MZA Associates Corporation

Detailed Capabilities Overview

September 2017

Distribution A: Approved for Public Release

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- Commodity Jurisdiction determinations have established that the Atmospheric Turbulence Profilers and Diagnostic products are regulated by the EAR and most are classified as EAR99. Commodity Jurisdiction determinations have established that various adaptive optics components including deformable mirrors and wavefront sensors are designated as defense articles under Category XVIII(e) of the United States Munitions List (USML).
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Introduction

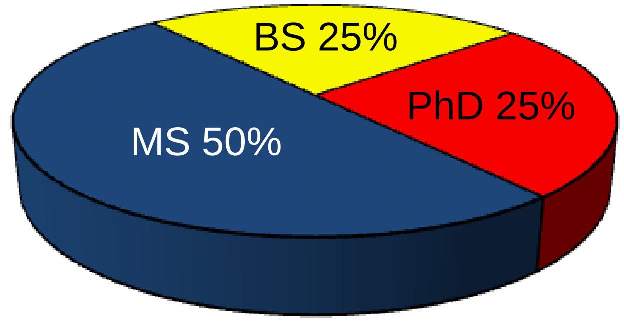
- **MZA is a small business that specializes in the modeling, simulation, and analysis (MS&A), design, development, engineering, and testing of advanced optical and control systems for High Energy Laser Weapon Systems (HELWS) and advanced surveillance systems (ISR).**
- **MZA has provided more than twenty-five years of support to a broad range of US Department of Defense (DoD) research organizations and provides some of the most formidable capabilities in the concept development, analysis, modeling, systems engineering, manufacturing, integration and test of HELWS.**
- **MZA's staff consists of some of the world's experts in the fields of advanced beam control analysis and design, beam control component and system development, aero-optical and aero-mechanical effects, atmospheric propagation, and laser engagement analysis.**
- **No other single organization of any size provides equivalent breadth and depth of engineering, analysis, and manufacturing capabilities for HELWS beam control systems.**

MZA's Core Capabilities

- **Laser Weapon & Optical Sensing Modeling & Simulation**
  - WaveTrain - Integrated physics-based simulation
  - Atmospheric and aero-effects modeling
  - Beam control and propagation scaling models
  - Systems engineering models
  - Laser resonator device modeling
- **Laser System Design, Development, Integration & Testing**
  - Beam Control
  - Imaging
  - Laboratory and field experimentation
  - Experimental analysis
  - Turbulence profiling
  - Aero optics
- **Adaptive Optics & Beam Control Hardware**
  - High-speed tracking and wave front compensation devices
  - High Power Deformable Mirrors (HPDMs)
  - Real-time and distributed control systems
  - Optical telescopes and beam directors
  - Experimental optical measurement devices
  - Atmospheric measurement devices

MZA is a world leader in the modeling, analysis, and development of directed energy and imaging systems

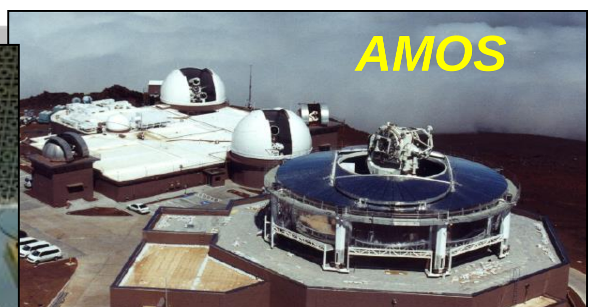
- Beam control and imaging systems
- Adaptive optics design and implementation
- Atmospheric and aero optical effects
- High energy laser systems engineering
- Target signatures and vulnerability
- High speed target tracking
- Laser communications
- LADAR/LIDAR applications
- Deformable mirrors and wavefront sensors



WaveTrain

wave optics made easy/ier

MZA's modeling and analysis software has been used on nearly every major HEL program of the past twenty years.



February 11, 2010
First Boost-Phase Ballistic Missile Shootdown
USAF
ED
00-0001
U.S. AIR FORCE
MZA
Twenty Years
of Excellence in
Directed Energy
mza.com
MZA
target
atmosphericpath
platform
WaveTrain
wave optics made easy/ier

MZA Supports the Development of Major Directed Energy Weapons Systems

- Navy Fixed-Wing Demonstrator (AeroFWD, ONR/NAVAIR)
- Self-Protect High Energy Laser Demonstrator Advanced Technology Demonstration (SHiELD ATD, AFRL)
- Beam Control System Integration Laboratory (BC-SIL, SMDC)
- Helicopter Beam Director for High Energy Fiber Laser (HEFL HBDS, ONR)
- Demonstrator Laser Weapons System (DLWS, AFRL/DARPA)
- High Energy Liquid Laser Area Defense System (HELLADS, DARPA)
- Airborne Aerooptics Laboratory (AAOL, HEL-JTO)
- High Energy Laser Mobile Test Truck (HELMTT, SMDC)
- Next Generation Airborne Laser (NGABL, MDA)
- WSMR Solid State Laser Test Bed (SSLTB, SMDC)
- Airborne Laser Test Bed (ALTB, MDA)
- Robust Electric Laser Initiative (RELI, HEL-JTO)
- Joint High Power Solid State Laser (JHPSSL, HEL-JTO)
- High Energy Laser Future Air Demonstration (HELFAD, AFRL)
- Tactical Relay Mirror System (TRMS, AFRL)

MZA's Major & Recurring Customers

- **Air Force Research Laboratory (AFRL/RD-RY-RQ-RV)**
- **High Energy Laser Joint Technology Office (HEL-JTO)**
- **Missile Defense Agency (MDA)**
- **Defense Advanced Research Projects Agency (DARPA)**
- **Naval Air Systems Command (NAVAIR)**
- **Army Space & Missile Defense Command (SMDC)**
- **Office of Naval Research (ONR)**
- **Arnold Engineering Development Center (AEDC)**
- **Naval Research Laboratory (NRL)**
- **Air Force Institute of Technology (AFIT)**
- **Naval Postgraduate School (NPS)**
- **US Aerospace and Defense Contractors**

  Lockheed Martin, General Atomics, Textron, Raytheon, SAIC, Boeing, Schafer, Parsons, Radiance, Kratos

- **US Educational Institutions**

  Notre Dame, U of Dayton, UCLA, U of MD, U of Central FL

Overview of
Hardware Development Efforts

Lightweight Compact Beam Directors

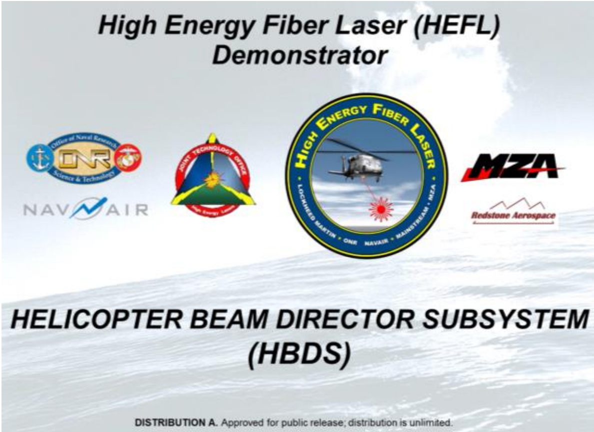
Addressing a high priority need identified by the Air Force Research Laboratory, MZA undertook the challenge to develop lightweight compact beam directors for high power laser applications.

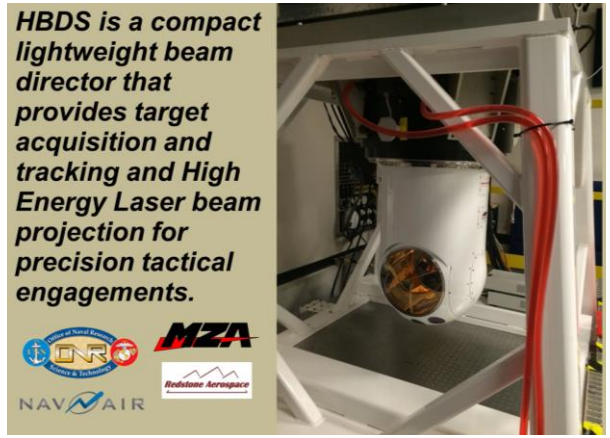
The result has been the development of MZA's Othela line of beam directors that utilize the latest technologies in opto-mechanical materials, gimbals, optical coatings, and sensors to reduce the number of high power optics in order to institute on-gimbal beam control concepts.

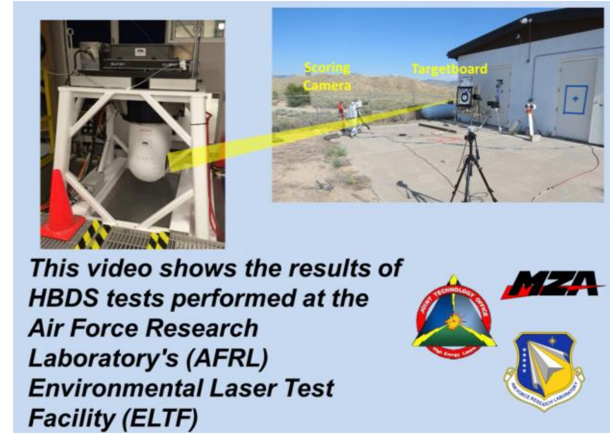
- **Integrated on-gimbal beam control systems.**
- **Line-of-site stabilization and wave front compensation.**
- **< 1 cubic meter in volume**
- **< 500 lbs.**
- **Designed for high power laser applications.**
- **On-axis and off-axis telescope designs.**

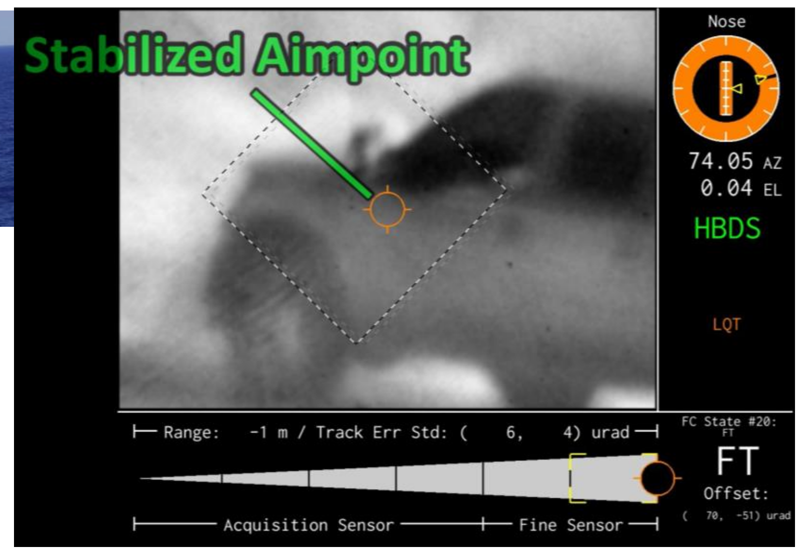
High Energy Fiber Laser (HEFL)
Helicopter Beam Director System (HBDS)

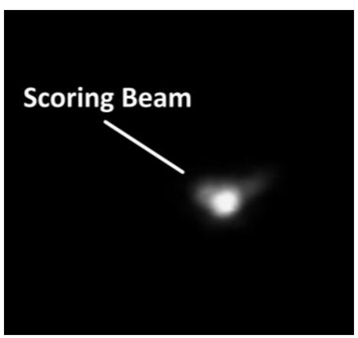
See movie at: https://www.youtube.com/watch?v=Bqc4YCVcJ9g&feature=youtu.be

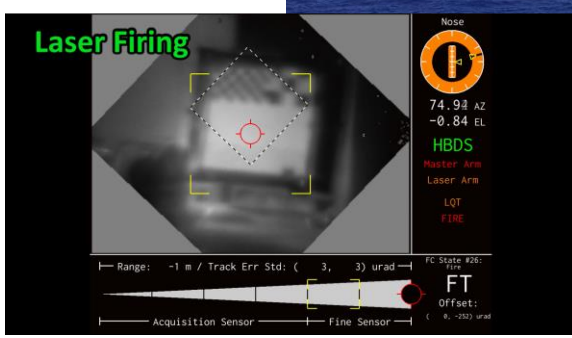






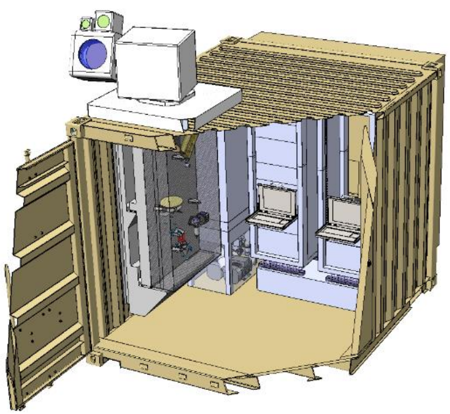




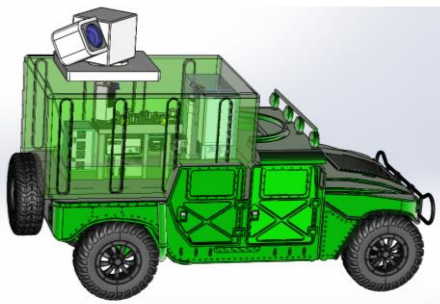


HELWS Concept Engineering

Near-Term Deployable Low Cost C-UAS

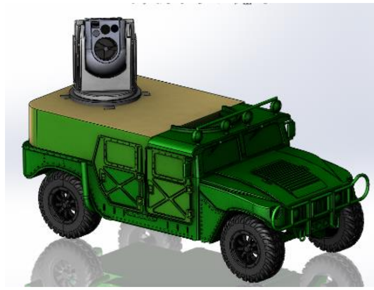


Near-Term Portable Low Cost C-UAS

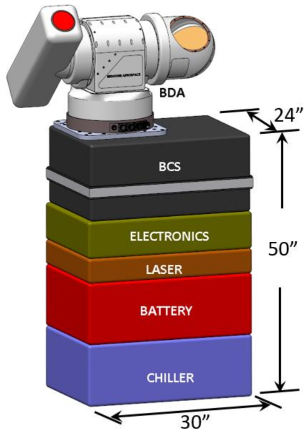


20 cm Class Apertures 3-10 kW applicable to C-UAS Missions

Near-Term On-the-Move C-UAS

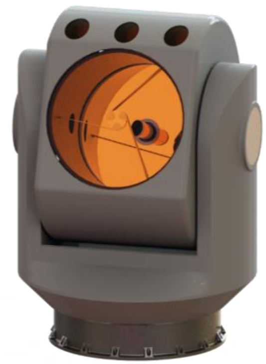


Small SWaP Modular On-the-Move C-UAS



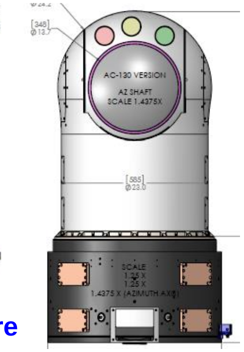
< 1000 lbs suitable for numerous military vehicles

Scalable HELWS Architectures to address C-UAS and C-RAM for Ground, Maritime, and Flight Environments



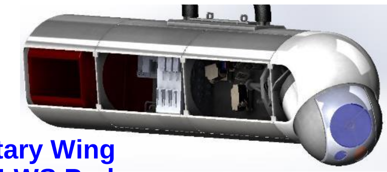
50 cm Aperture 60-120 kW HEL

23 cm Aperture 28 kW HEL



30 cm Aperture 60-120 kW HEL

Future Objective Airborne HELWS



Rotary Wing HELWS Pod Architectures

28kW High Energy Fiber Laser System

23cm / 28kW Helicopter Beam Director Subsystem

Atmospheric Characterization Devices

- **MZA manufactures atmospheric profiling devices that can be used to establish requirements for ISR and beam control system performance.**
- **The techniques utilized have been proven in multiple experiments.**

MZA Path-Resolved Optical Profiler System (PROPS), PR-05-600

Description

MZA's Path-Resolved Optical Profiler System (PROPS) measures turbulence strength along a line of sight. Turbulent wavefront measurements are sampled with a telescope-mounted sensor on both sides of the propagation path from multiple sources, from which C_n^2 is derived. These turbulent fluctuations significantly affect high resolution imaging sensors and can reduce efficiency of laser beam projection for directed energy, illumination and optical communications. The same phenomena also give insight into other aspects of the atmospheric path, including evapo-transpiration measures critical to water and agricultural management activities.

