Development of a Deformable Mirror for High-Power Lasers

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Mirror Technology Days
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Outline

- Introduction & Project Goal
- Deformable Mirror Modeling
- Drive Electronics, Packaging, and Coatings
- Device Demonstrations
  – Prototype Demonstration
  – Full-Scale Device
- Conclusions and Future Work

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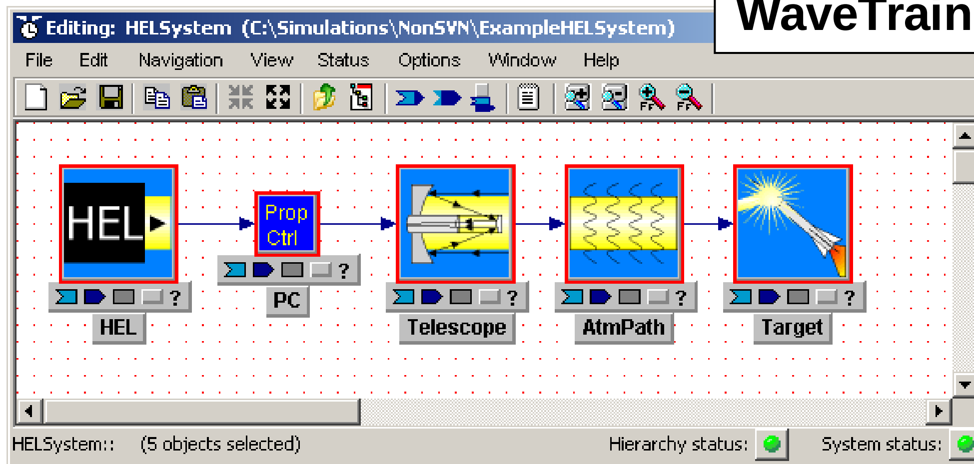
Introduction to MZA & AOS

- MZA was founded in 1991 to support the government directed energy community.
  – WaveTrain – Connect the blocks wave-optics and AO modeling software
- Active Optical Systems, LLC, was founded in 2005 to commercialize adaptive optics hardware.

WaveTrain



1" Diameter DM Before Packaging

HV Drive Electronics

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Project Goal

- Develop two deformable mirrors capable of being used in high power laser applications.
- Devices should be
  – 2” in diameter
  – sufficient to compensate an example laser gain medium aberration
  – Capable of being addressed from a PC
  – Completed in ~6-8 weeks
  – $78k

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DM Aberration Compensation Modeling

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Modeling Question: How many actuators? What spacing?

- Procedure
  - Influence functions (IFs) were determined from an analytical expression for a small area force on a clamped plate model.
  - Use the IFs to fit the aberration and determine Strehl ratio using the integral form assuming a flat intensity.
- Developed a program to determine the optimum actuator spacing based on the aberration measured from a slab solid-state laser gain medium.
- Decided to not clip the corner actuators, but instead move them in.

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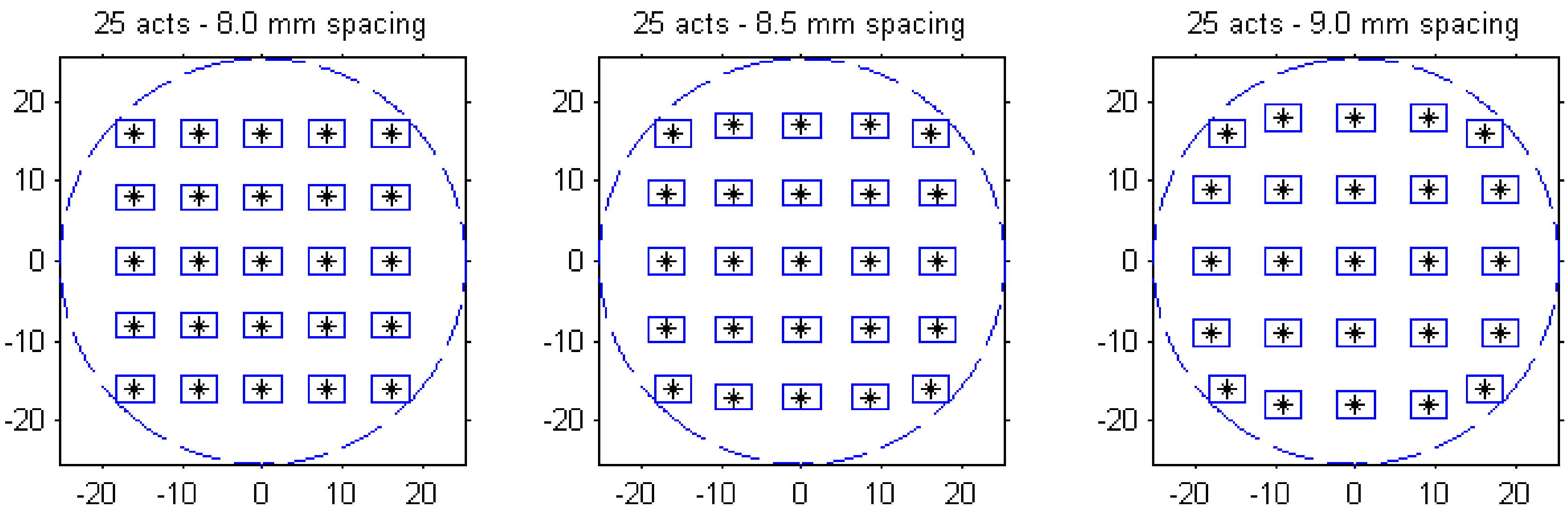
Actuator Configurations



Select Actuator Configurations

- 25 Actuators
- Actuator Spacing from 6 to 11.25 mm

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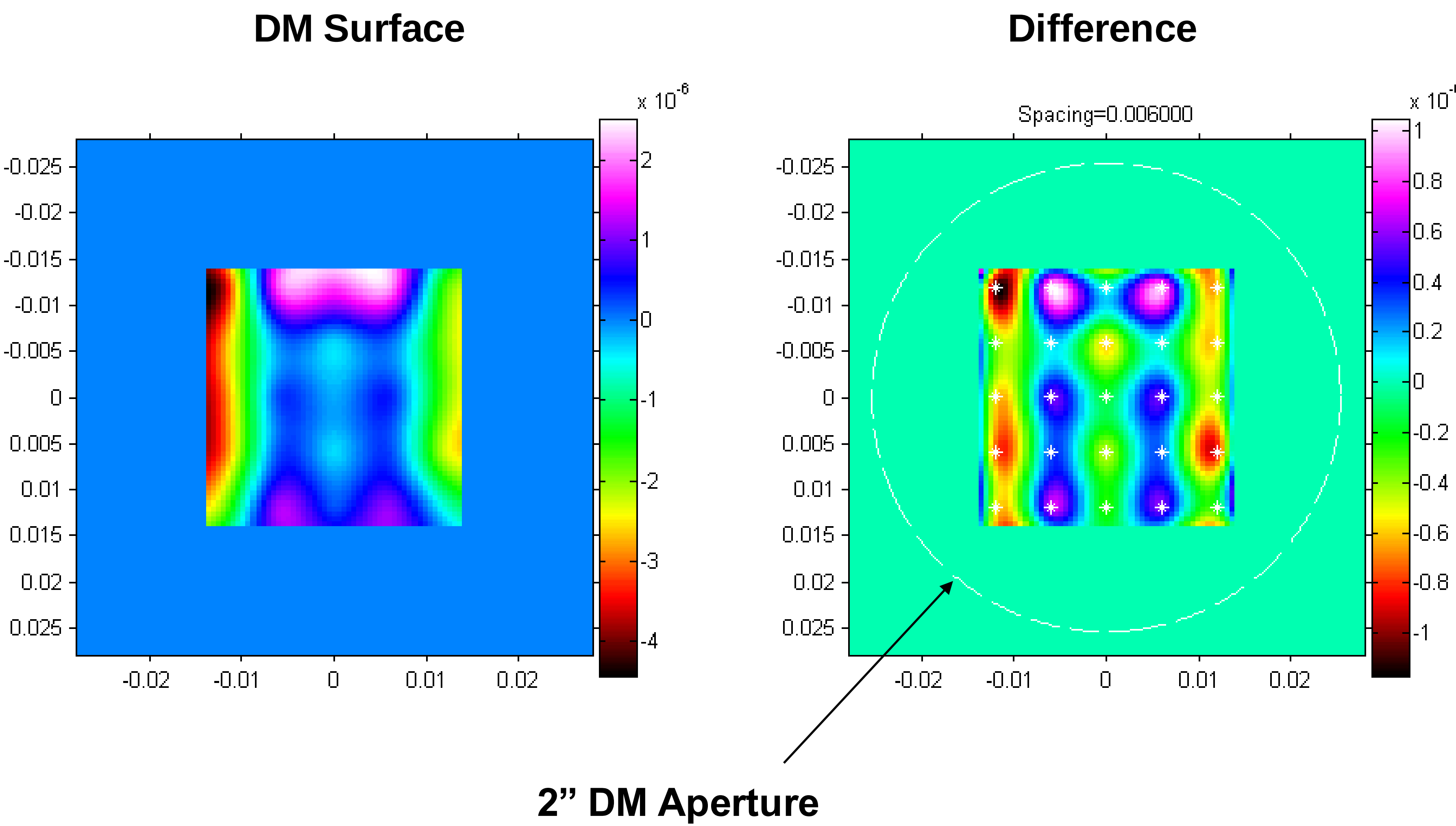
Example 1 - 6.00 mm spacing, 25 acts



