Temporal and Spatial Characterization of Polymer Membrane Deformable Mirrors

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Outline

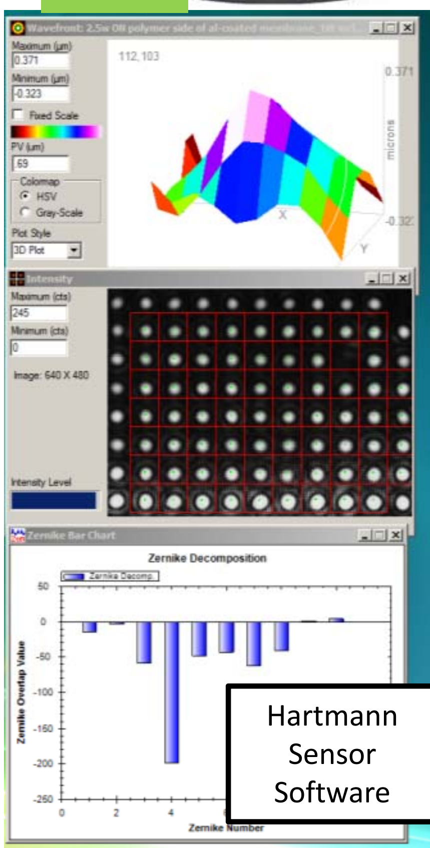
- Introduction
- Spatial Response Characterization
- Temporal Frequency Response
- Conclusions & Future Work

AOS Products

Hartmann & S-H Wavefront Sensors

Webcam HWFS

$1.5k

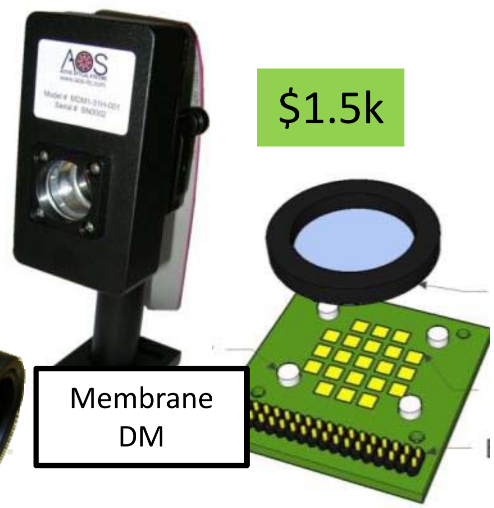


Hartmann Sensor Software

$6k

Firewire HWFS

Deformable Mirrors



$1.5k

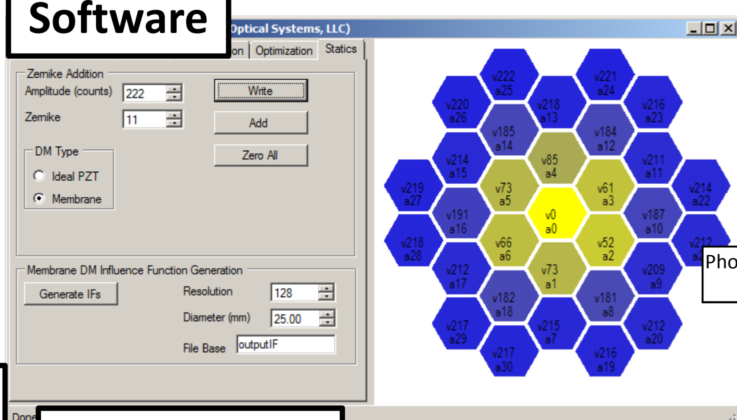
Membrane DM

Computer Interface Electronics

$5k

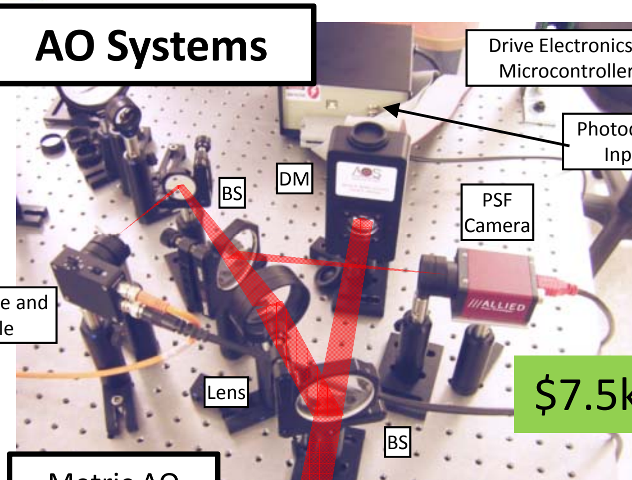
USB Drive Electronics

Software



DM Controller

AO Systems



$7.5k

Metric AO System

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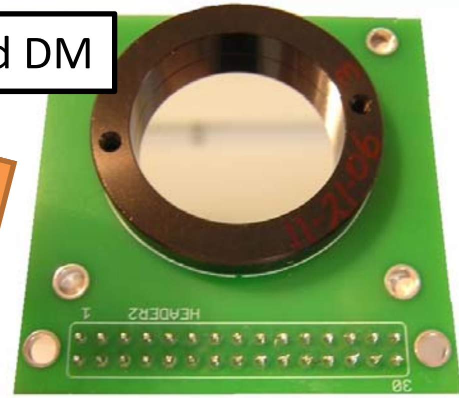
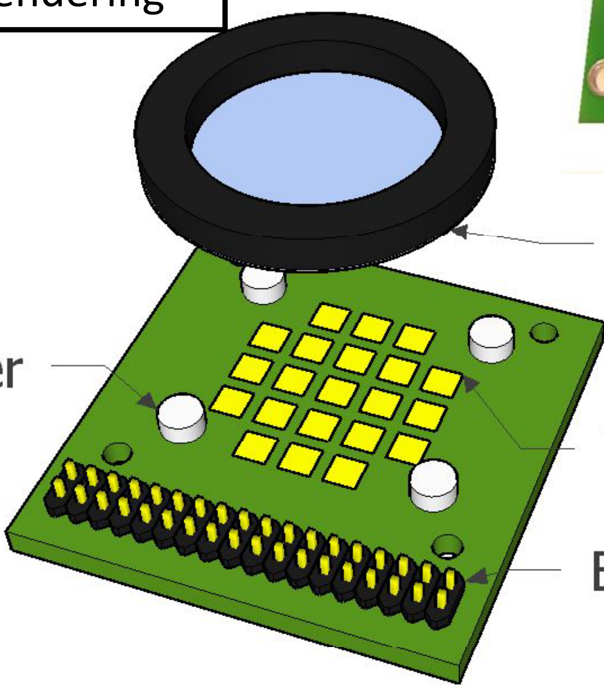
Membrane Deformable Mirror Architecture

Assembled DM



Packaged DM

DM Assembly Rendering



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Why Polymer Membrane DMs?

- One of the barriers mass use of AO technology is cost.
- MEMS DMs are low-cost in high volume, but the requirement of a clean-room makes the NRE and initial costs very high.
- Polymer Membrane DMs are much less expensive and are very effective at laser beam shaping, and aberration compensataion.

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Typical 1" DM Specifications

Parameter	Min	Typical	Max	Notes
Mechanical				
Number of Actuators	1	25		
Surface				
Aluminum Coating Reflectivity (Visible)	80%			High Reflectivity Possible
Surface Quality		λ/2		per inch - typically ...igmatism
HR Coating Damage Threshold (J/cm^2)				...easured with a 11ns ...64 nm laser pulse
HR Coating Cost		[illegible]		...er Lot of ~10
Actuation				
Focus Throw (um)		10		300 V, 25 mm diameter
Resonance Frequency (Hz)		500		25 mm diameter (Al-coated)
Focal Length (m)		3		25 mm diameter

Can we quantify this better?

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Spatial Response of Polymer Membrane DMs

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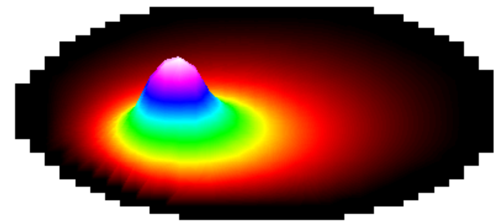
Membrane DM Influence Functions

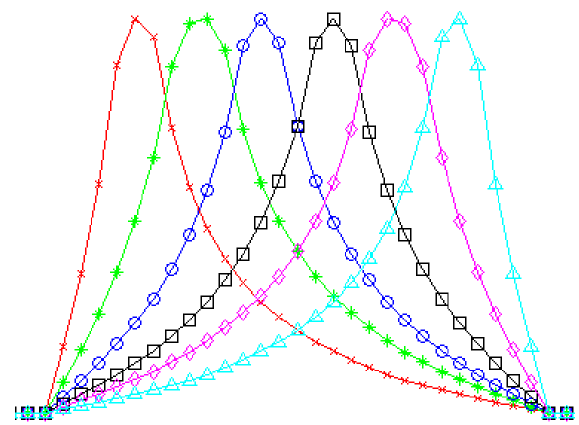
$$\nabla^2 z = \frac{F}{T}$$

- The membrane DMs architecture behaves the same independent of the architecture because the physics of the shape is the same including:
  - MEMS
  - Metal Membranes
  - Polymer Membranes

