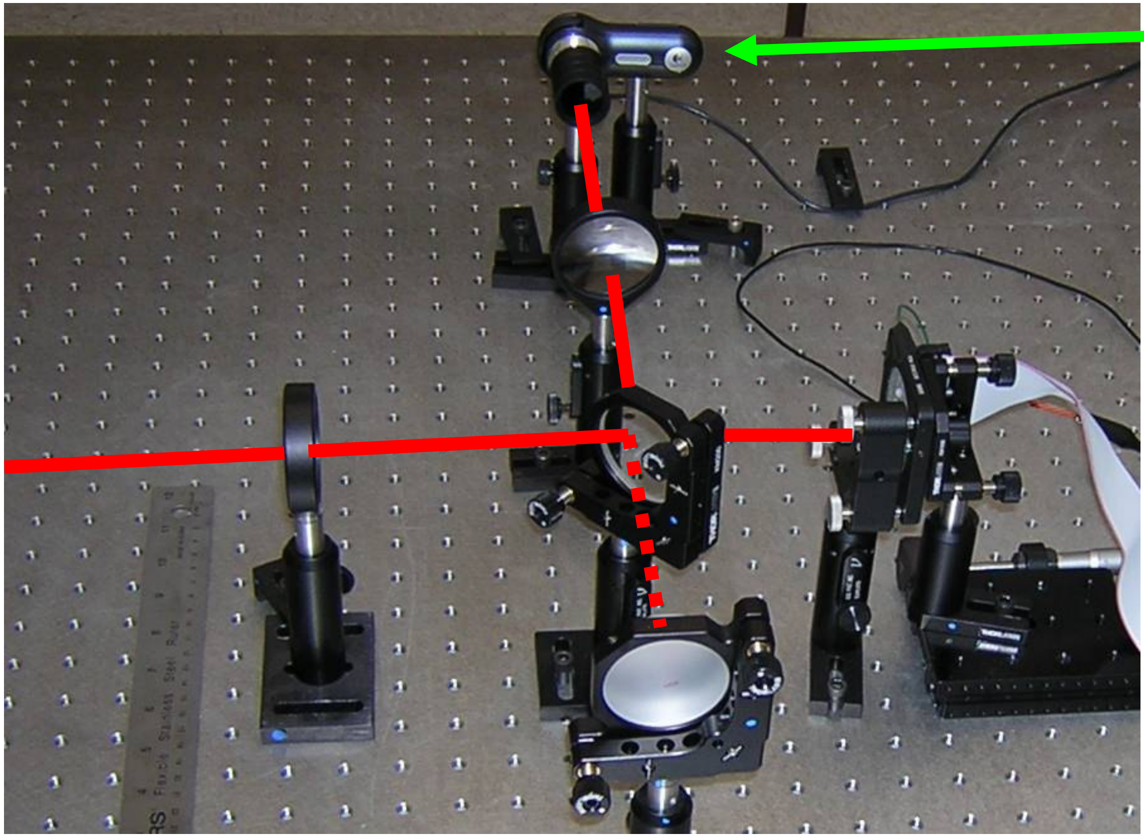
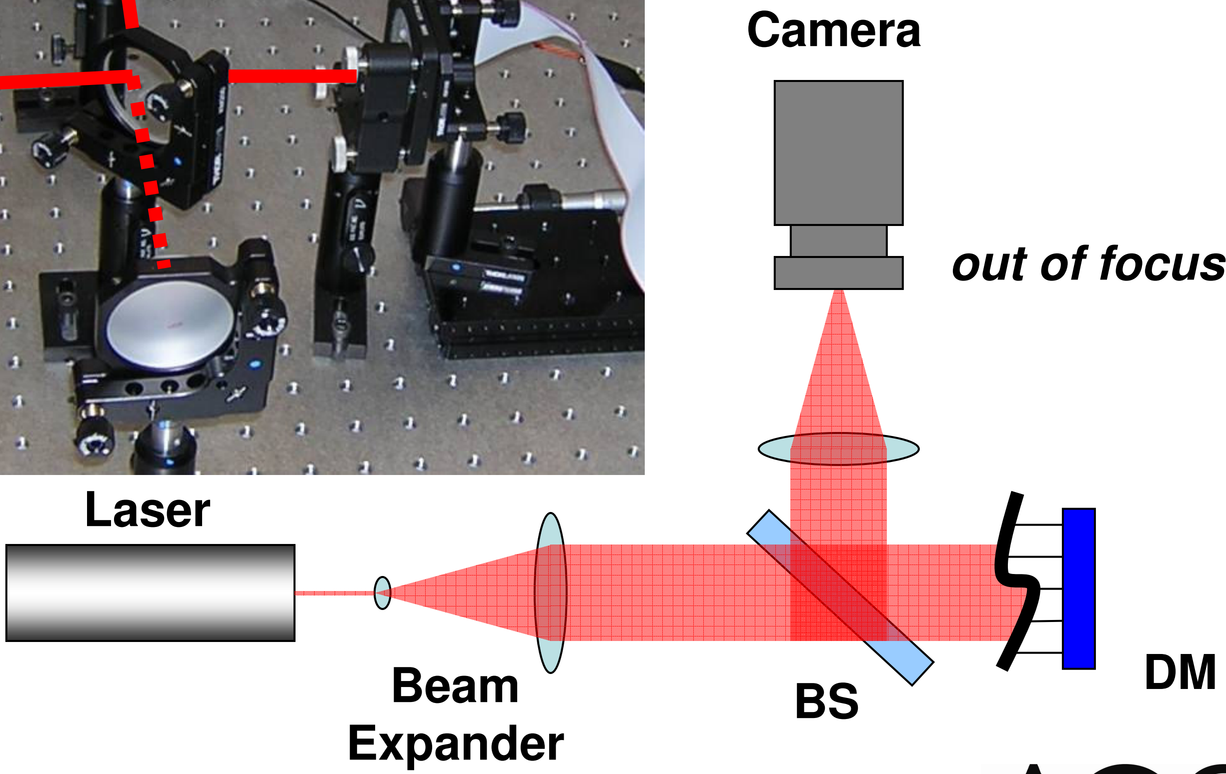
Demonstration System Architecture





