Adaptive Optics with Adaptive Filtering and Control

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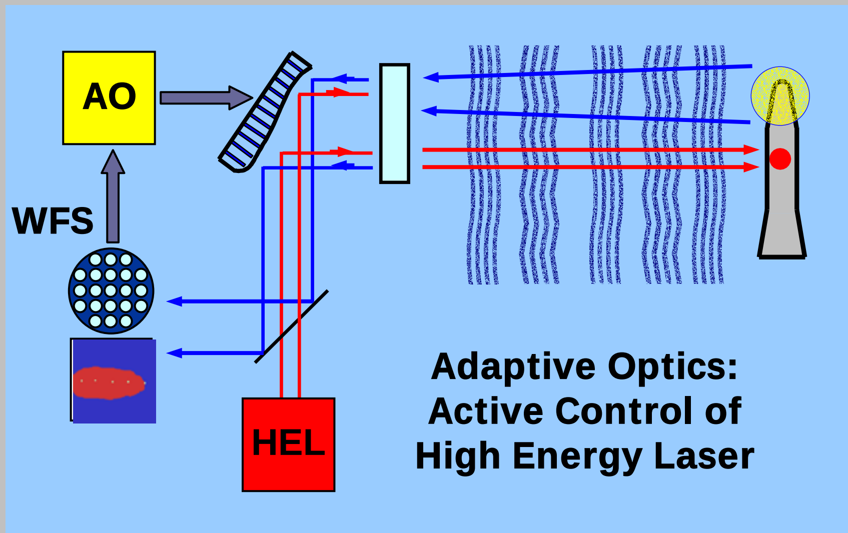
Abstract

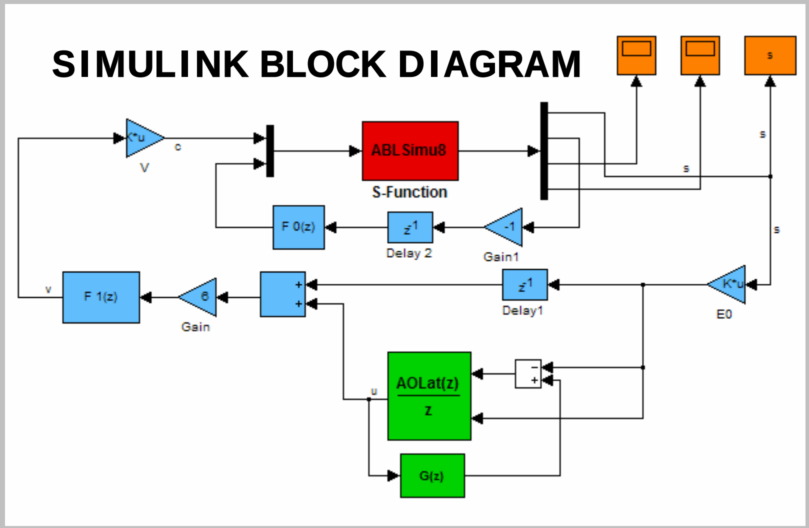
This presentation describes improved adaptive and quasi adaptive filtering and control methods for adaptive optics. Adaptive compensation is needed in many adaptive optics applications because wind velocities and the strength of atmospheric turbulence can change rapidly, rendering any fixed-gain reconstruction algorithm far from optimal. The performance of the new methods is illustrated by application to recently developed simulations of high energy laser propagation through extended turbulence.

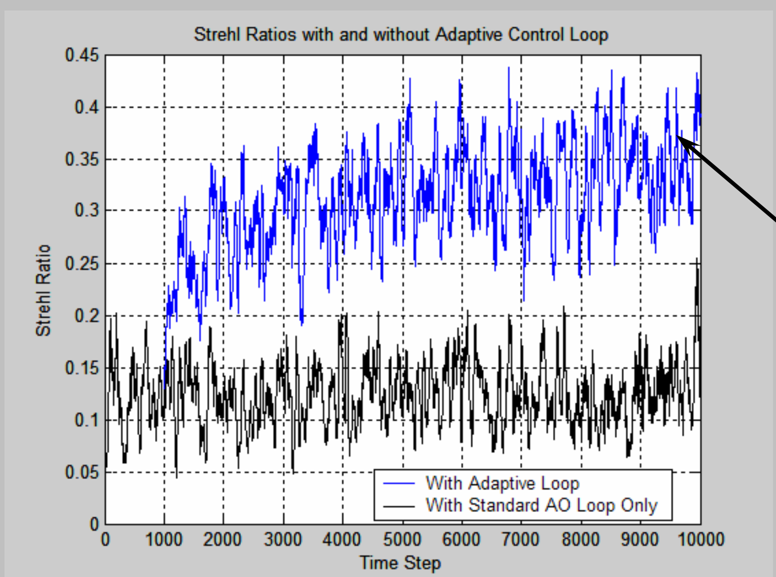
The presentation covers three advances over our previous publications on the use of adaptive filtering and control in adaptive optics. First, the adaptive loop is designed to use the closed-loop wavefront sensor vector as the input to the adaptive loop, as opposed to the estimate of the open-loop wavefront sensor vector used in previous publications on this subject. Second, it is demonstrated that a quasi adaptive loop, which updates gains periodically from short data sequences, often is as effective as the fully adaptive loop, which updates gains at every time step. Finally, the adaptive optics simulations presented here are much more realistic than those in our previous publications because a recently developed adaptive optics simulation with high-fidelity wavefront propagation model and detailed sensor characteristics, including nonlinearities, is used.

Adaptive Optics for HEL Beam Control

UCLA, Mission Research Corp., Tempest Technologies







Red Block: WaveTrain HEL System Model (Matt Whiteley, Mission Research Corp.)