Unique Advantages

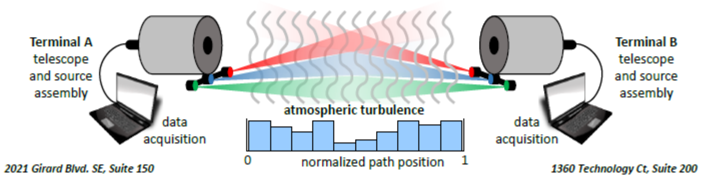
- Resolves C_n^2 turbulence strength along path
- Automatic computation of:
  - Rytov number
  - Scintillation index
  - Fried's coherence diameter
  - Isoplanatic angle
  - Cross-wind speeds
  - Greenwood and Tyler frequencies
- Time-resolved wavefront measurements
- 5+ km range between terminals
- Automatic collection, processing, & reporting
- Operator data quality feedback
- Eye-safe, non-laser sources
- Output supports ATMTools and WaveTrain

Applications

- Laser propagation path characterization
- Atmospheric imaging diagnostics
- Optical communications link performance
- Evapo-transpiration and water management
- Include profiles in wave-optics simulations
- Enables custom MATLAB analysis

Operation

Identical PROPS optical transceiver terminals are placed on each side of a propagation path which typically extends up to 5 km or longer given favorable atmospheric transmission. The terminals transmit multiple wavelength sources and image each source with sensitive cameras which record the deviation or "dancing" of each source and its intensity fluctuation. These measurements are processed and communicated bi-directionally using a built-in wireless link. The unique geometry of PROPS enables resolution of changes in turbulence along the path resulting from the surface features along that path. PROPS processing also estimates cross-wind speeds as seen from both sides of the path. PROPS automatically collects, processes, catalogs, and reports these data for future reference. Output data is uniquely formatted to enable theoretical turbulence calculations and for customized wave-optics simulations.



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MZA DELTA Imaging Path Turbulence Monitor, PM-02-600

Applications

- Passively monitors turbulence conditions
- Laser propagation path characterization
- Atmospheric imaging diagnostics
- Optical communications link performance
- Evapo-transpiration and water management
- Include turbulence profiles in wave-optics simulations
- Enables custom MATLAB analysis

Unique Advantages

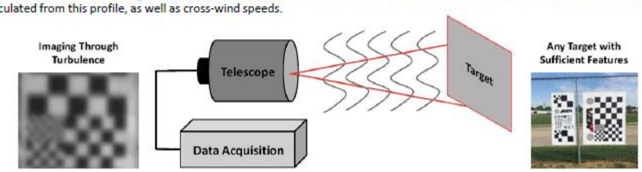
- Bounds C_n^2 turbulence strength along path
- Automatic computation of:
  - Rytov number
  - Scintillation index
  - Fried's coherence diameter
  - Isoplanatic angle
  - Cross-wind speeds
  - Greenwood and Tyler frequencies
- 2 km range from target to receiver
- Automatic collection, processing, and reporting of turbulence diagnostics
- Portable and compact system
- Passive operation—no external sources required for diagnostic target
- Output supports ATMTools and WaveTrain

Description

MZA's Delayed Tilt Anisoplanatism (DELTA) method measures turbulence strength along a line of sight. These turbulent fluctuations, commonly observed as twinkling of distant lights or stars, significantly affect high resolution imaging sensors and can reduce efficiency of laser beam projection for illumination and optical communications. The same phenomena also give insight into other aspects of the atmospheric path, including evapo-transpiration measures critical to water and agricultural management activities.

Operation

The DELTA system is place at one end of the path, with a target or object with multiple, trackable features on the opposite end. Depending on the size of the target and the optics on the telescope, a range of ½ to 2 kilometers can be achieved. Once initial setup has been conducted, user desired parameters are adjusted such as feedback period, duration of observation and stored output info. A sequence of imagery is collected and the deviation or "dancing" of feature points on the target is recorded. The DELTA method measures the differential jitter of feature pairs as a function of angular separation. Using multiple pairs at various degrees of separation, a non-uniform C_n^2 profile is estimated using additional atmospheric estimation software. Turbulence statistics are calculated from this profile, as well as cross-wind speeds.



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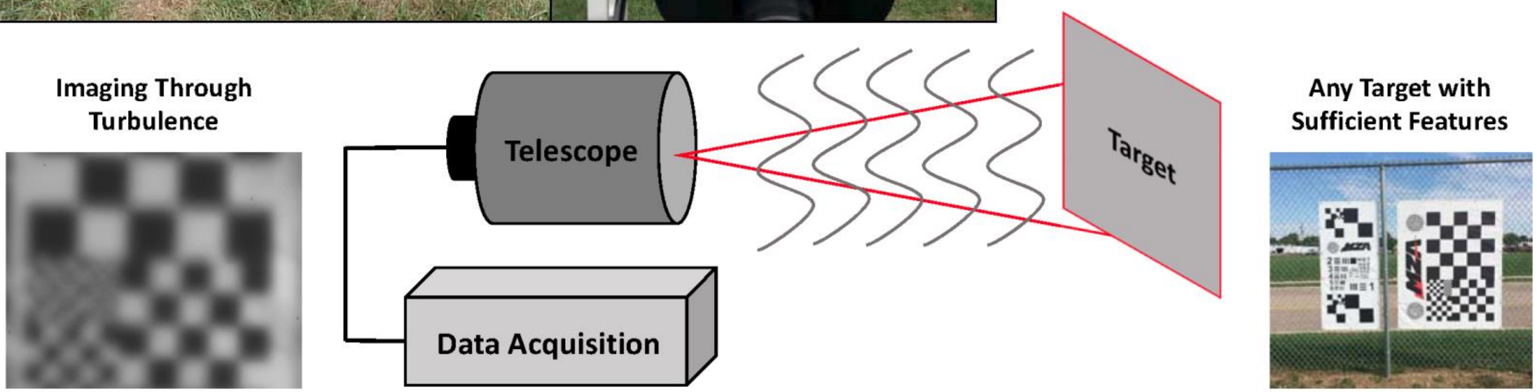
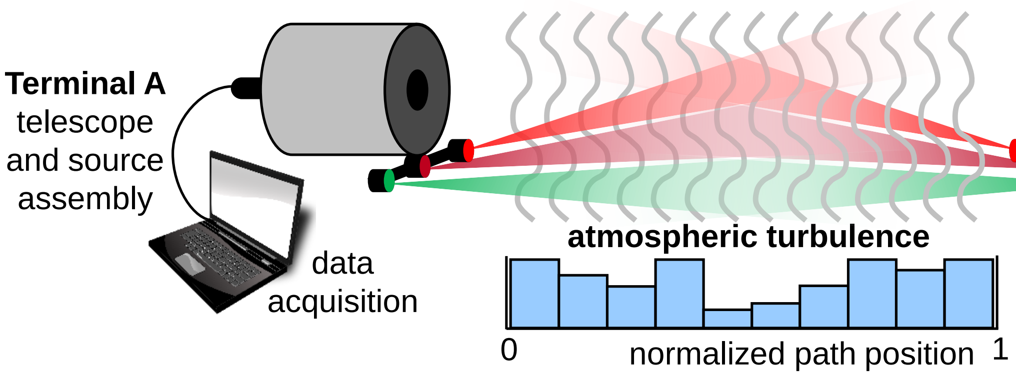
DELTA Atmospheric Characterization

Model: PM-02-600, Single-Ended

- Passively monitors turbulence conditions
- Provides C_n^2 bounds over propagation path
- Provides wind speed
- Compact and portable
- Output atmospheric diagnostics compatible with ATMTools and WaveTrain

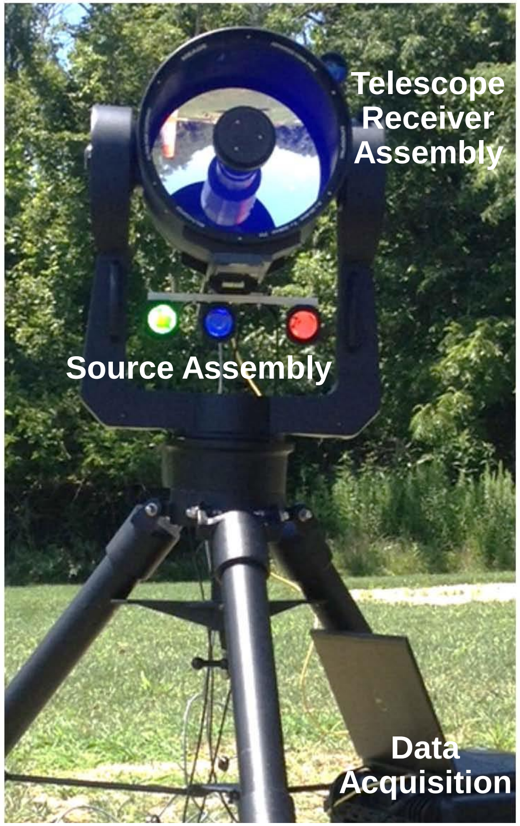


Dual-Ended Path-Resolved Turbulence Profilers



Applications

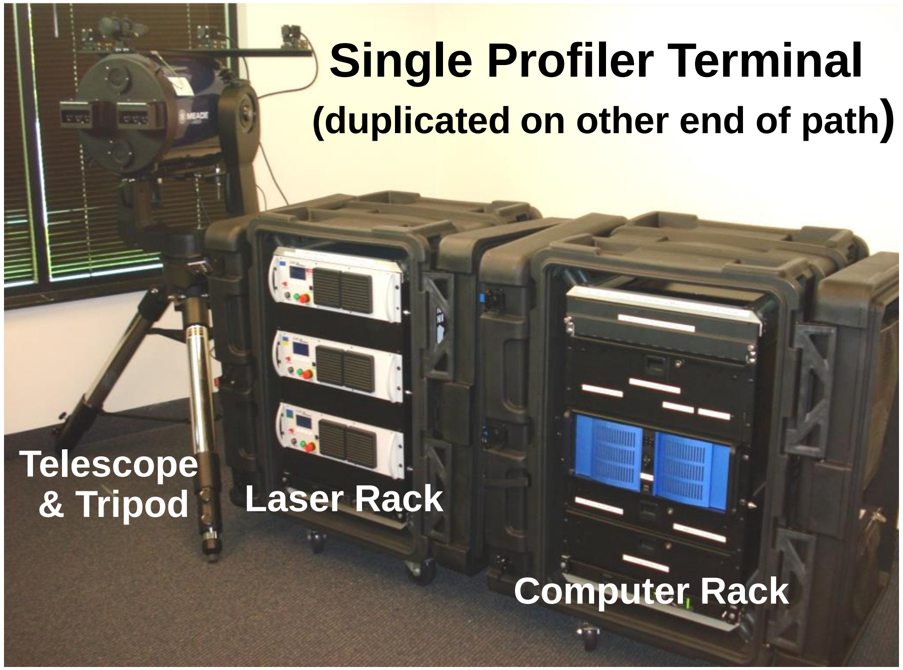
- Laser propagation path characterization
- Atmospheric imaging diagnostics
- Optical communications link performance
- Evapo-transpiration and water management
- Include profiles in wave-optics simulations
- Enables custom MATLAB analysis



Model: PR-05-600, Range: 0.5 - 5 km

- **Estimates C_n^2 values in bins along a line-of-sight**
- **Assists in understanding of optical system propagation performance including fades, dropouts, bit error rate (BER), etc.**

Single Profiler Terminal
(duplicated on other end of path)