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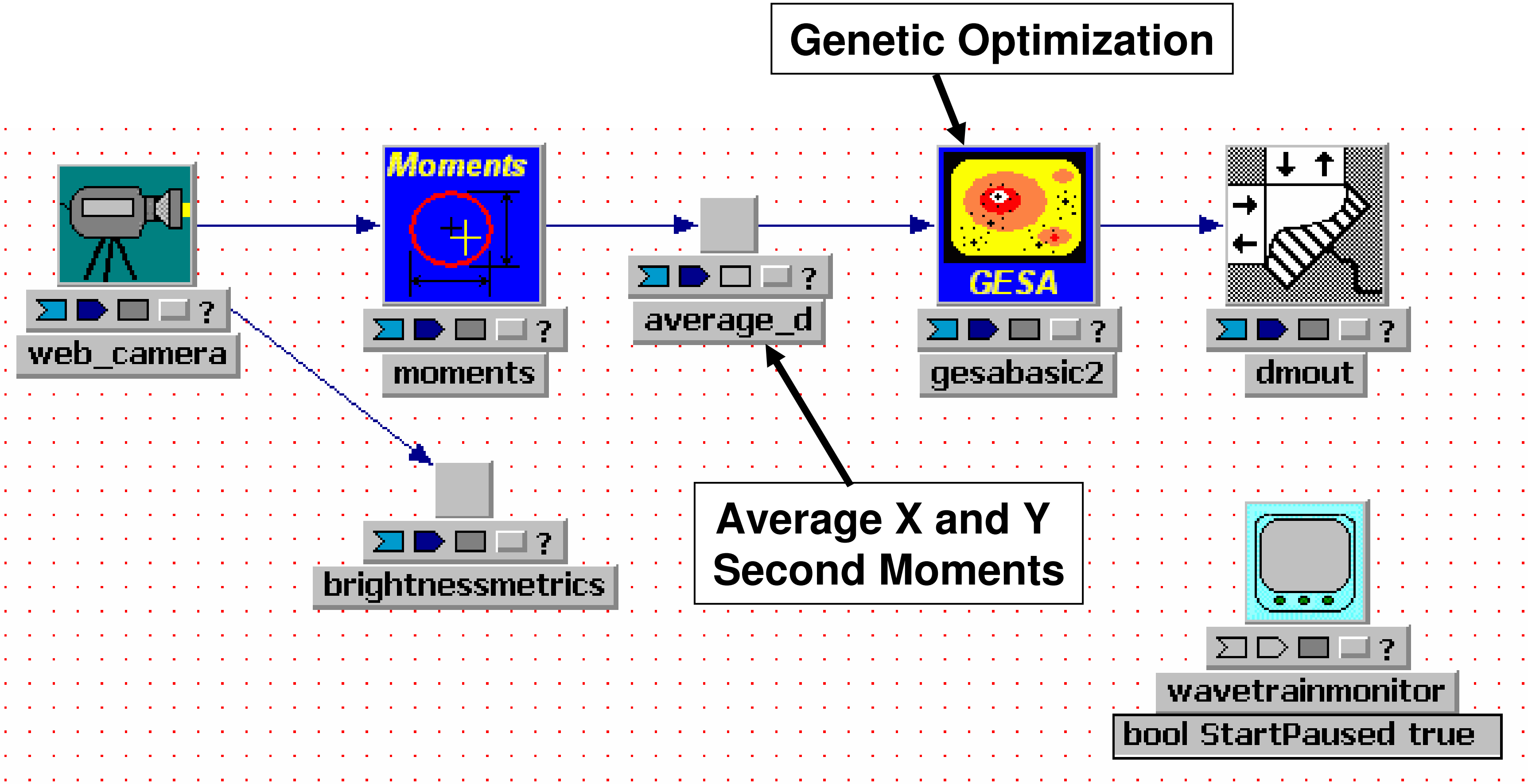
WaveTrain Control Software



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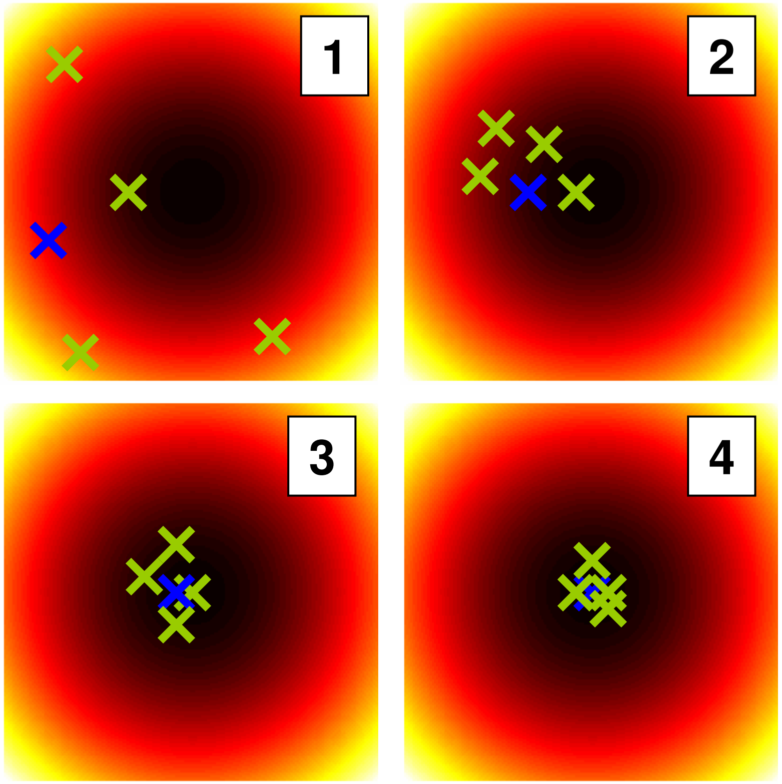
Guided Evolutionary Simulated Annealing (GESA) Algorithm

1. Generate a set of families with one parent and a set of children within an initial Gaussian radial distribution.
2. The best child becomes the parent
3. Generate new children with less radius
4. Go to 2.