Blue Blocks: Standard AO loop

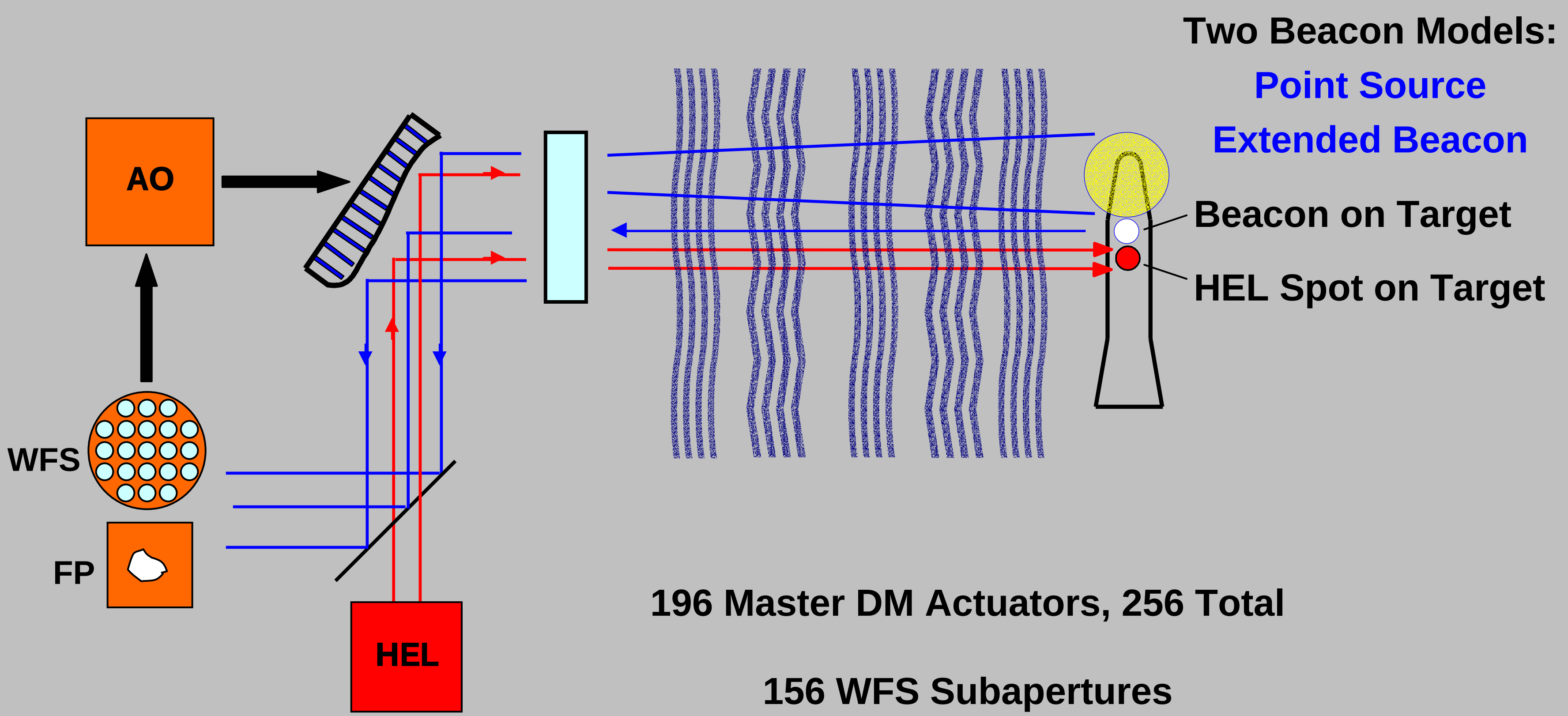
Green Blocks: Augmentation with adaptive filtering and control (UCLA)

Adaptive control loop significantly improves beam control and increases intensity of energy focused on target.

On-Target Intensity (Strehl Ratio) for Two Controllers:

New Adaptive Control Loop, Standard AO Loop

WaveTrain* Model of a High-Energy-Laser System
(Mission Research Corporation)