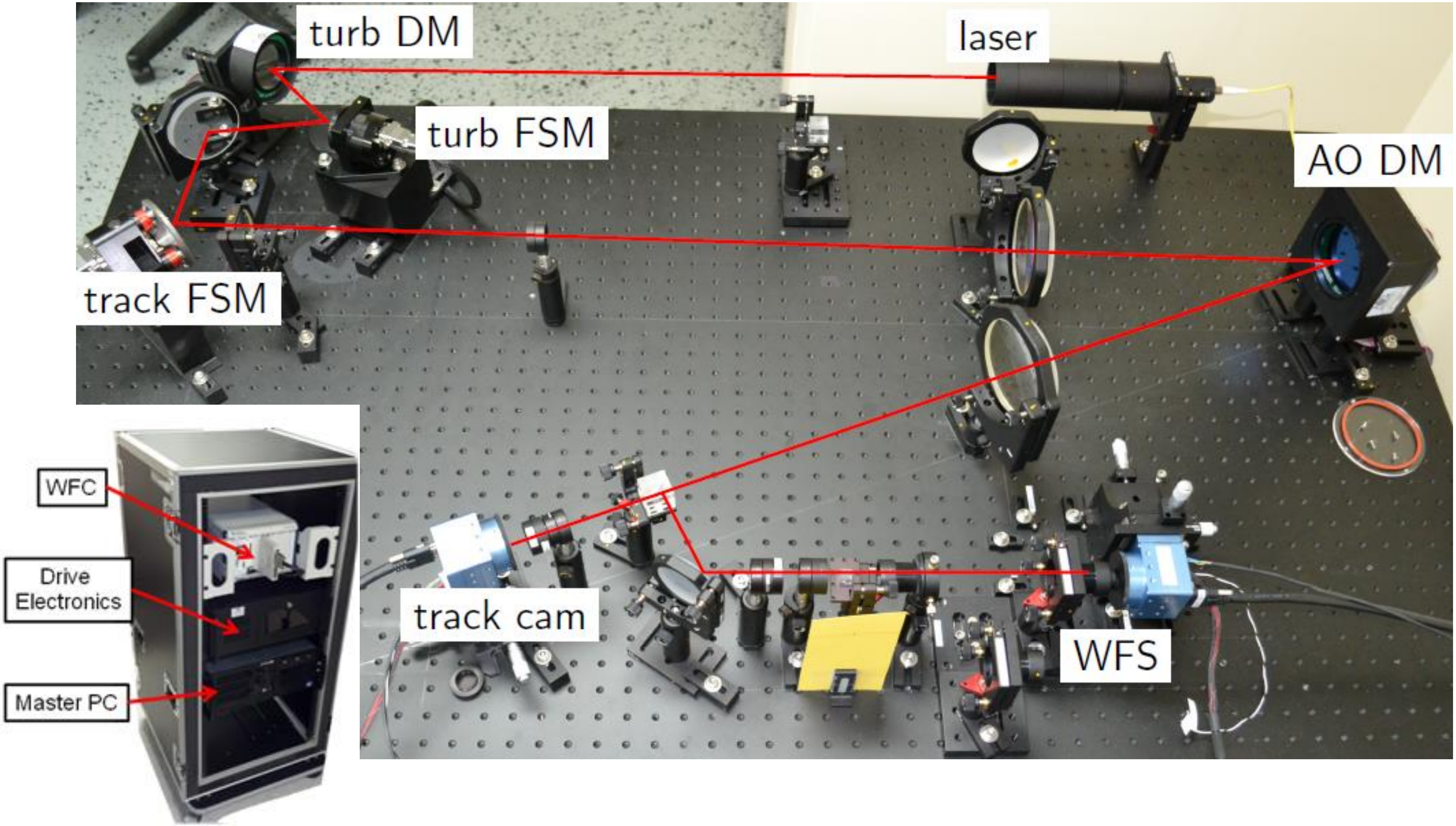


Model: PR-50-1500, Range: up to 200 km

Atmospheric Characterization Devices Export/ITAR Controls

- **Commodity Jurisdiction determinations have established that the Atmospheric Turbulence Profilers and Diagnostic products are regulated by the EAR and most are classified as EAR99.**
- **PROPS Model PR-05-600 can be exported without restriction.**
- **We have not gotten a CJ on DELTA Model PM-02-600, but because it is a fundamentally simpler device, believe that when completed, the CJ will find the device to be EAR99.**
- **The distinction with respect to the exportability of the PROPS devices seems to be the range at which the device can operate and the use of lasers (as opposed to LEDs) as sources.**

High-Speed Optical Tracker and Adaptive Optics System



- **Full system including deformable mirror, high-speed wavefront processor, and track+AO controls built by MZA**

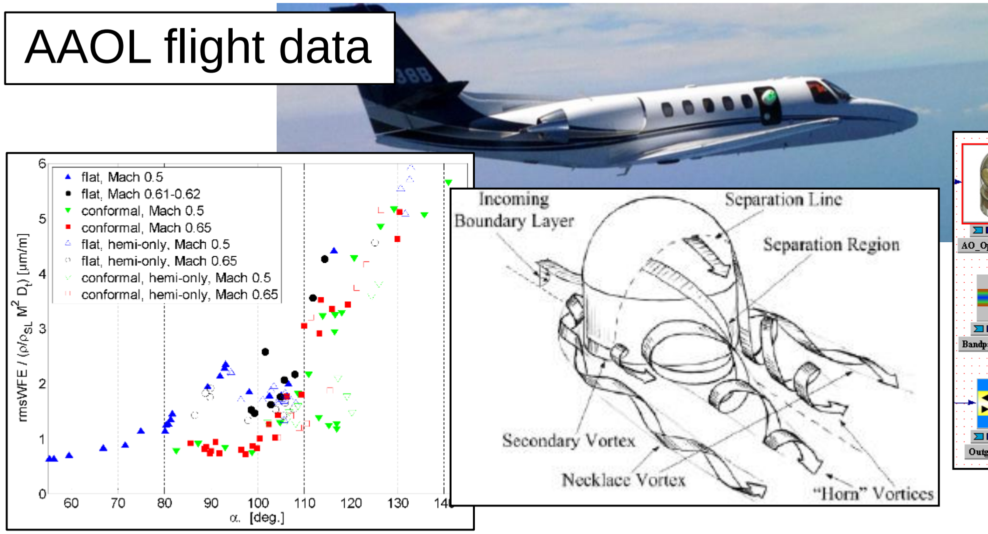
North Oscura Peak Facility

MZA…

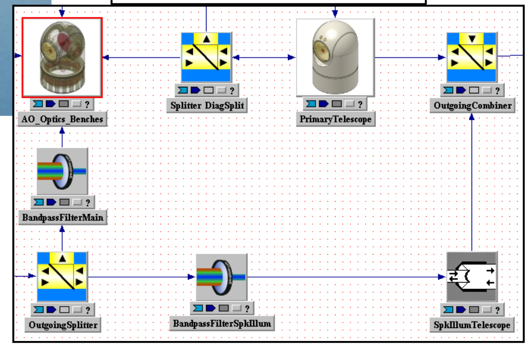
- **Developed the specifications for the 1-meter telescope and then assisted in its procurement and installation.**
- **Designed and implemented the Coude path.**
- **Designed illuminator insertion optical path.**
- **Implemented numerous embedded systems for atmospheric characterization, system monitoring, safety, and diagnostics.**

Predictive Control for AO

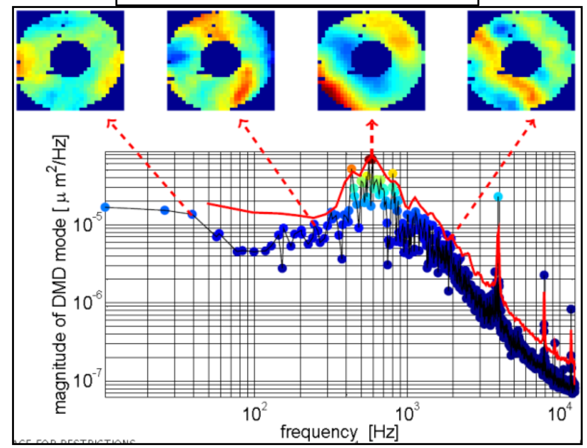
AAOL flight data



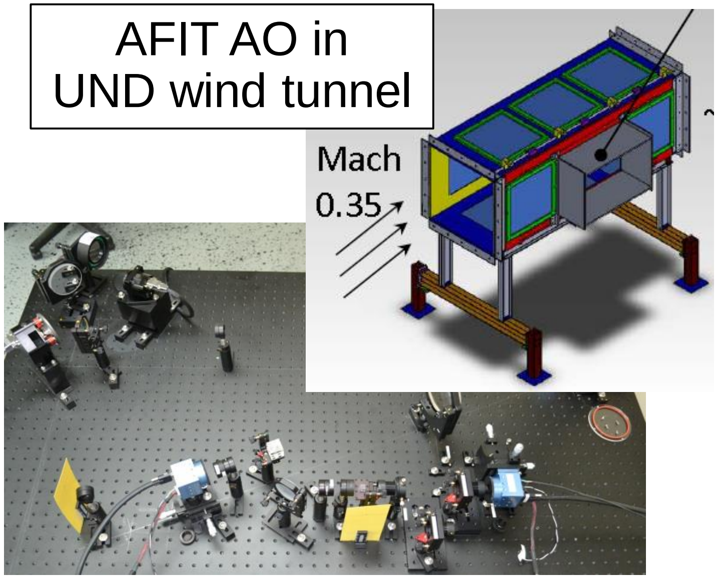
Wave-Optics Simulations



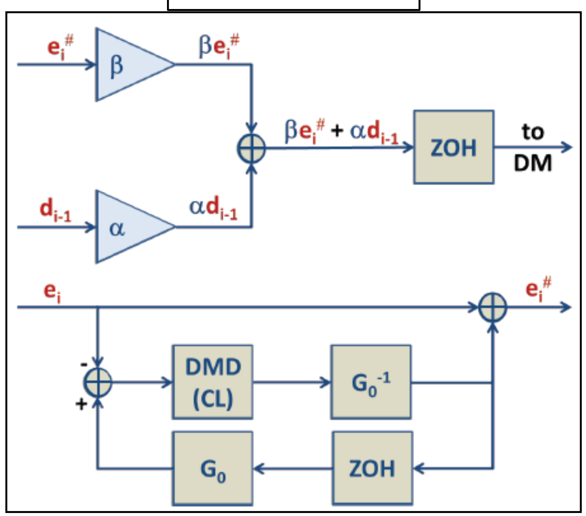
Dynamic Mode Decomposition



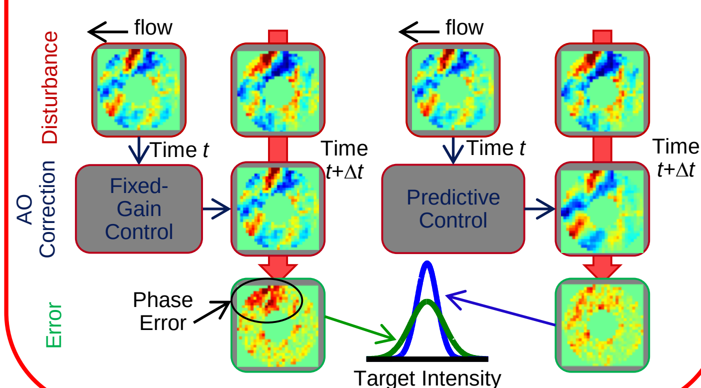
AFIT AO in UND wind tunnel



Predictive Control

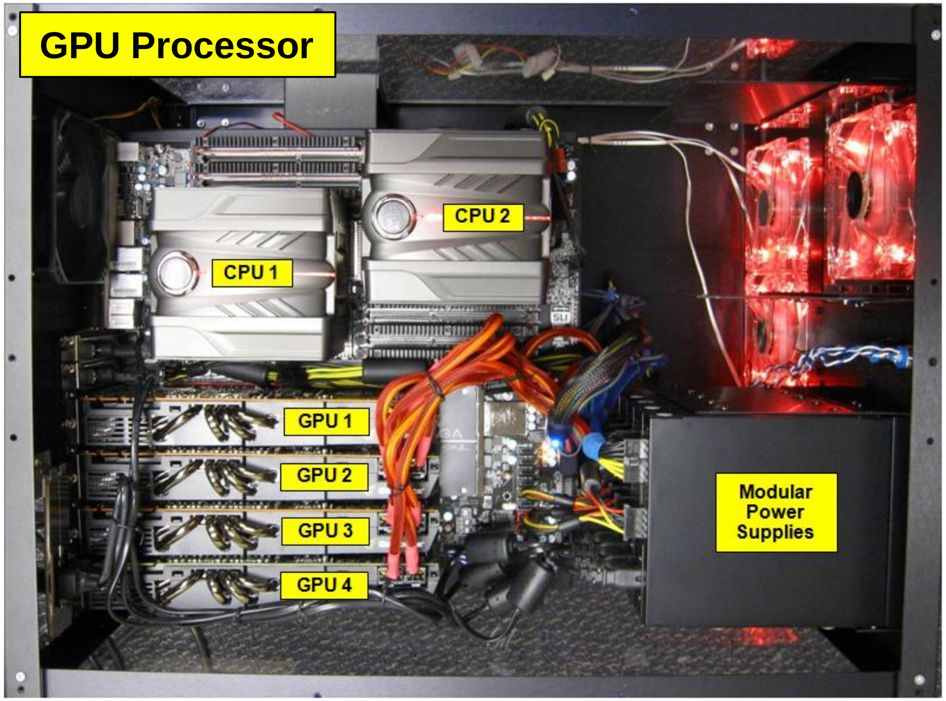


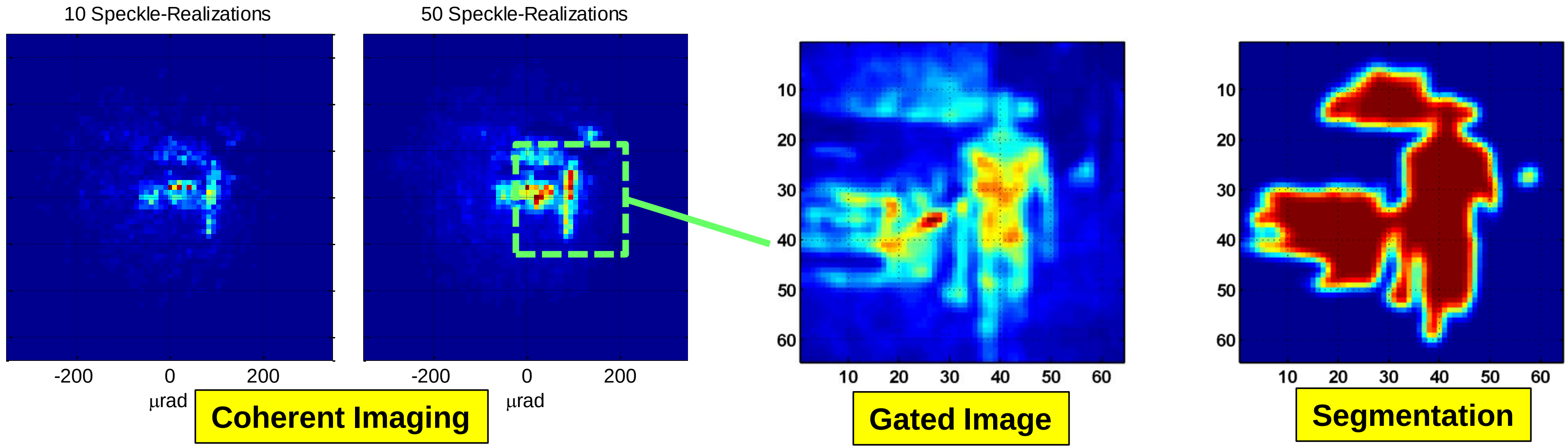
More Power on Target



Sparse Aperture Image Synthesis, Compensation, and Tracking Processor

- High-bandwidth processing capability required for phased array imaging applications
- Spatial-heterodyne imaging provides complex field data allowing for fully digital phasing
- Parallel GPUs give significant performance boost over CPUs
- COTS hardware





RWPII - 09/2017

Active Optical Systems

(http://www.activeopticalsystems.com/)

MZA's beam control hardware component affiliate.