- Convergence when
  - no/minimal change or
  - set number of iterations



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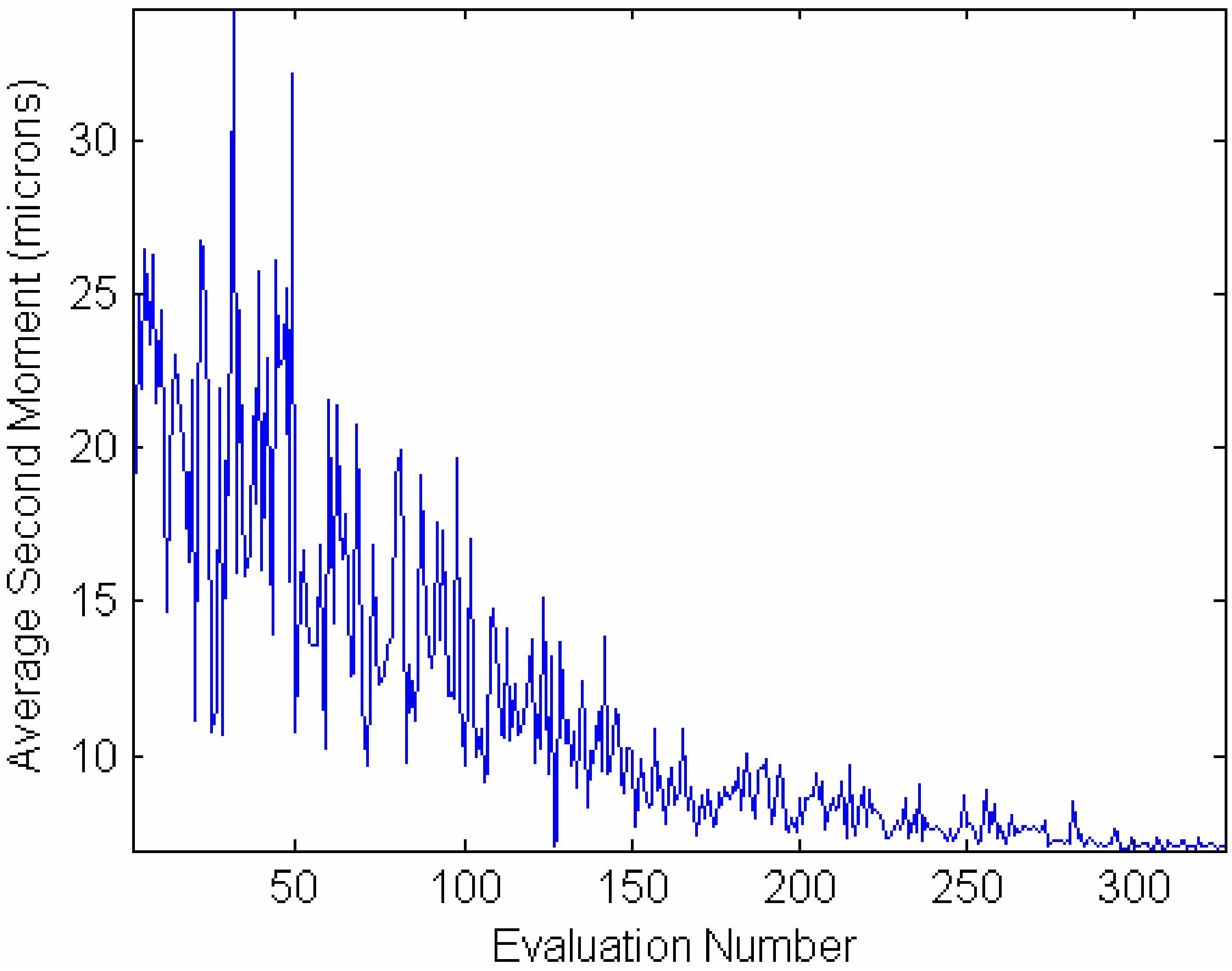
GESA AO Metric



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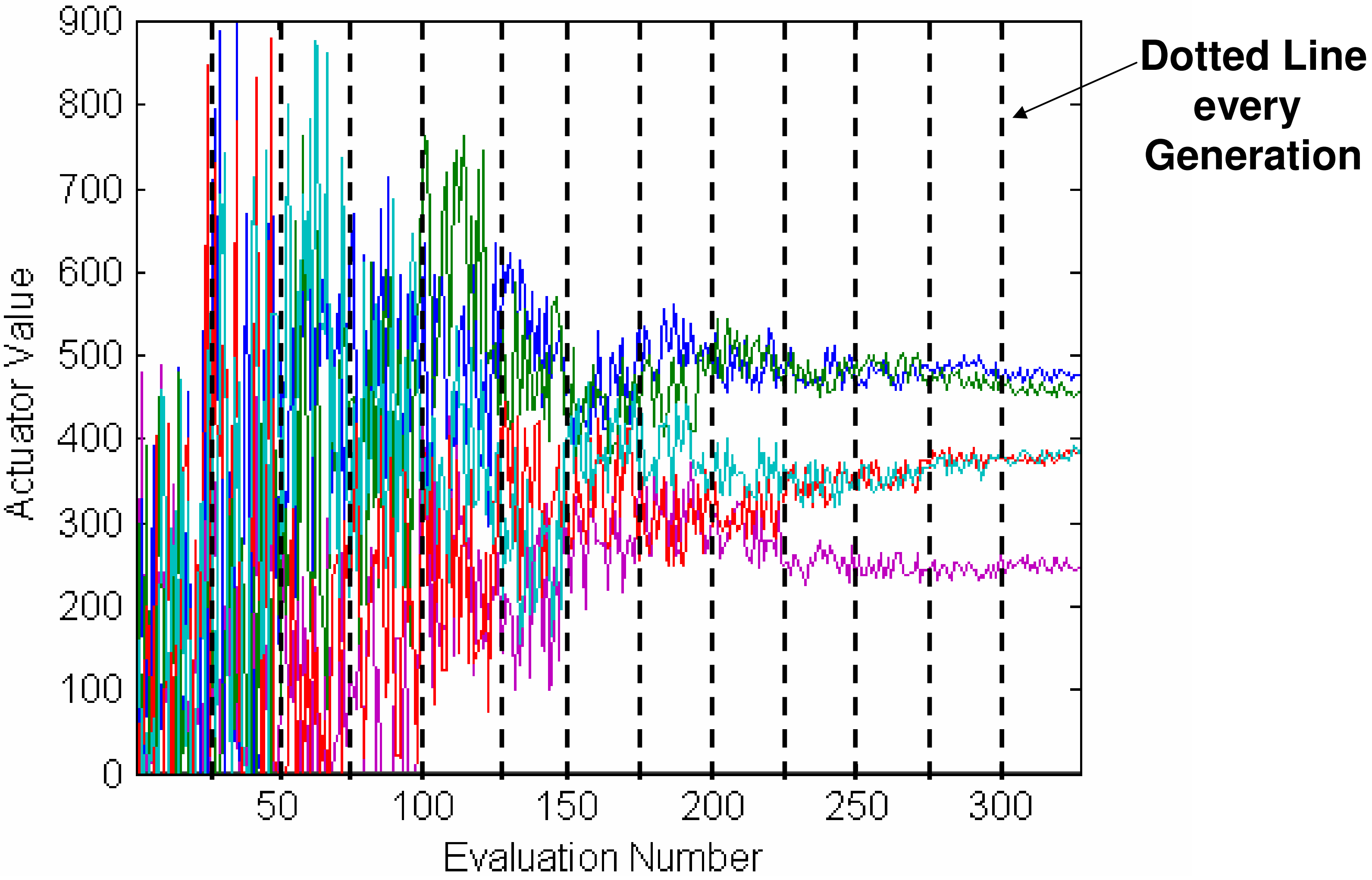
GESA Actuator Commands