196 Master DM Actuators, 256 Total

156 WFS Subapertures

Path length = 266,700 m

Target Altitude = 29,000 m

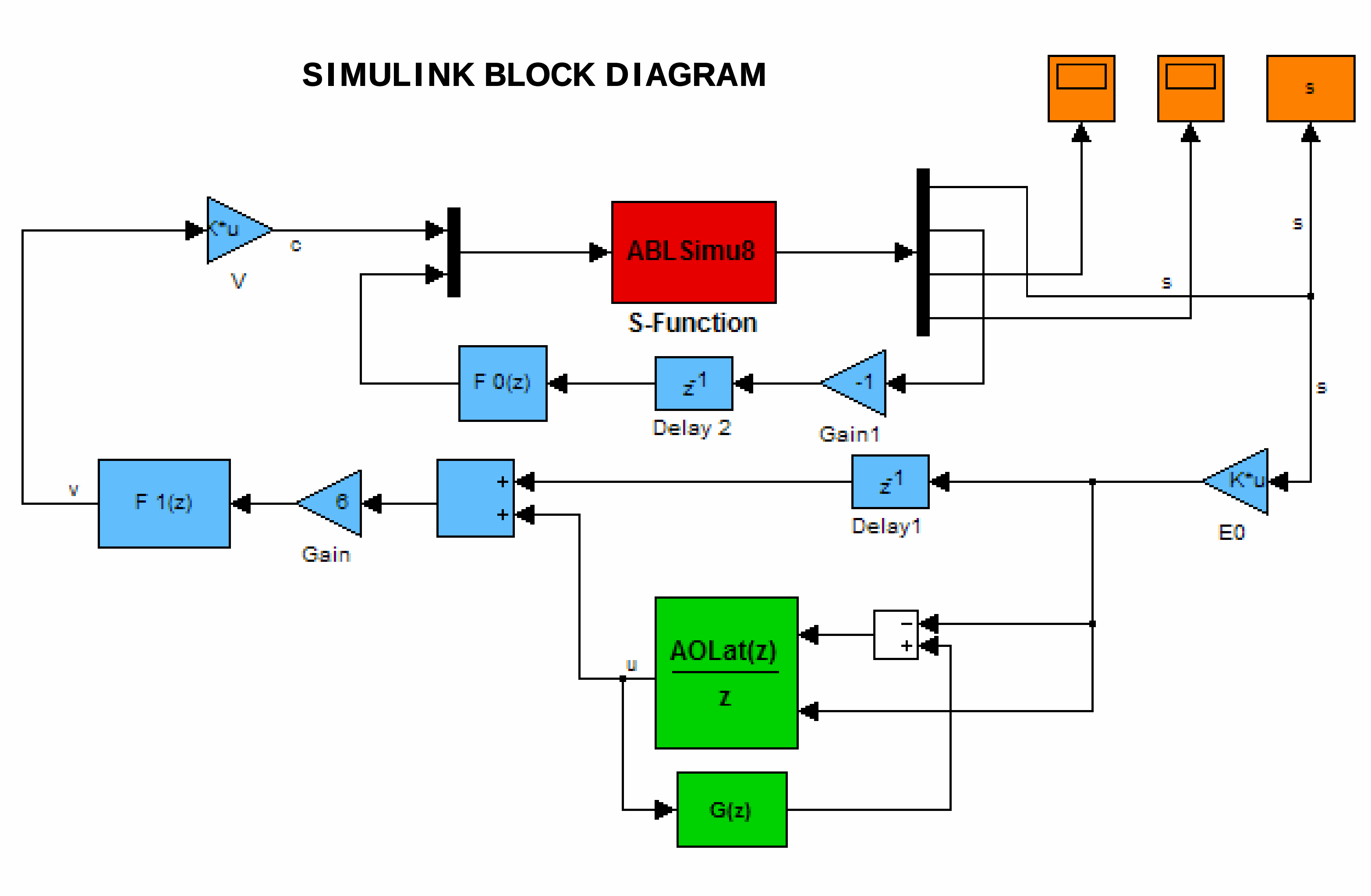
ABL Altitude = 12,200 m

Target Speed = 1620 m/s

ABL Speed = 200 m/s

* WaveTrain is a product of MZA Associates Corporation. The model used in this research is based on non-sensitive features of HEL systems.

SIMULATION MODEL 1

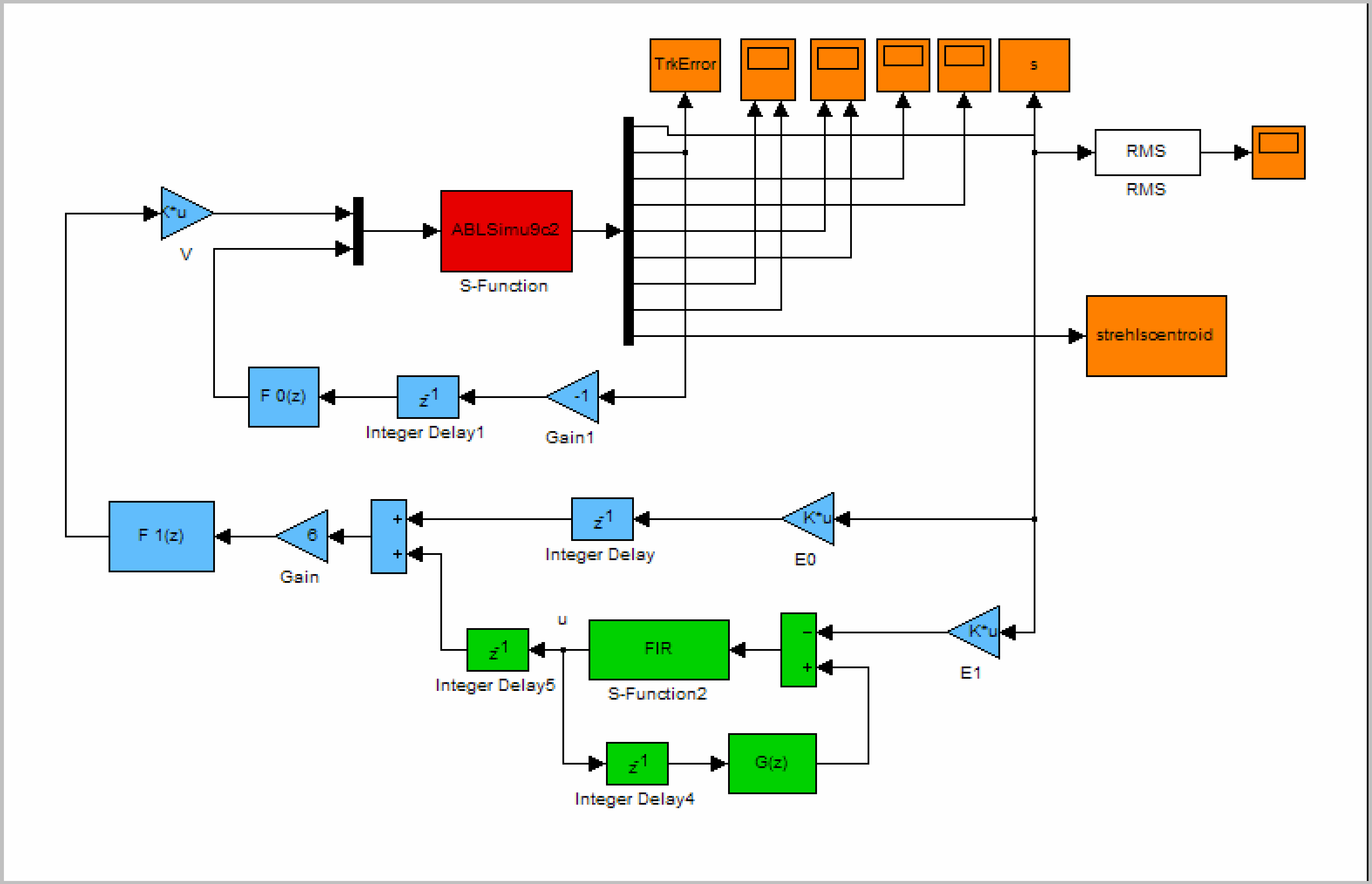


Red Block: WaveTrain HEL System Model

Blue Blocks: Standard AO and Track Loops

Green Blocks: Adaptive Control Loop

SIMULATION MODEL 2



Red Block: WaveTrain HEL System Model

Blue Blocks: Standard AO and Track Loops

Green Blocks: Fixed-gain Control Loop

Multichannel Adaptive Lattice Filters
for
Filtering, Identification, and Control

- Recursive least-squares (**RLS**) **lattice filters** produce **faster adaptation** (convergence) than algorithms based on stochastic-gradient (LMS) adaptation.

- RLS lattice filters produce **true minimum-variance performance** in the presence of **broad-band** noise.

- **UCLA Algorithms**: **Orthogonalization** of multiple channels eliminates need for matrix inversions.