Membrane DM Influence Functions



Normalized Influence Function Cross-Sections



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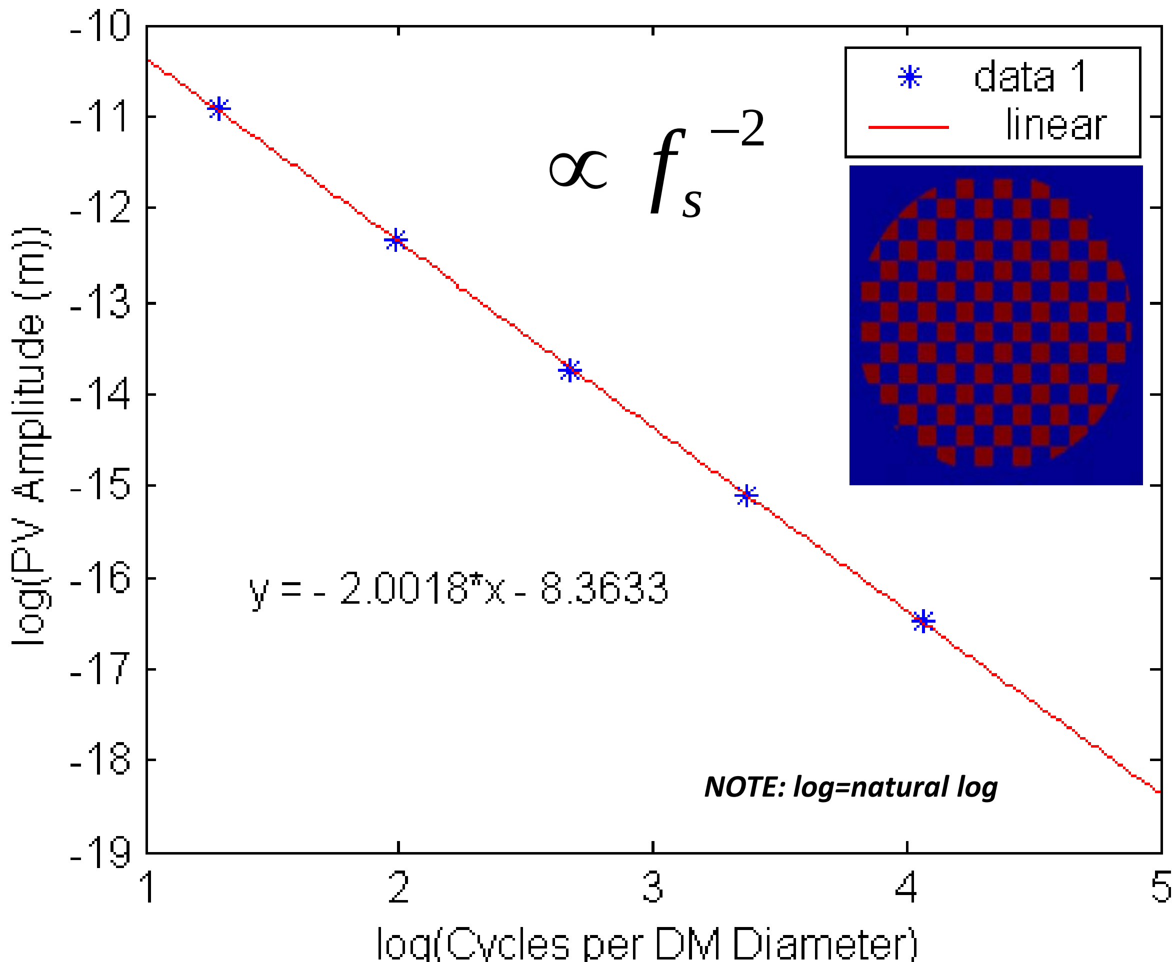
Prior Analysis of Membrane DM Spatial Frequency Roll-Off

- We applied a varying spatial frequency waffle pattern to a membrane DM.
- The amplitude of the response fell off as $1/f_s^2$.



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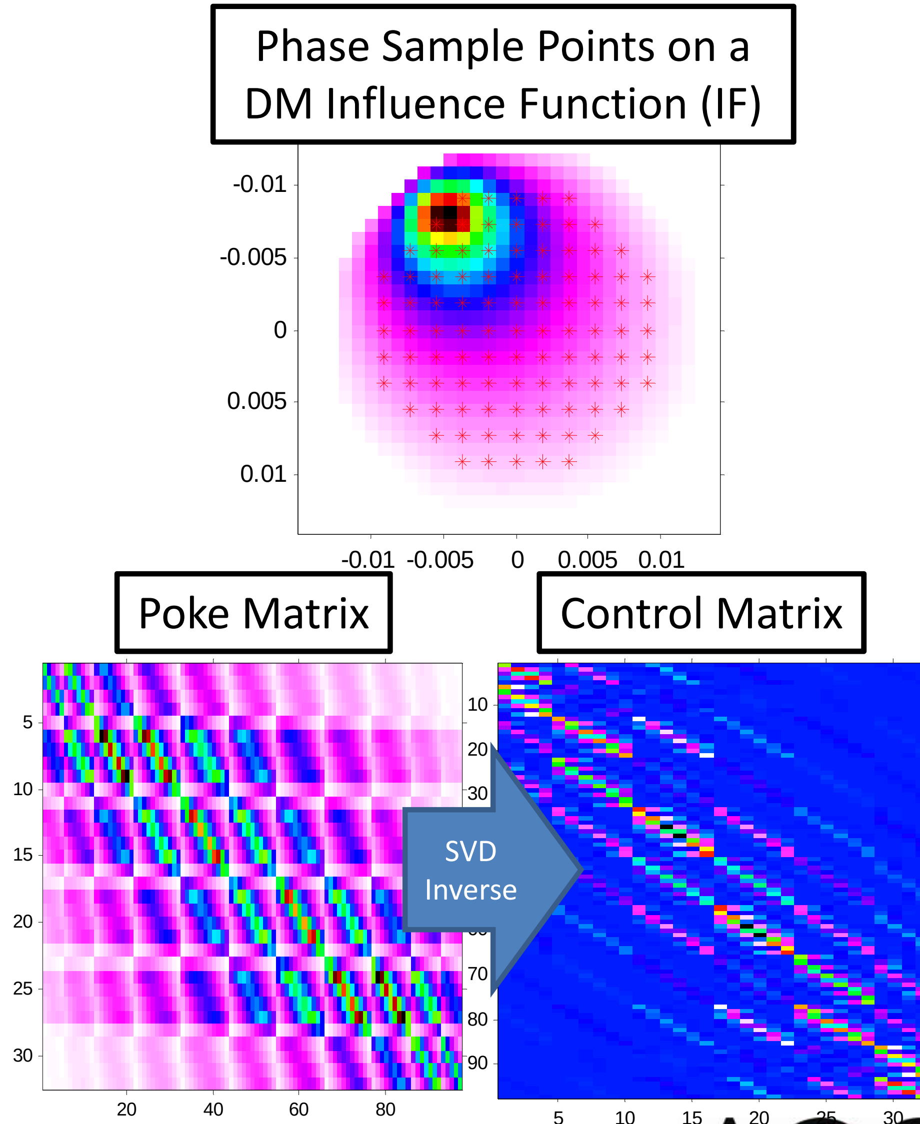
Modeling Procedure

- Scale IFs such that the sum of all IFs = 10 microns PV of focus.
- Sample ~90 points over central 80% of the DM diameter on a set of IFs from a membrane DM to create a poke and control matrix.
- Use matrix-based phase control to create a representation of a set of Zernikes.

$$commands = \Gamma \cdot \phi_{Zernike}$$



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Zernikes Grouped Into Radial Order