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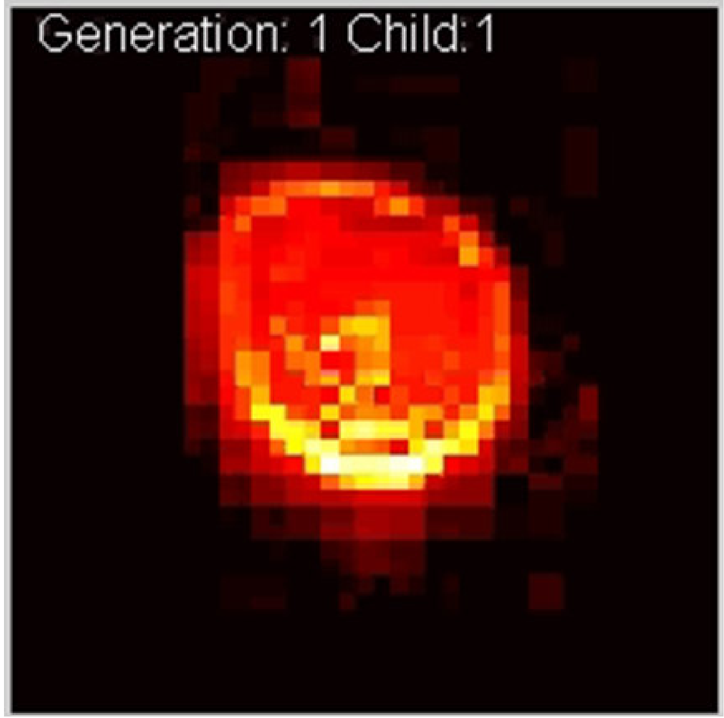
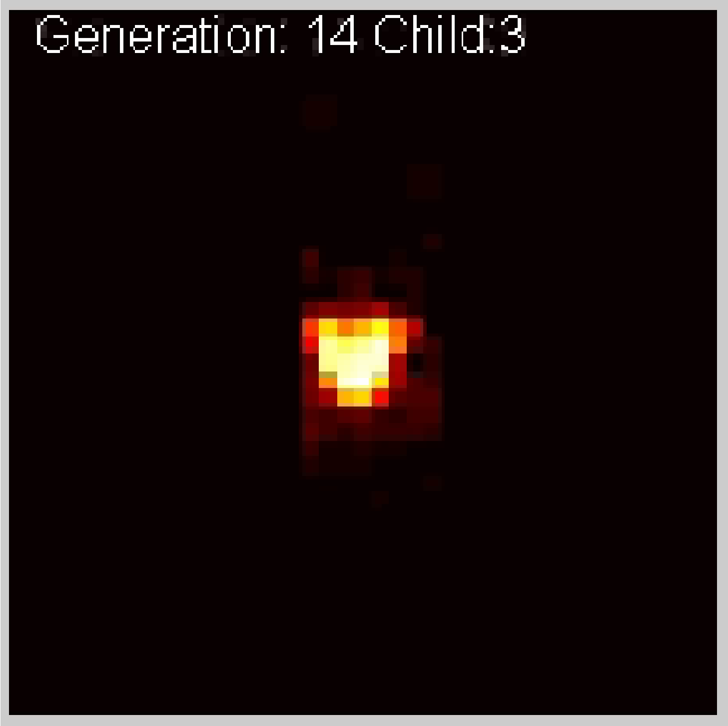
GESA Camera Image





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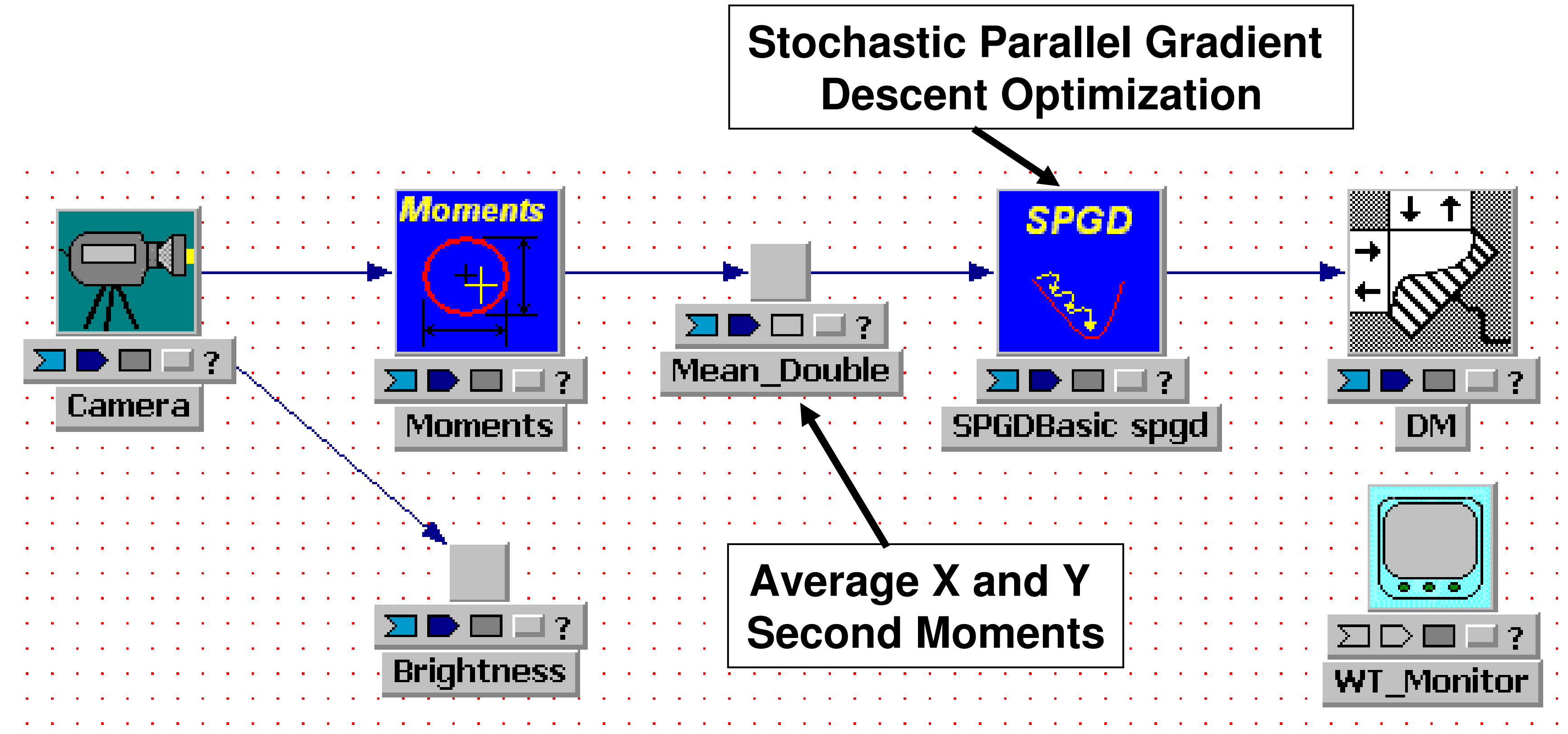
SPGD WaveTrain Control Software