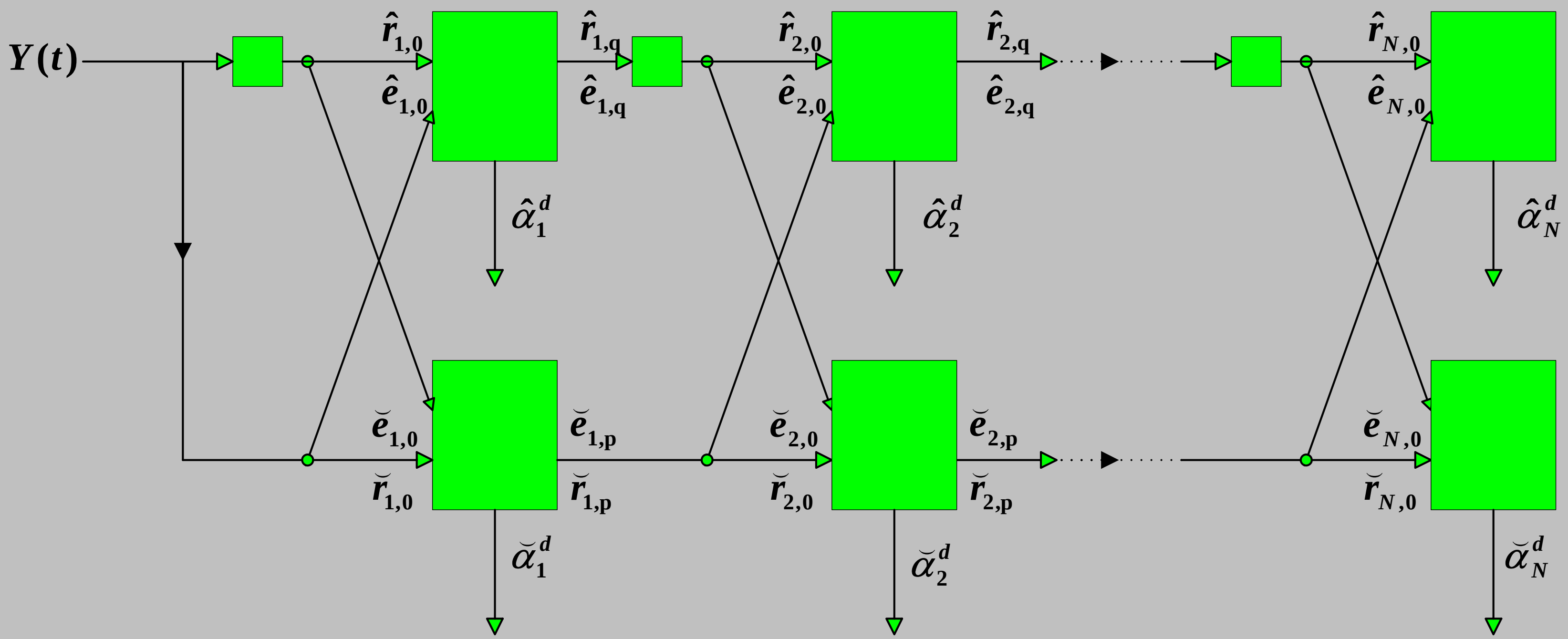
Properties of Lattice Filters

- **Fast** real-time computation

- Numerically **stable** for number of channels > 100, filter order > 100

- Excellent **VLSI** realization

Residual-Error Lattice Filter



* $Y(t) = [y(t) \quad u(t)]$
* $\hat{e}$: forward - propagating forward error
* $\hat{r}$: forward - propagating backward error
* $\breve{e}$: backward - propagating forward error
* $\breve{r}$: backward - propagating backward error

Well chosen DM modes are essential for adaptive loop in AO.

- Control channels are uncoupled for adaptive loop, allowing much faster convergence to optimal gains.
(Modes need to be orthogonal in actuator space.)

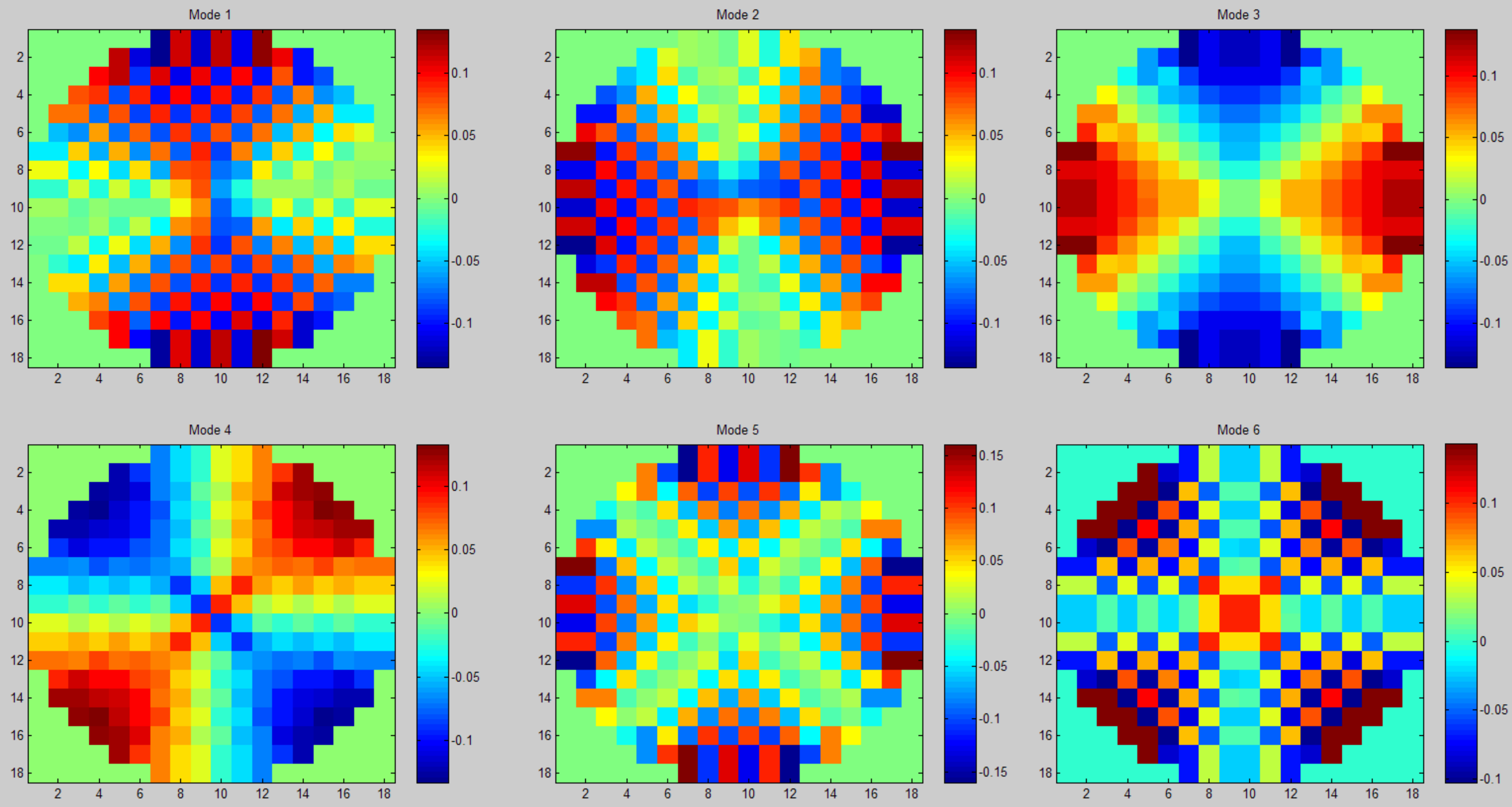
- Spatial filtering removes high-frequency noise and marginally controllable optical modes.