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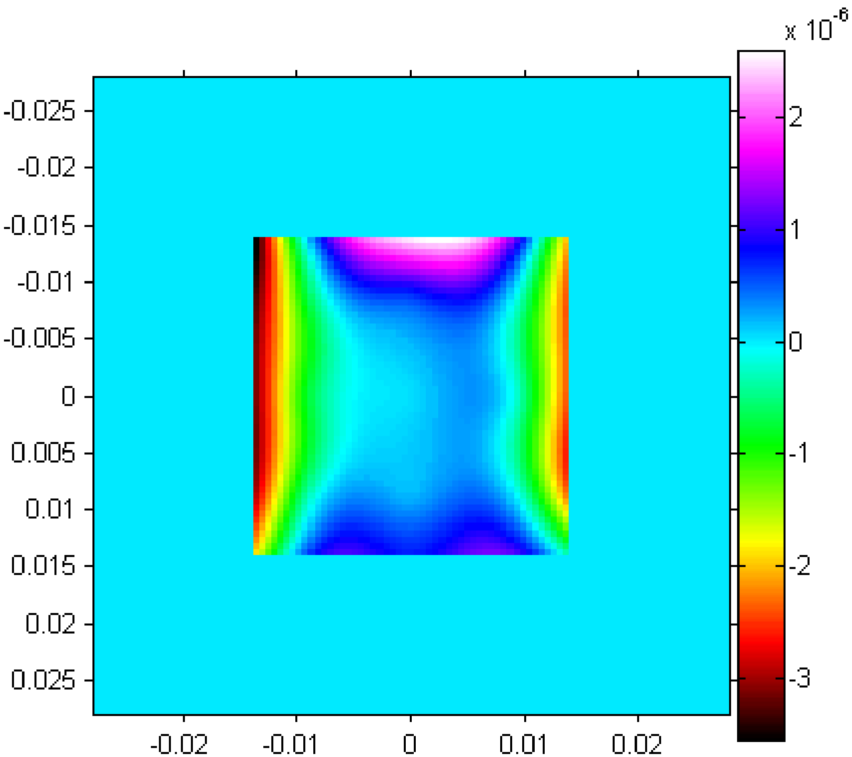
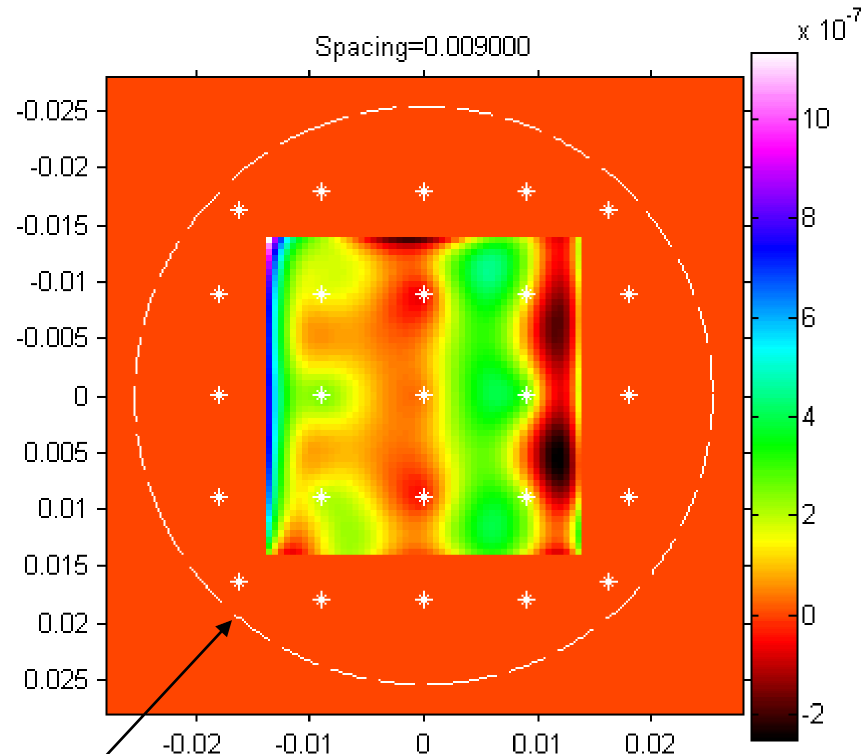
Example 2 - 9.00 mm spacing, 25 acts

DM Surface



Difference



2” DM Aperture

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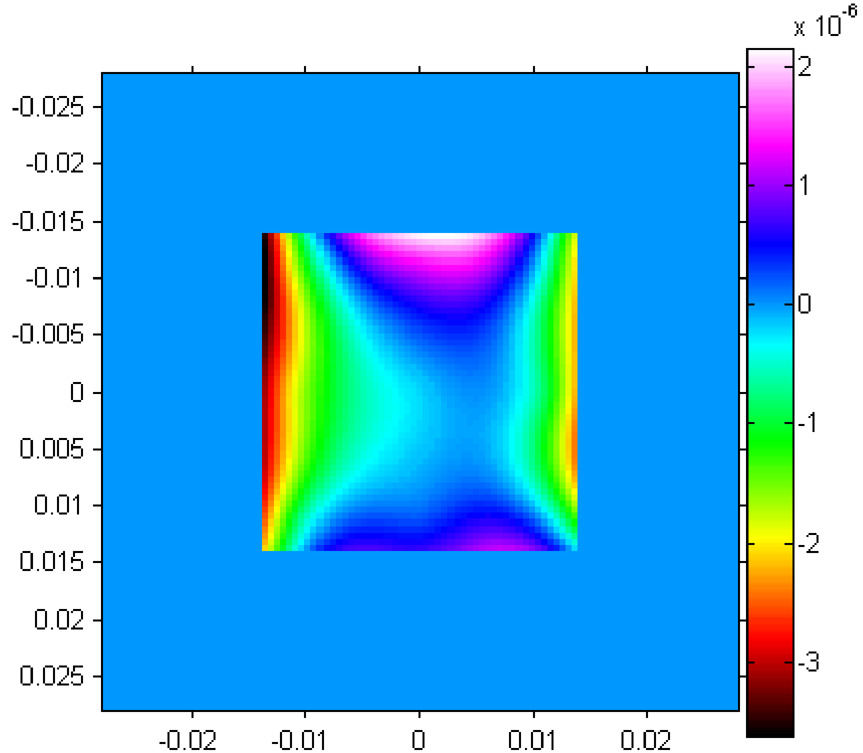
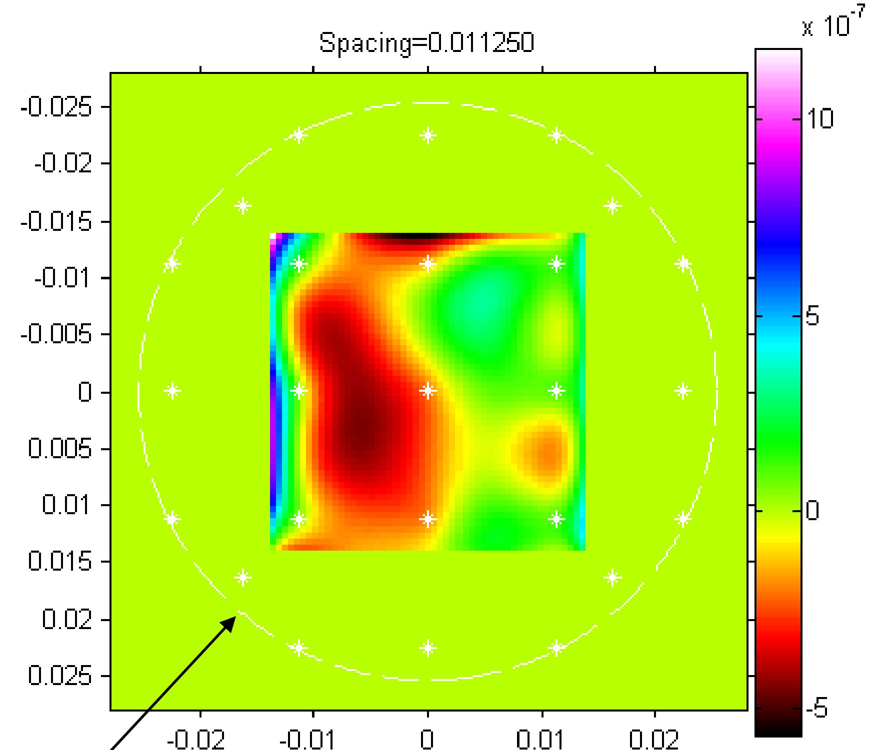
Example 3 - 11.25 mm spacing, 25 acts