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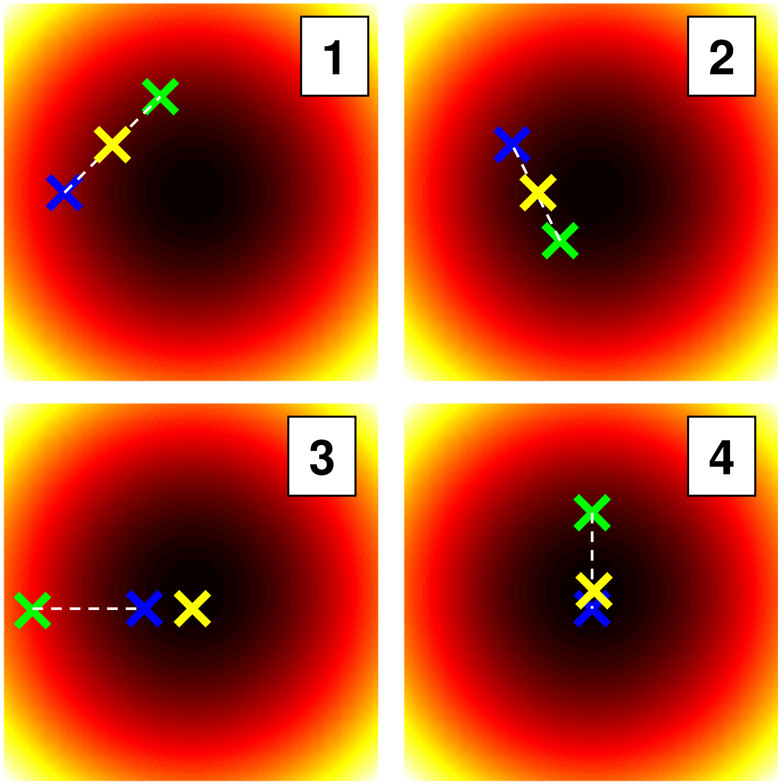
Stochastic Parallel Gradient Descent (SPGD) Algorithm

1. Start with a point in the error space.
2. Take a step in a random direction to another point.
3. Find the "optimum" position based on the gradient.
4. Repeat to 2



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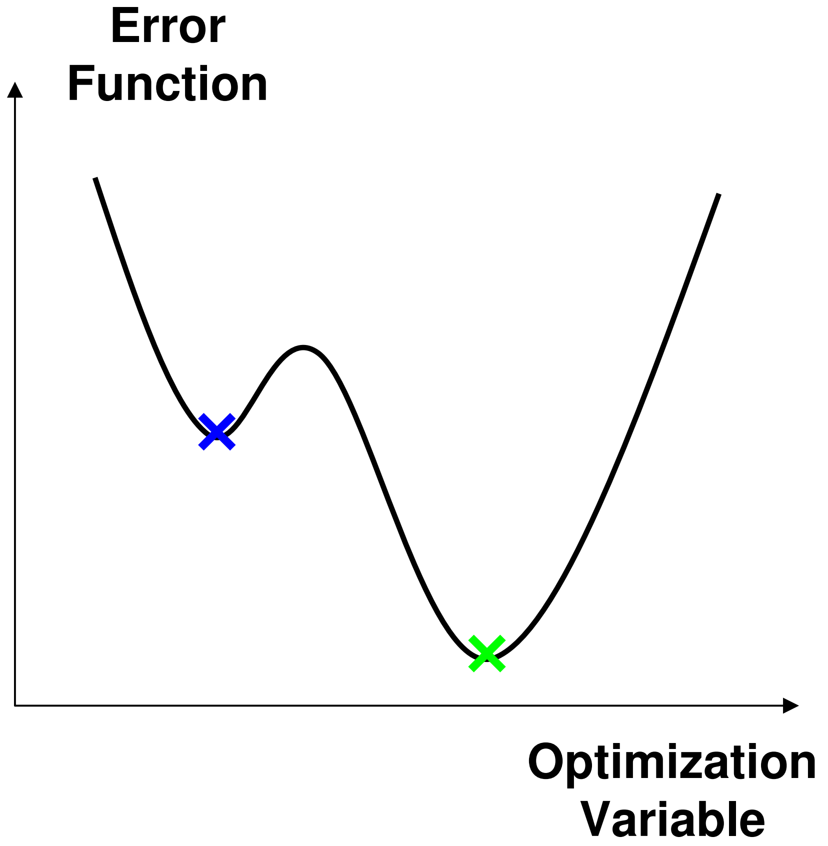
Comparing GESA and SPGD

- SPGD is faster in a smooth error space with no local minima.
- GESA is less sensitive to local minima.