- **MZA created Active Optical Systems, LLC (AOS) to develop and commercialize low-cost, compact adaptive optics components.**
- **AOS manufactures deformable mirrors for low and very high power laser applications.**
- **AOS also provides numerous types of optical sensors intended to provide wave front control (beam shaping) and aim point maintenance.**
- **AOS uses the latest COTS technology to reduce the cost of implementing high-performance computer control systems.**

The DSB identified a need in the U.S. directed energy industrial base for beam control and deformable mirrors.

Defense Science Board
Task Force
on
Directed Energy Weapons

December 2007

Office of the Under Secretary of Defense
For Acquisition, Technology, and Logistics
Washington, D.C. 20301-3140

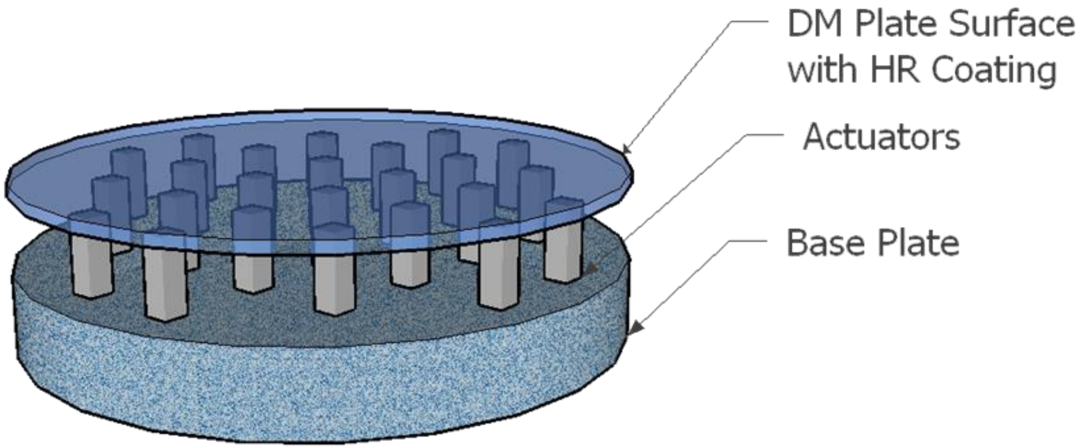
- The lack of directed energy production programs or the serious prospect of significant production programs has jeopardized the supporting industrial base. There is essentially one U.S. vendor capable of supplying deformable mirrors.
  - *The Deputy Secretary of Defense should direct the military departments to provide overall vision and strategic plans for developing relevant directed energy capabilities that can provide visibility into the likely future business case for sustaining directed energy industry capabilities.*
- The nation's technical capabilities in HEL components and sub-systems are thin and have, in some cases, atrophied. The situation in large high-power optics and beam control is particularly fragile depending on a single vendor at best.

  USD (AT&L) should direct a survey of laser component capability and produce a plan for sustaining access to the required capability.

MZA and AOS have stepped up to this challenge. We are now the second US provider of high power deformable mirrors. We have also significantly improved the state-of-the-art in beam control systems engineering.

MZA/AOS High Power Deformable Mirrors

- 100 kW average power for up to 5 seconds over a 6 cm^2 area with < 1 deg. C temperature increase.
- Tested up to 250 kW CW.
- Rapid fabrication possible.
- More than 50 high power DMs delivered



We offer complete systems that include the DM, compact high-voltage drive electronics and full adaptive optic feedback control systems.

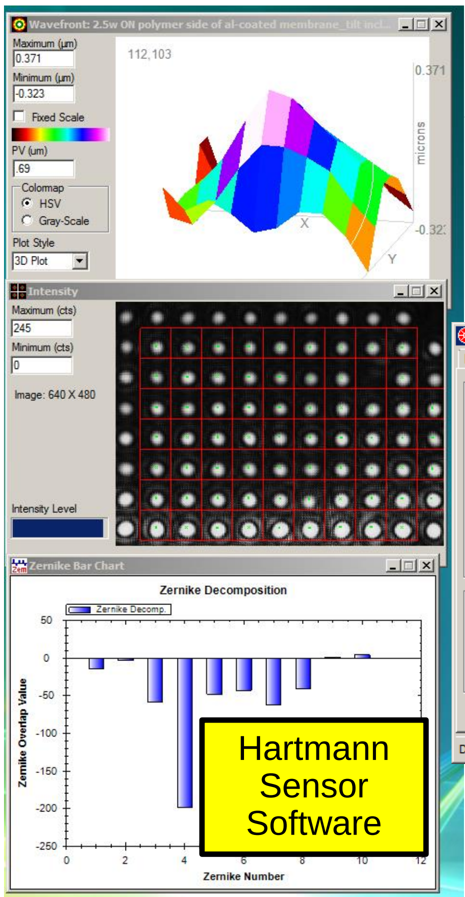
Develops and manufactures adaptive optics components and systems

ACTIVE OPTICAL SYSTEMS

Wave front Sensors

Webcam Wave front sensor

Firewire Wave front Sensor



Hartmann Sensor Software

Deformable Mirrors

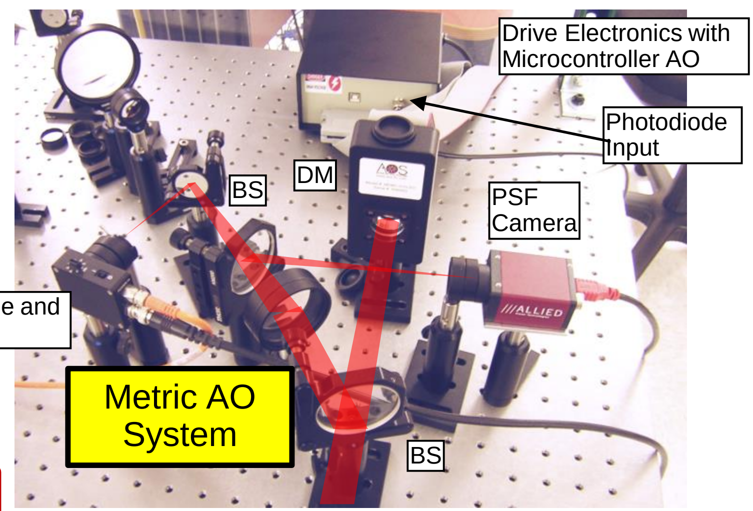
Membrane Deformable Mirror

PZT Deformable Mirror

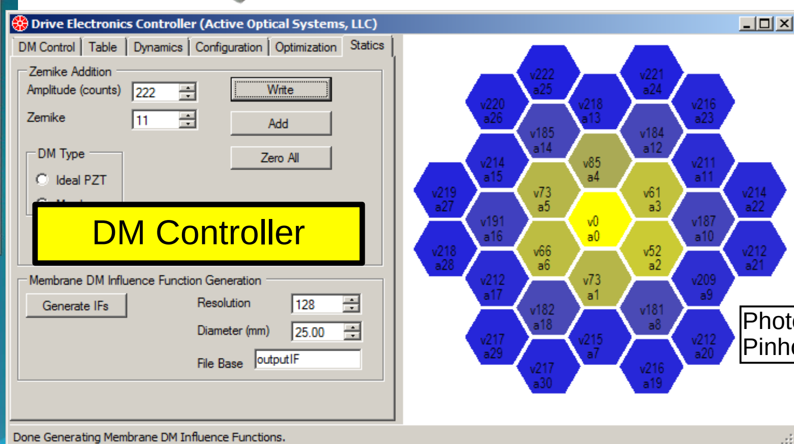
Computer Interface Electronics

USB Drive Electronics

AO Systems



Metric AO System

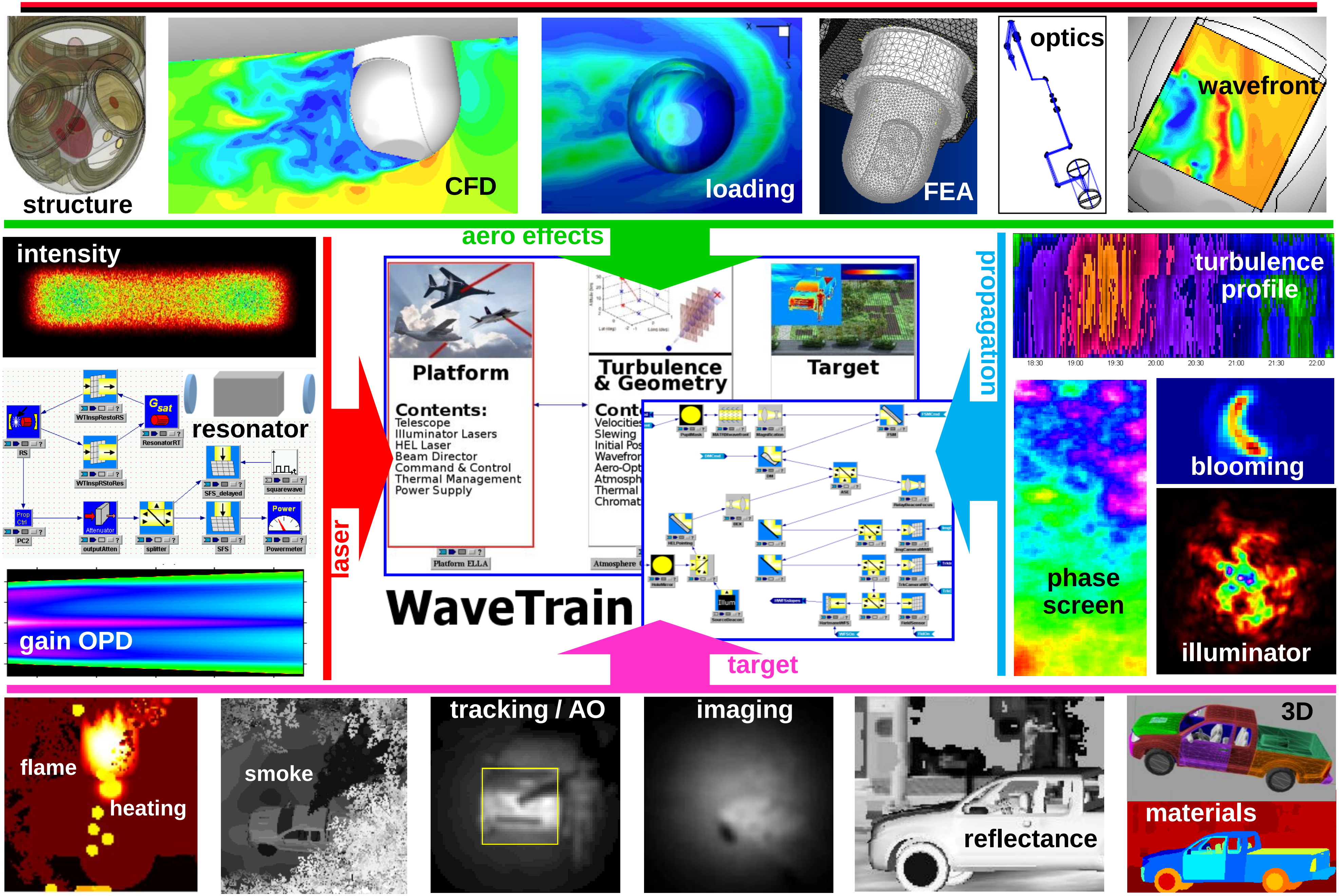


DM Controller

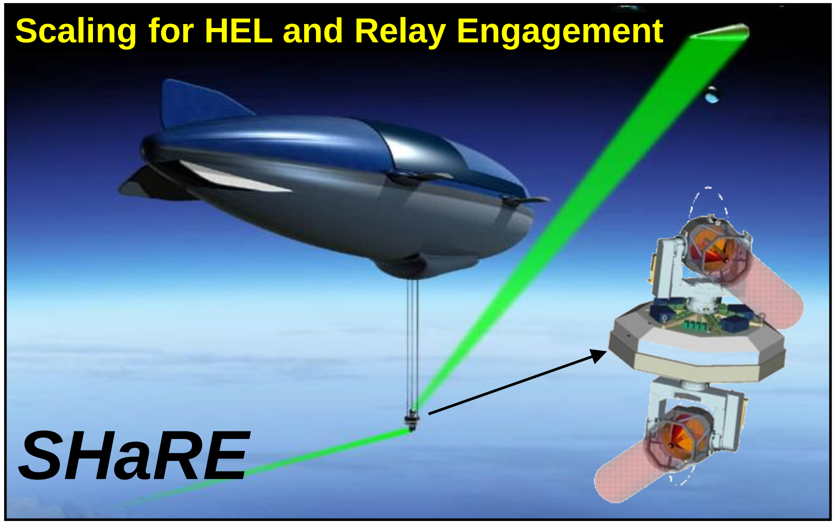
Wave front Controller Software

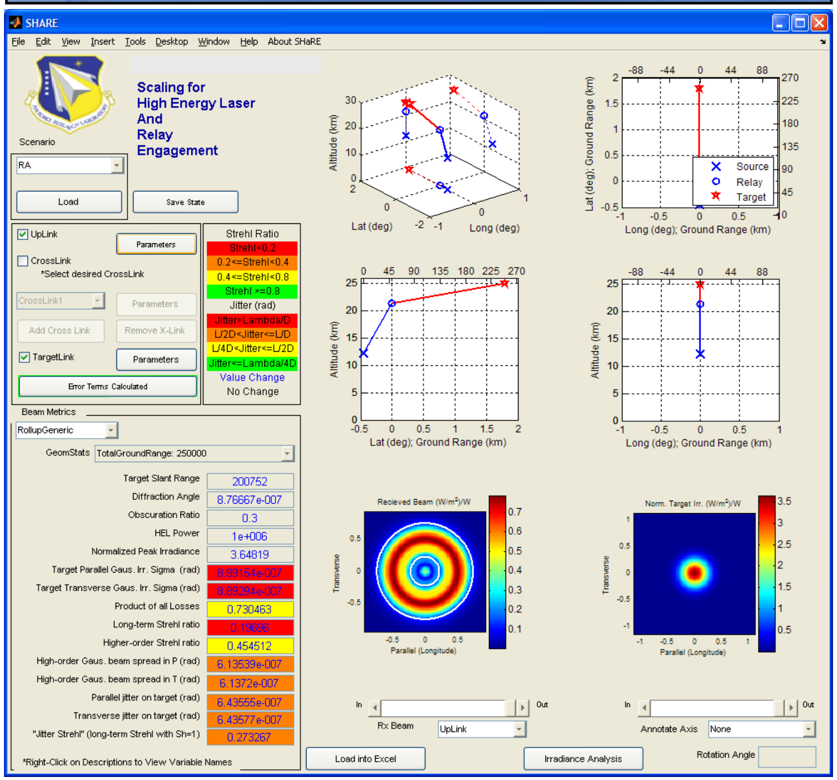
Overview of
Modeling & Analysis
Capabilities

