Experimental Beam Control using WaveTrain

Justin Mansell, Morris Maynard, Steve Coy, and Robert Praus
MZA Associates Corporation

Arturo Jacobs
Boeing-SVS

jmansell@mza.com

Outline

- Relay Mirror Application
- AO System Modeling
- AO System Design
  - Optical Design
  - Software Methodology
- System Construction and Results

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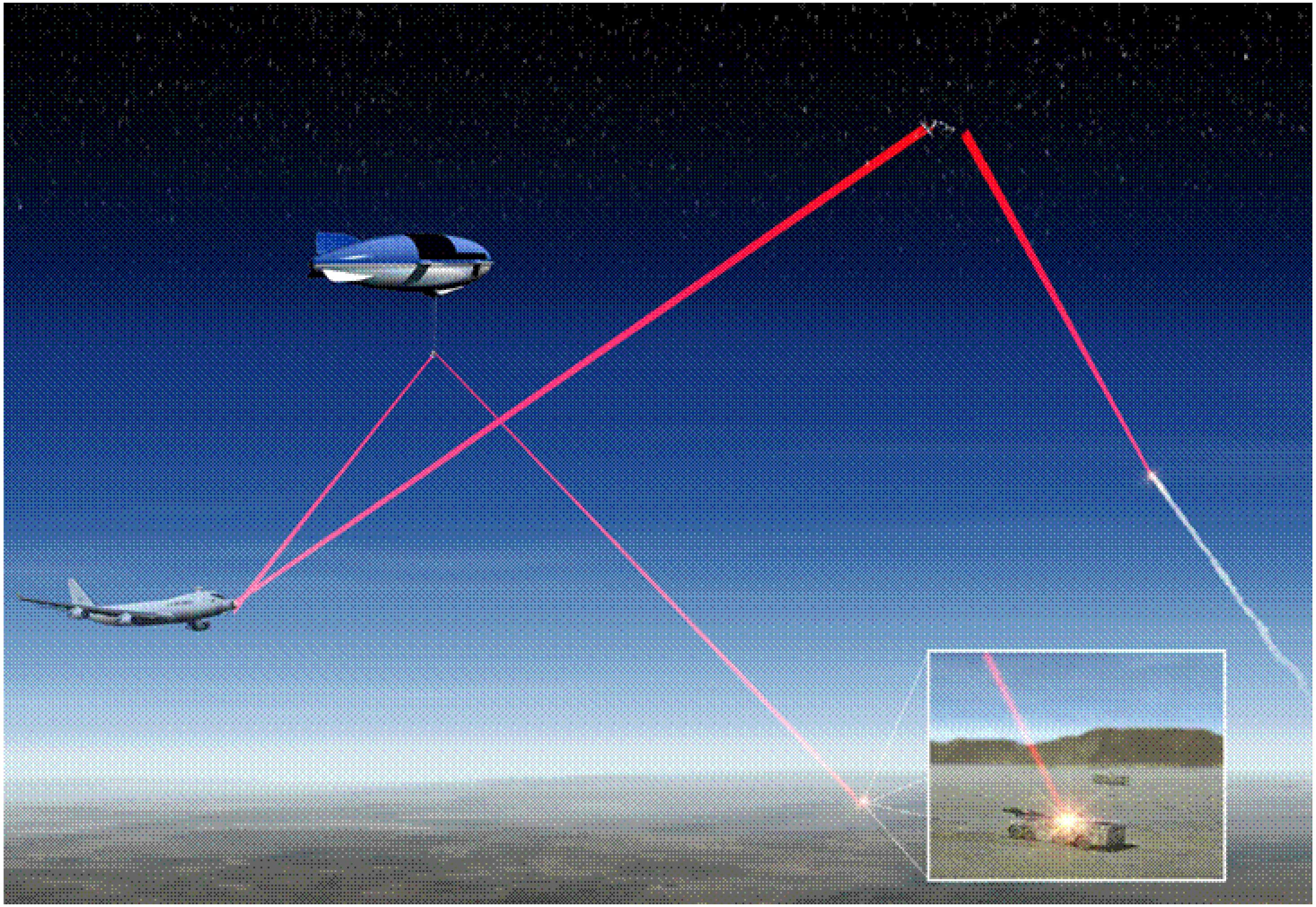
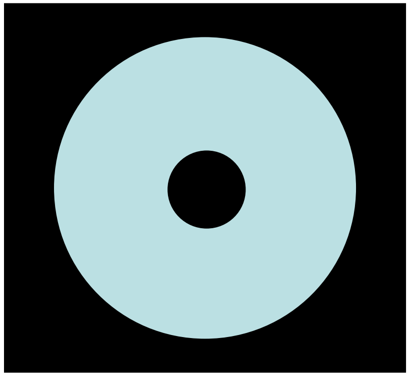
Relay Mirror Application



Picture provided by Boeing-SVS

PROBLEM: Optical Throughput & Beam Quality



Cassegrain Aperture

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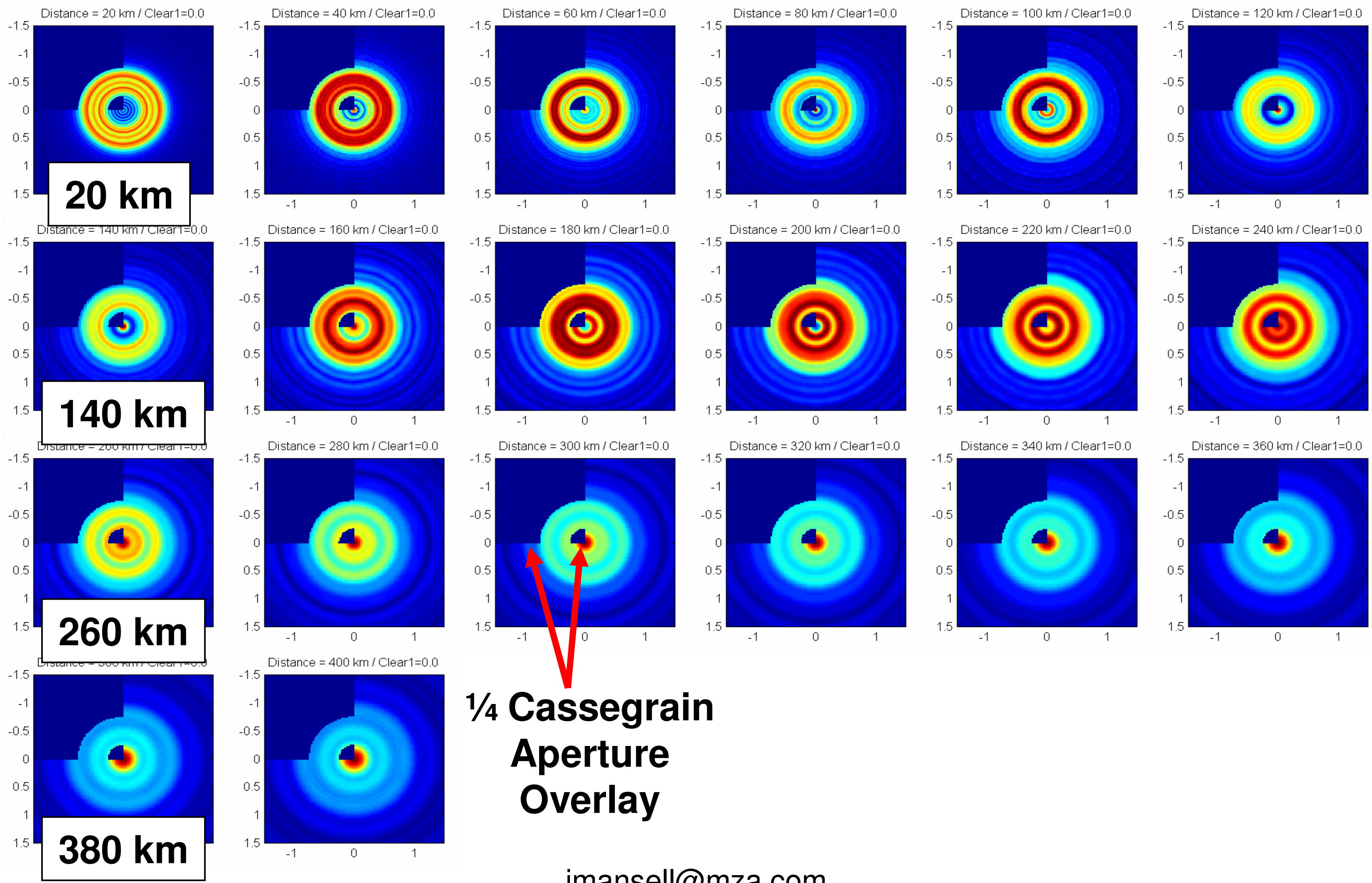
Propagation without Turbulence