$\propto r^1$ X and Y Tilt

$\propto r^2$ Focus & Astigmatism

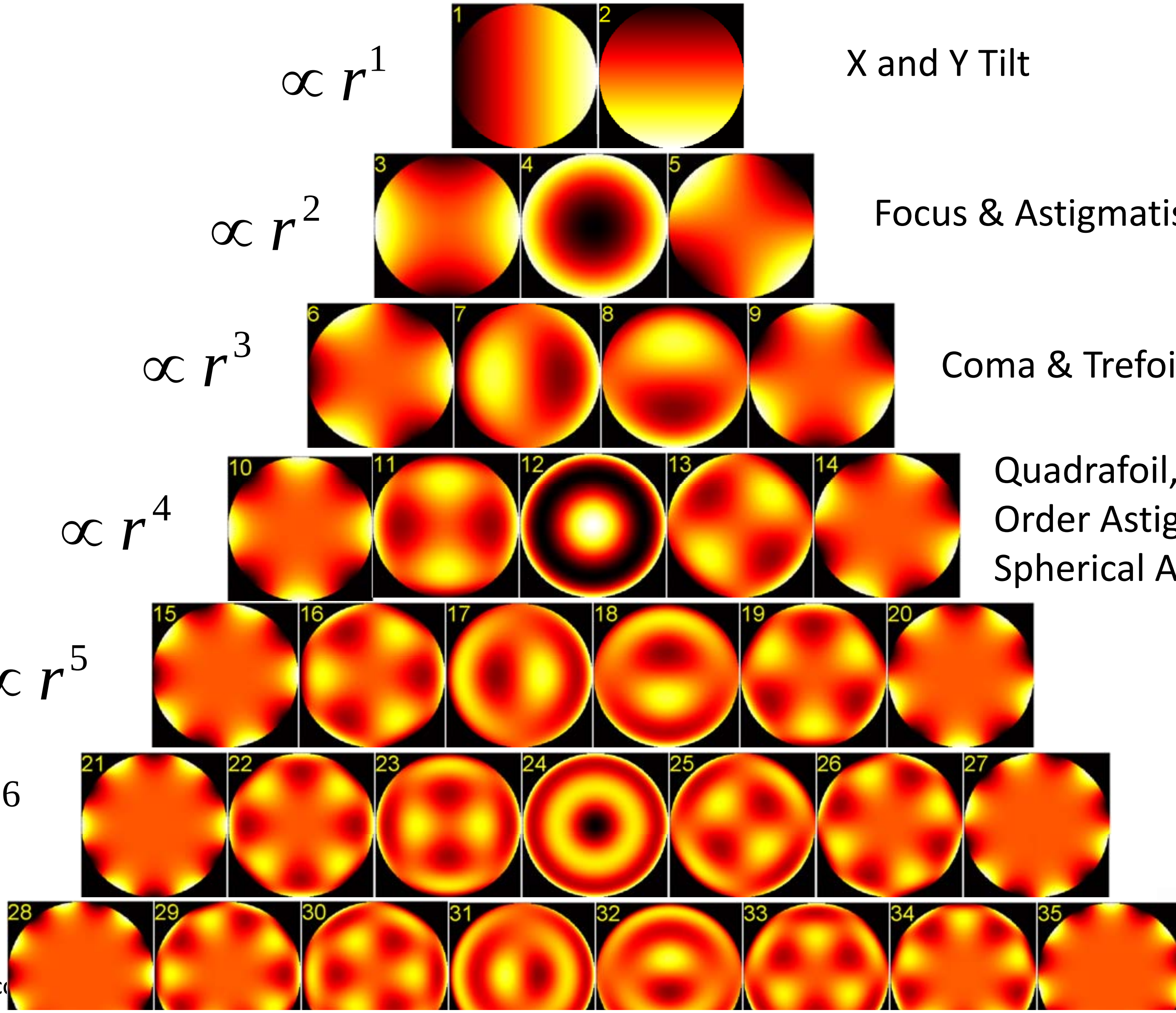
$\propto r^3$ Coma & Trefoil

$\propto r^4$ Quadrafoil, Higher-Order Astigmatism, & Spherical Aberration

$\propto r^5$

$\propto r^6$

…



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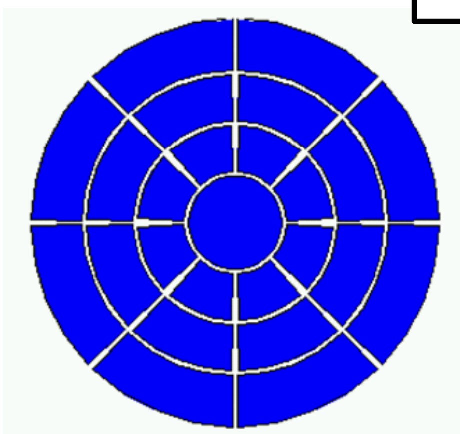
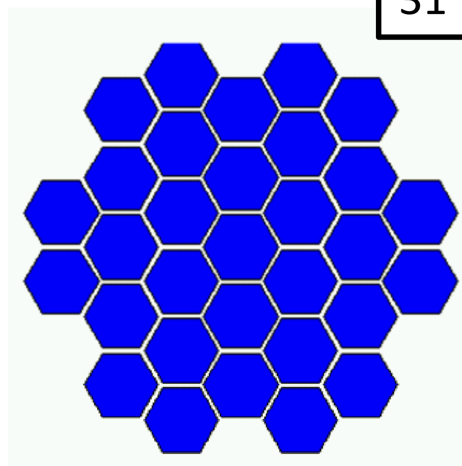
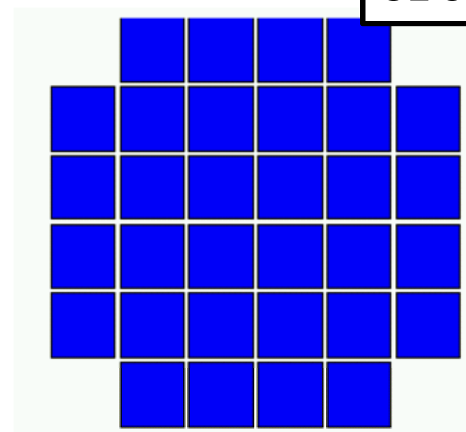
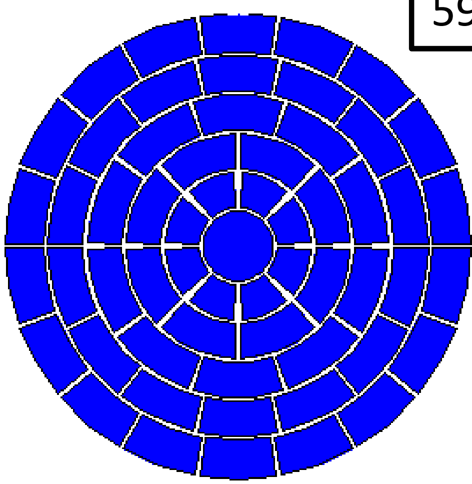
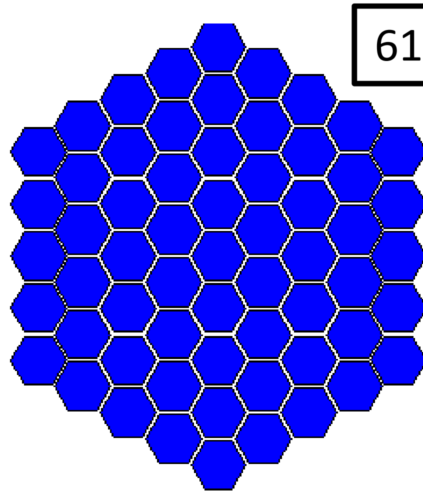
Tested Actuator Patterns

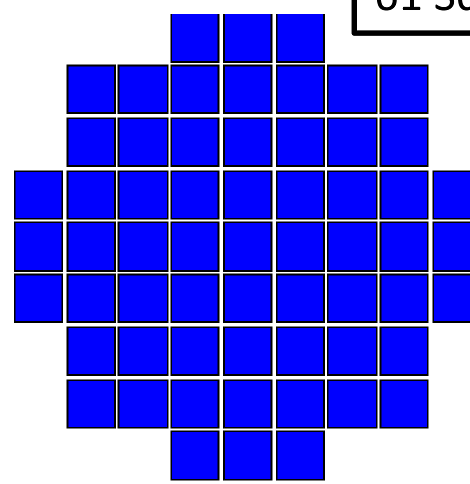

25 A


31 Hex


32 Sq


59 A


61 Hex


61 Sq

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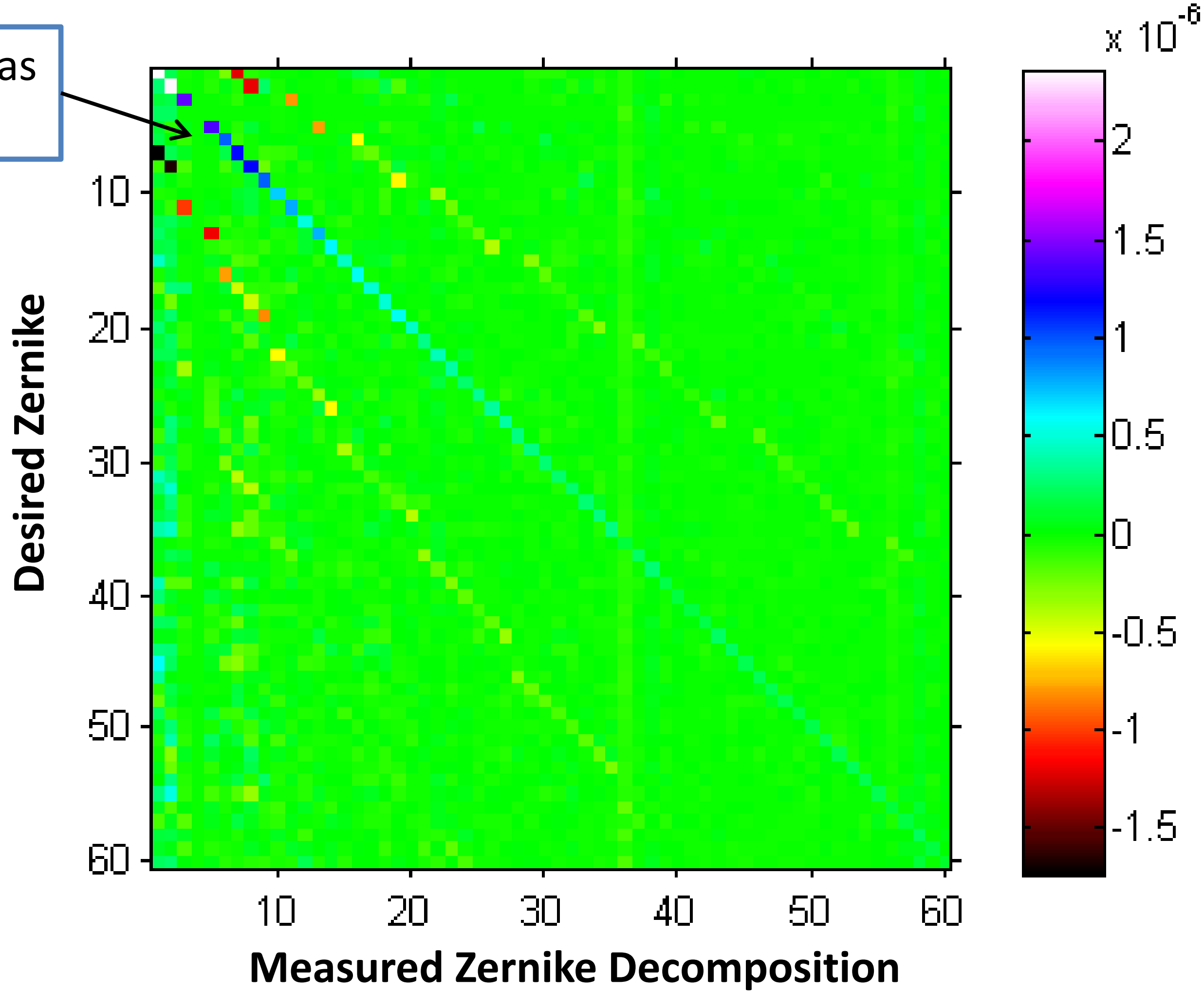
Zernike Fitting Results for a 61-Actautor Square Grid DM