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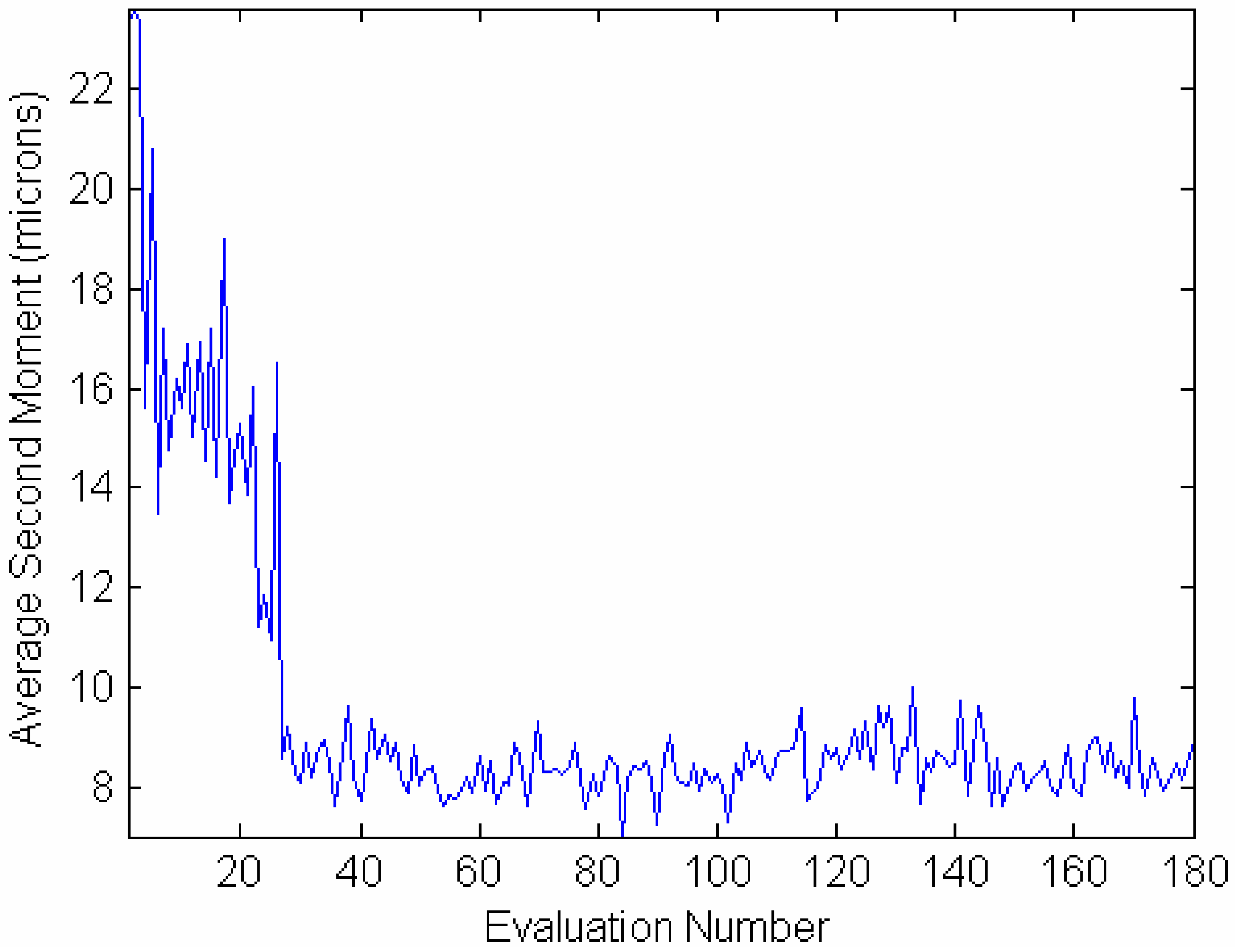
SPGD AO Metric



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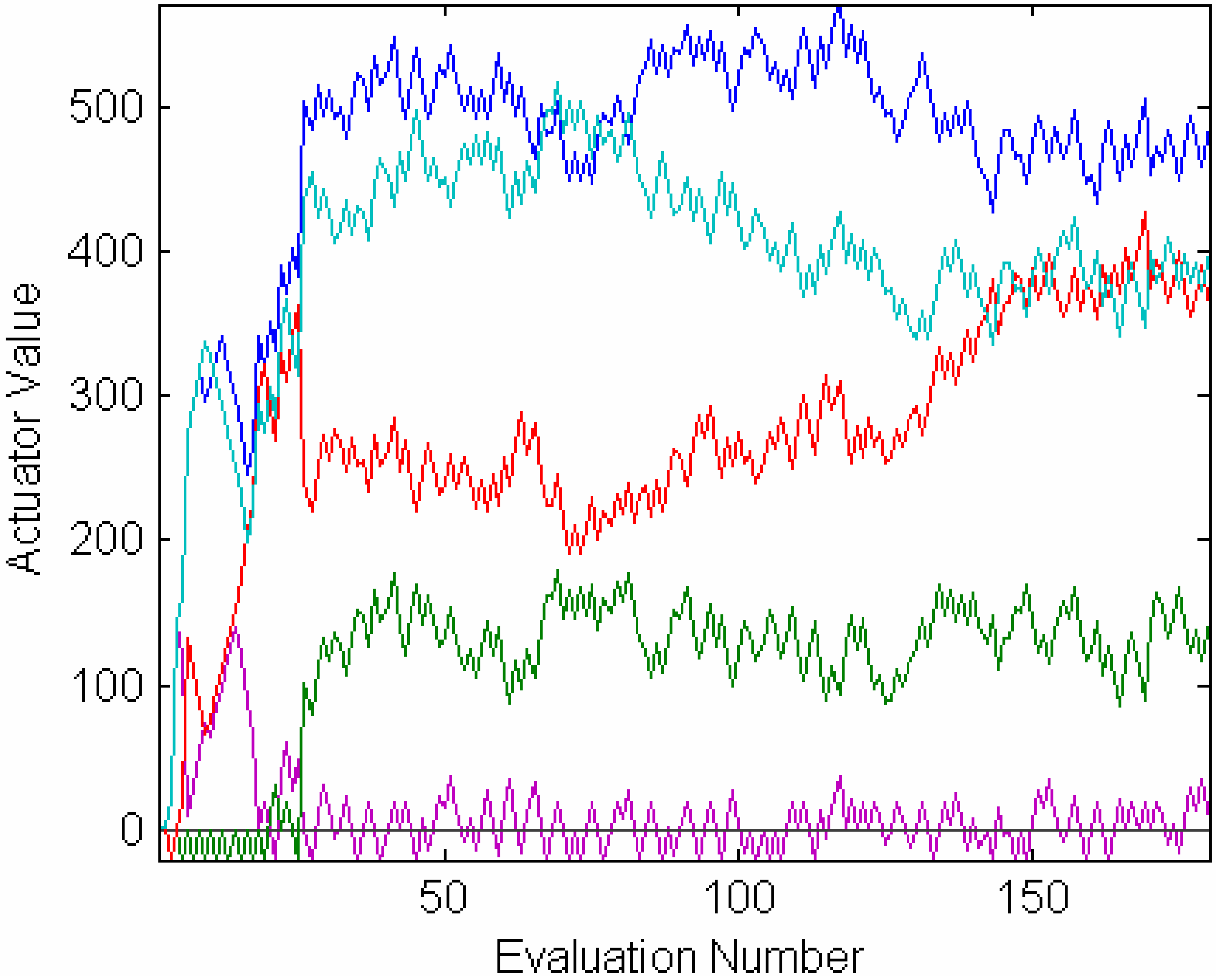
SPGD Actuator Commands