DM Surface



Difference



2” DM Aperture

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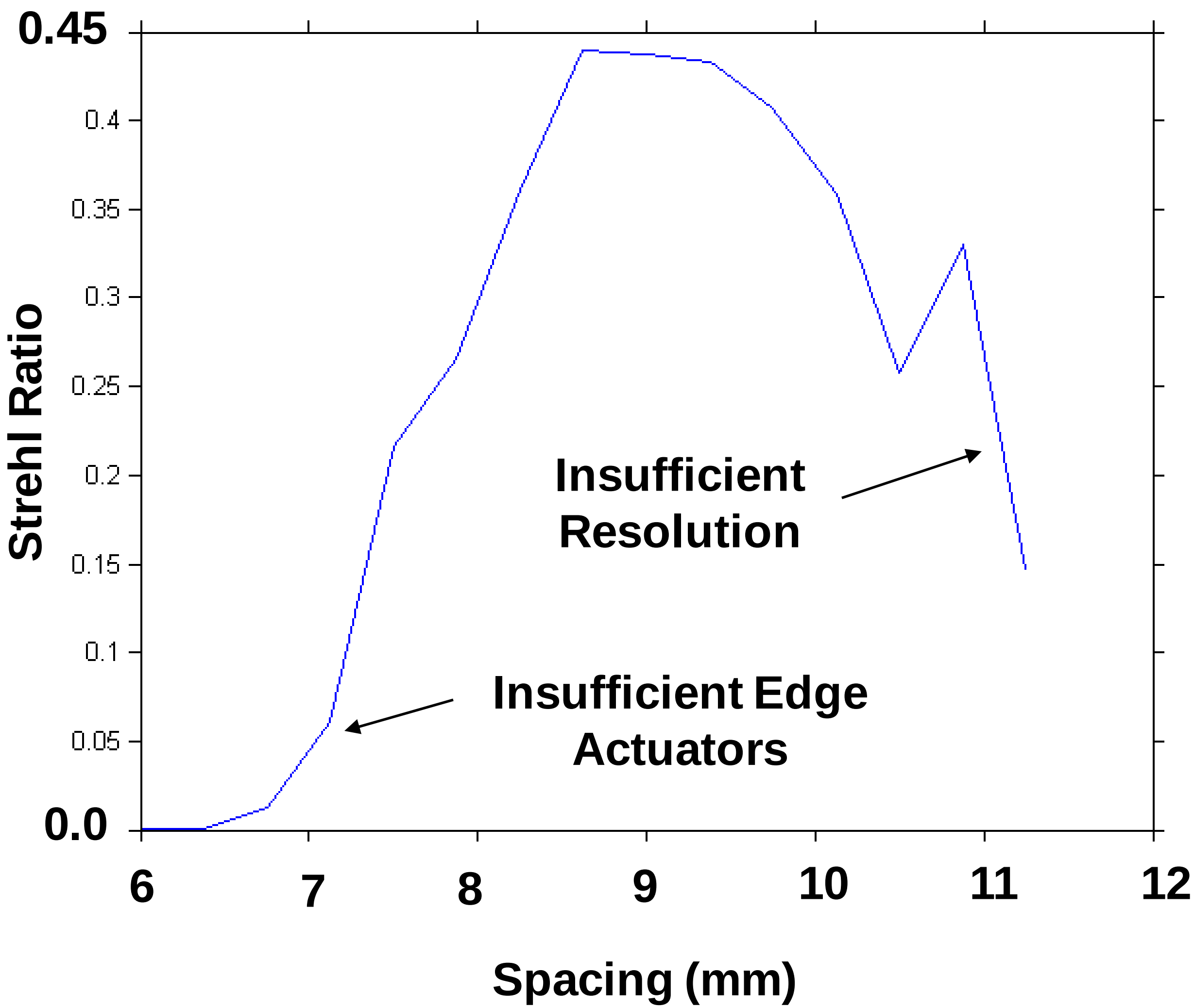
Strehl Ratio for 25 Actuators



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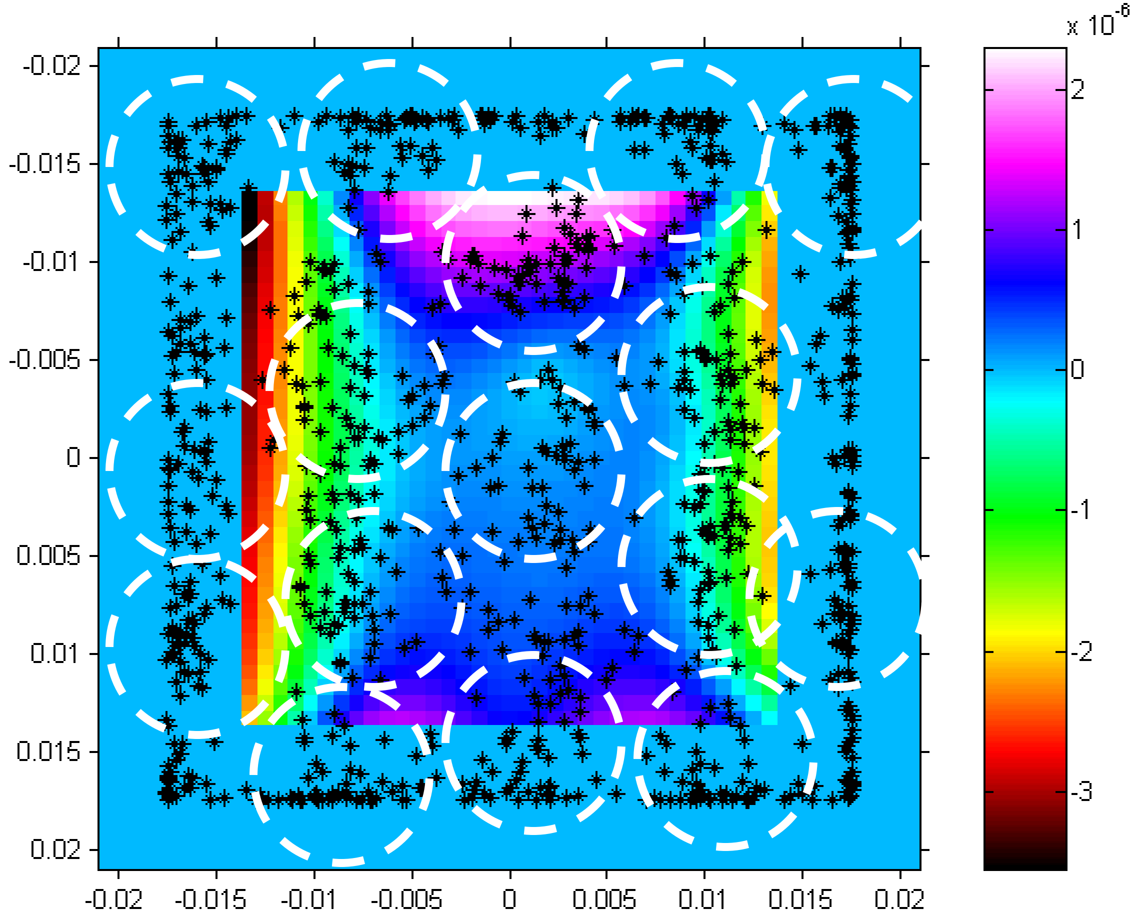
Clusters in Non-Grid Positioning



~15 Actuators

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Modeling Conclusions

- We decided to maintain a square grid instead of an arbitrary positioning to maximize potential for use for varying aberration shapes.
- We found that for the aberrations seen typically in this laser development, the best spacing was around 9 mm.

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Drive Electronics, Packaging, and HR Coatings

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Drive Electronics

- We found that we could use the existing MEMS / membrane electrostatic deformable mirror drive electronics for the PZT DMs.
- The drive electronics uses a simple USB interface via the virtual COM port.
- The 10% to 90% rise time was ~35 ms for 70V potential difference across the ~200 nF capacitive load of the actuator.
  - Can be augmented to increase the speed.