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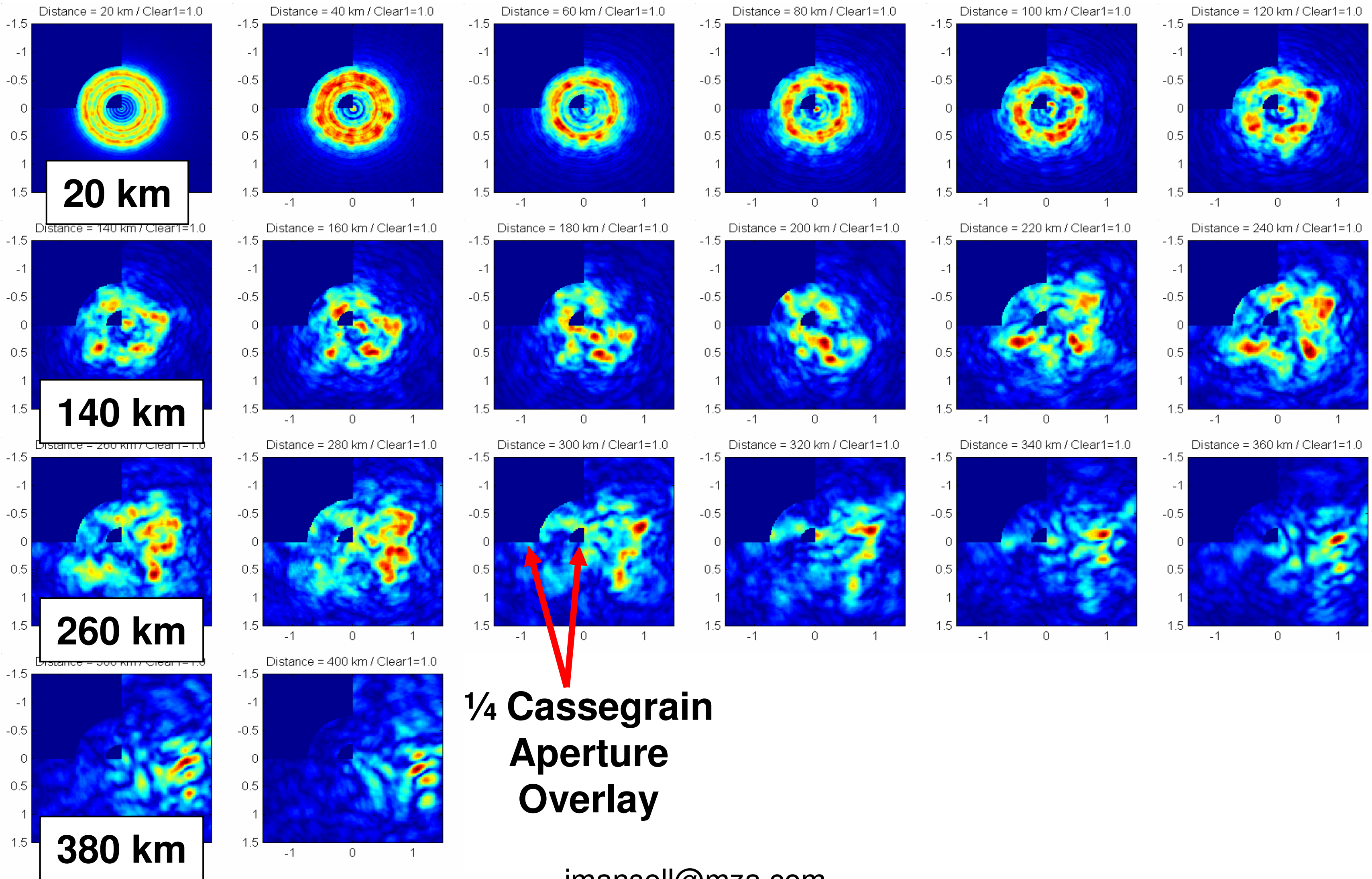
Propagation with Turbulence



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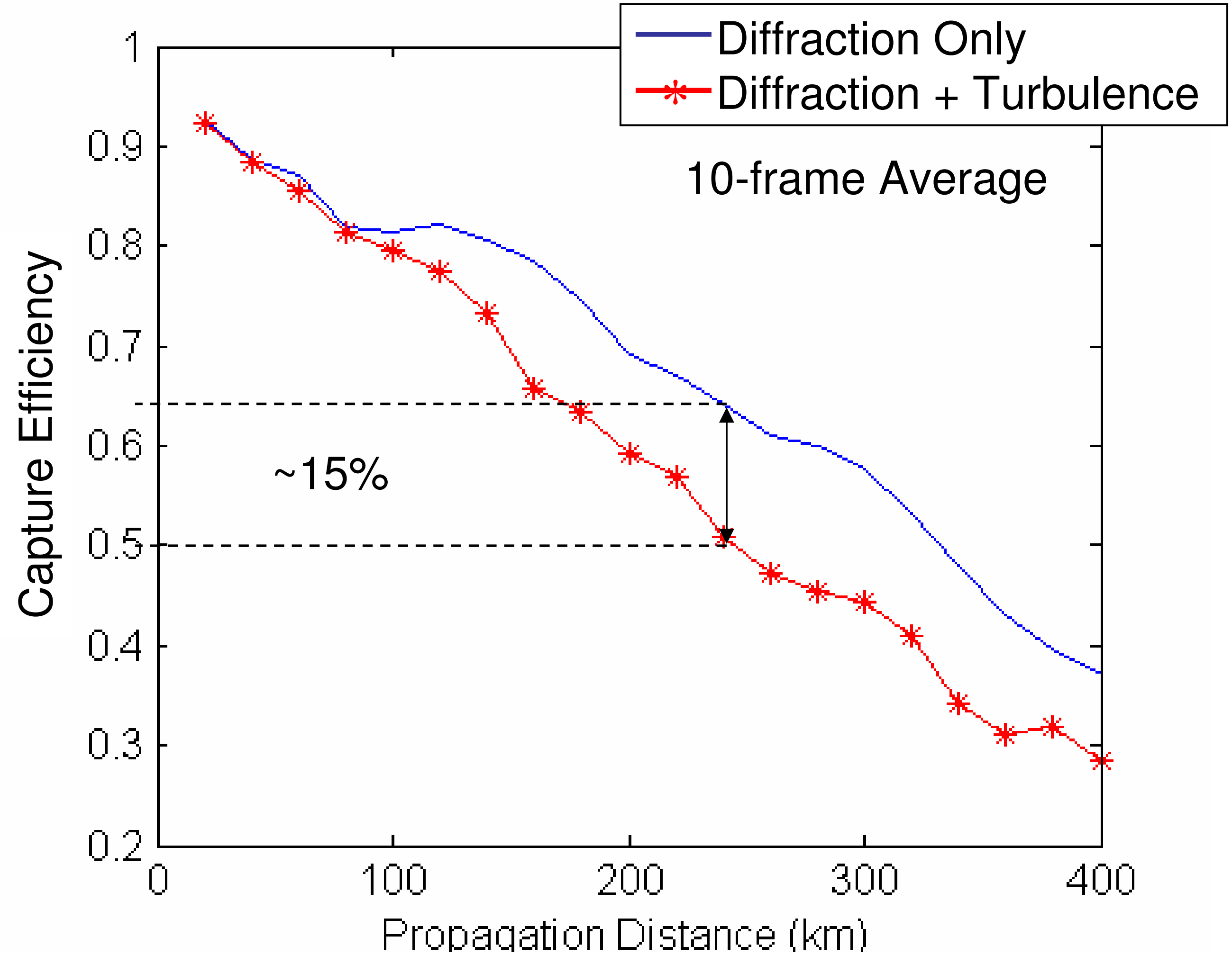
Capture Efficiency



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Existing Modeling

- WaveTrain has been used to model many different relay mirror engagements.
- Based upon this modeling, it has been shown that AO improves the relay efficacy.
- Boeing-SVS was interested in doing a laboratory demonstration of this system using low-cost AO hardware in their inventory.

Modeled AO System:

Can we build a useful AO system with what we have?

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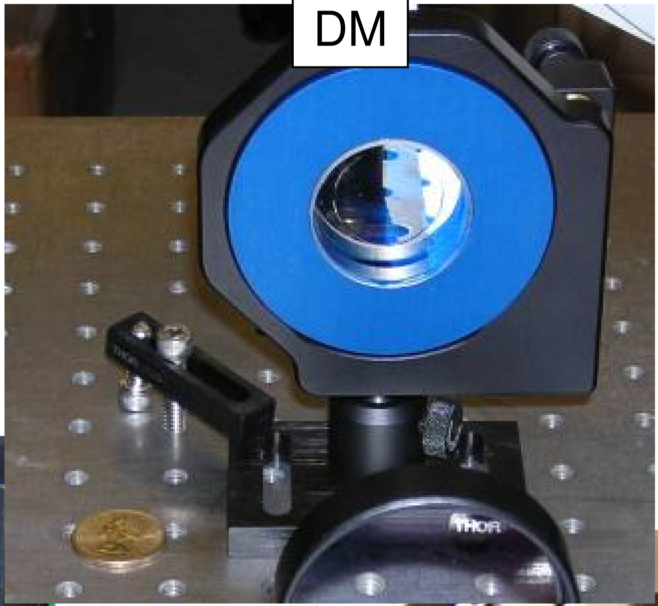
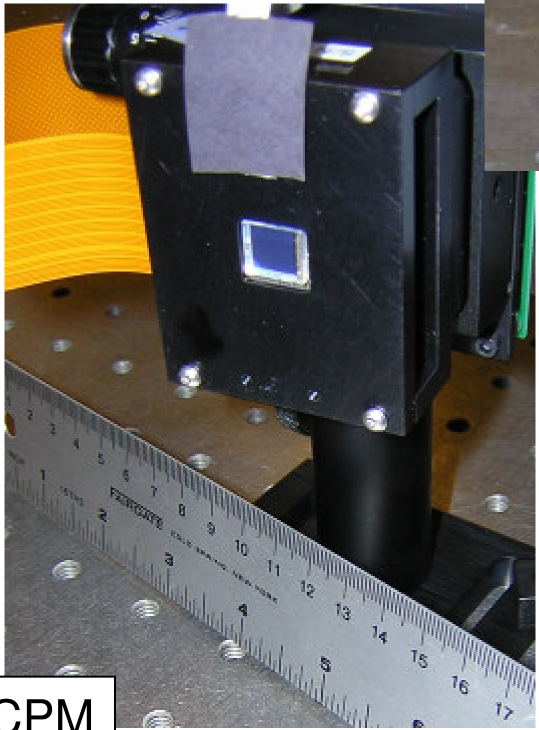
Existing AO Hardware at SVS