Focal bias was removed



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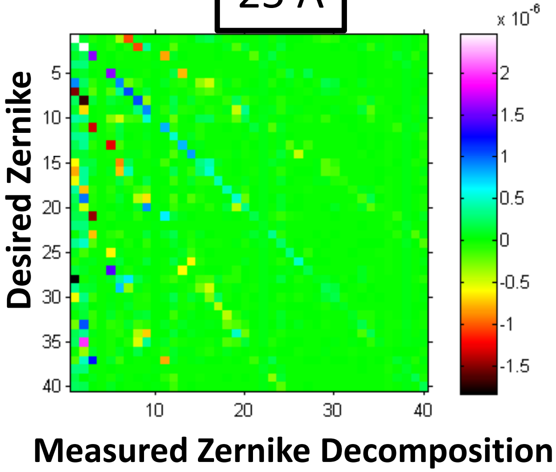
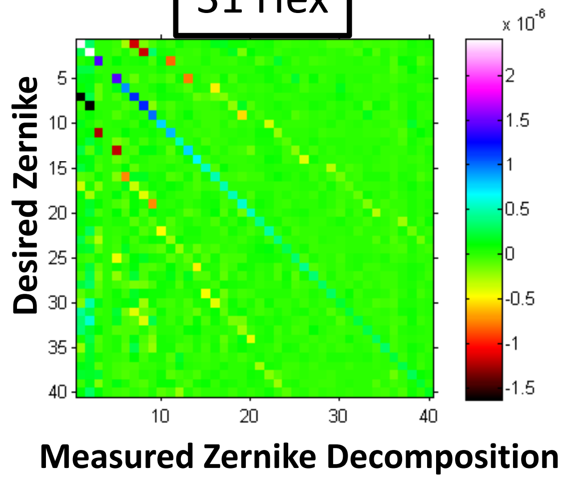
Summary for All Actuator Patterns

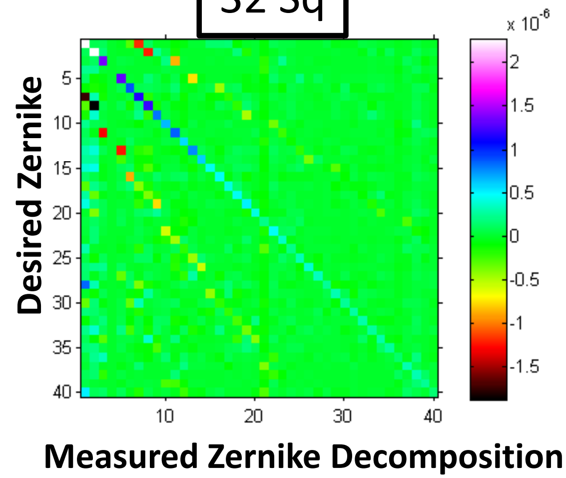
25 A



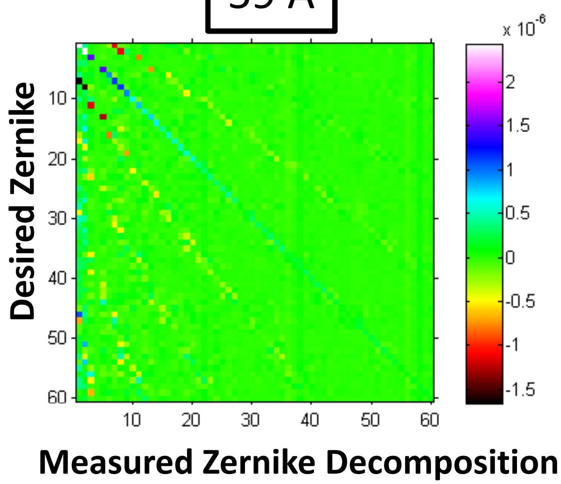
31 Hex



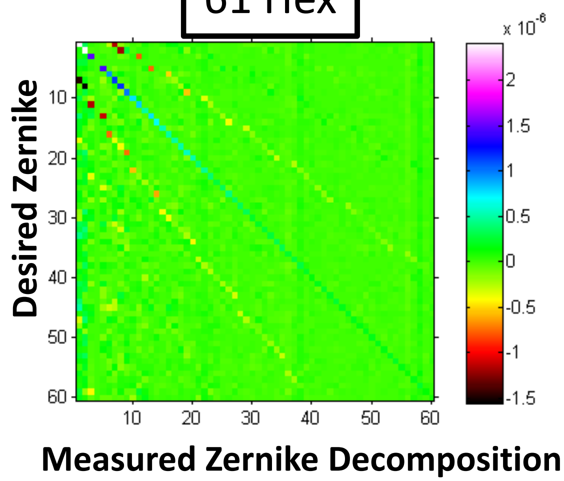
32 Sq



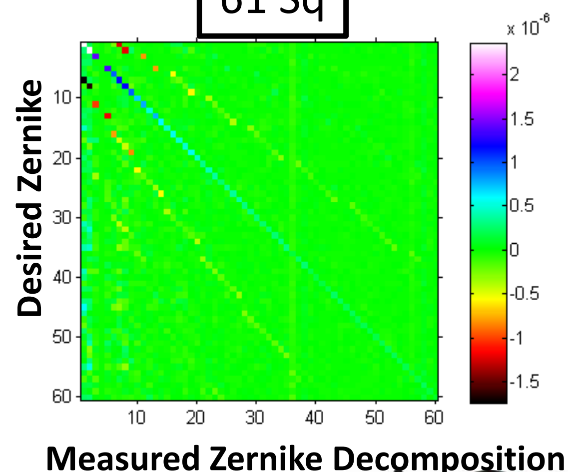
59 A



61 Hex



61 Sq



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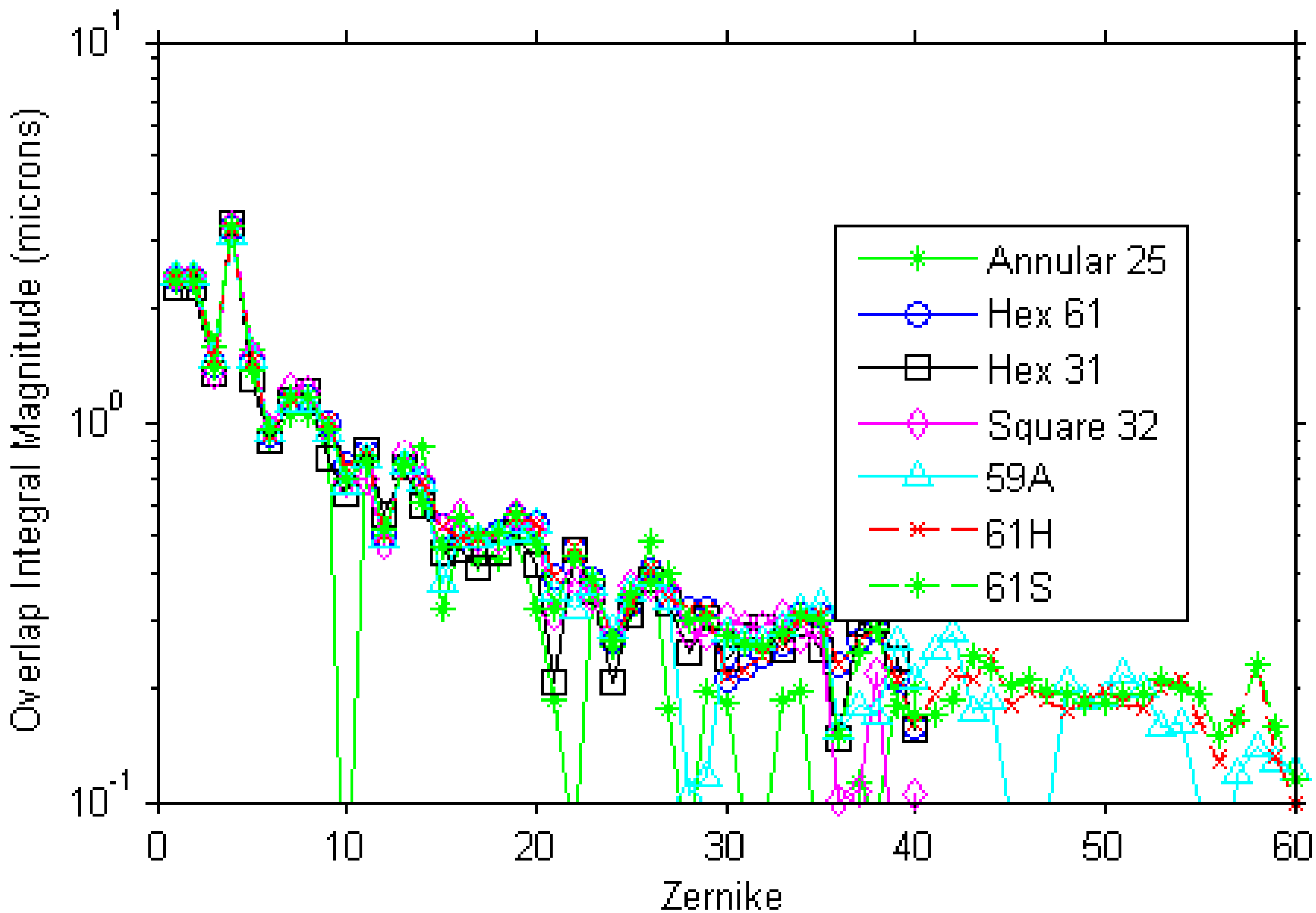
Summary for Various Actuator Patterns