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Package Photograph

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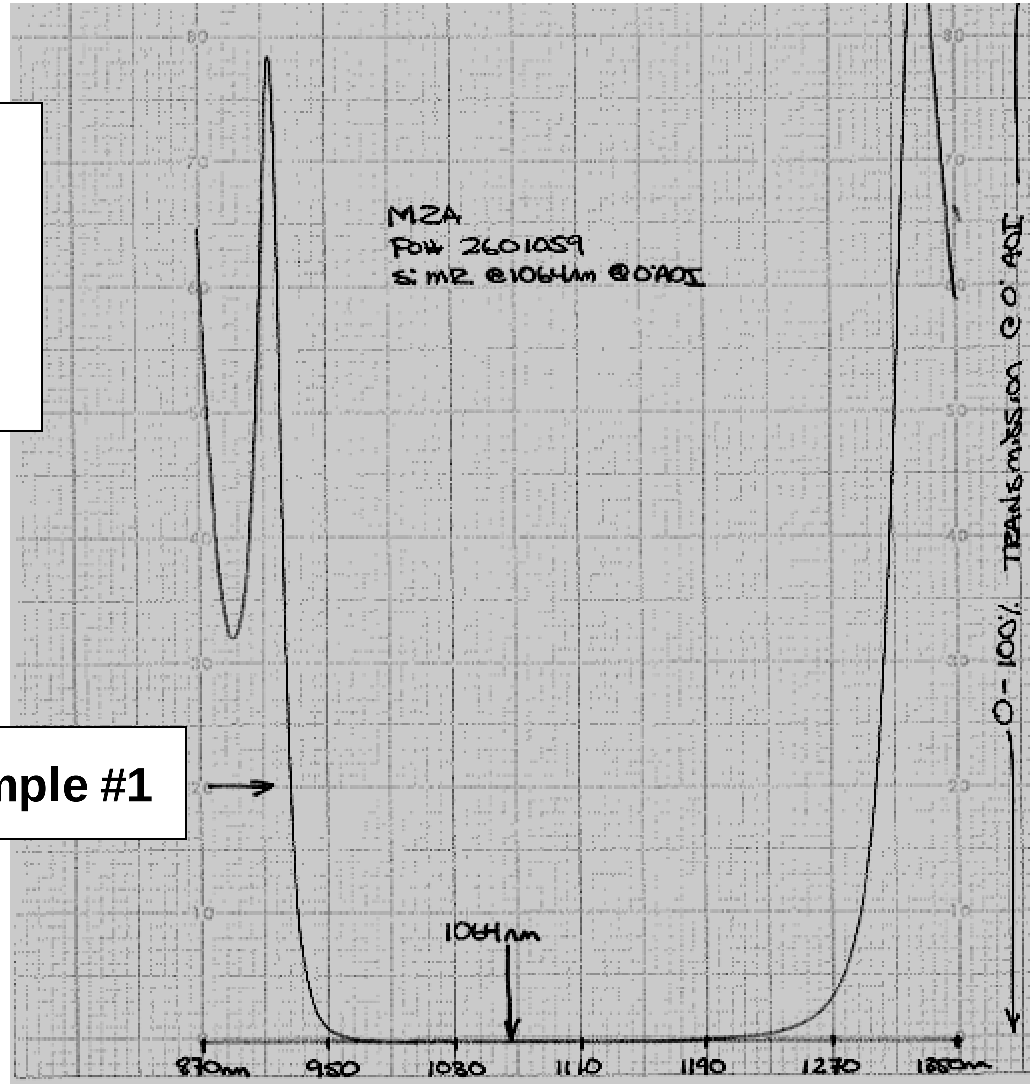
HR Coating Measured Transmission

18 pair high reflectivity stack (99.98% calculated)

Sample #1



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Scaled-Down Prototype Demonstration

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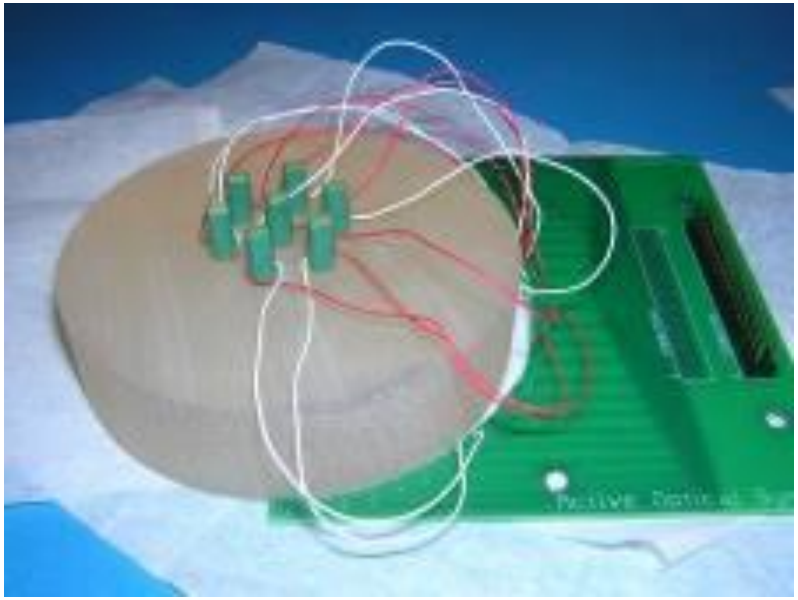
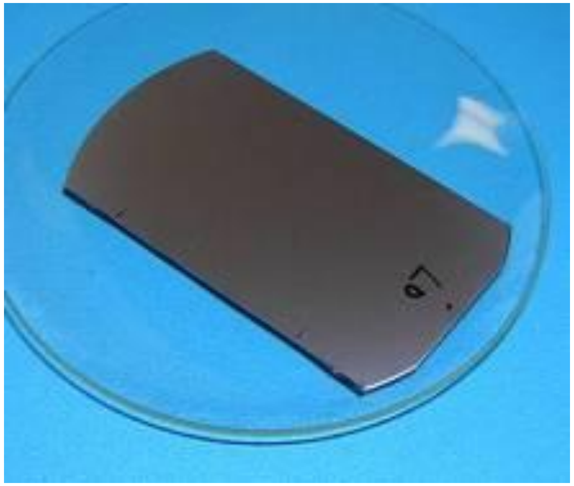
Prototype Device

- 1-mm thick silicon faceplate with a high reflectivity multi-layer dielectric stack at 1064nm without a backside coating
- 7 PZT actuators on a 12 mm pitch





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30-V Influence Functions

Curvature induced by coating stress

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Full-Scale Deformable Mirror Demonstration

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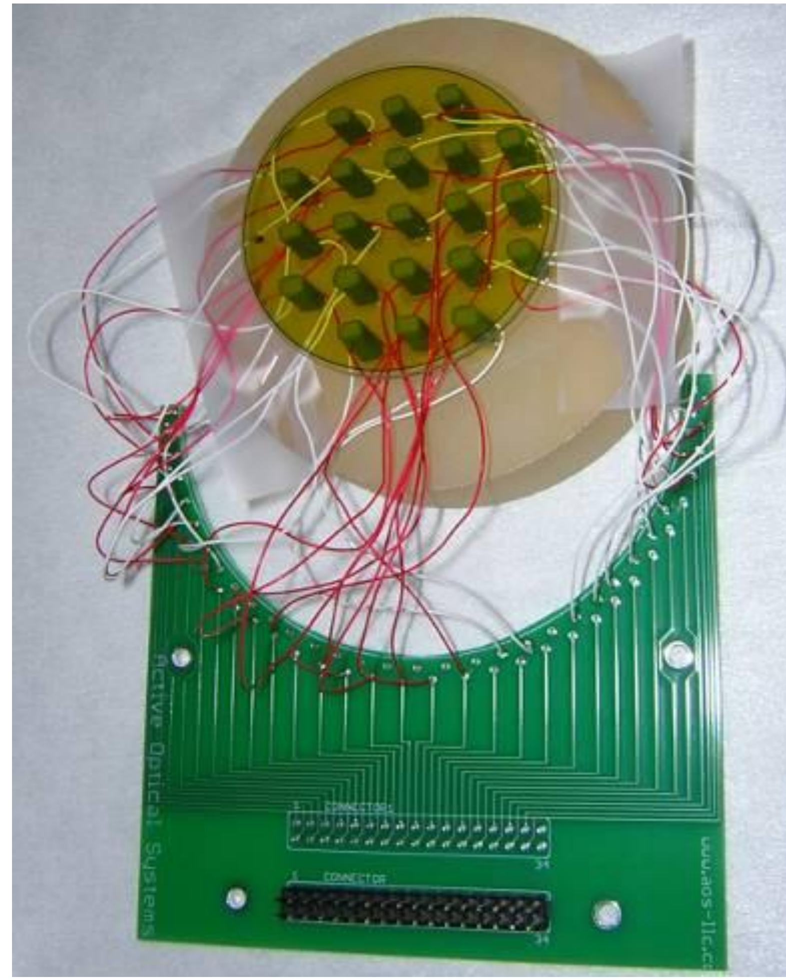
Full-Scale DM Development

- 21 PZT actuators on a 9 mm pitch
- Face plate was changed to 1.4mm thick Zerodur