DM





LCPM

WFS

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Key Component Specifications

Device	Specifications
LC SLM	7.68 mm square (15-µm pixels, 512x512)
DM	25 mm (17mm actuated) 37 hex grid actuators / ~2.4 mm spacing
WFS	88x66 array of lenses (~5000 lenses) 72 µm square / 2-mm focal length (6.3 x 4.8mm)

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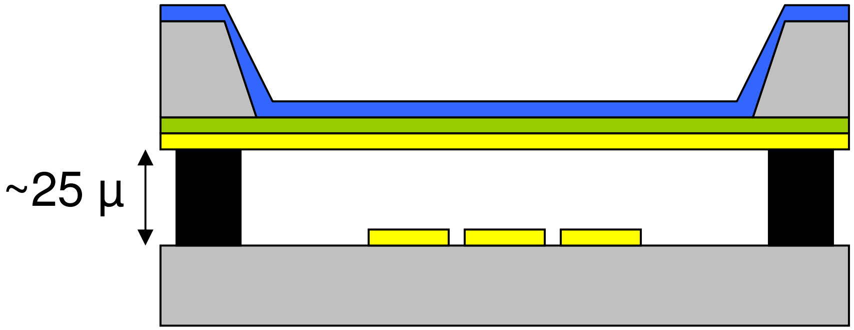
The Membrane Deformable Mirror

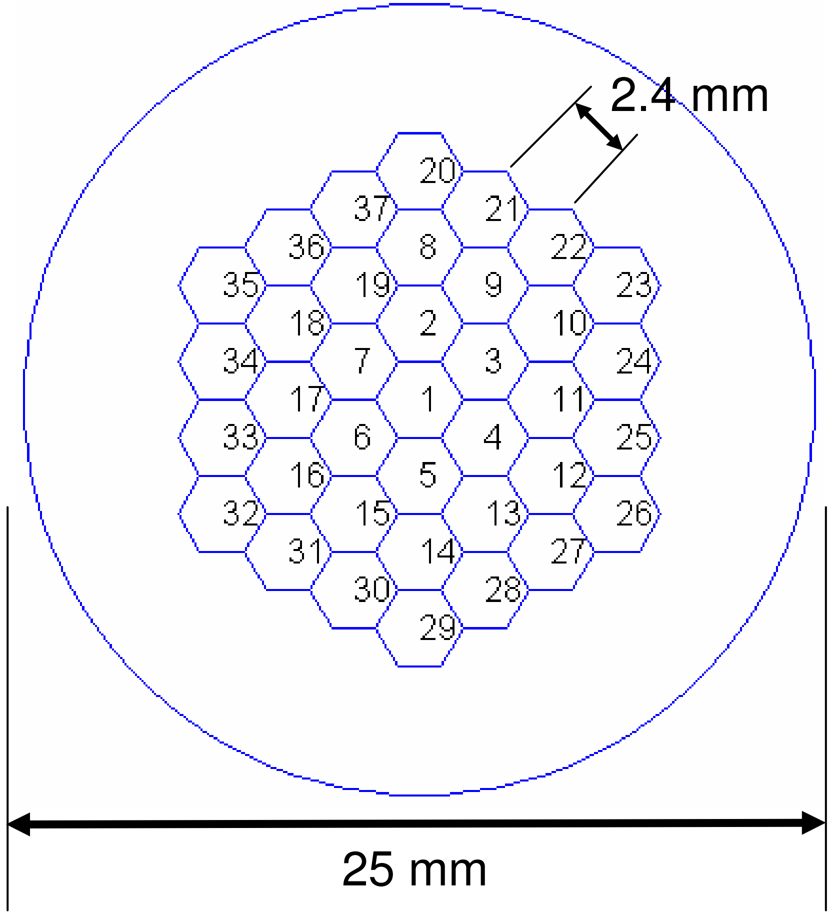
Cross-Sectional View



Key

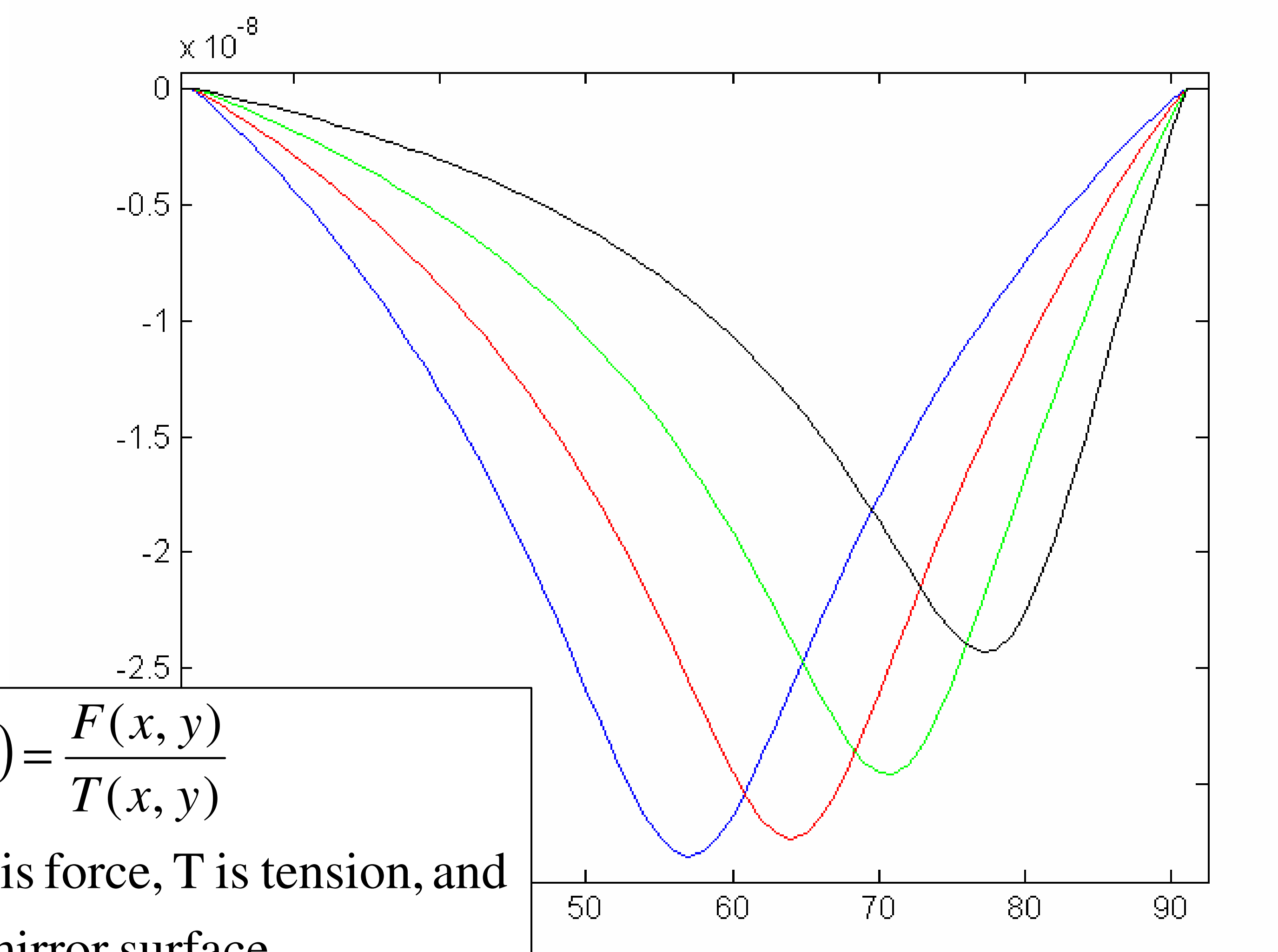
- Silicon
- Silicon Nitride
- Metal
- Reflector
- Spacer & Bond