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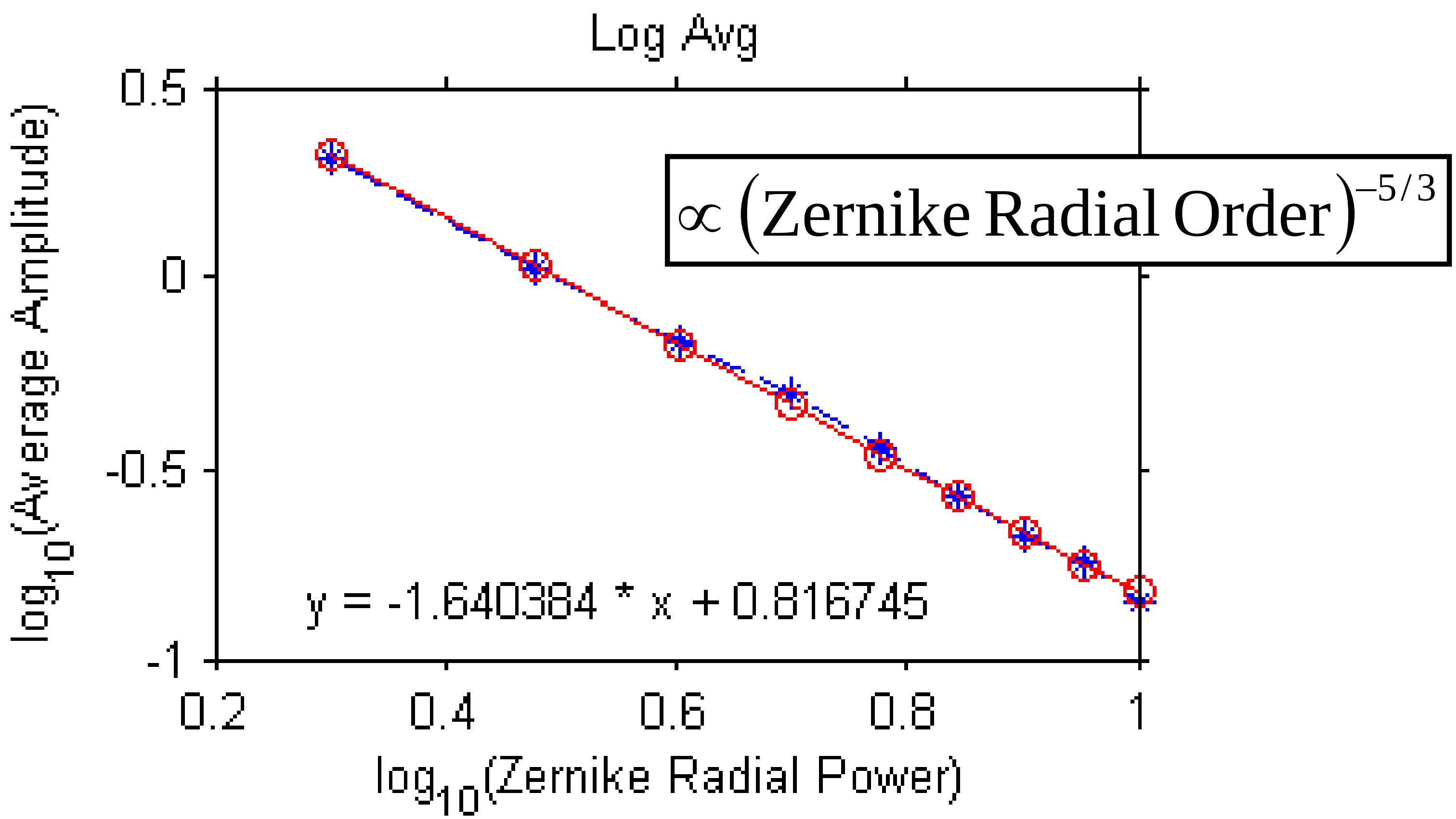
Analysis of Zernike Fitting Results



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Spatial Frequency Response Conclusions

- Most actuator patterns were able to recreate the low-order Zernike patterns well.
- The amplitude of the Zernike fits fell off with higher orders.
  - Fall-off in amplitude was proportional to the (Zernike radial order)$^{-5/3}$.
- Future Work:
  - Examine maximum number of actuators that are useful for compensation or generation of Kolmogorov turbulence

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Temporal Frequency Response of Polymer Membrane DMs

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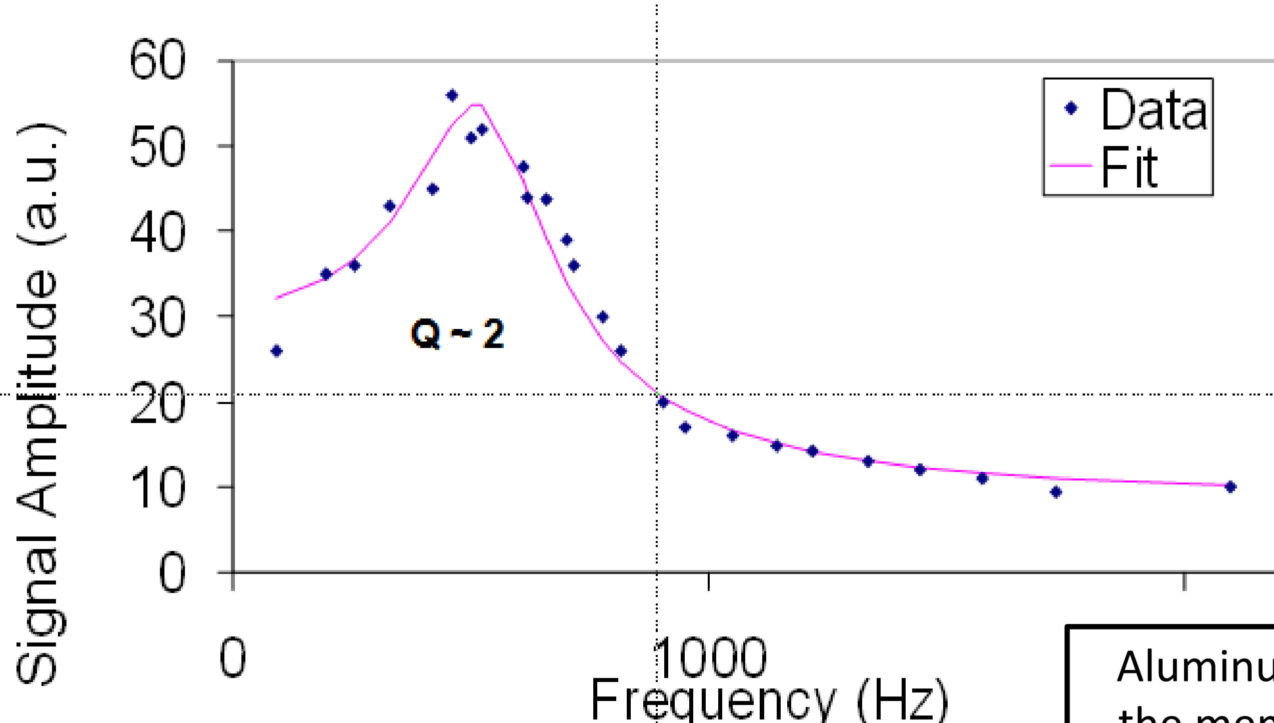
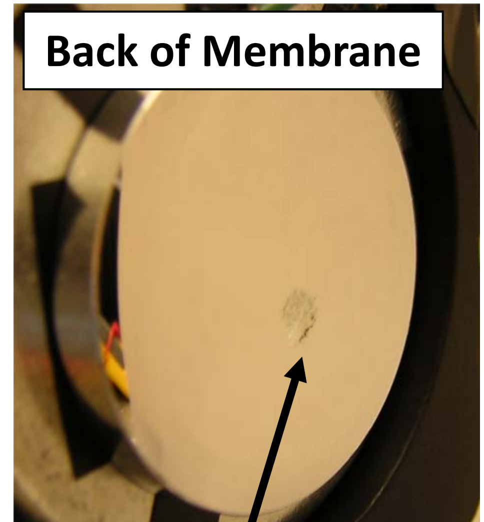
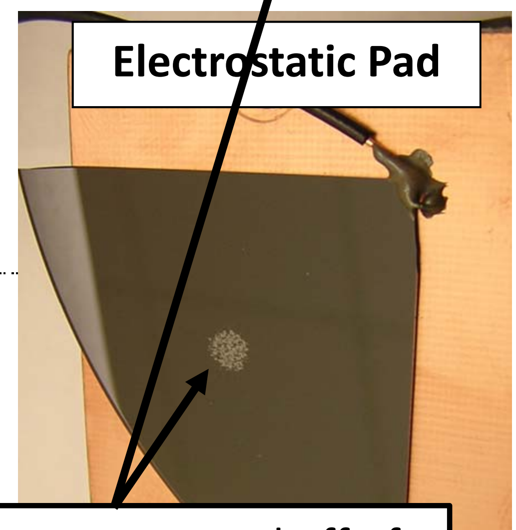
Prior measurements showed a 550 Hz resonance.

- Our prior work on frequency response done with a solid silicon electrode pattern showed a ~550 Hz resonance.



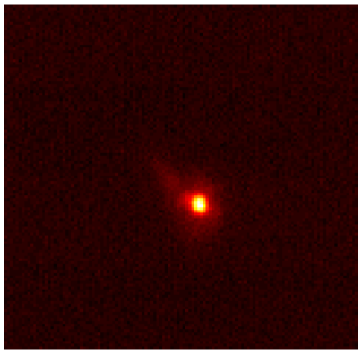




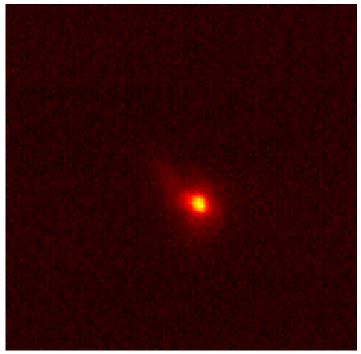
Aluminum was sputtered off of the membrane onto the silicon during electrostatic snap-down.