Examples of Modes

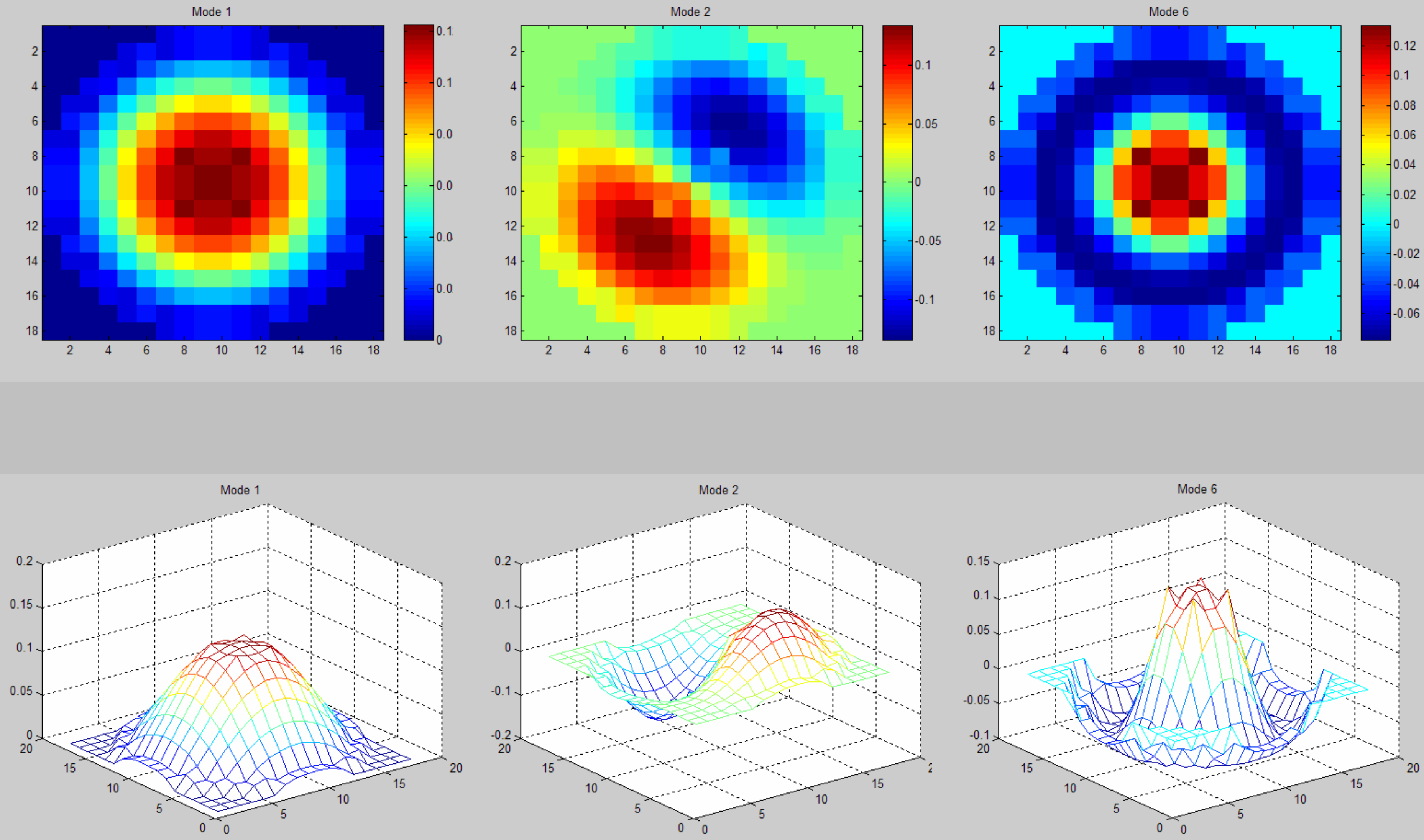
- Two-step process starting with Zernike polynomials
- Singular-value decomposition of poke matrix or least-squares reconstructor
- Frequency-weighted modes computed from DM geometry and poke matrix