Actuator Layout



NOTE: Assumed actuator size = 80% of actuator separation

Membrane DM Influence Functions



$$\nabla^2 z(x, y) = \frac{F(x, y)}{T(x, y)}$$

where F is force, T is tension, and z is the mirror surface

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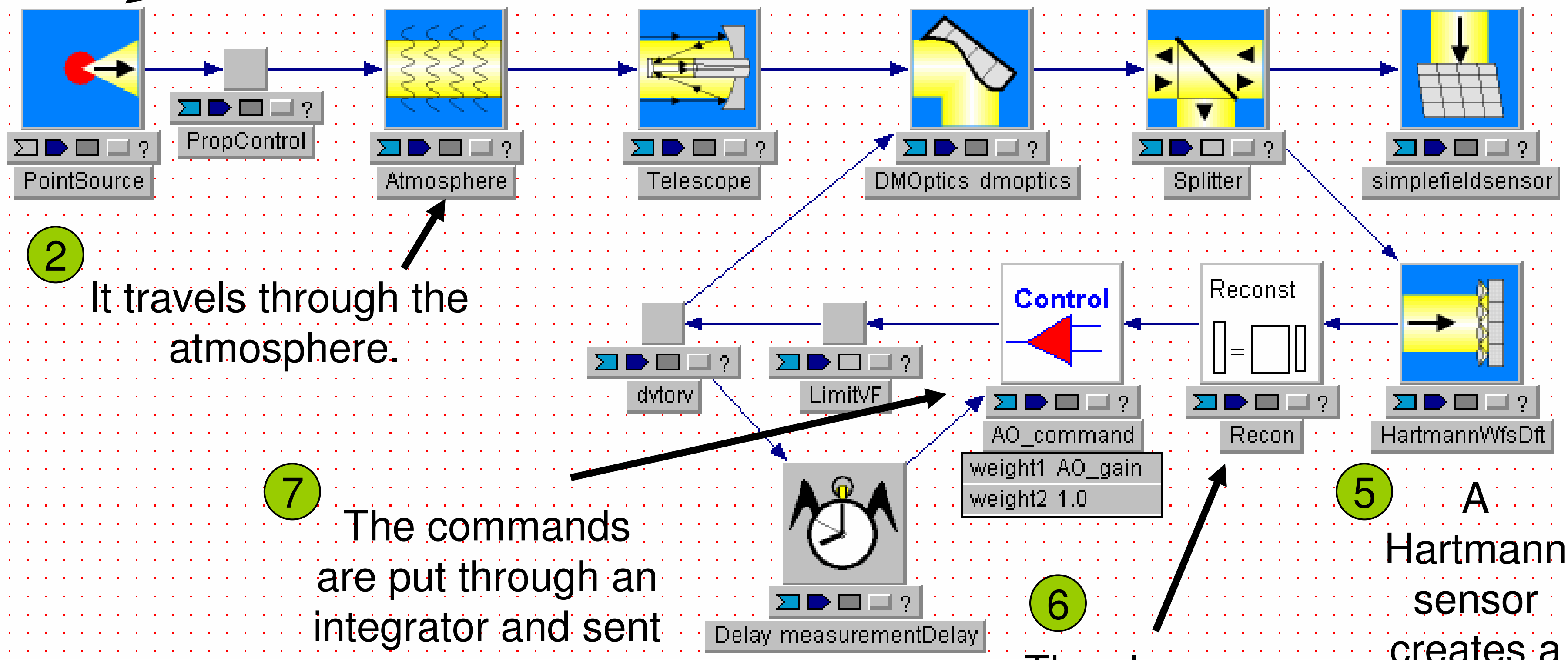
Basic WT Beam Control

1 Light is emitted from a point source.



2 It travels through the atmosphere.

3 A telescope collimates it.

4 Light reflects from a DM

5 A Hartmann sensor creates a vector of slopes.

6 The slopes are multiplied by a reconstructor matrix to create DM commands.

7 The commands are put through an integrator and sent to the DM.

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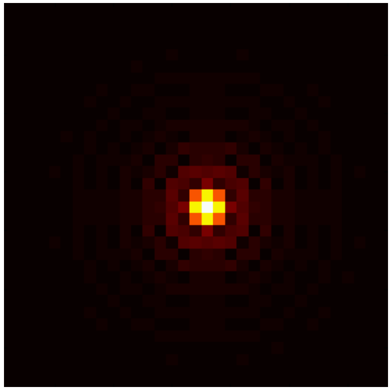
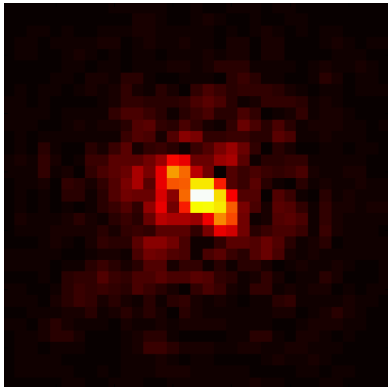
Effect of Turbulence on Image Quality

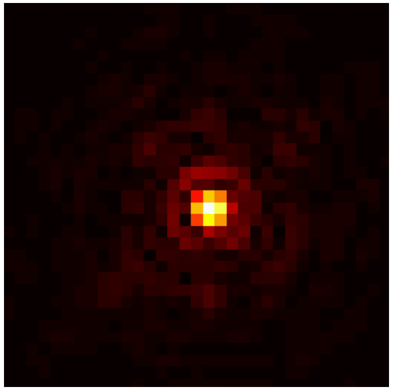
Ideal



Real without Adaptive Optics



Real with Adaptive Optics



Setup: *D/r_0=3.0, One phase screen, 50 m/s wind velocity*

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AO System Design

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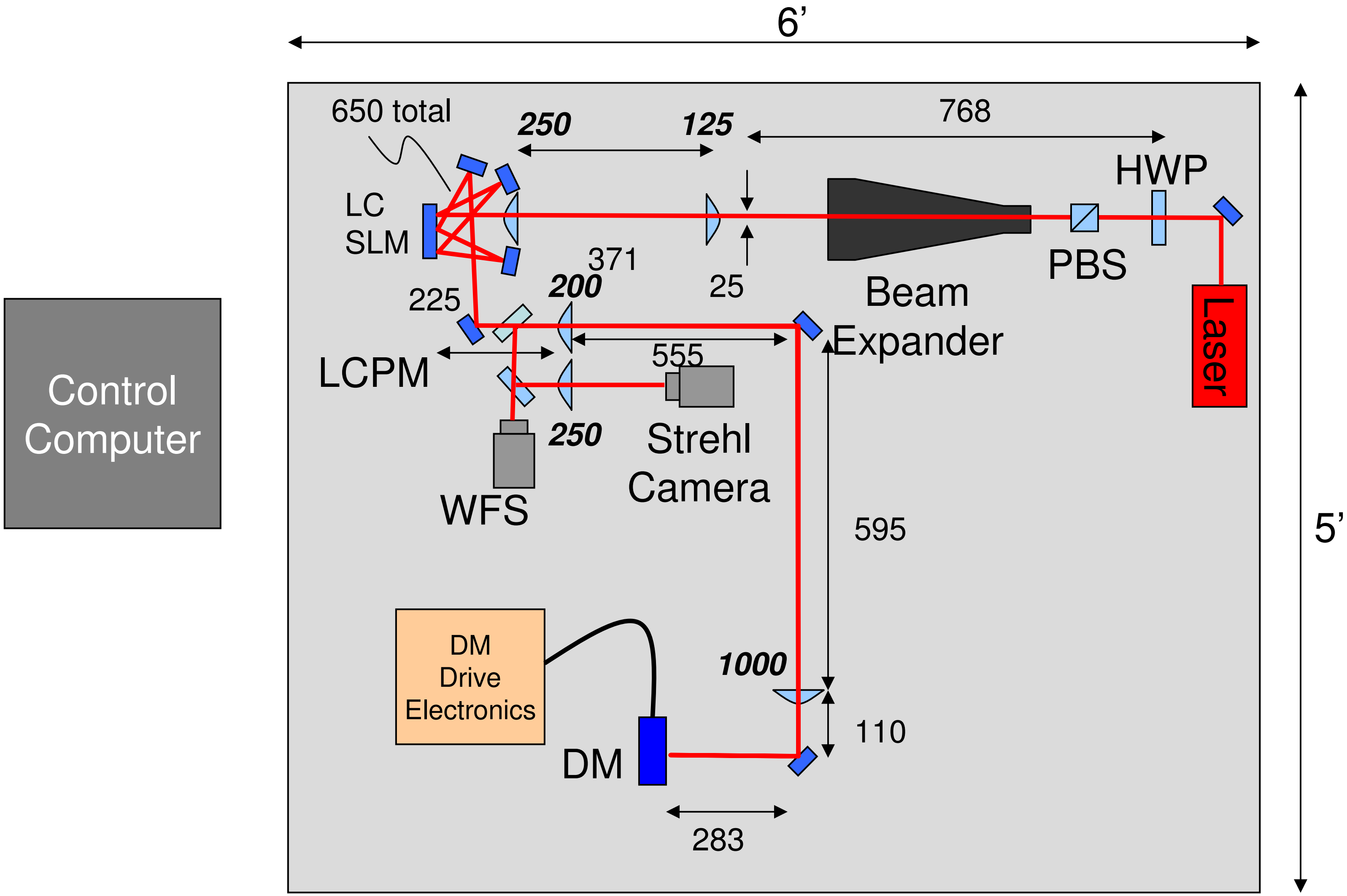
AO Project Goals

- Short Term (6-months):
  - Develop a complete functioning AO system to demonstrate atmospheric aberration compensation.
  - Anchor the AO laboratory results to the WaveTrain model.
- Long Term (6-18 months):
  - Explore advanced throughput enhancement concepts.