Long Exposure Closed Loop Strehl Ratio

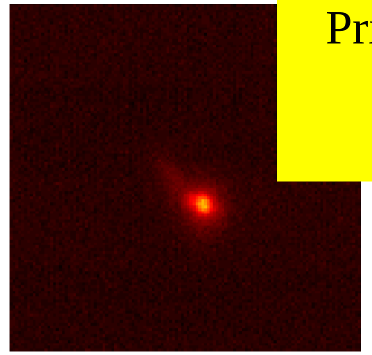
Prior laboratory work showed capability to compensate Kolmogorov turbulence



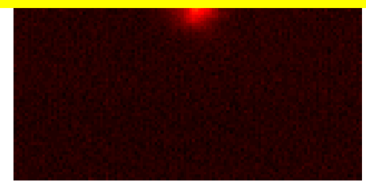
Strehl=0.28



Strehl=0.20

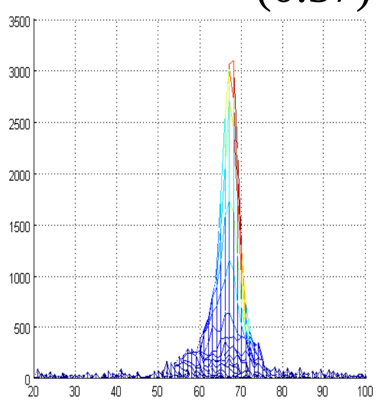


Strehl=0.15



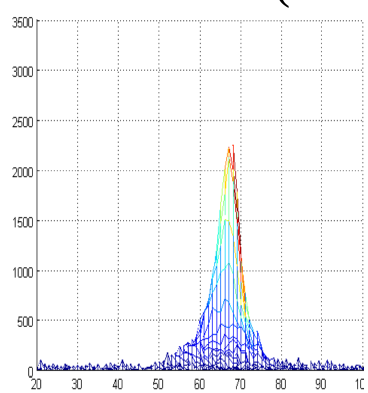
Strehl=.05

(0.37)



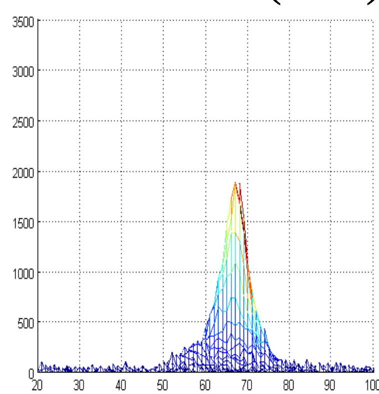
10 Hz

(0.25)



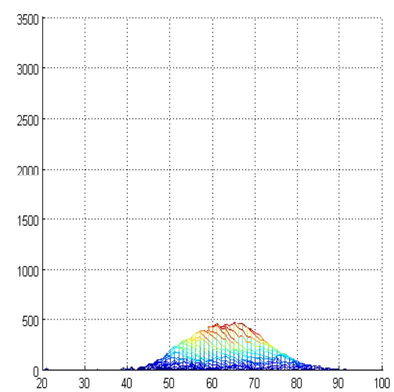
40 Hz

(0.16)



60 Hz

Predicted Strehl



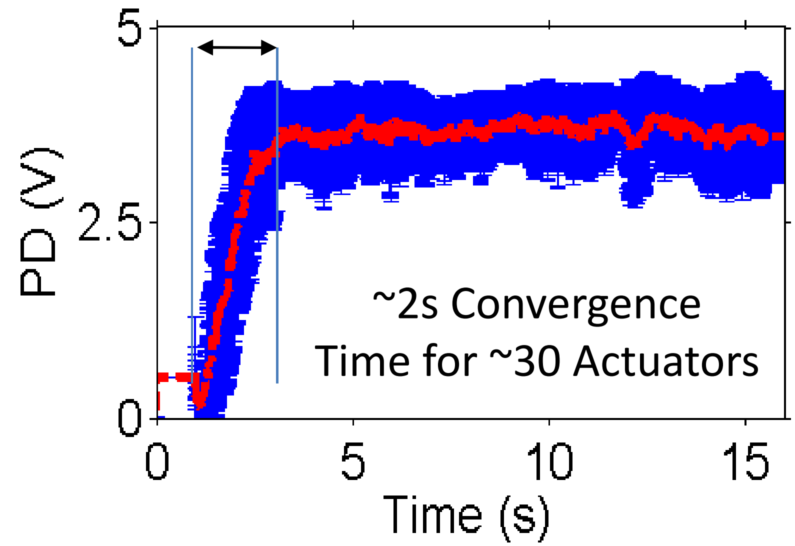
Open Loop

D. Dayton et al., "Characterization Of A Novel Electro-Static Membrane Mirror Using off-the-Shelf Pellicle Membranes", Conference on Adaptive Optics for Industry and Medicine 2007 (Galway, Ireland).

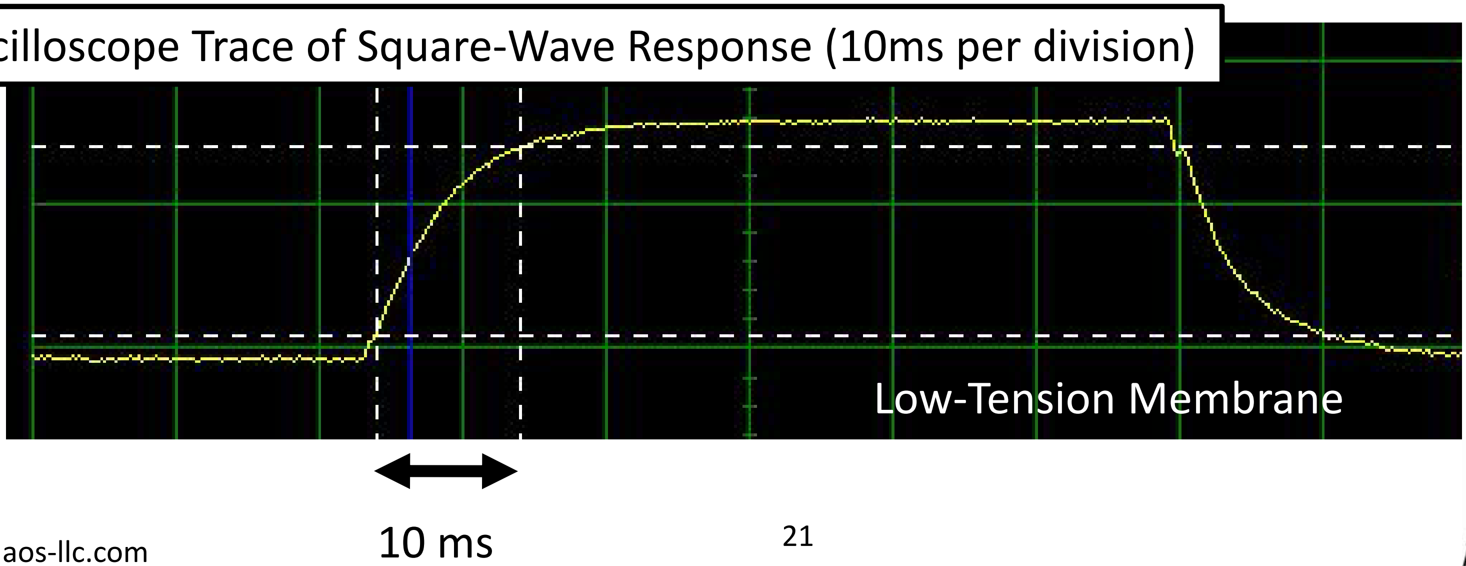
We measured a 10 ms rise and fall time on a membrane DM.

- During the 2007 work on making a metric AO system we found that we needed a settling-time delay.
- After this work we measured a 10%-90% rise time of ~10 ms.

SPGD System Testing Results



Oscilloscope Trace of Square-Wave Response (10ms per division)



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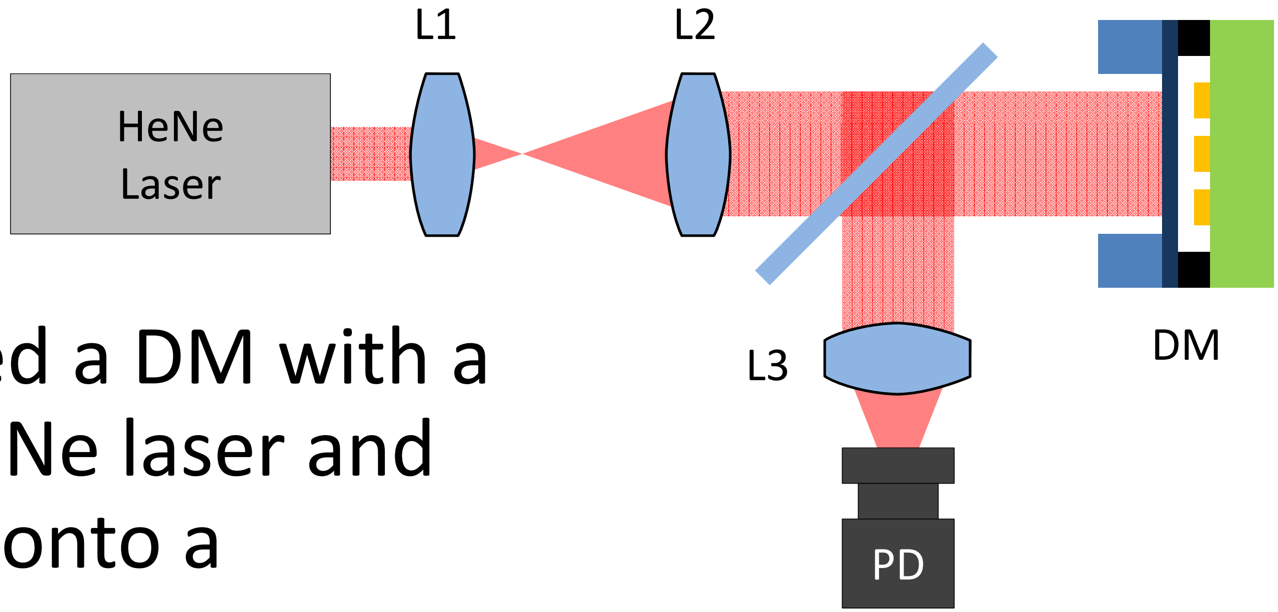
Measurement Setup



- We illuminated a DM with a collimated HeNe laser and sent the light onto a photodiode.
- The modulated spatial phase caused an intensity variation in the photodiode.