OLD MODES from SVD of recon

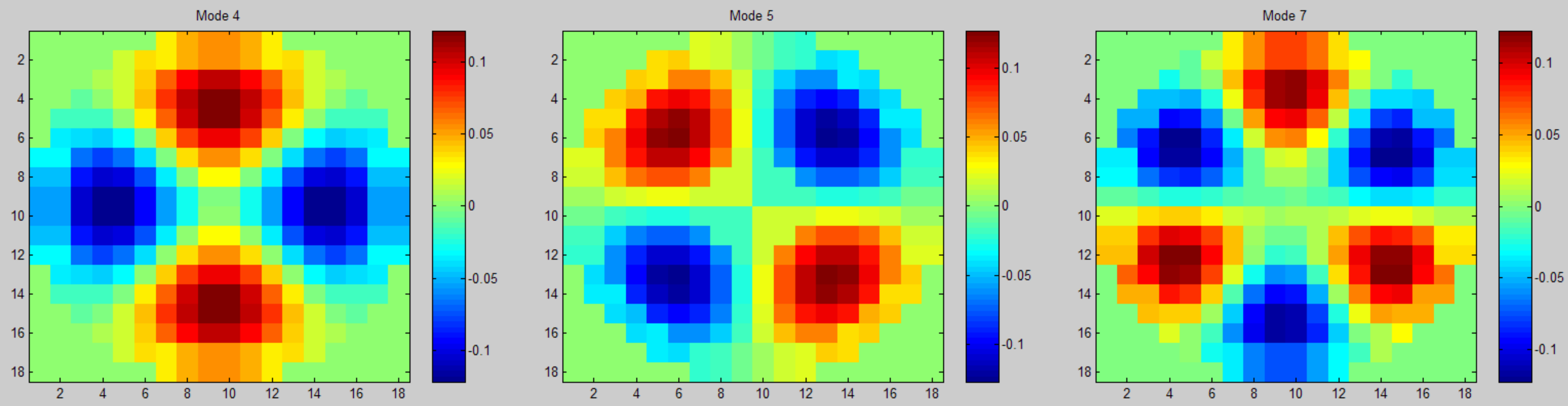
First 6 of 194

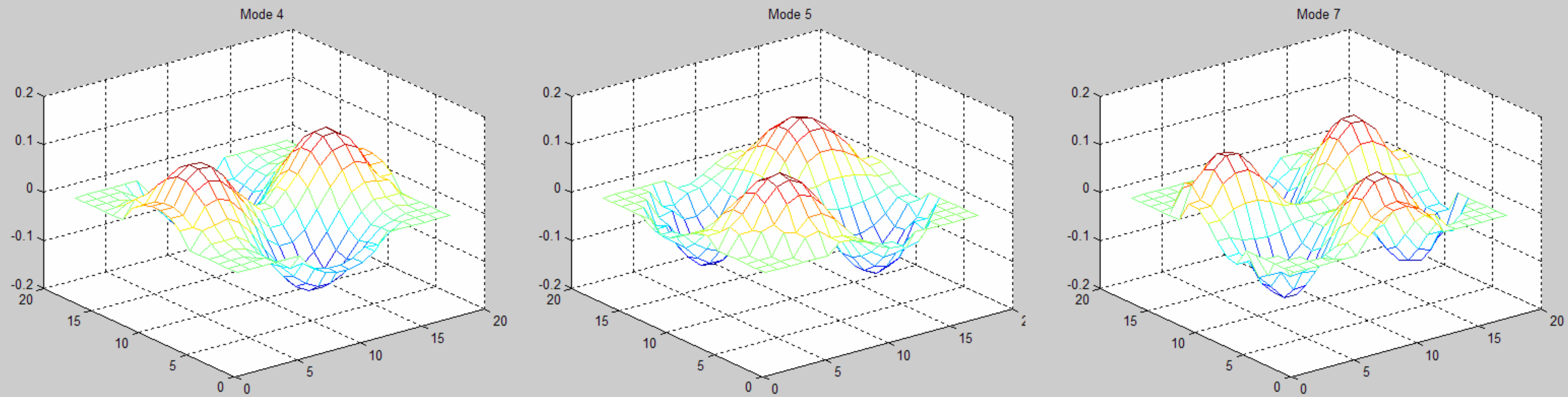


New AO Modes Optimized to Maximize Low-Frequency Modal Power

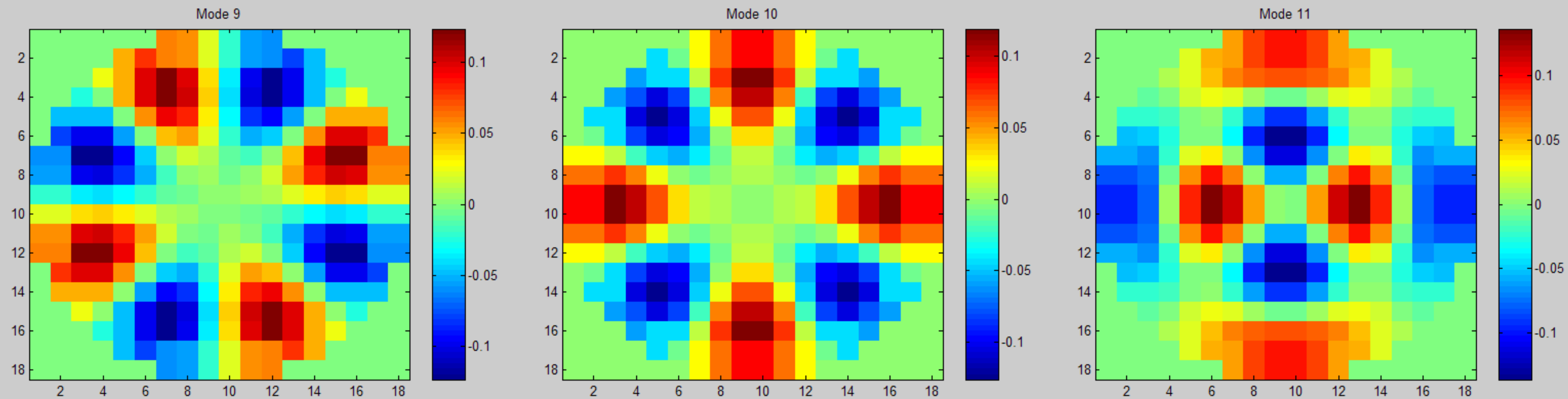


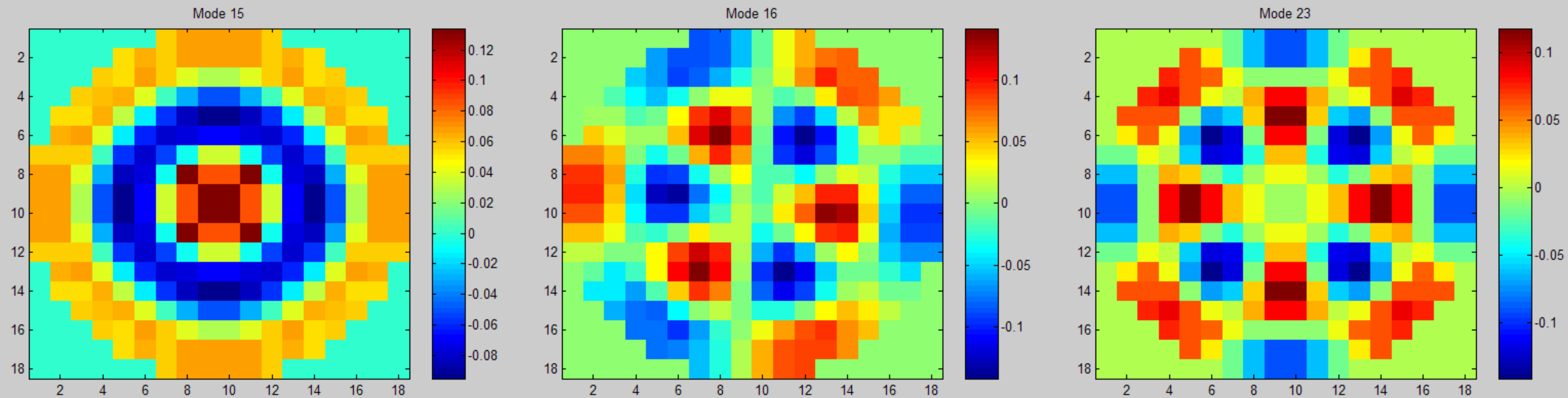