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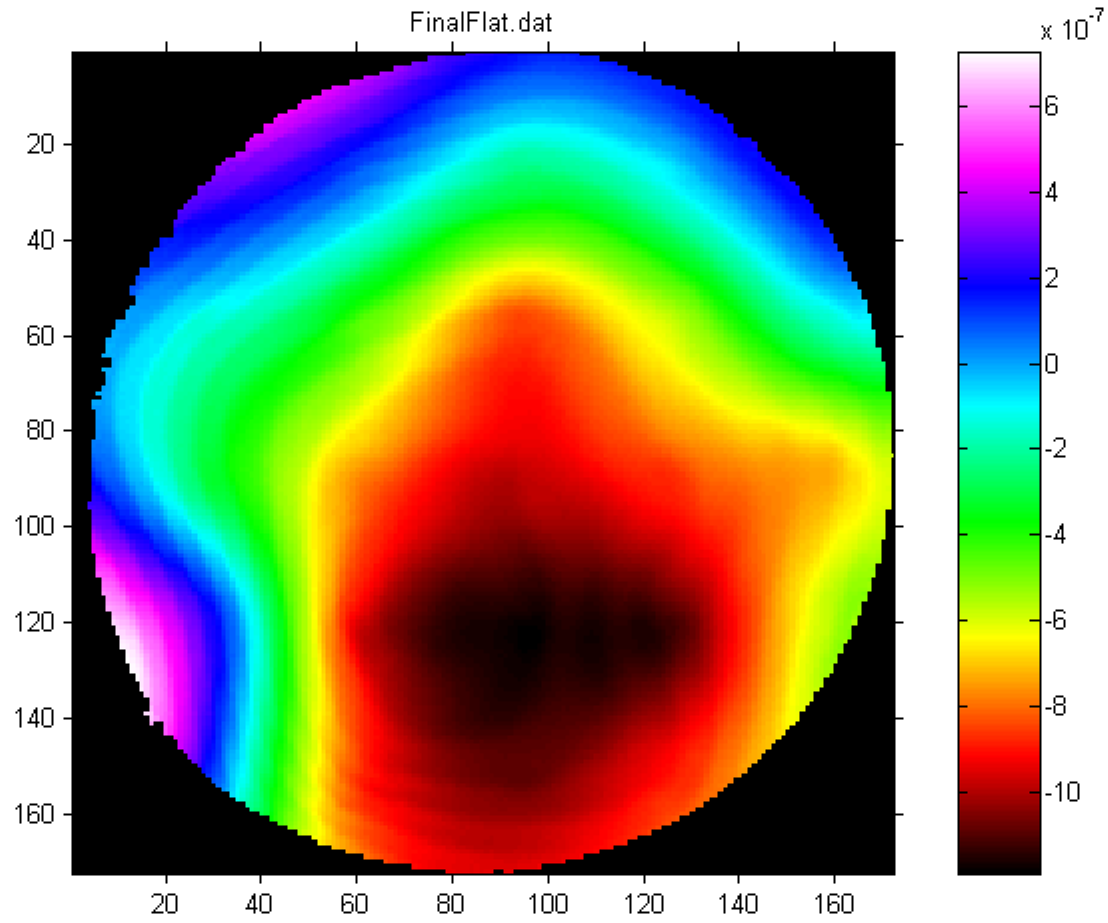
Static DM Surface

RMS = 447 nm, but there are low-order terms that could be removed actively…



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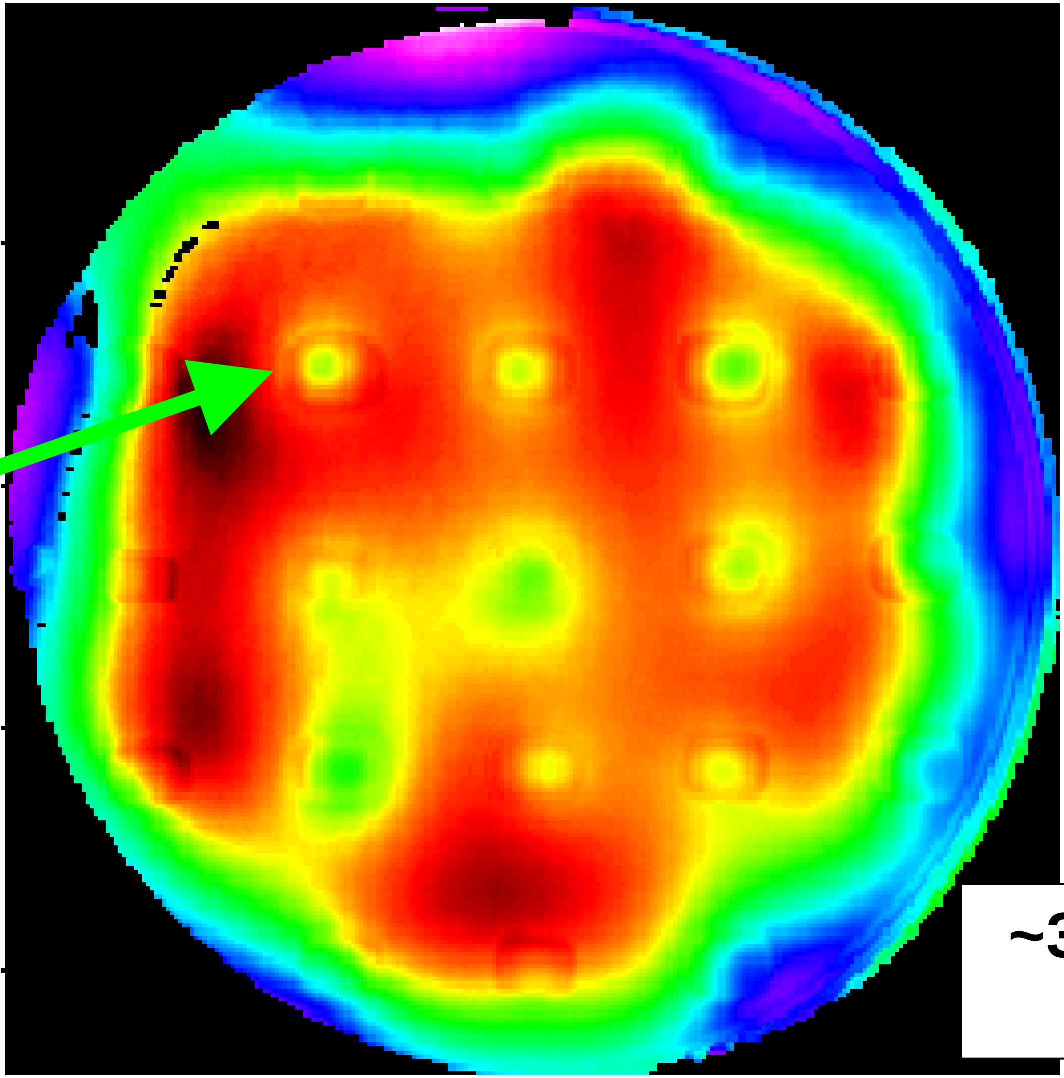
Manually Actively Flattened



Small Static Distortion at Actuators

~31 nm RMS = λ/30

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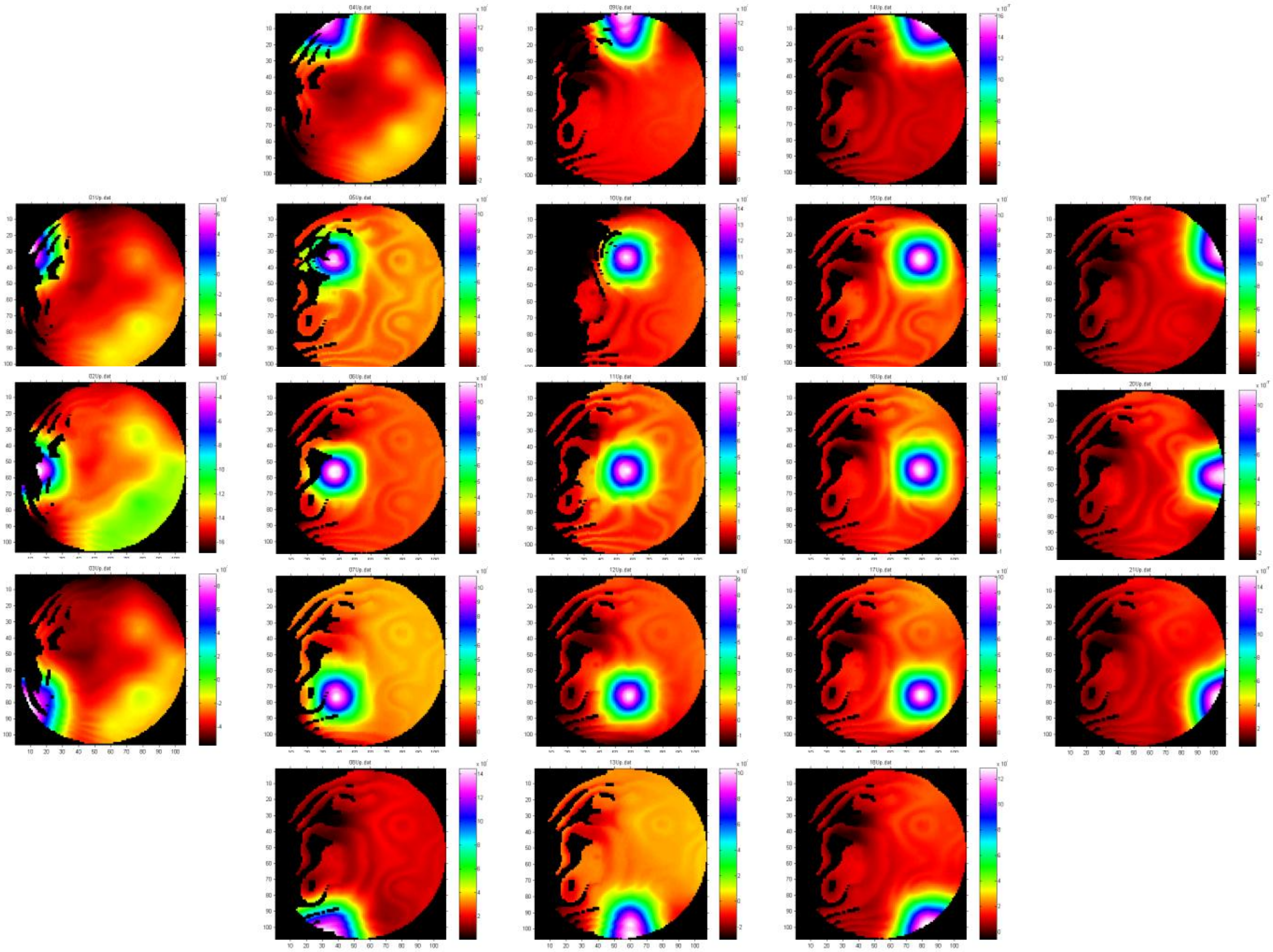
DM 1 Up Influence Functions