Intensity Transport Equation Approximation

$$\nabla \phi \propto I(+\Delta z) - I(-\Delta z)$$

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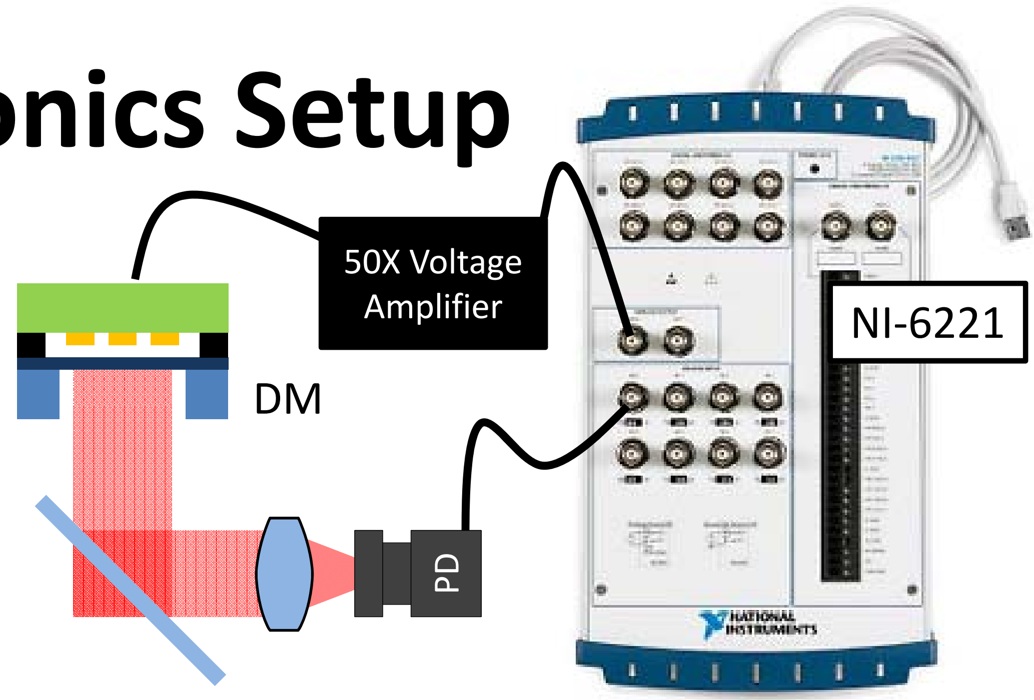
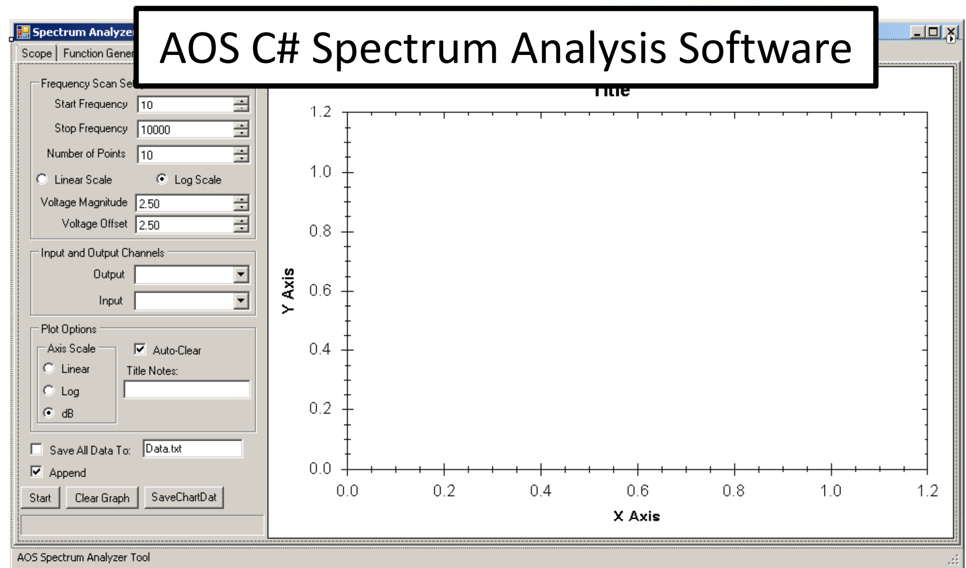
Electronics Setup

- **Drive Electronics:** Used a National Instruments (NI) 6221 driving an Apex op-amp non-inverting amplifier
- **Photo-Diode:** Signal from the silicon photodiode was digitized by the 6221.
- **Software:** Wrote custom C# application to scan drive frequency and measure results.





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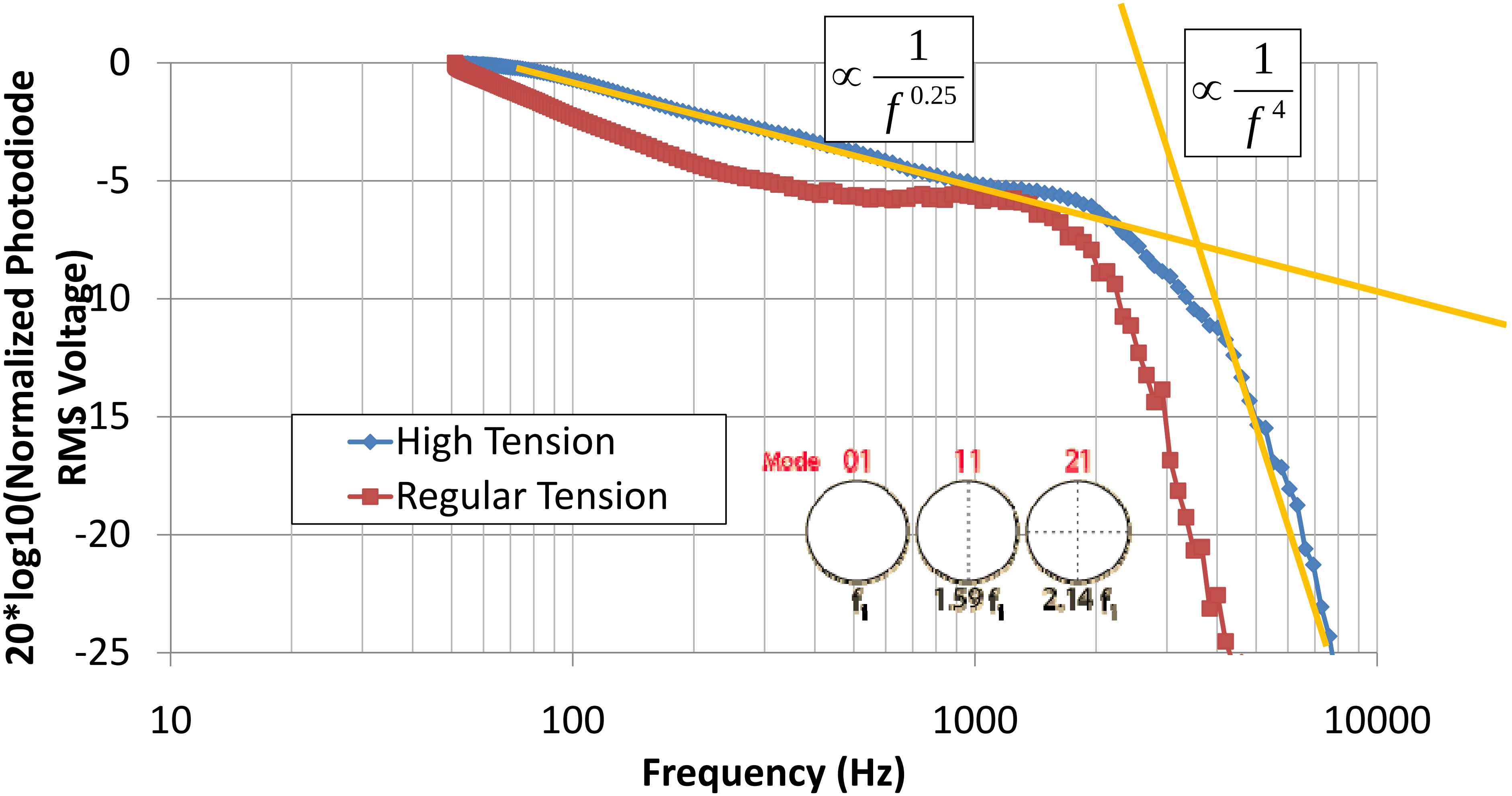
Measurement Results