Integrated End-to-End Modeling



Scaling for High Energy Laser and Relay Engagement (SHaRE)

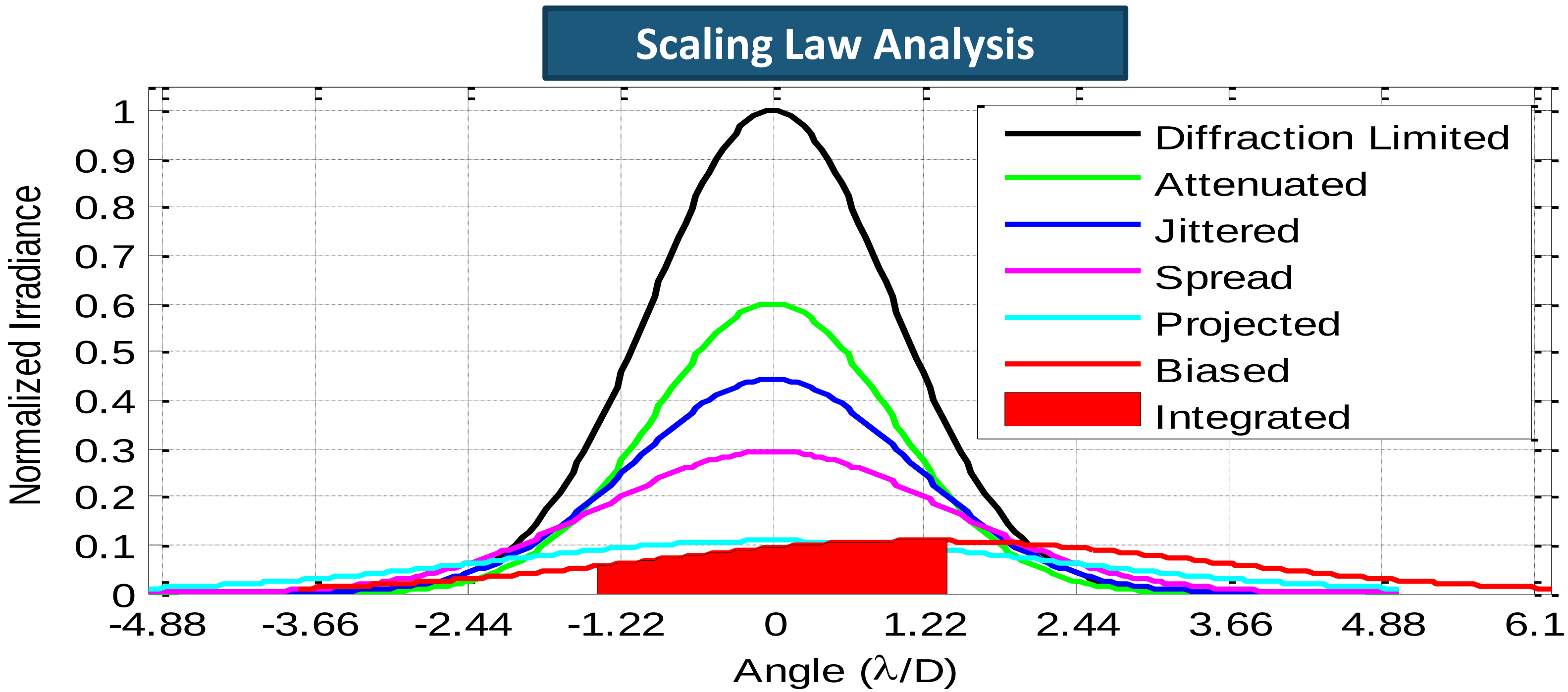




- **Original development sponsored by AFRL/DE Relay Mirror Program**
  - AFRL/RD approves distribution
  - MATLAB toolbox for Govt & Govt Contractors
- **Used to model <u>strategic</u>, <u>tactical</u>, <u>ground-based</u>, and <u>maritime</u> direct attack and relay HEL systems**
  - Based on work for MDA (BMDO), 2001
  - Built on ~10 years of scaling law modeling for ABL
  - Scaling law approaches augmented or innovated for relay uplink
- **Modularity supports the addition of new effects and anchoring of isolated and composite relations to both wave-optics and experimental results.**
- **Enables consideration of wide range of physical effects on laser performance**
  - Laser: power, wavelength, beam quality
  - Platform: transmitter, jitter, aero-optical
  - Atmosphere: extinction, turbulence, thermal blooming
  - Beam control: finite bandwidth, anisoplanatism, sensor SNR
  - Target: velocity, engagement geometry

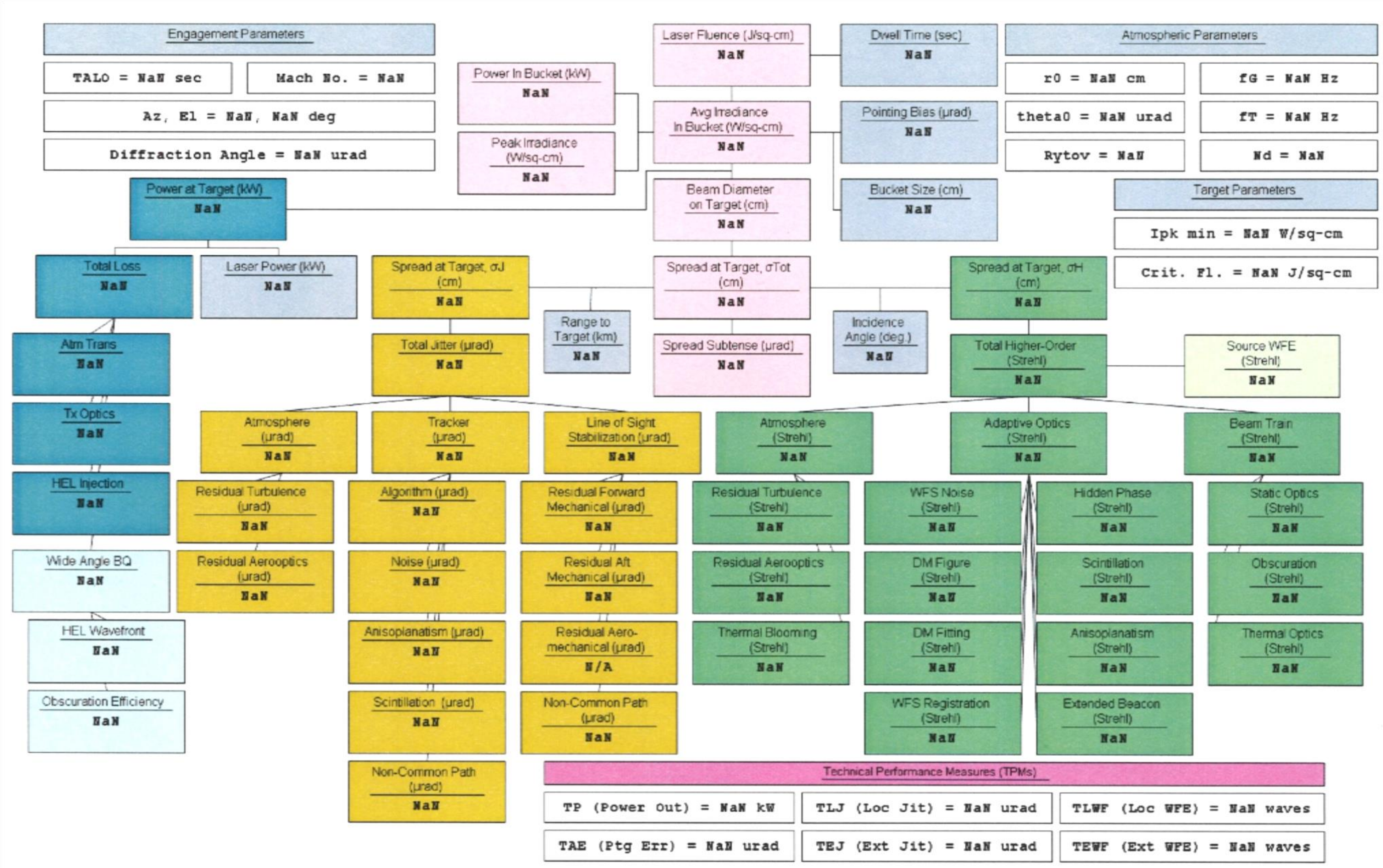
Scaling Law Analysis

- **Beam control metrics take into account the transmission losses, aimpoint error, and beam spread due to jitter and higher-order effects.**
- **The instantaneous power is projected onto the vulnerable region of the target.**
- **The power is then integrated in space and time to compute a fluence on target.**
- **Target vulnerability criteria are applied to determine whether and when sufficient fluence has been deposited on target.**



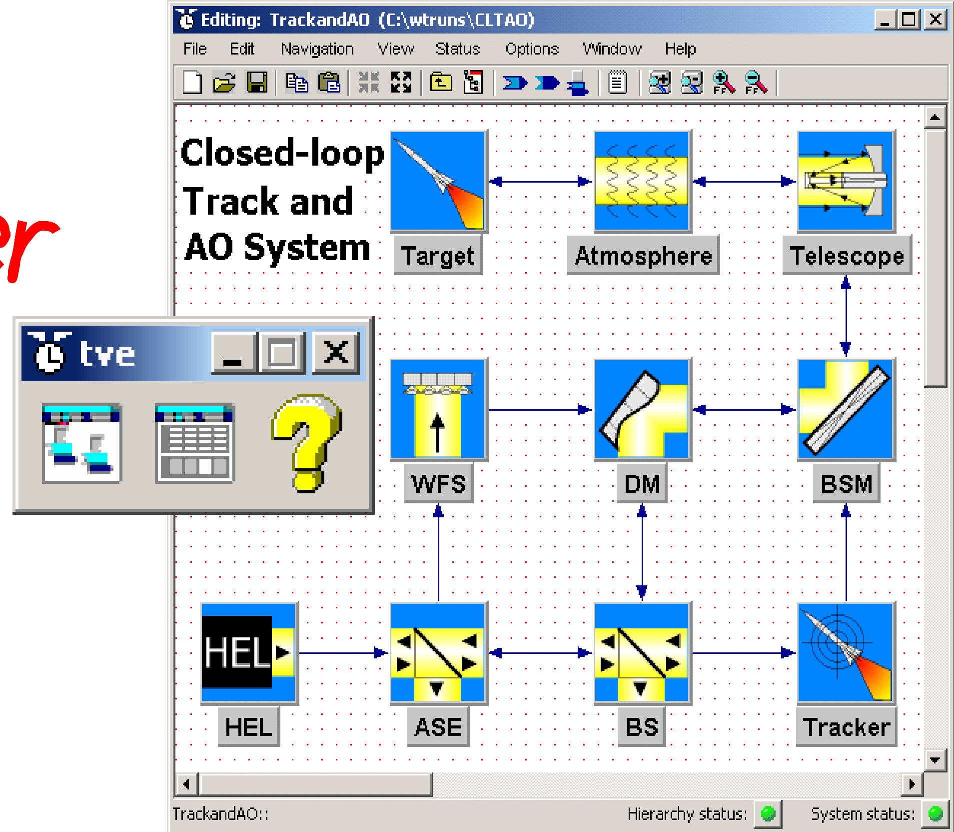
Tactical Beam Control Error Tree

SHaRE generates error trees which can be customized to support requirements analysis and flowdown for a given system design.



WaveTrain

wave optics made easy/ier

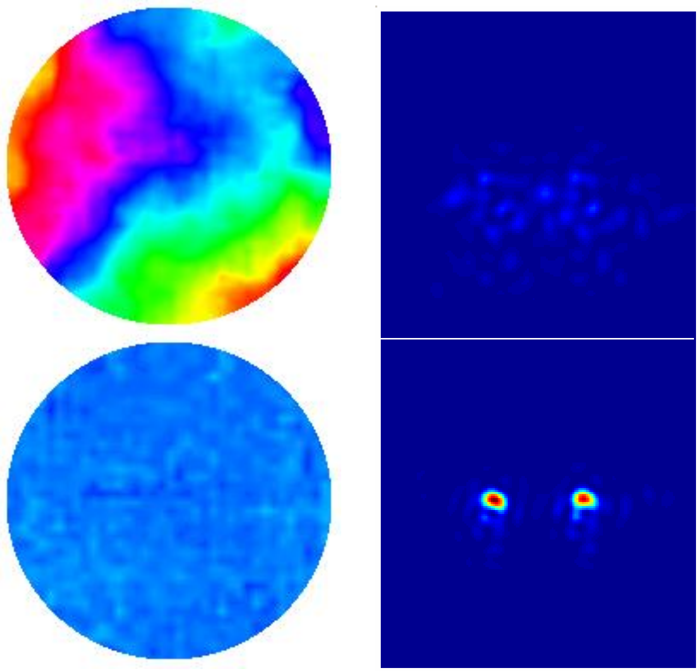


The Challenge of Wave Optics Simulation

Wave optics simulation is a crucial technology for the design and development for advanced optical systems. Until now it has been the sole province of a handful of specialists because the available codes were extraordinarily complicated, difficult to use, and they often required supercomputing resources.

Without Adaptive Optics

With Adaptive Optics



Phase Image

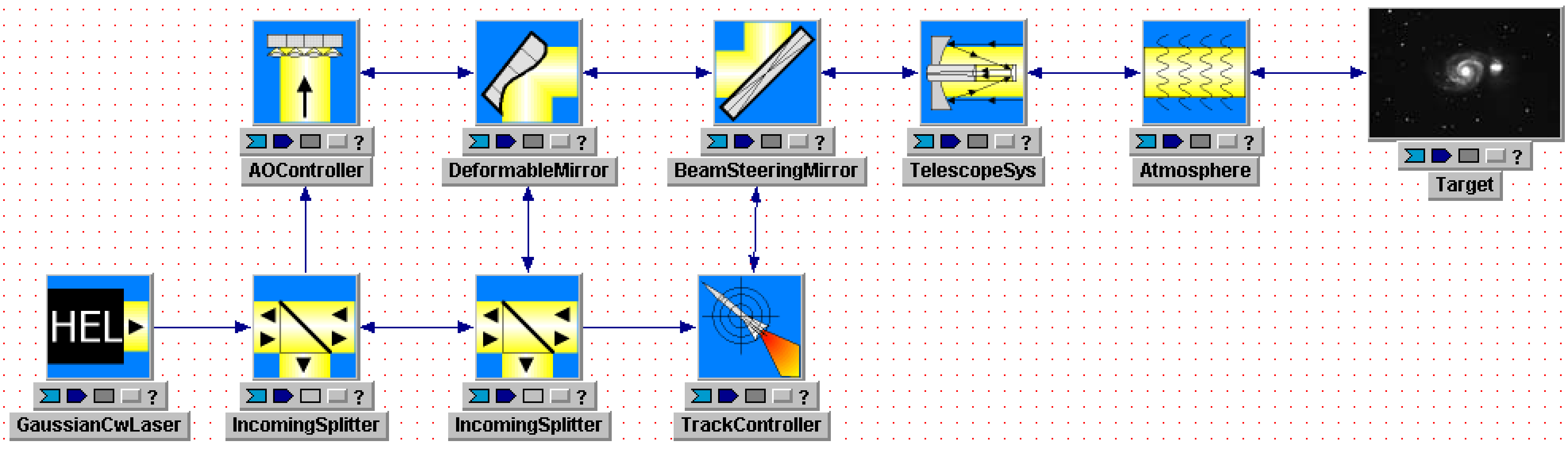
The Solution is WaveTrain

WaveTrain puts the power of wave optics simulation on your PC. Through an intuitive connect-the-blocks visual programming environment, you can assemble beam lines, control loops, and complete system models, including closed-loop adaptive optics (AO) systems.