New AO Modes Optimized to Maximize Low-Frequency Modal Power





With Increasing Mode Number, Radial and Circular Frequencies Increase

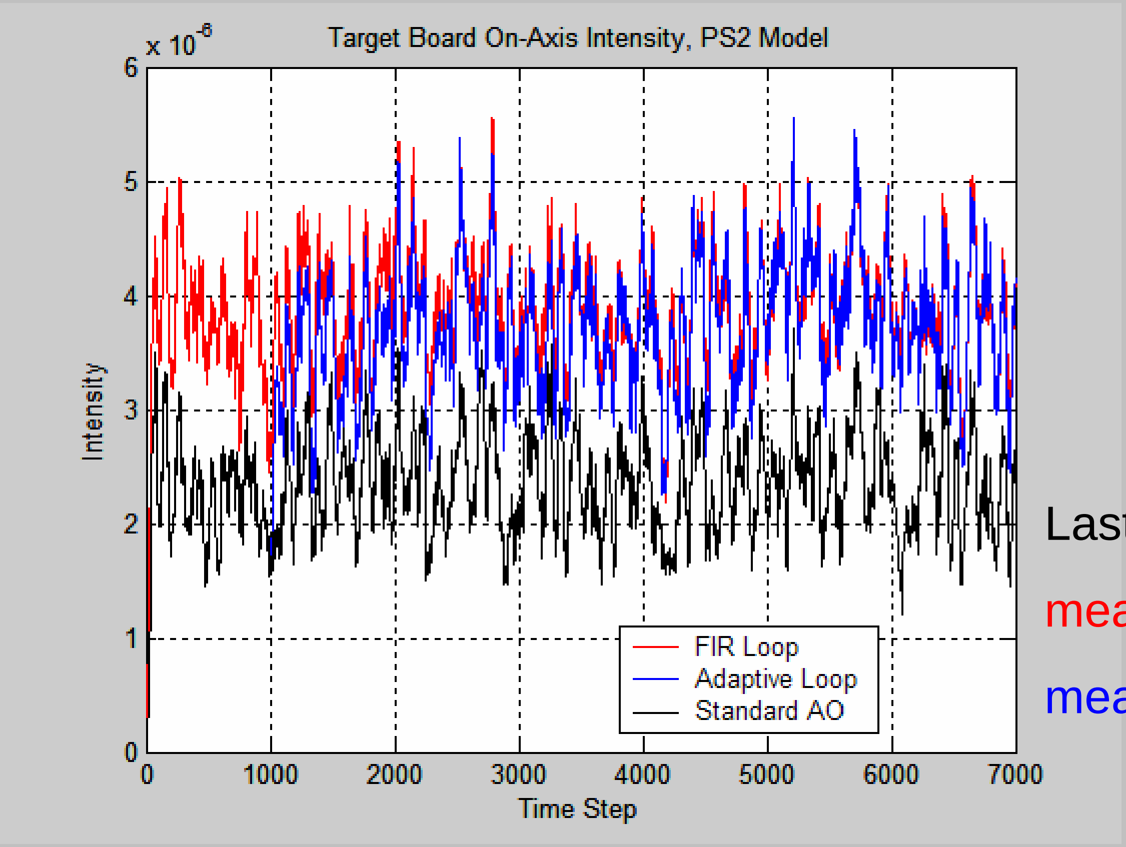




Results for Point Source Beacon

16 Phase Screens

Target Board On-axis Intensity



Last 2000 Steps:

mean/mean = 1.67

mean/mean = 1.64

Red: Fixed-gain FIR identified with different random seed, 80 new modes

Blue: Adaptive control loop with 1000 learning steps

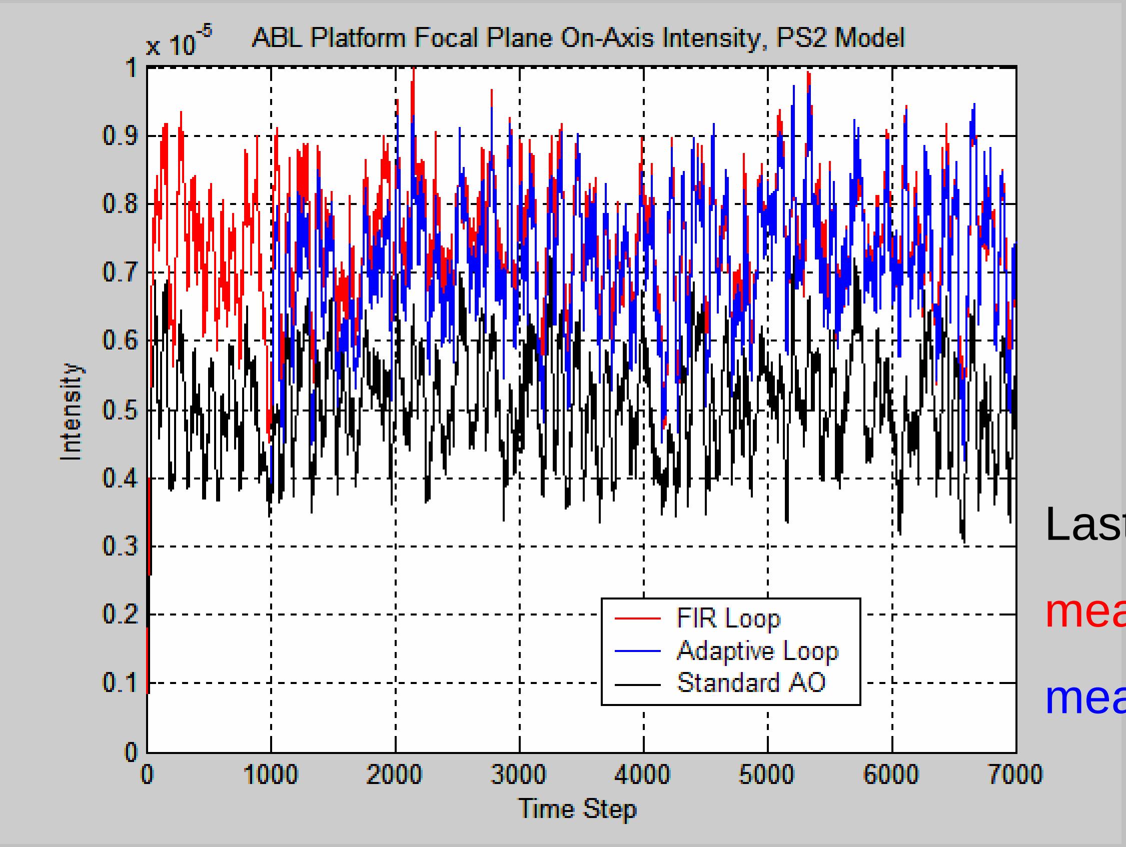
Black: Standard AO and track loops

All AO loops tilt removed

Results for Point Source Beacon

16 Phase Screens

Focal Plane On-axis Intensity



Last 2000 Steps:

mean/mean = 1.50

mean/mean = 1.47

Red: Fixed-gain FIR identified with different random seed, 80 new modes

Blue: Adaptive control loop with 1000 learning steps

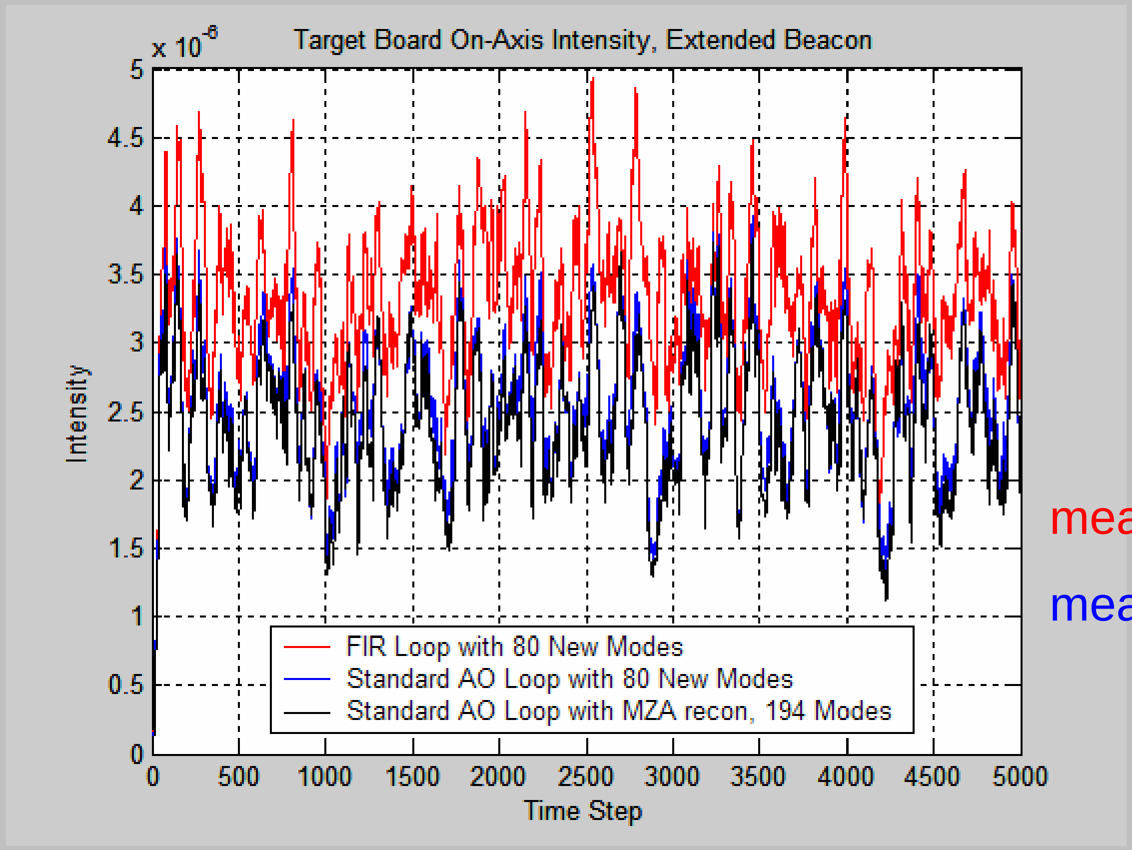
Black: Standard AO and track loops

All AO loops tilt removed

Results for Extended Beacon

16 Phase Screens, 8 Speckle Realizations

Target Board On-axis Intensity



mean/mean = 1.38

mean/mean = 1.05

Red: Fixed-gain FIR identified with different random seed, 80 new modes

Blue: 80 New modes, Standard AO and track loops only

Black: 194 Modes, Standard AO and track loops with MZA recon

All AO loops tilt removed

REFERENCES

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