http://hyperphysics.phy-astr.gsu.edu/Hbase/music/cirmem.html

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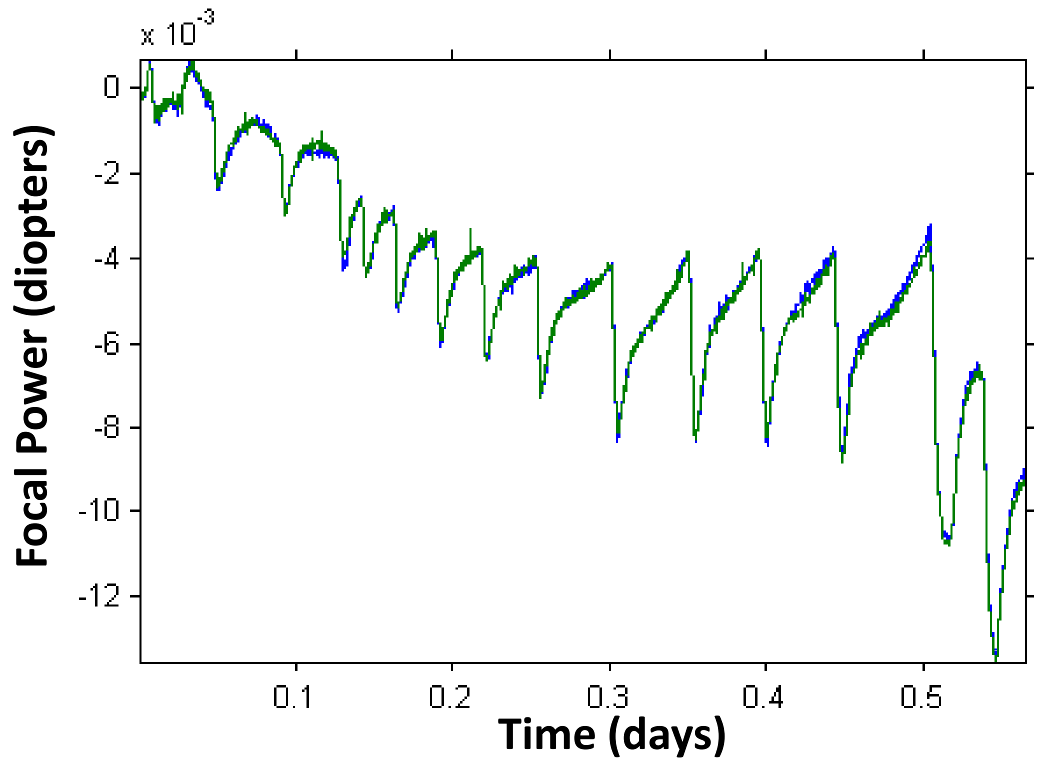
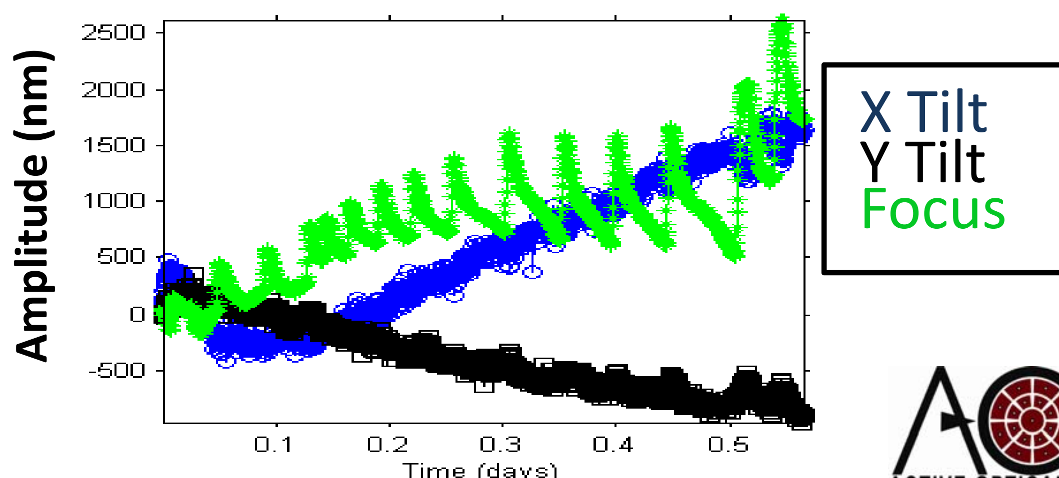
Long Term Drift in Focal Bias

- We placed a DM under 50% displacement bias and measured the change in the focal length over time.
- The focal power varied a small amount over time consistent with an air conditioning variation.





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Observed Environmental Effects

- Air Damping
  - We found that there was a slow ~$f^{-0.25}$ roll-off in frequency response before the resonance that we are attributing to air damping
- Humidity
  - We have observed a reduction in tension in high humidity. This is a known issue with nitrocellulose.
- Temperature
  - We found a slow low-amplitude variation in the bias state of the DM over hours that correlates well with air conditioning.

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Temporal Frequency Response Conclusions

- With the new high-tension membrane DMs we see a higher resonance frequency and a reduced effect of the air damping.
- Future Work:
  - Fix humidity and air damping issues by investigating different membrane material, sealing the membrane in metal coatings, and investigating low-pressure operation

Conclusions

- Spatially, we find that the polymer membrane DM performs like other membrane DMs.
  - $(\text{Zernike Order})^{-5/3}$
- Our polymer membrane DMs have shown enhanced temporal frequency response capability by increasing the membrane tension.
  - Resonance > 500 Hz
- We are working to mitigate humidity and air damping effects.

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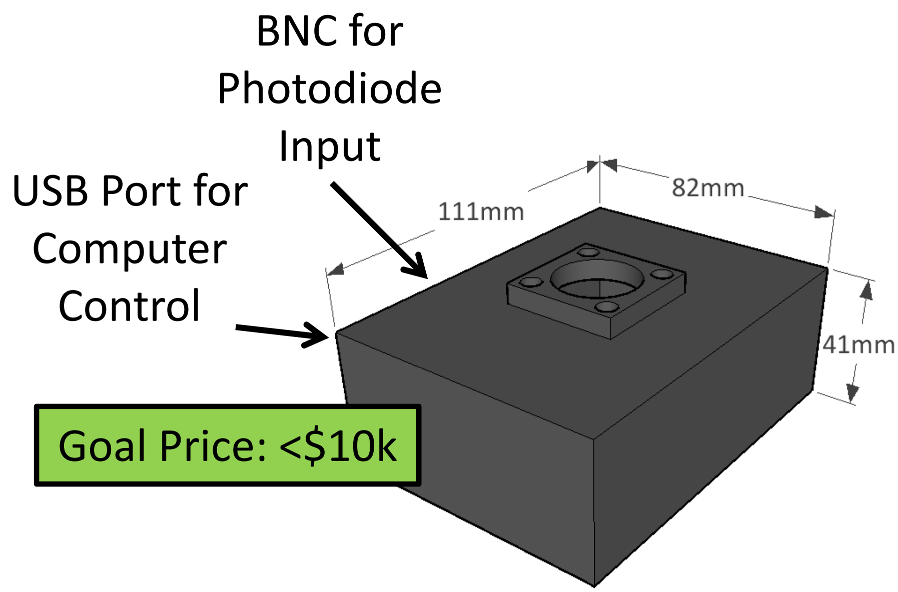
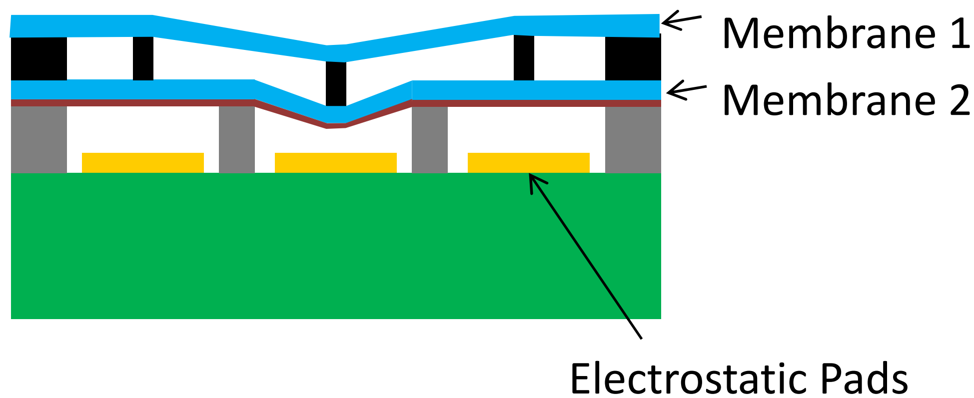
Select Future Work

- Integrated Drive Electronics, Metric AO & DM
- Inexpensive High-Speed Wavefront/Metric Camera Sensors
- 3-Layer Architecture Membrane DMs
  - Higher-Power
  - Faster
  - Larger Actuator Count





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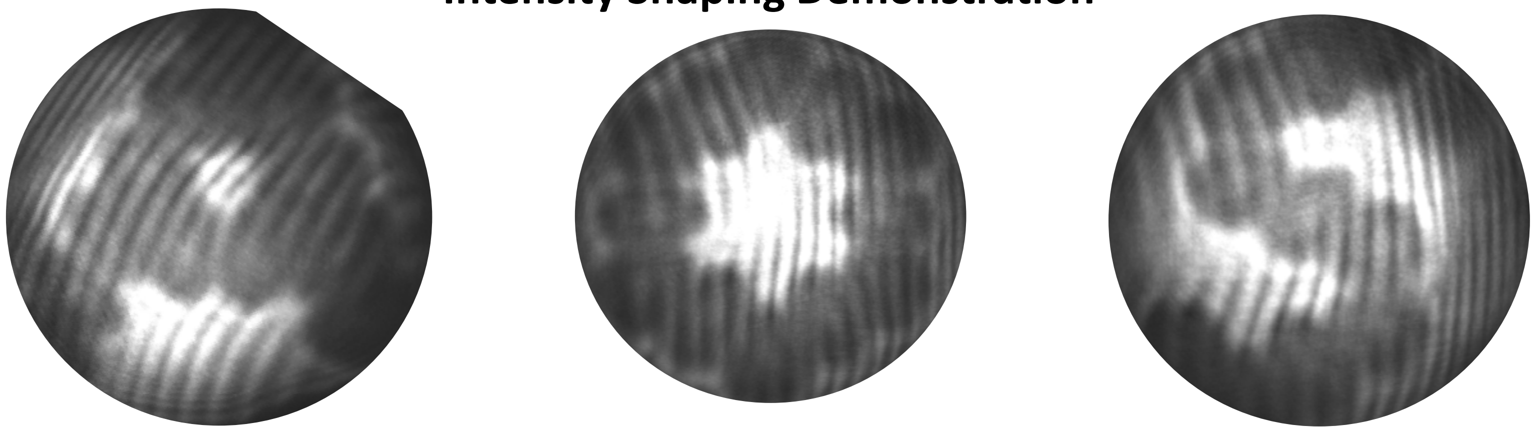
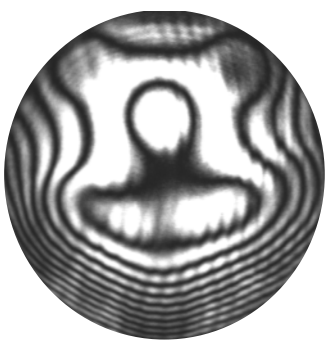
Intensity Shaping Demonstration



Questions?

Happy DM Interferogram



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