Triple-Pass Optical Setup



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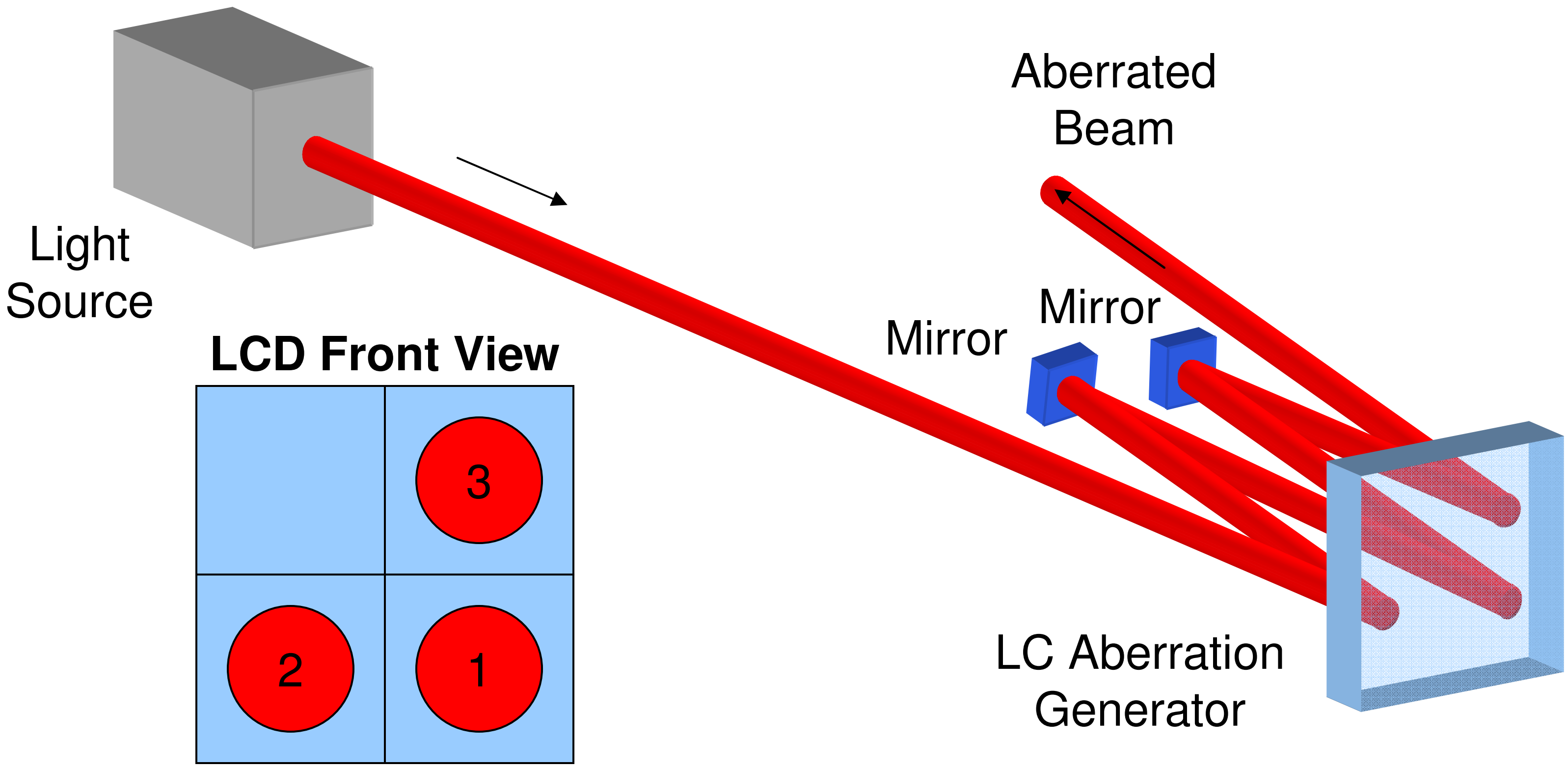
Triple-Pass Aberration Generator



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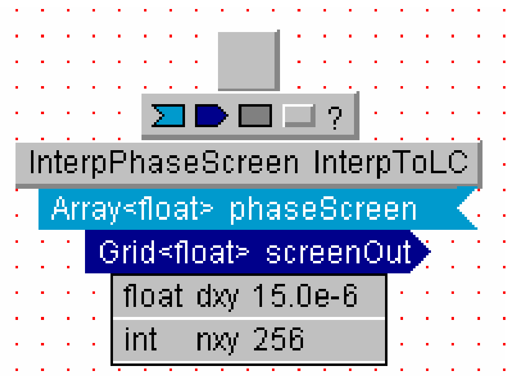
Software Implementation Strategy

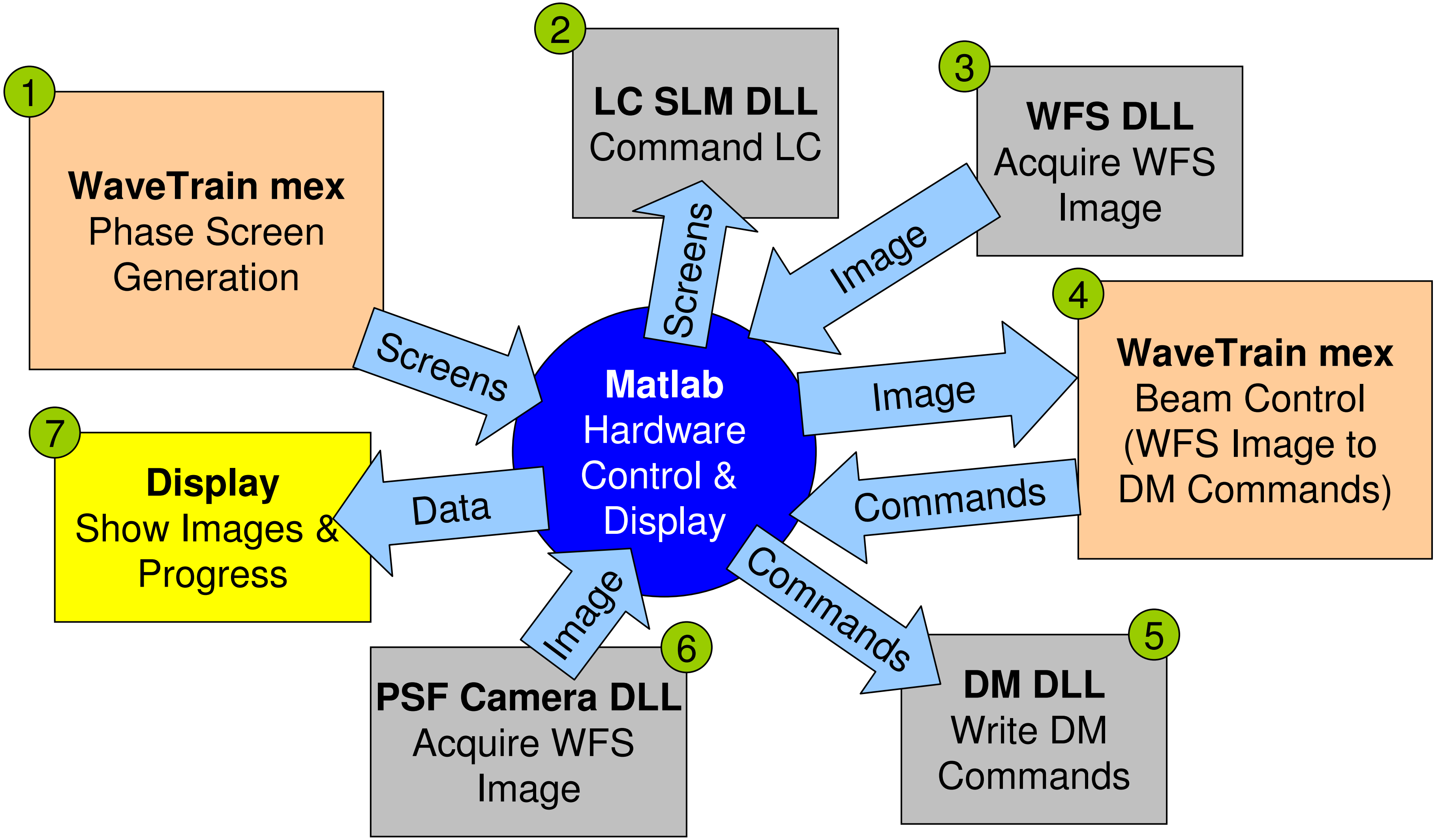
- We recognized that the setup, alignment, and characterization of the hardware would take a substantial portion of the allotted time.
- This did not leave a lot of time for software development.
- We chose to try to leverage the investment already made in WT software to avoid costly duplicative software development.

WT Data Processing Components

- Components built for signal processing can be triggered in several ways:
  - Output Requested
  - Input Changed
  - Temporal Triggering
- These components are well suited for arbitrary signal processing, like is done in Simulink or LabView.