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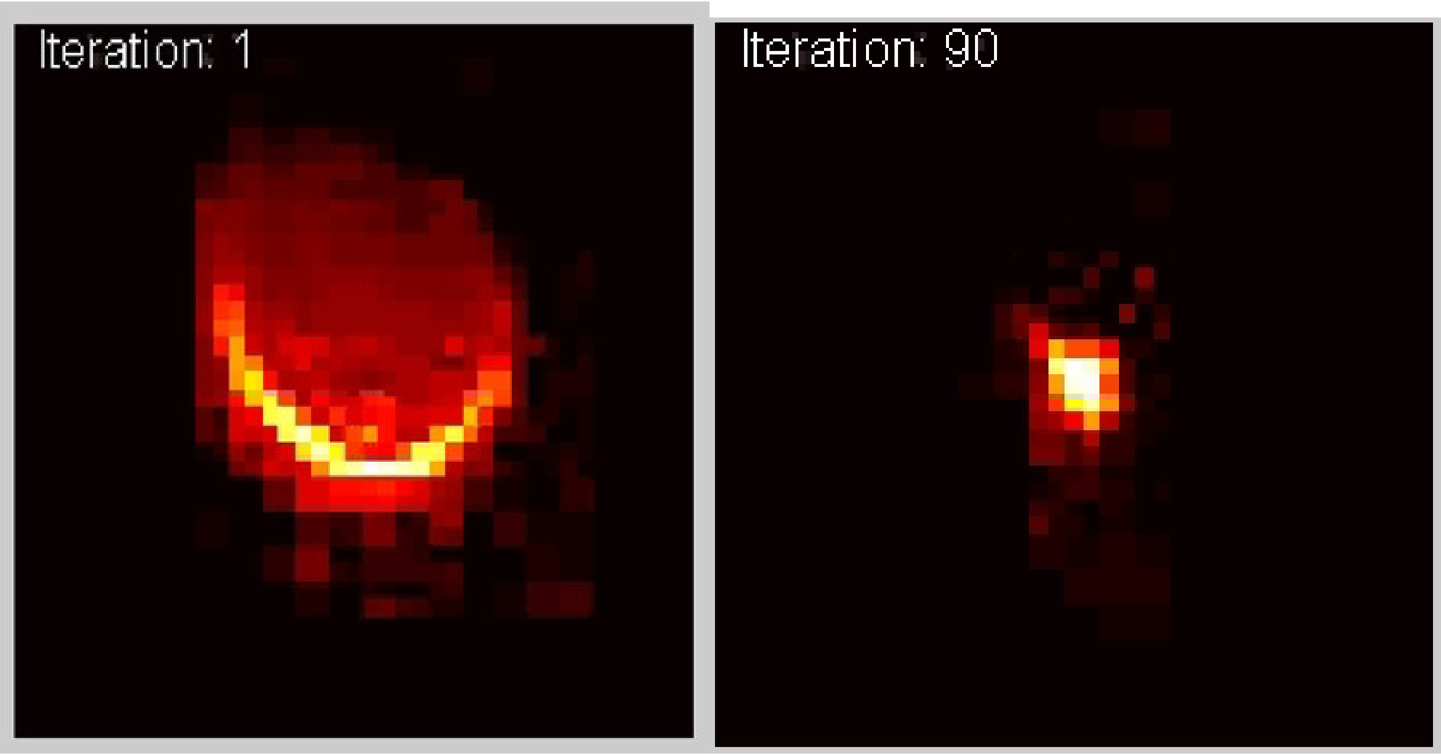
SPGD Camera Image



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  - High-Speed Imager
  - "Packaged" AO Systems
  - Target Costs
- Conclusions

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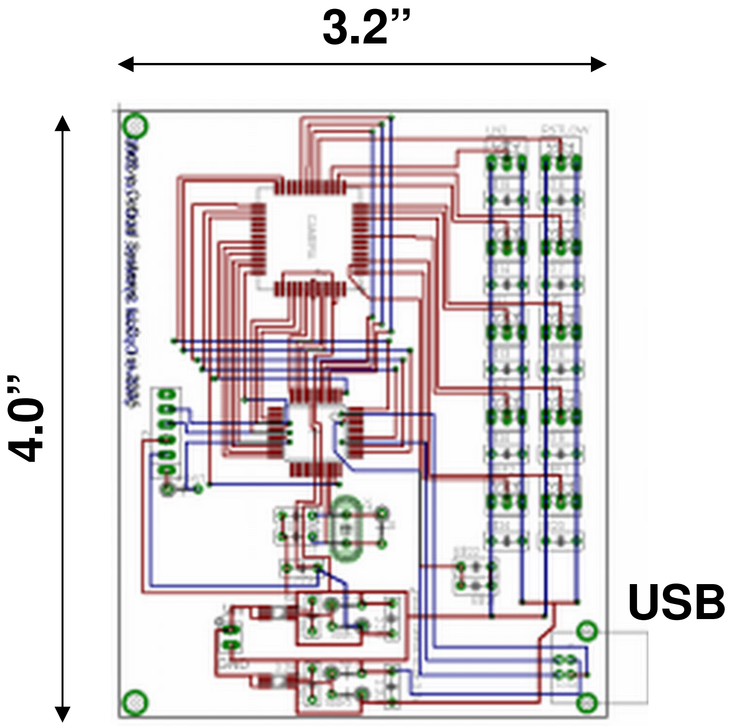
High-Speed Imager