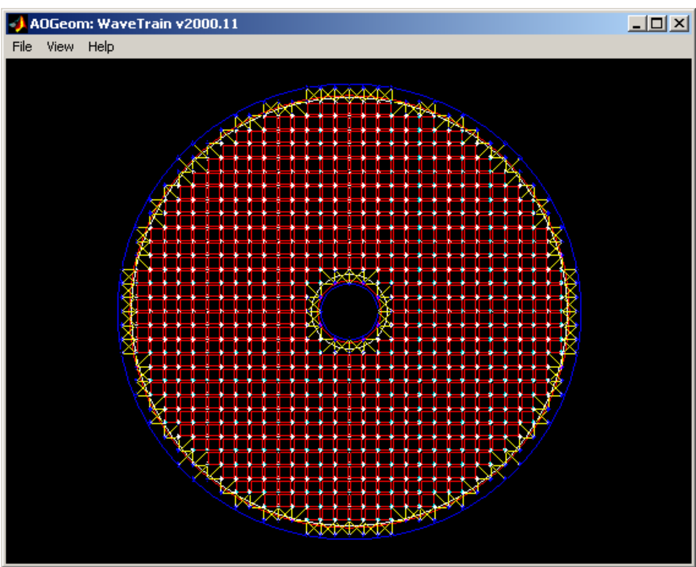
MZA Associates Corporation

For more information:
wavetrain@mza.com
www.mza.com
(505) 245-9970

A Basic WaveTrain Model



Starfire Optical Range 3.5 meter Telescope Model (Version 1.0)



Starfire Optical Range (SOR) imaging and adaptive optics model.

MZA

Dynamic Runs

Track and Science

Major Parameters:

Runsets:
SOR3501Runbs1

1 x Clear-1 atmosphere.

Wind was 5 m/s at low altitudes and 15 m/s at high altitudes.

10 phase screens.

256x256 propagations with 0.04 cm spacing.

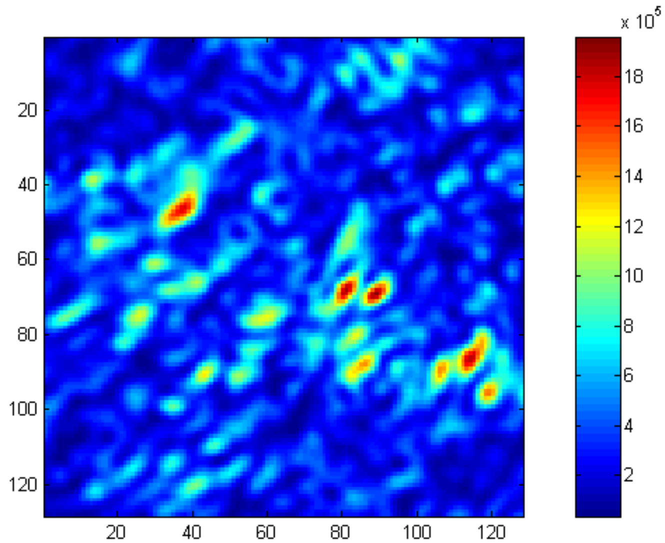
Point source beacon

Dual point sources separated at 0.3 arcsec. as celestial objects.

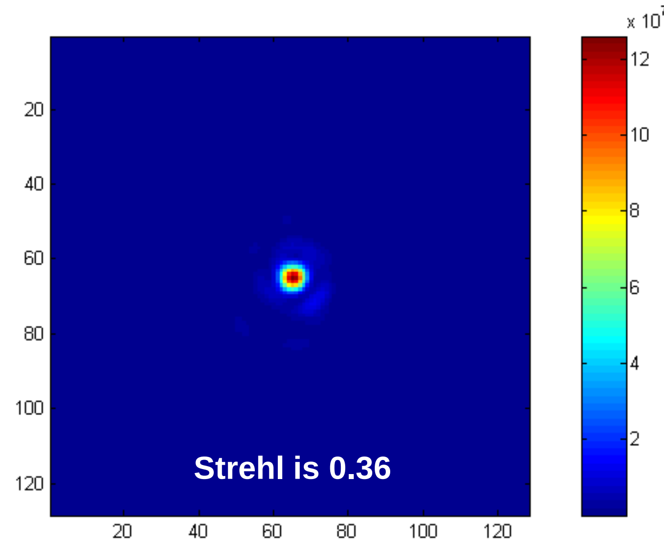
Resolved wavefront sensor (instead of 2x2 quad cell)

Est. AO closed-loop system bandwidth is about 50 Hz at -3dB

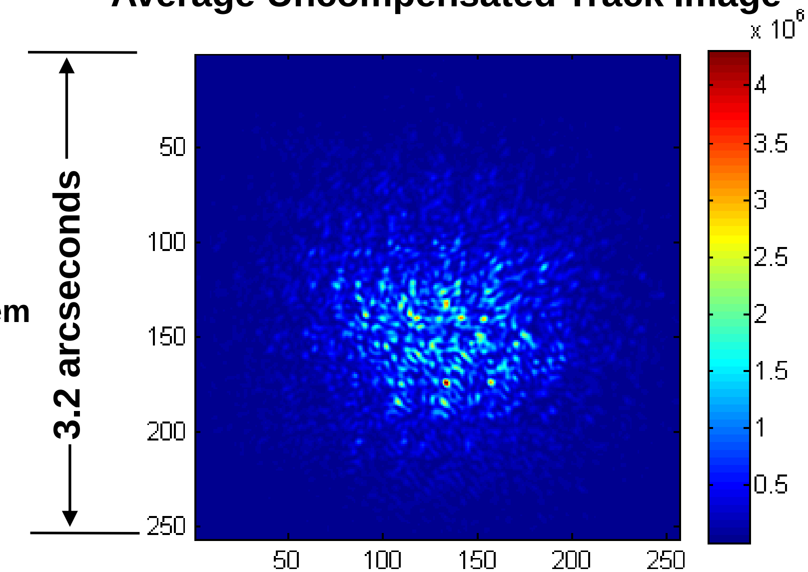
Est. Track closed-loop system bandwidth is about 240 Hz at -3dB.



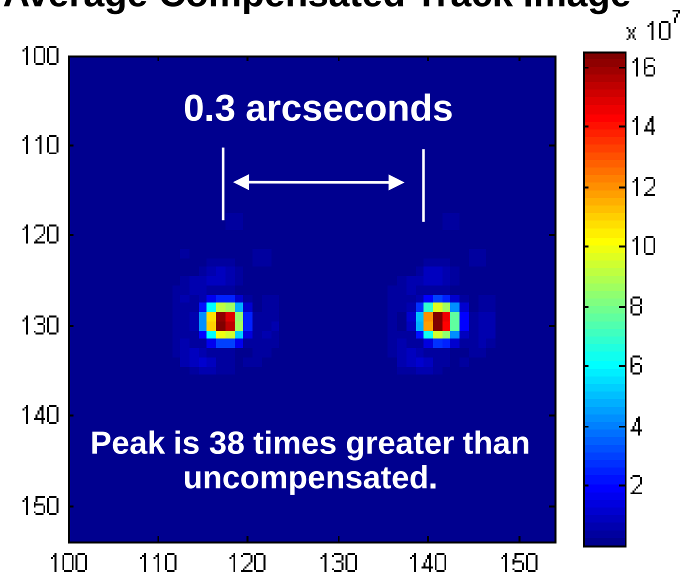
Average Uncompensated Track Image



Average Compensated Track Image



Average Uncompensated Science Image



Average Compensated Science Image (zoomed)

Wavefront Compensation

Static Run – Field and DM

Major Parameters:

Runset:
SOR3501Runa1w0

1 x Clear-1 atmosphere with no wind.

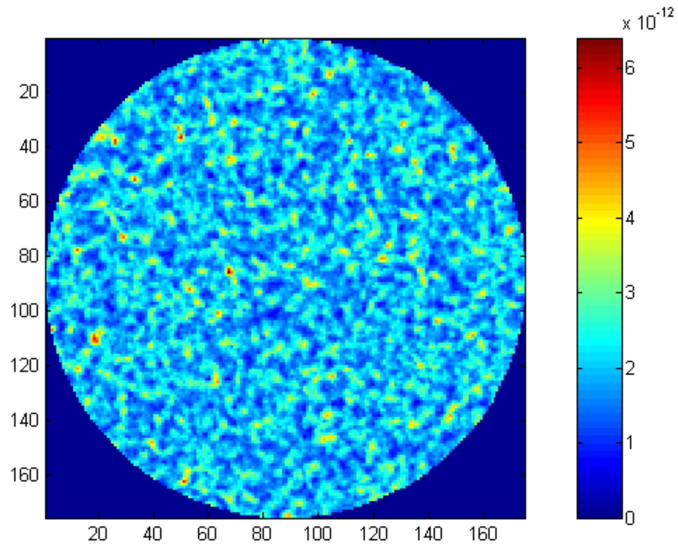
10 phase screens.

512x512 propagations with 0.02 cm spacing.

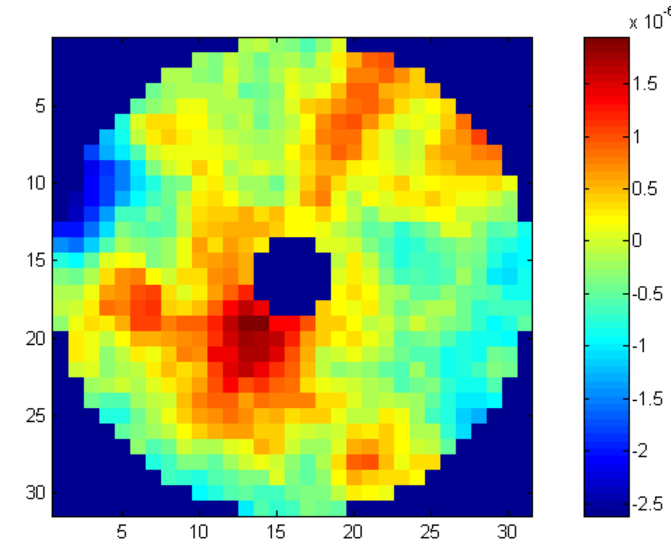
Point source beacon

Dual point sources separated at 0.3 arcsec. as celestial objects.

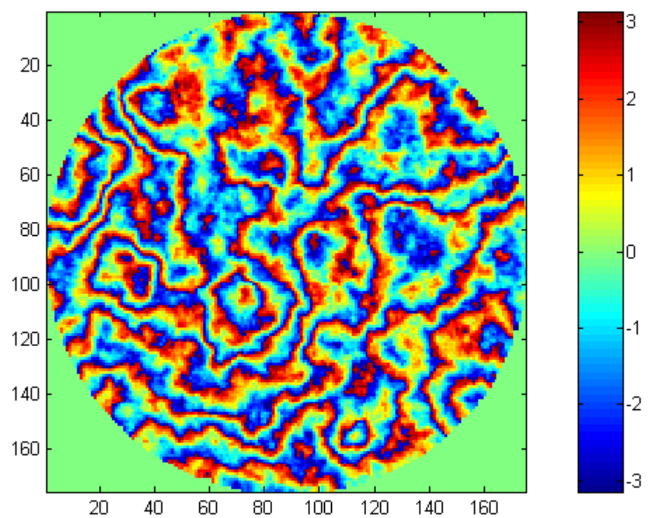
Resolved wavefront sensor (instead of 2x2 quad cell)



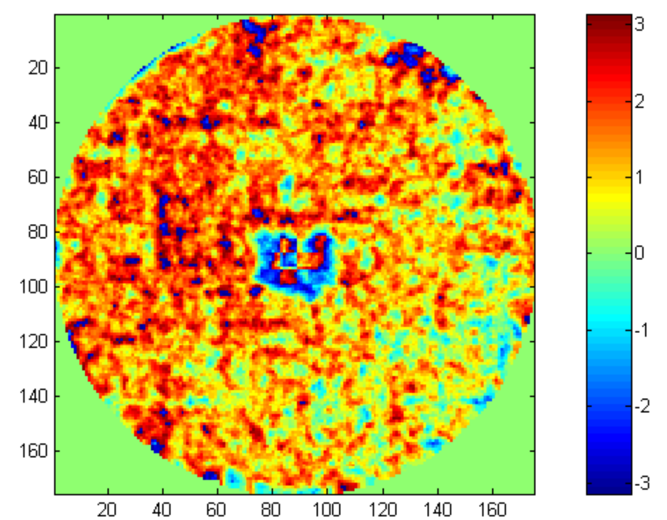
Pupil Irradiance



Final DM Actuator Positions



Initial Uncompensated Pupil Phase



Final Compensated Pupil Phase

Wavefront Sensor Model

Static Run – WFS

Major Parameters:

Runset:
SOR3501Runa1w0

1 x Clear-1 atmosphere with no wind.