Implementation Summary



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Software Additions and Modifications

- Atmospheric Path Model
  - Modify code to output phase screens
- MEMS Membrane DM Components
  - Include anti-snap-down software
- Hartmann WFS Components
  - Added input for reference spot locations
  - Added inputs for designating pixel areas for centroiding
  - Added a Southwell wavefront reconstructor
- Liquid Crystal Components
  - Created WT components to handle non-linear response and the static aberration of the LC backplane

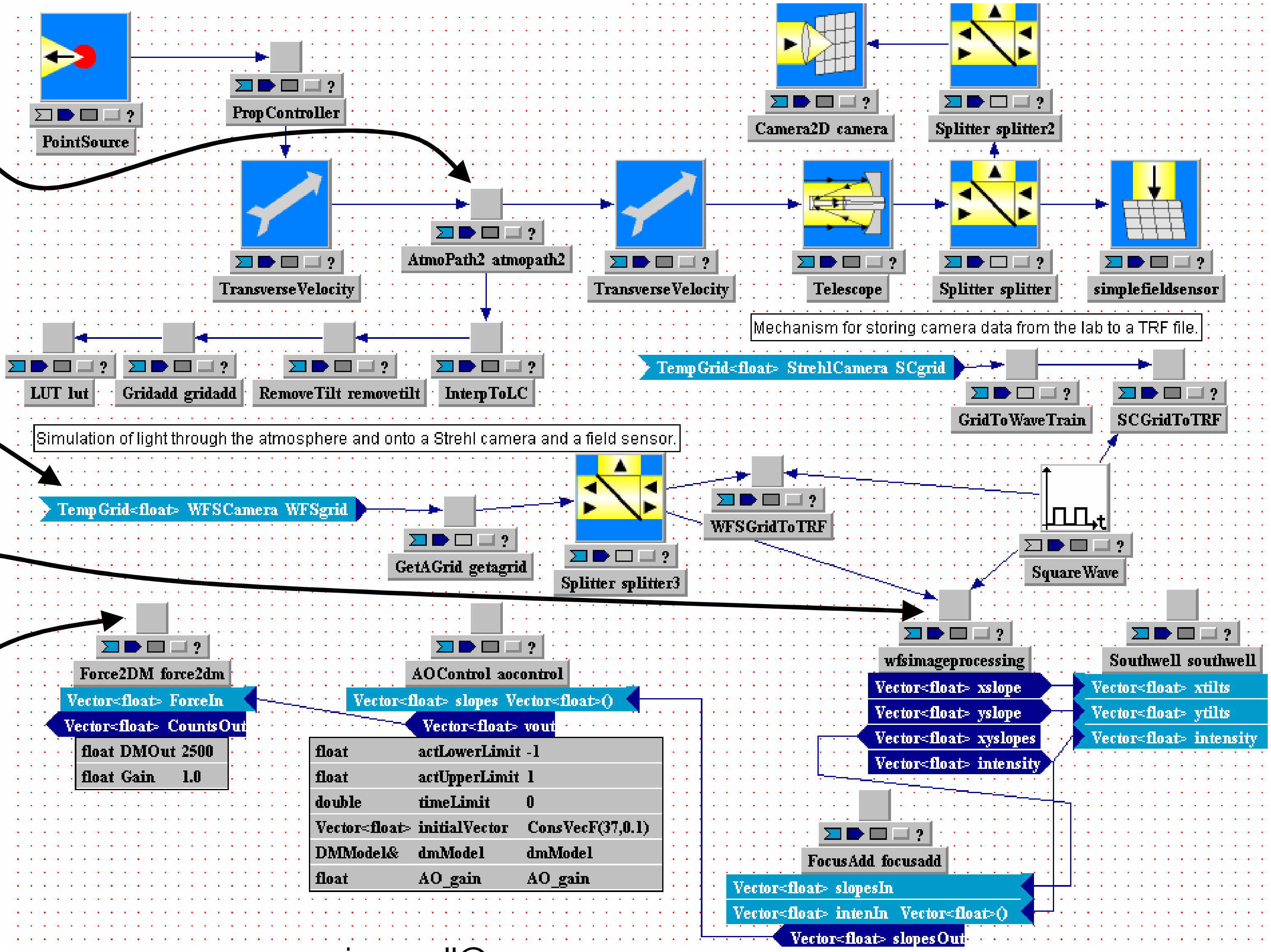
WaveTrain Setup

WT generates a phase screen ready for the LC.

A WFS camera image is input to the system.

Slopes are calculated.

The forces and voltages are calculated from the slopes and sent to the DM.



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Laboratory Results

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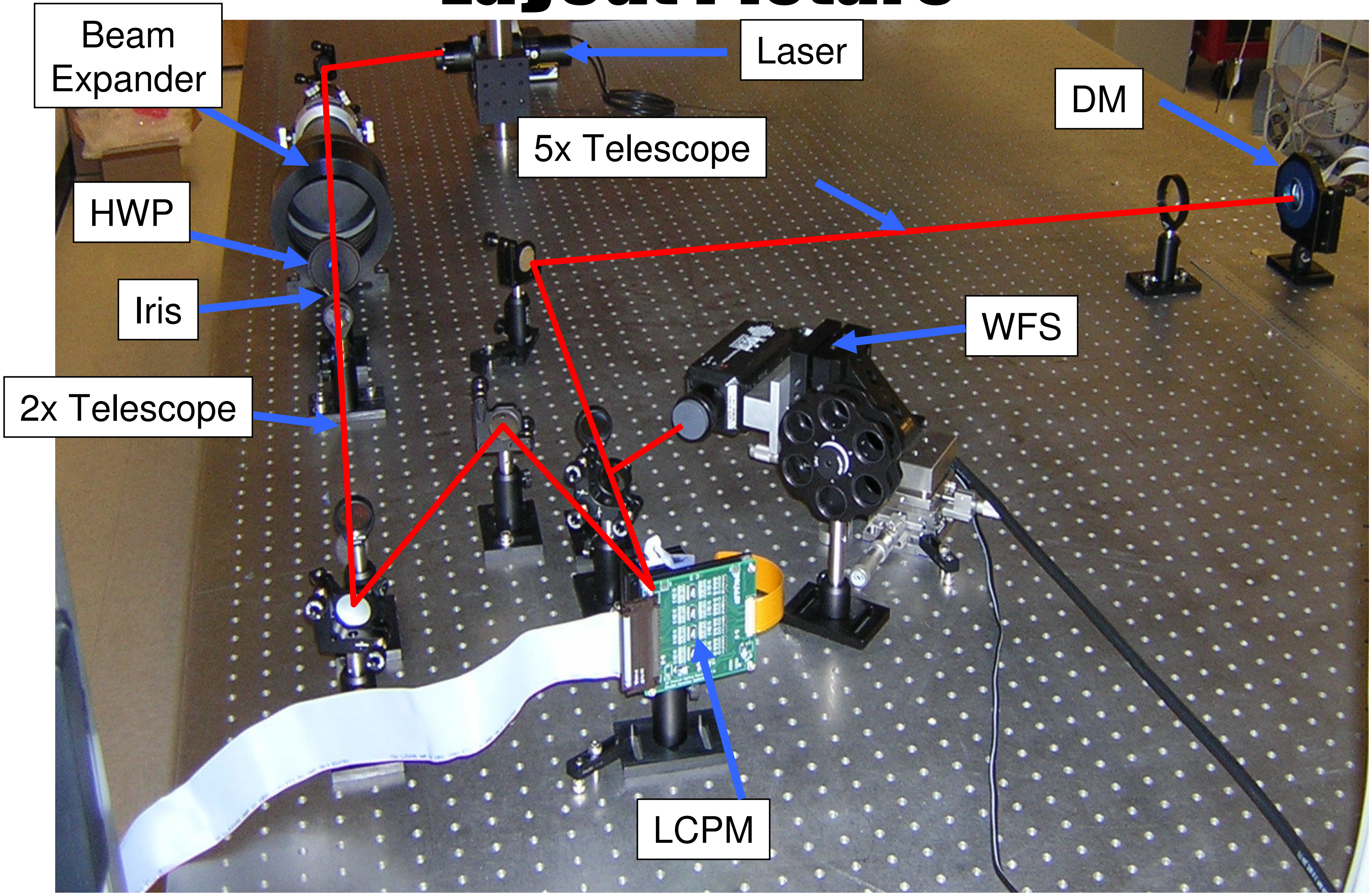
Layout Picture



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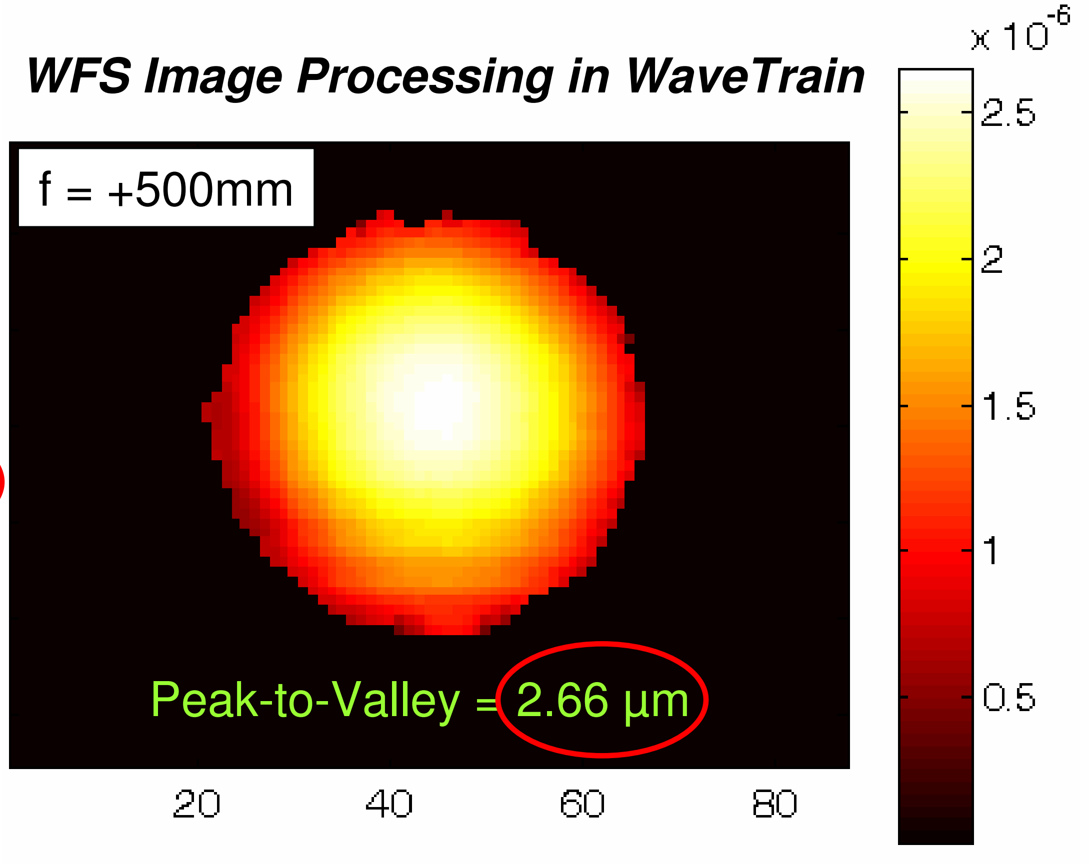
WFS Measurement