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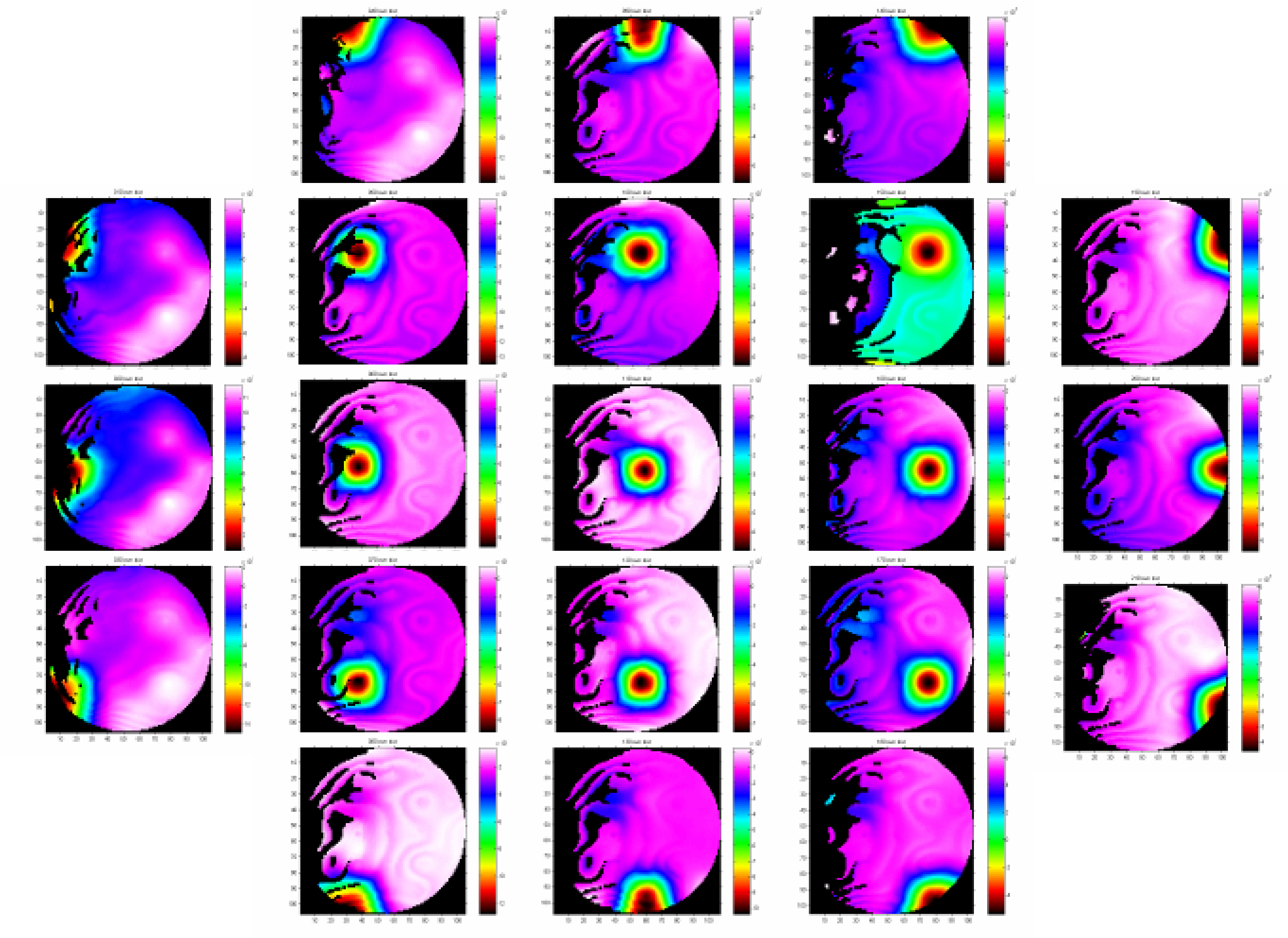
DM 1 Down Influence Functions



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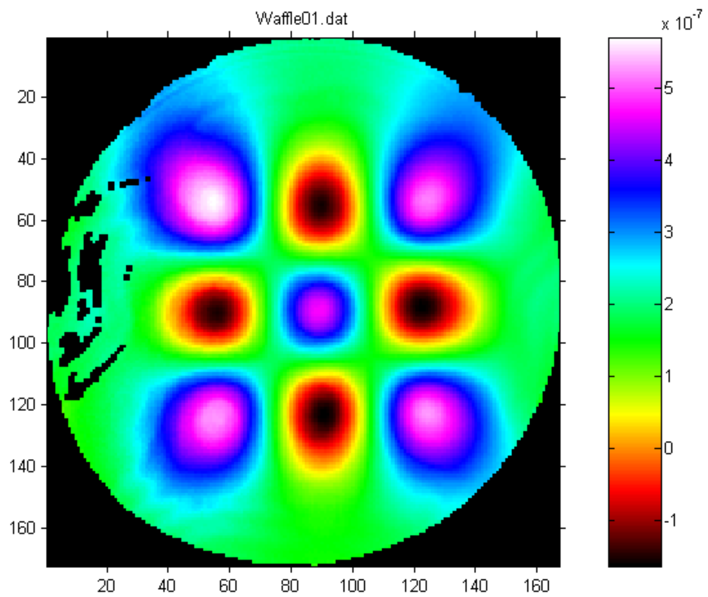
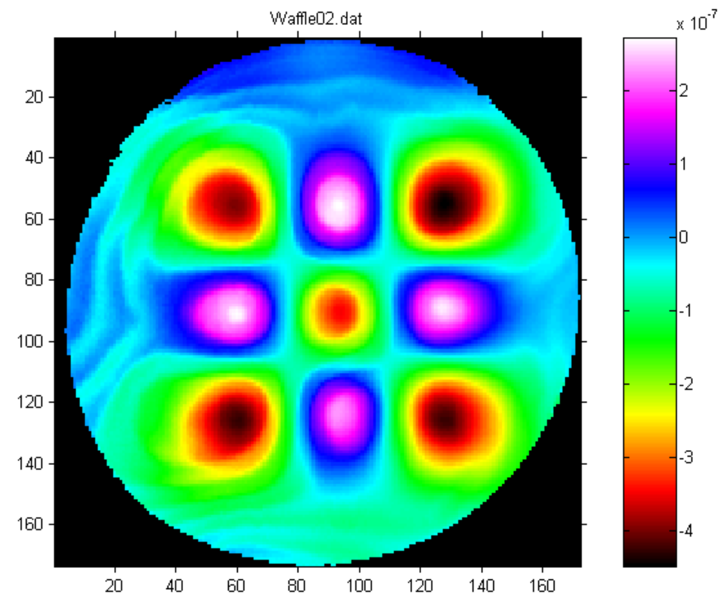
Central 3x3 in Waffle