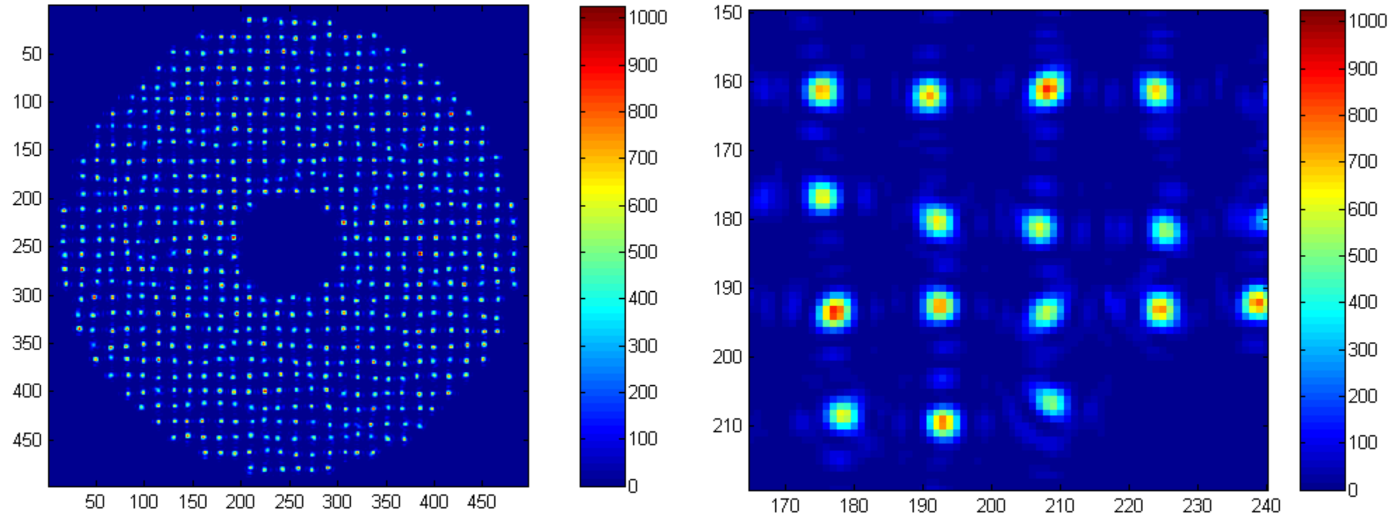
10 phase screens.

512x512 propagations with 0.02 cm spacing.

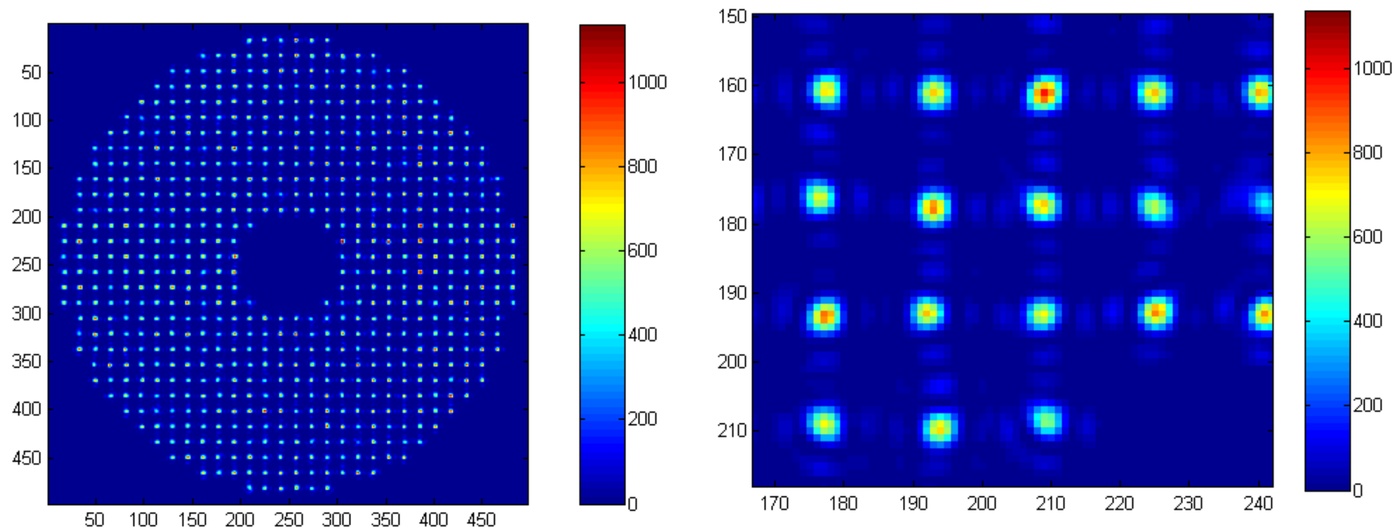
Point source beacon

Dual point sources separated at 0.3 arcsec. as celestial objects.

Resolved wavefront sensor (instead of 2x2 quad cell)



Initial Uncompensated WFS Subaperture Spots **Zoomed**



Final Compensated WFS Subaperture Spots

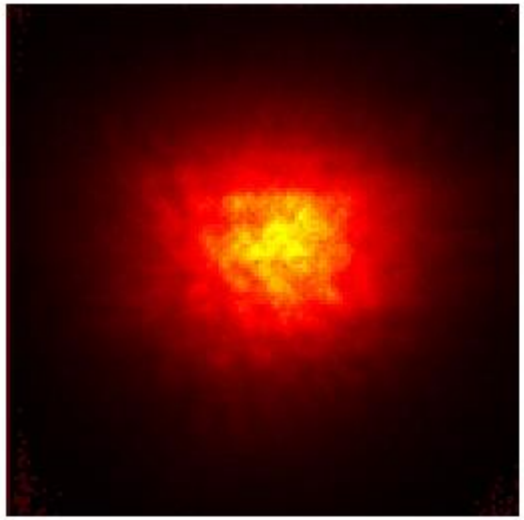
Comparison with Published SOR Results

First light for the adaptive optics system on the 3.5-m telescope at the Starfire Optical Range occurred in September, 1997. This astronomical I Band compensated image of the binary star k-Peg was generated using the 756 active actuator adaptive optics system.

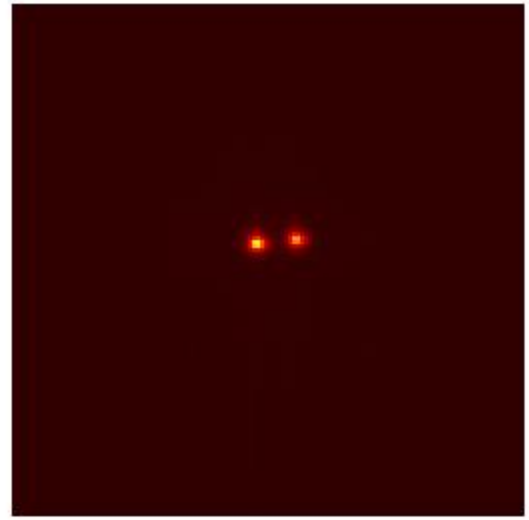
Actual Data

From the SOR website.

Atmospheric conditions, camera characteristics, and control loop parameters are not available.



Uncompensated Image



Compensated Image. 0.3 arcsec separation

Simulated Data

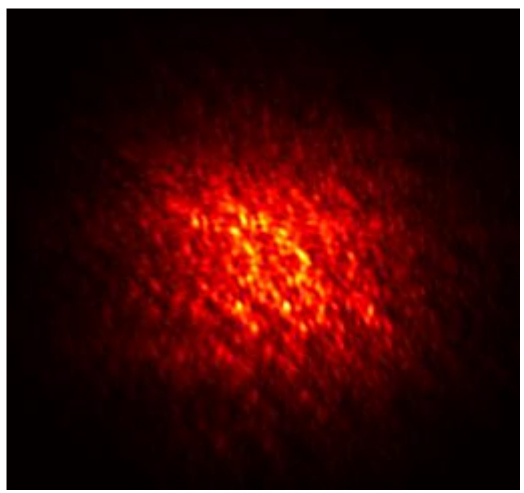
Runsets:
SOR3501Runa1w20 &
SOR3501Runa1w20ol

1 x Clear-1 atmosphere.

Wind was 20 m/s at all altitudes.

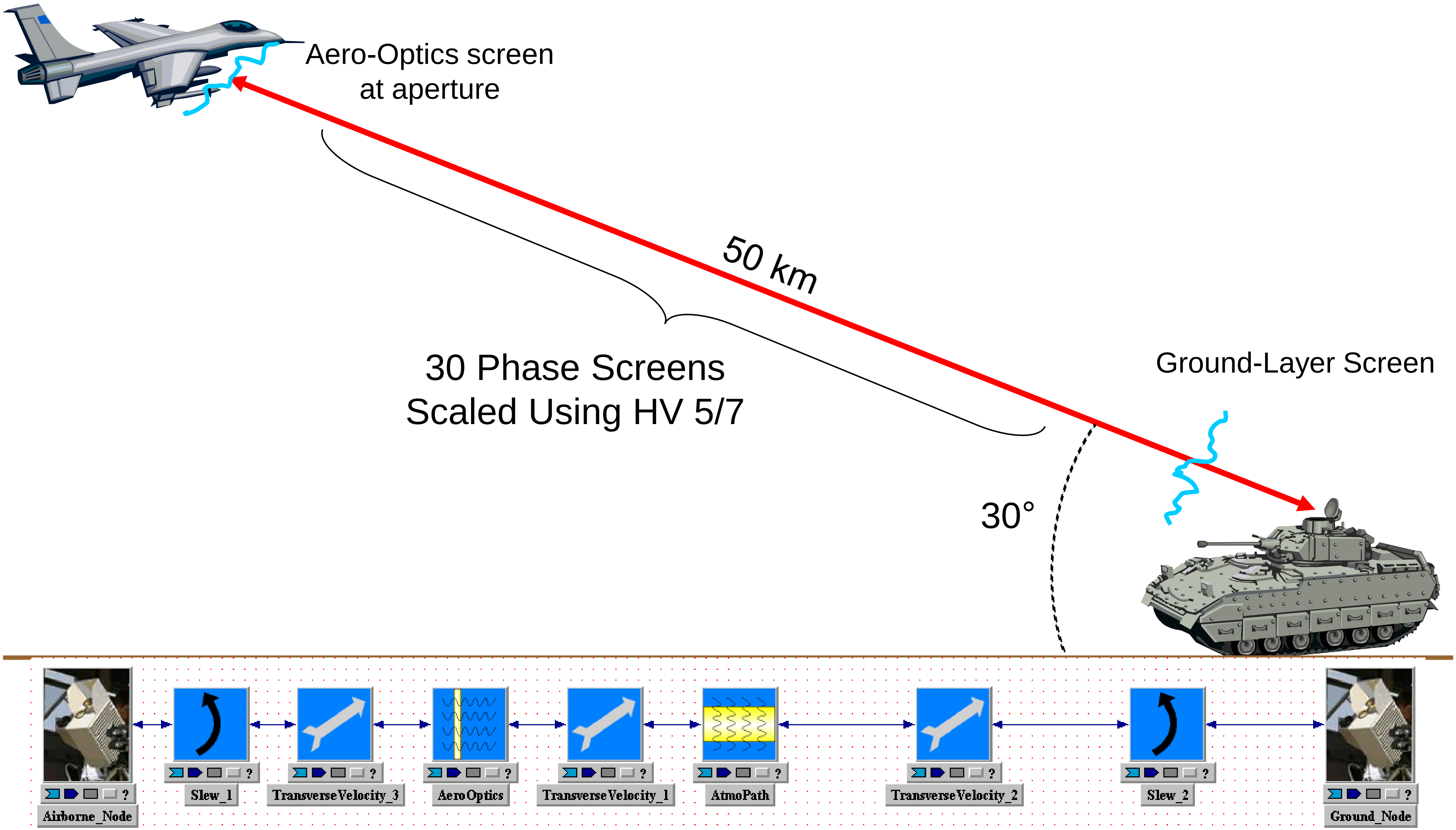
10 phase screens.

512x512 grid with 0.02 cm spacing.



MZA

Air-to-Ground Laser Comm System



Airborne Node

Node motion, pointing, and Aero-Optics

Atmosphere

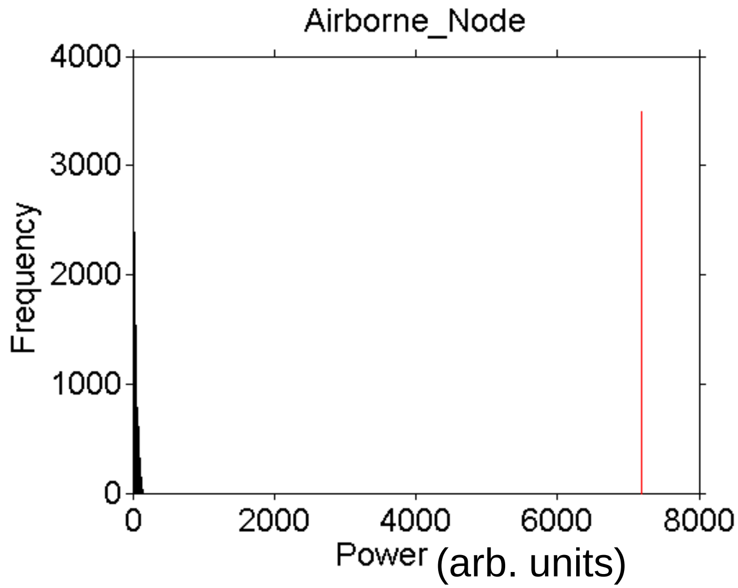
Node motion and pointing

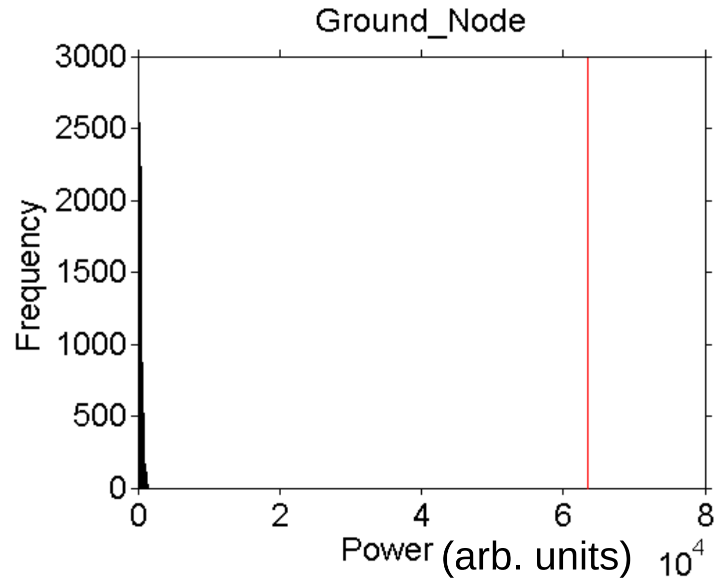
Ground Node

Laser Comm Terminal

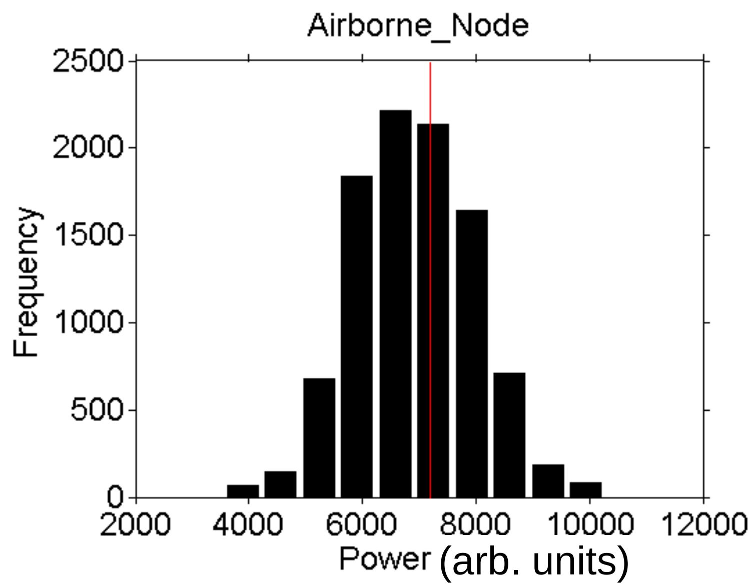
Adaptive Optics Increases Power Transmission from Transmitter to Receiver