Theoretical Peak-to-Valley

$$s = \frac{r^2}{2 \cdot ROC} = \frac{\left(\frac{3.24}{2} mm\right)^2}{2(500mm)} = 2.62\mu m$$



The measured wavefront amplitude matched within 2%

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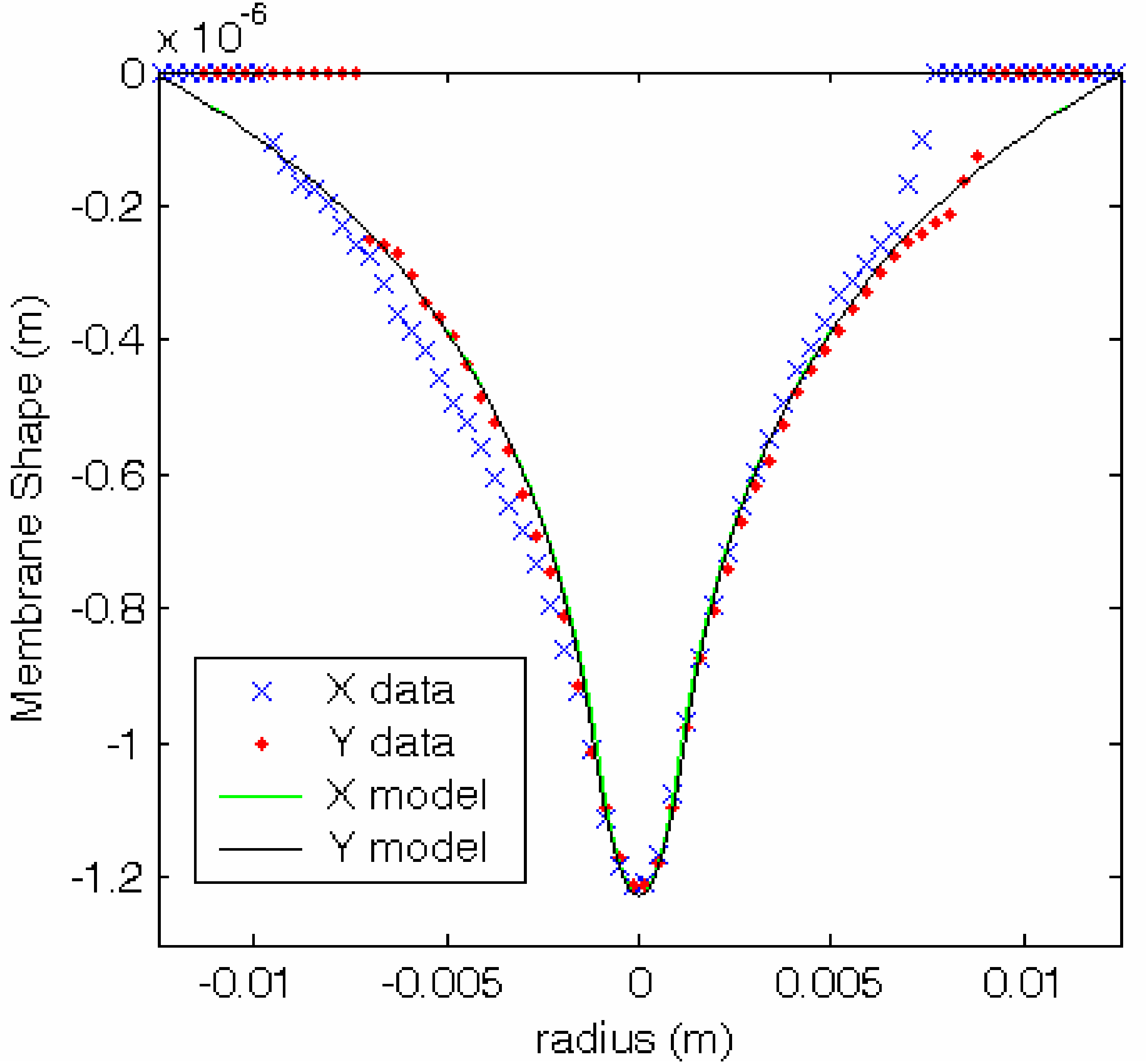
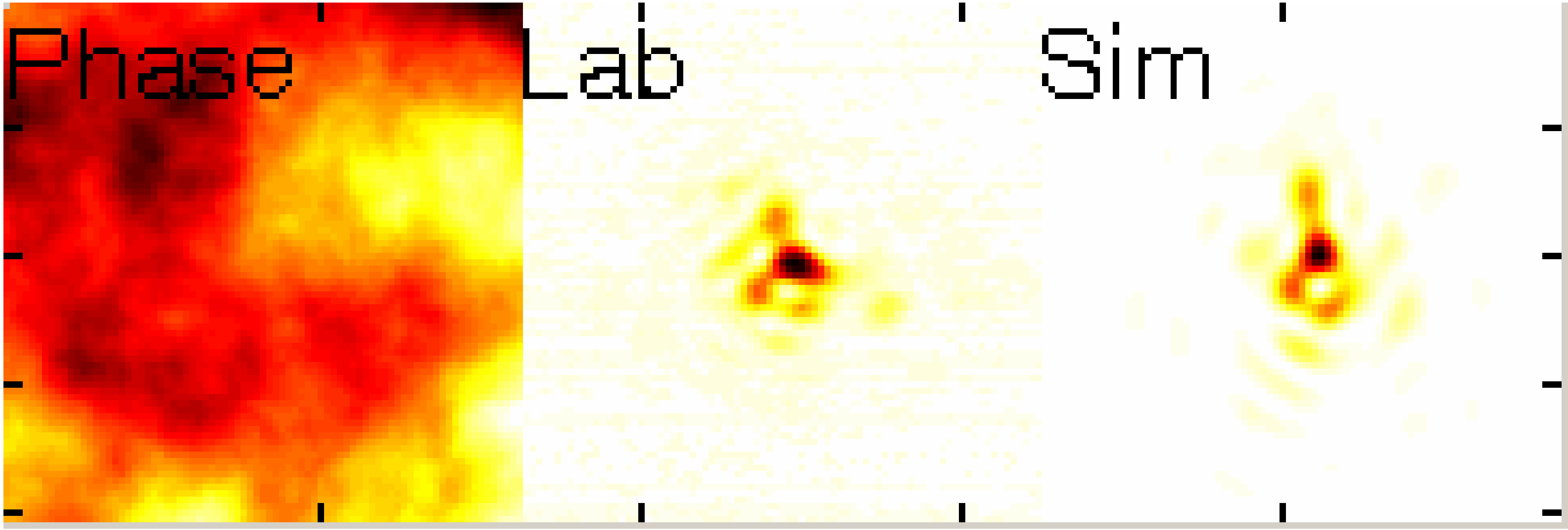
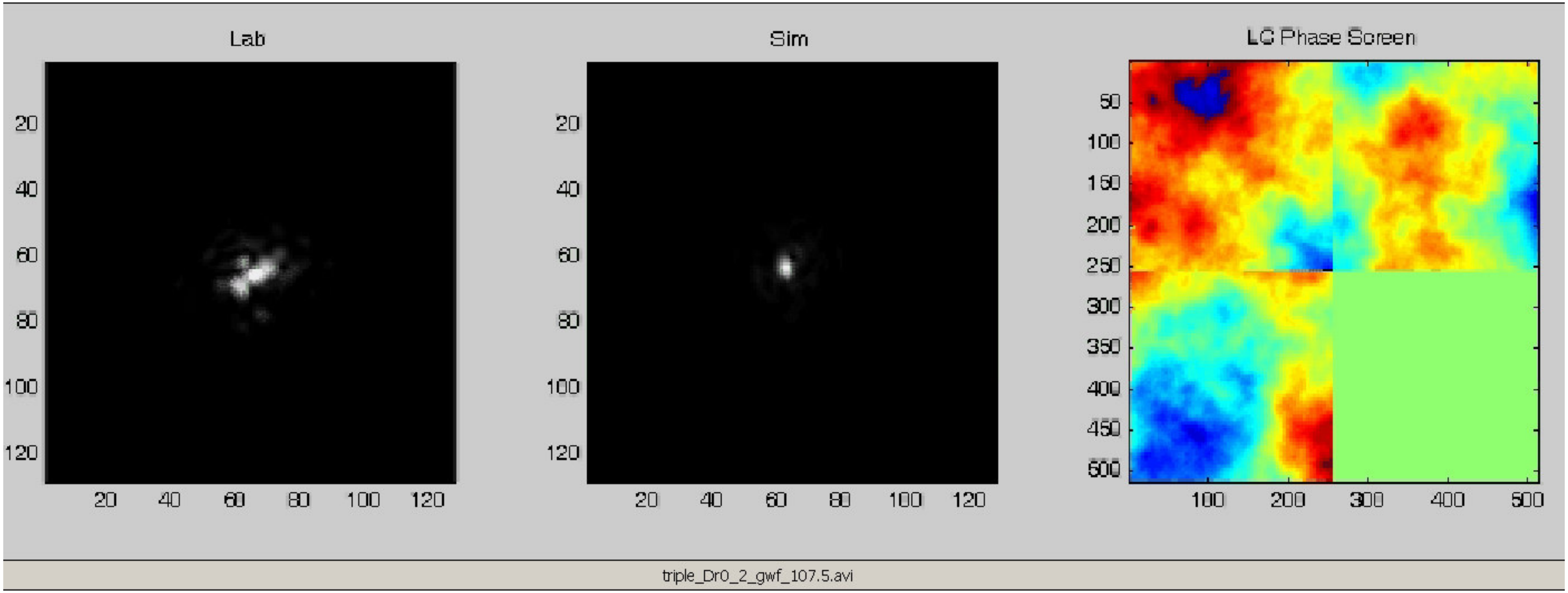
Comparison of DM IFs to Simulation