~0.8 wave PV



~0.8 wave PV

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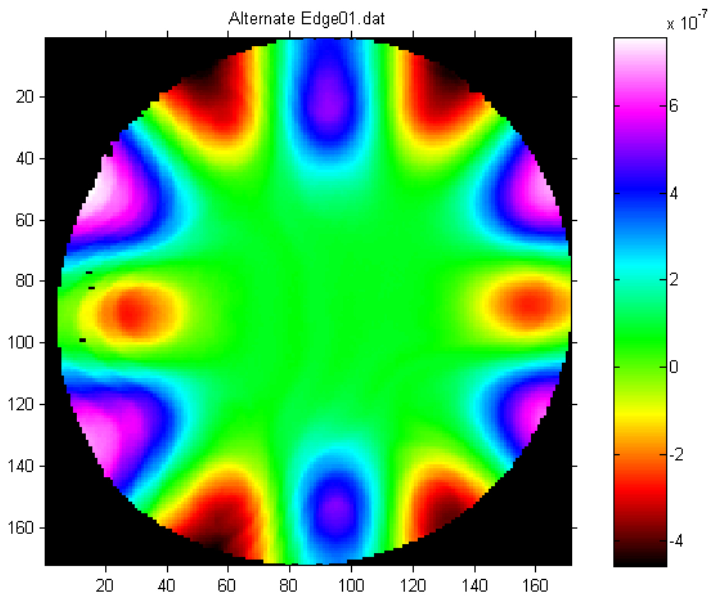
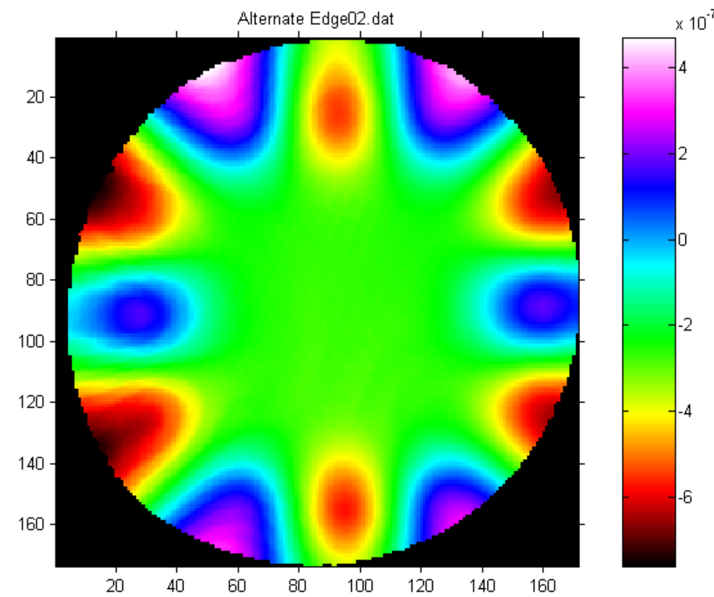
Alternating Edge Waffle



~1 wave PV



~1 wave PV

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Comparable Product Comparison

Vendor	Price with HR Coating	Lead (months)	Custom Device	Other Analysis
Xinetics	$45k + $30k coating	12+	Adds time and cost	
OKO	$25k	~3	Probably	Almost unusable surface quality
MZA	~$35k	~2	Yes!	Capable of creating a full system

OKO 109-ch DM*

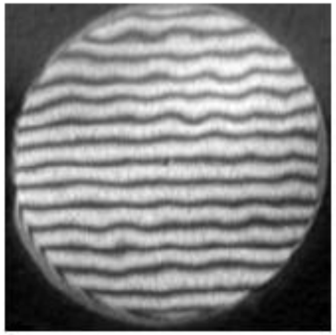

Fig.3. Corrected

RMS=0.04 μm

P-V=0.32 μm

0.64 μm PV WFE

**Taken from OKO advertisement*

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High Power Testing

- Tests were done using a cw 6 cm^2 1064 nm laser beam at nearly normal incidence with power levels of ~6 and ~12 kW
- The mirror surface was monitored with an interferometer at 860nm.

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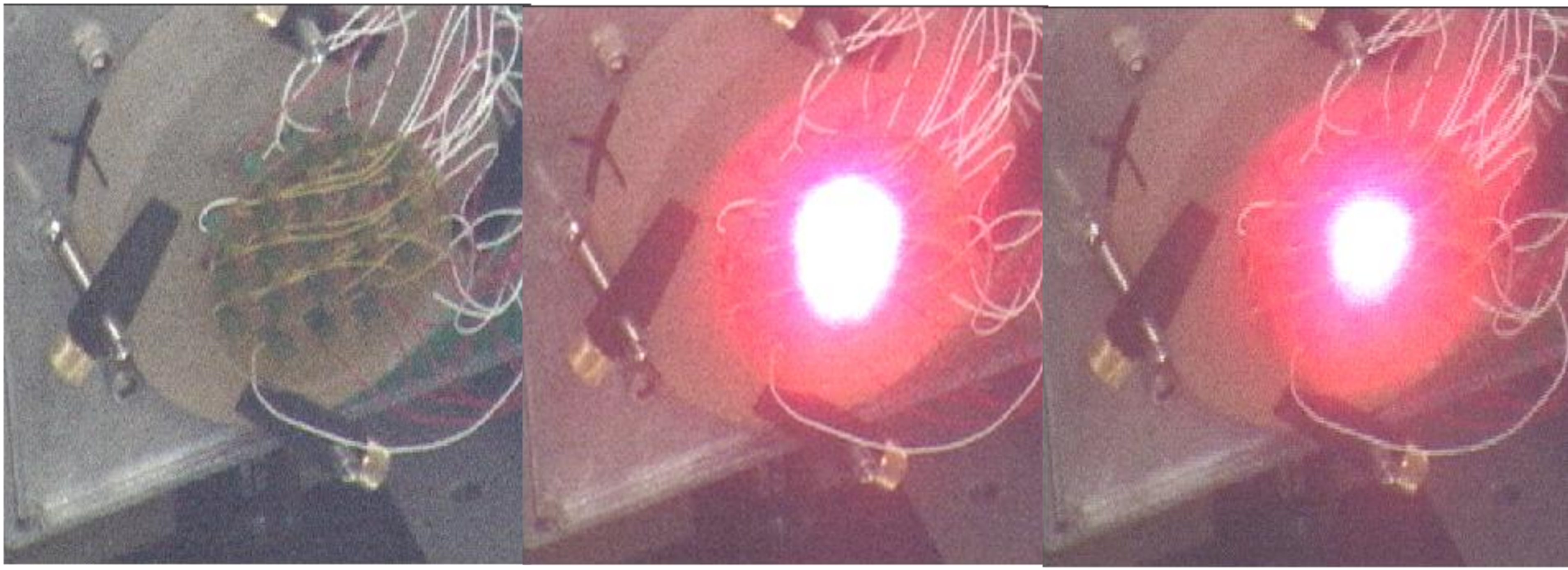
High Power Testing of DM1 – Double Side Coated



Before Laser Illumination | **Early Laser Illumination** | **After ~5.0s of Laser Illumination**

Saw no thermally induced distortions on the interferometer.

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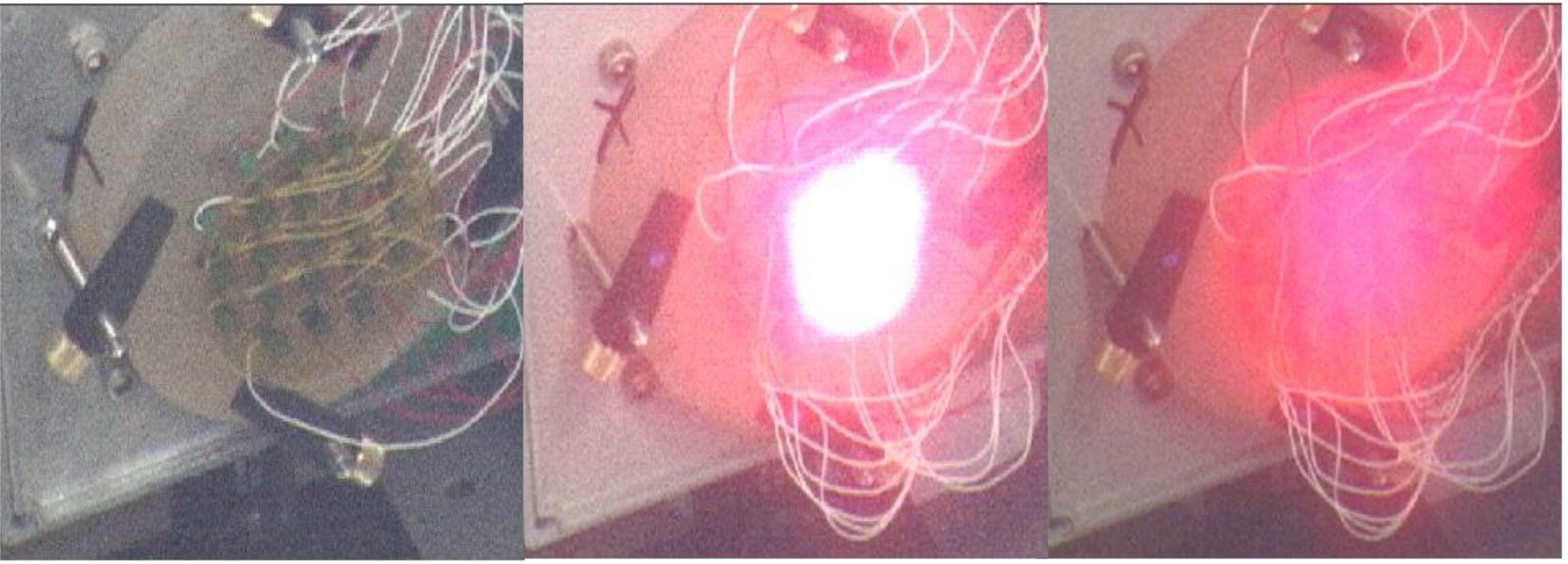
High Power Testing of DM2 – Single Side Coated



Before Laser Illumination | **Early Laser Illumination** | **After ~5.0s of Laser Illumination**

Saw only minor thermally induced distortions on the interferometer.