- Designed for simple on-board image processing
- Expected ~1000 frames per second (63x659 pixels)
  - Good for four-bin interferometers
- Target Cost ~$3k



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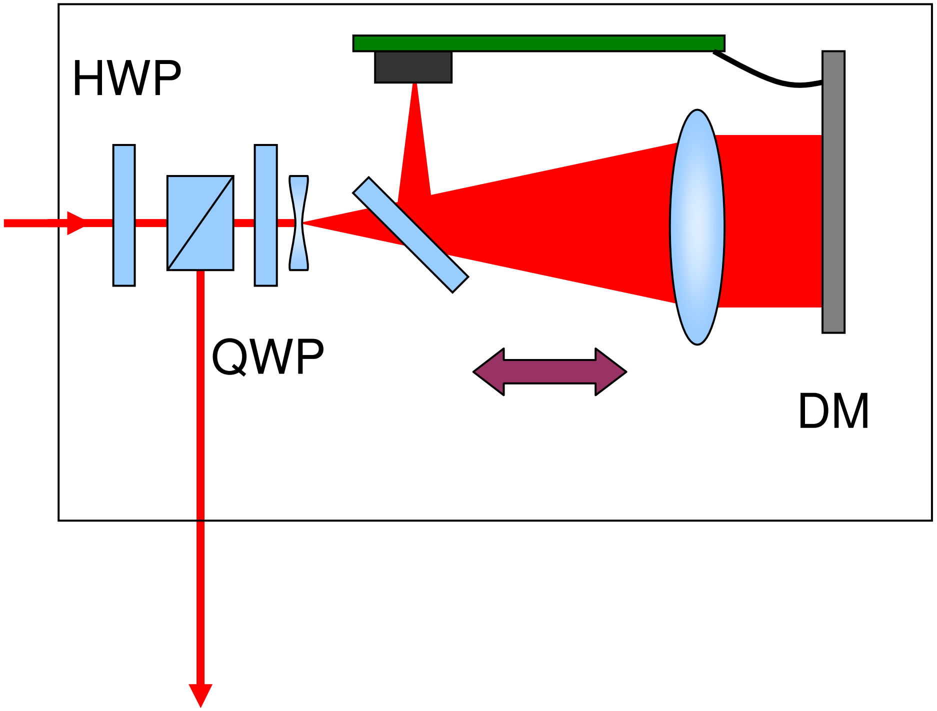
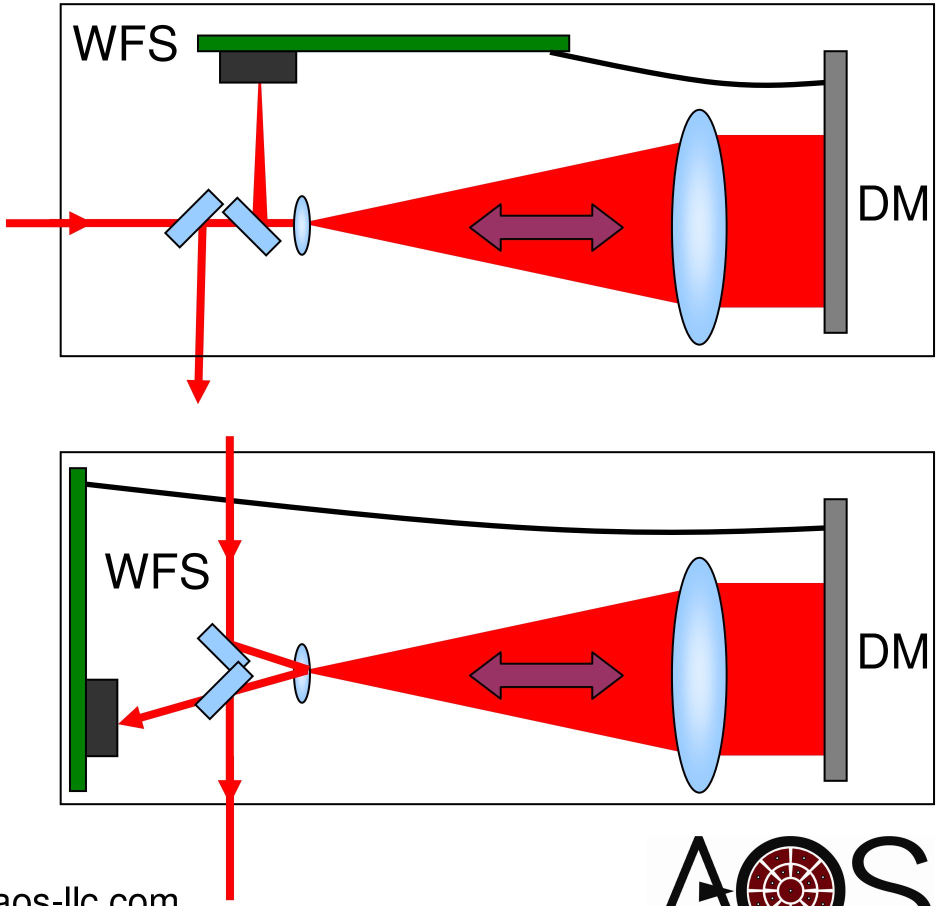
Packaged AO Systems

Laser Beam Shaping



Imaging



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Target Costs

Item	Target Release Date	Target Cost
32-Channel Drive Electronics	6/06	$5k
32-Channel Metal-Coated Deformable Mirror	6/06	$1.5k
Wavefront / Image Sensor	9/06	$3k
Complete AO System	9/06	$9,995

We have not completed the development of these products, so these are only cost estimates. Actual costs may differ.

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Conclusions

- AOS is developing novel low-cost AO systems
- Low-cost compact active optical systems will
  - enable AO to be added to more systems,
  - enable new systems to have more functionality, and
  - change the way optical systems are designed and built.
- AOS is building tomorrow's AO systems.

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Questions?

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