Comparison of Lab and Simulation Strehl Camera



Triple Pass



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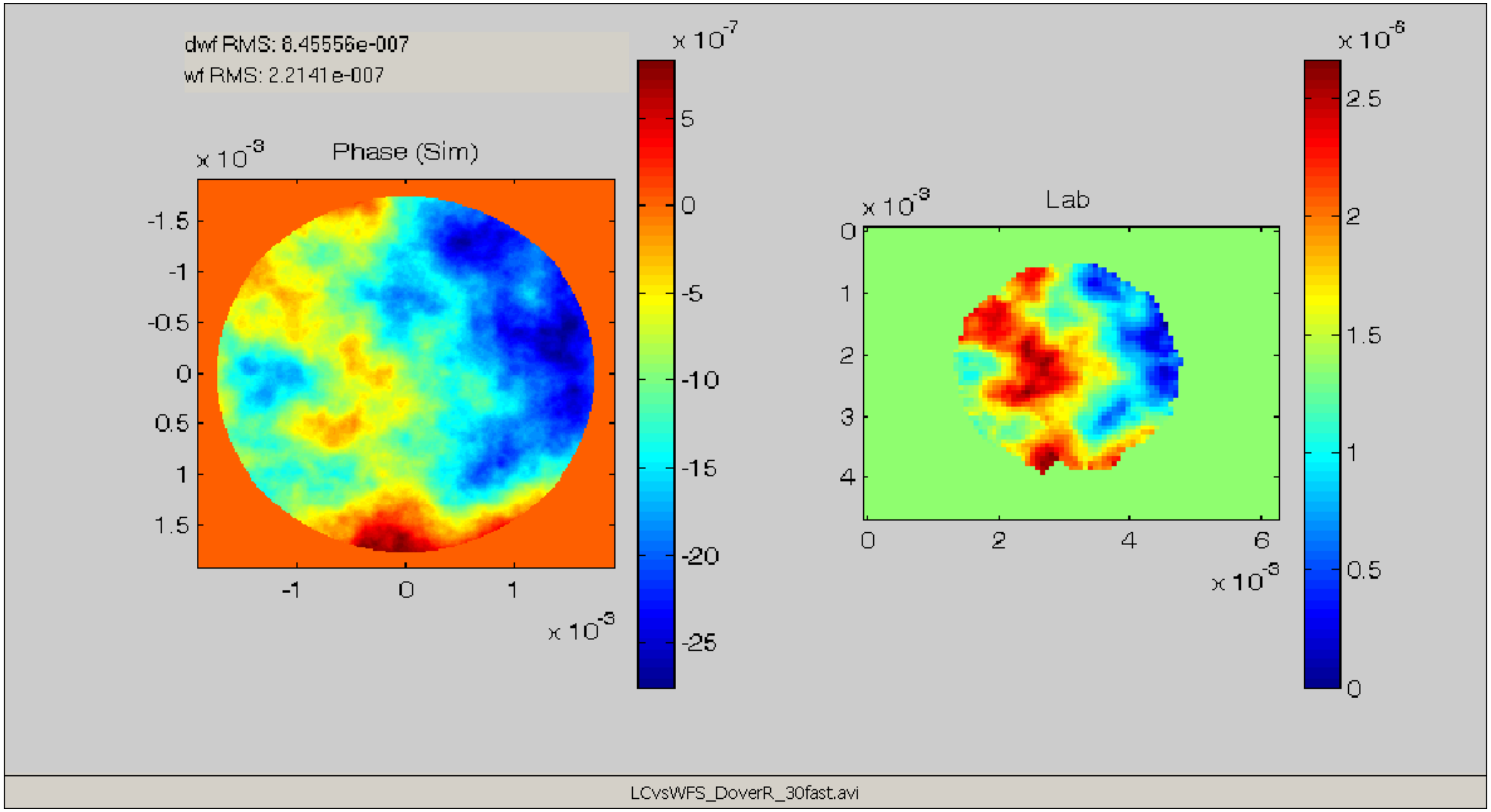
WFS Comparison

Phase Screen　　　　WFS Measurement



The measurements from the Shack-Hartmann wavefront sensor that were processed by WaveTrain matched the phase screen written to the LC within the noise floor of the sensor.

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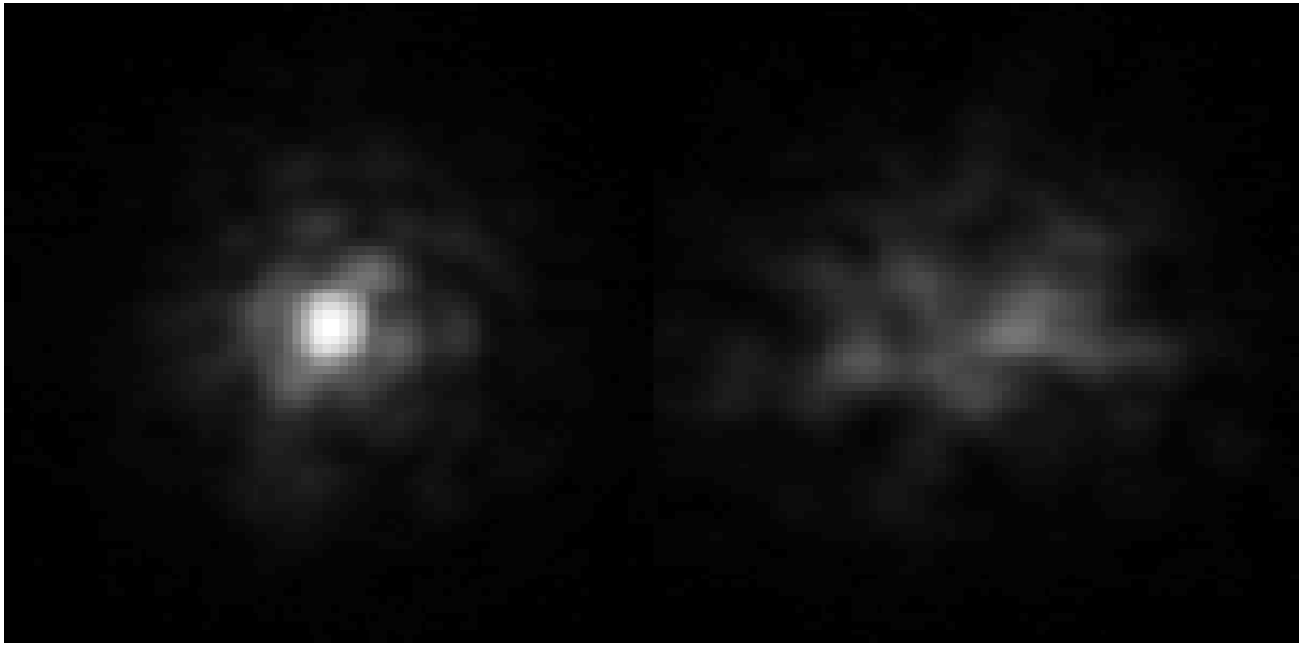
Closed-Loop Results



AO On AO Off

Averaged over 50 frames
$D/r_0 = 5$
$f_G = 100$ Hz, $f_{Loop} = 1000$ Hz
Modes removed: 2

Strehl Improvement:
2.12 (On / Off)
0.47 (Off / On)

jmansell@mza.com

Conclusions & Future Work

- WaveTrain was used as the processing core to implement a closed-loop AO system.
- The AO system components were anchored to a WaveTrain simulation.
- Future Work:
  - Anchor the WT system performance to the model.
  - Create WT components to direct write data to the hardware.
  - Use a shared memory buffer to communicate with a display and interface application.
  - Model advanced relay engagement concepts.

jmansell@mza.com