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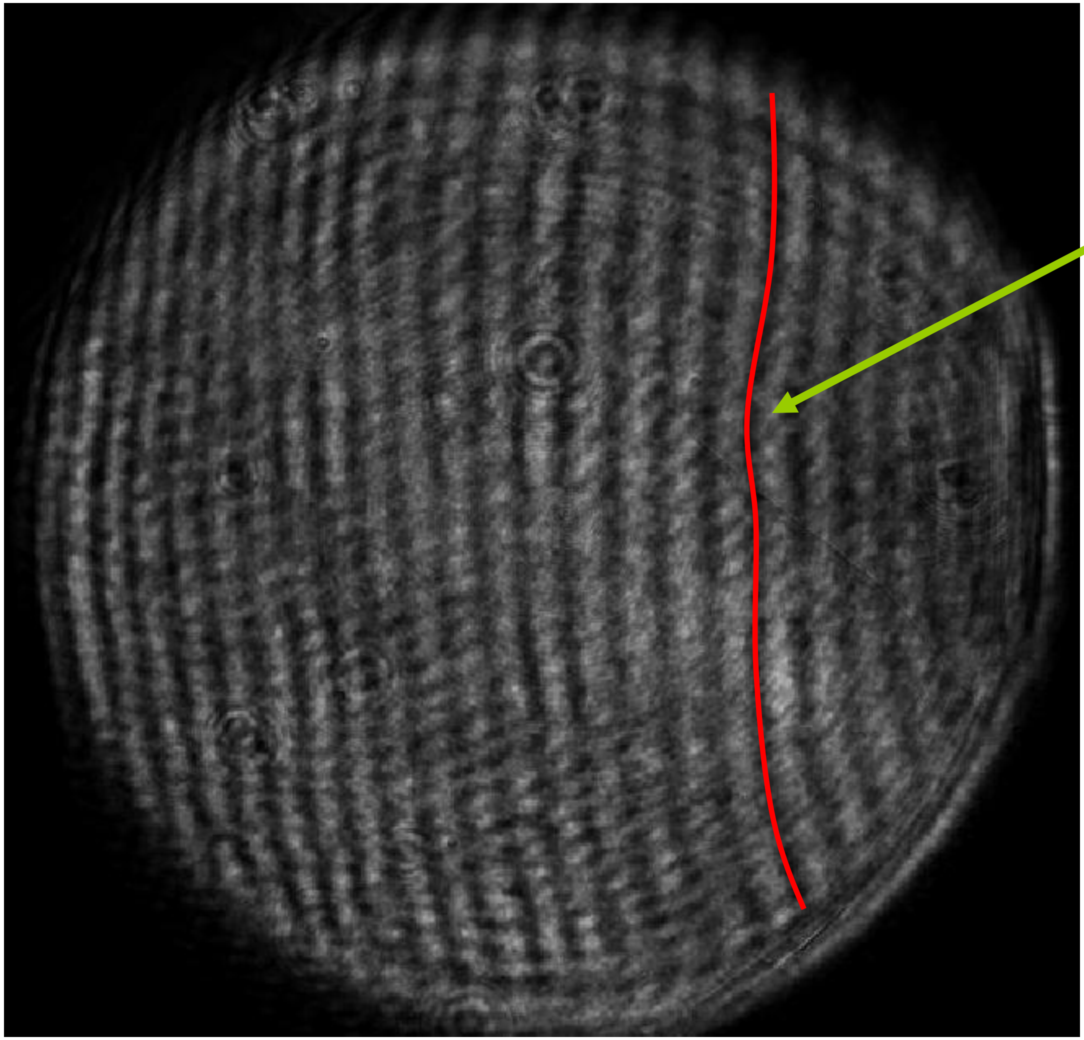
Interference Fringes from 860nm Probe during the 12 kW Testing of the Single-Side Coated DM



Slight bowing due to thermally induced distortions

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High Power Testing

- No visible thermally induced distortions on an 860-nm interferometer at 12 kW CW 1064nm power for double-side coated DM.
- ~λ/8 PV wavefront distortion for a single-side coated DM (~λ/20 RMS) at the actuator locations.

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High Reflectivity Coated Pellicle Deformable Mirrors

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Pellicle Deformable Mirrors

- AOS has productized polymer membrane deformable mirrors for low power operation.
- We added 2” and 3” pellicles to the HR coating runs.
- The resulting membranes were showing obvious warp due to the compressive stress of the coating, but the center of the membranes was still reasonably flat, so we tested a pellicle at high power.

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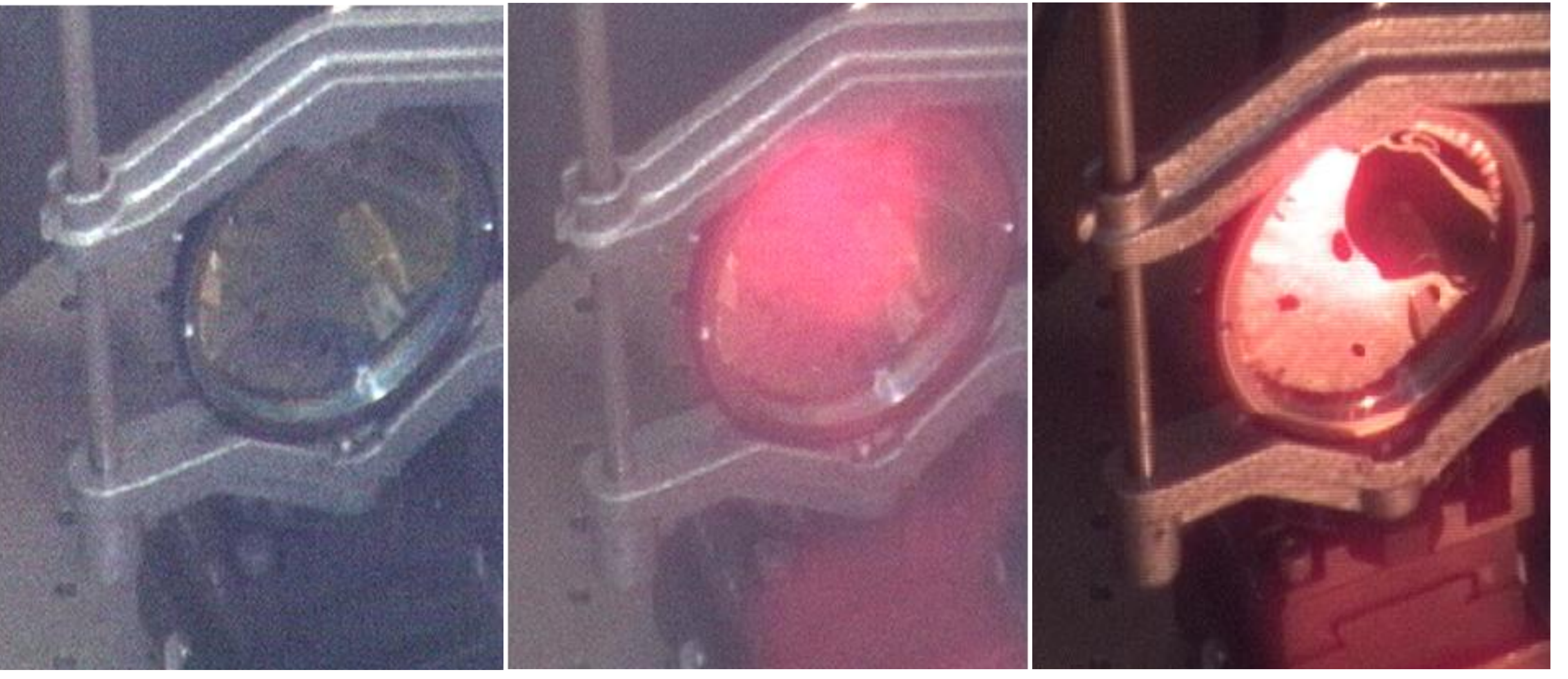
High Power Testing of Pellicles



Before Laser Illumination

Early Laser Illumination

After ~1.0s of 12 kW Laser Illumination

The pellicle survived the laser illumination with no permanent damage, but saw obvious and large magnitude thermally induced distortion.

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Conclusions

- We demonstrated a piezoelectric actuator high-reflectivity DM capable of withstanding 12 kW of CW 1064 nm laser radiation (2 kW/cm^2).
- In the future we would like to investigate the cause of the warping at the actuator connection sites and higher quality coatings.

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Acknowledgements

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Questions?

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