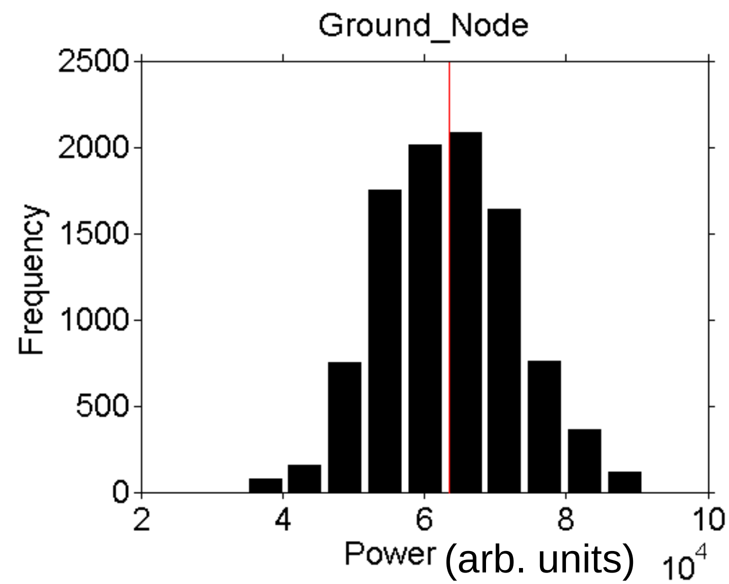
Transmission to Receiver without AO





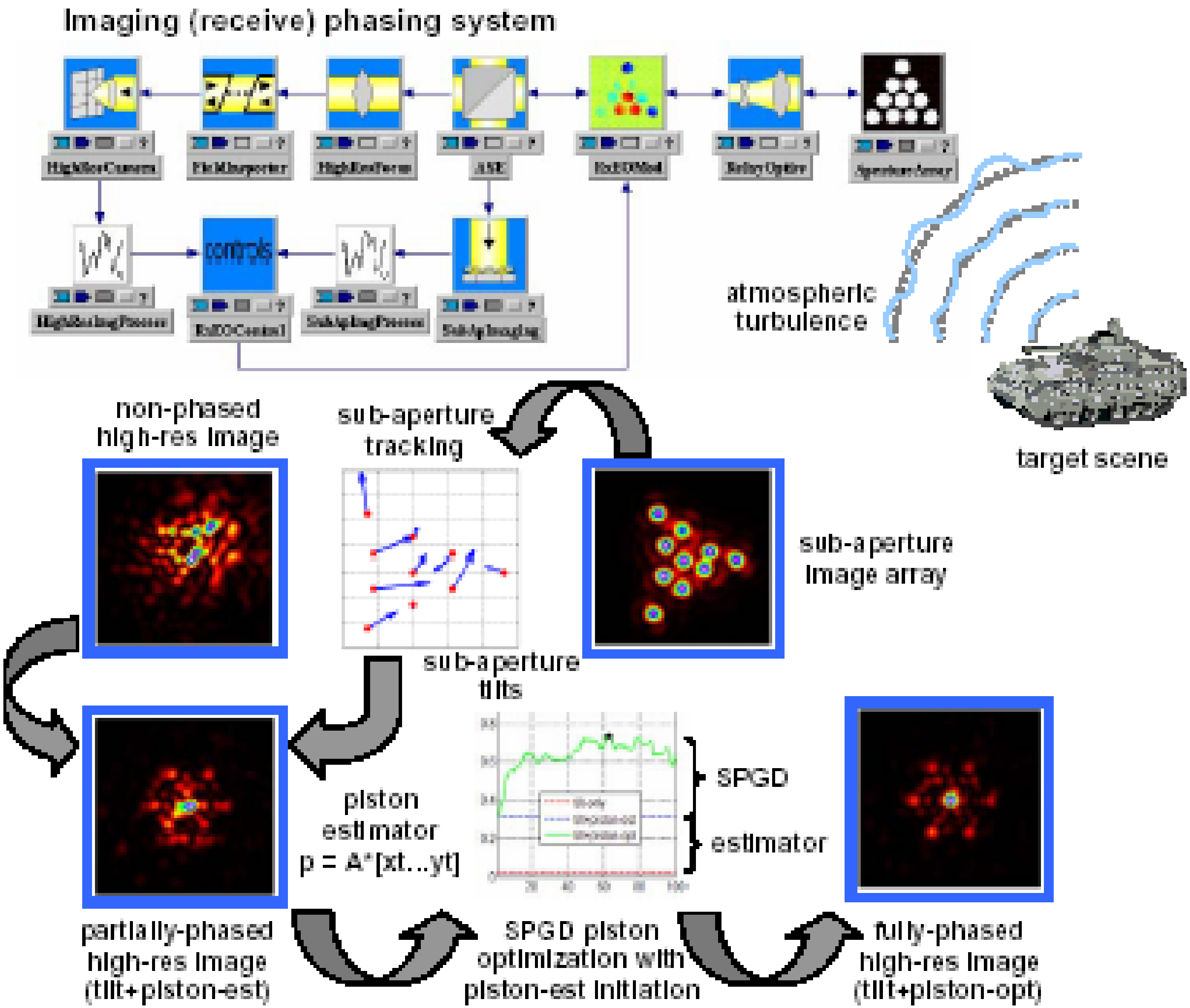
Transmission to Receiver with AO





RED LINE = Diffraction-Limited

Phased-Aperture Imaging
Concept



- We've developed new concepts for phased-aperture imaging.

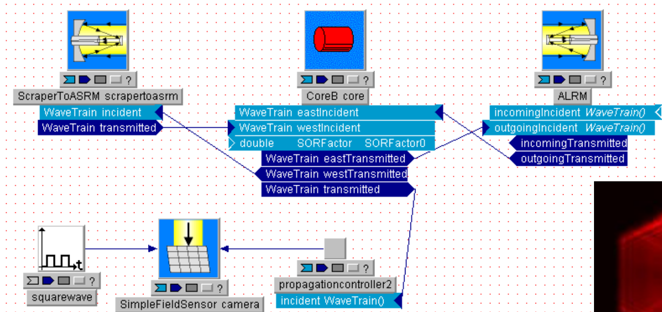
-The concepts can also be extended perform to phased-aperture beam projection.

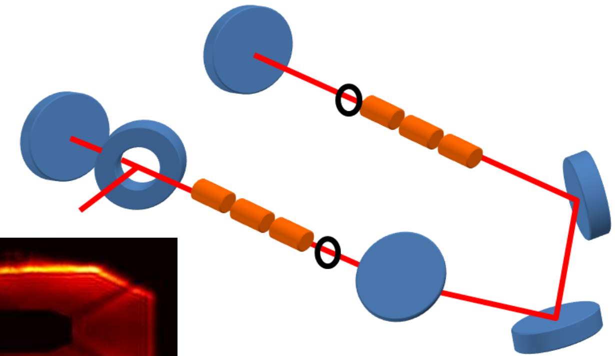
Overview of Laser Resonator Design and Analysis Capabilities

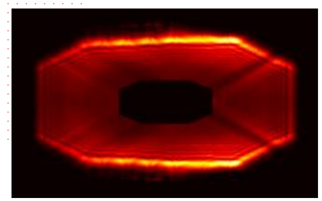
Laser Modeling with WaveTrain

- **High Power Solid-State Laser Modeling**
  - Slab lasers
  - Fiber lasers

COIL RESONATOR MODELING



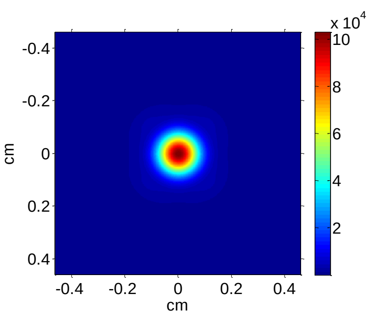


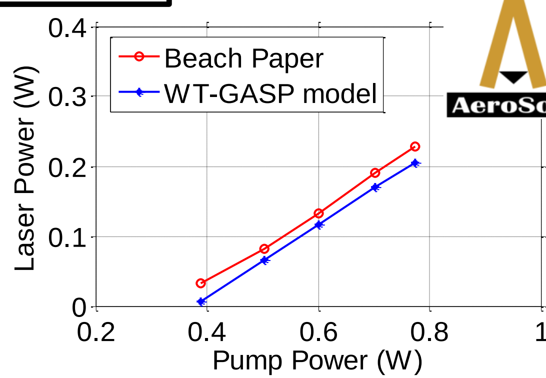


- **COIL Modeling**

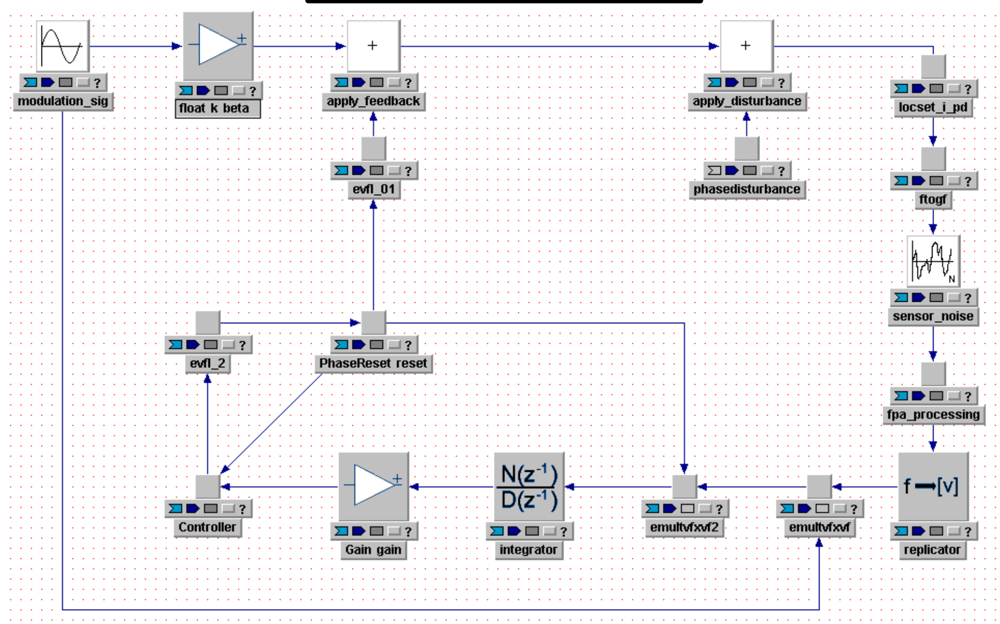
- **Diode Pumped Alkali Laser (DPAL) Modeling**

DPAL





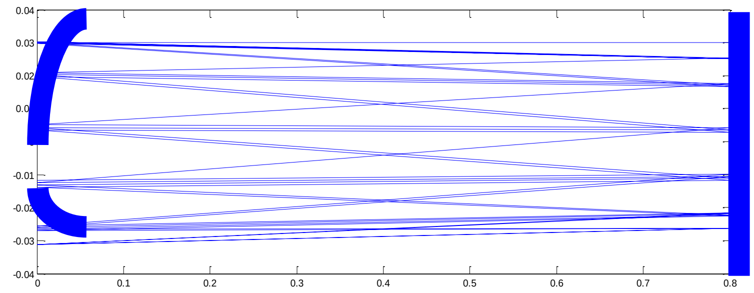
LOCSET FIBER PHASING

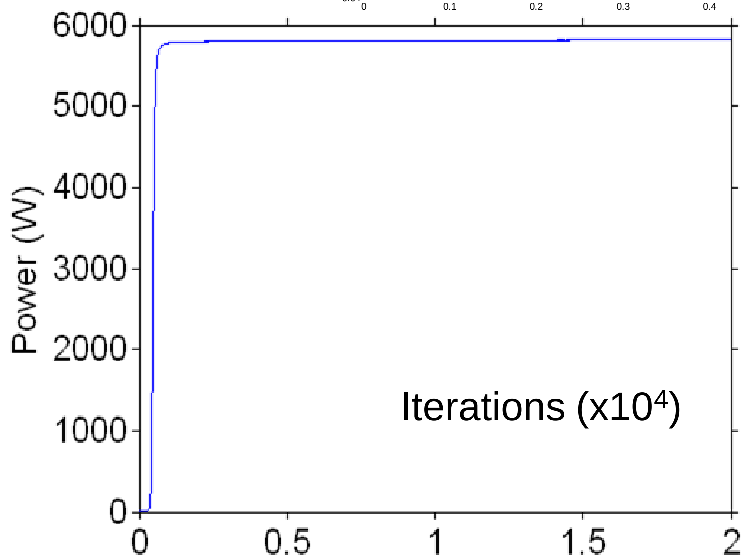


Massively Multi-Mode Stable Laser Modeling

- **MZA developed a new theory of numerical mesh requirements for stable resonators.**
  - Reduces the computational requirements required for accurate modeling.
- **MZA developed a technique for modeling multi-transverse modes that stabilized the power and matched with Rigrod theory.**

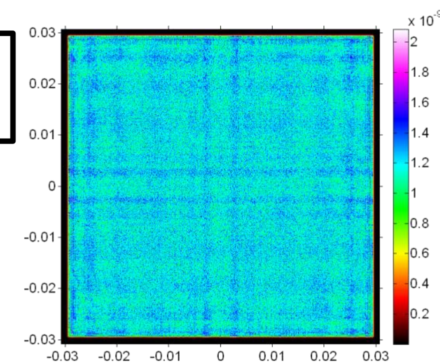
Self-Repeating Rays





Resonator power converges in very few iterations.

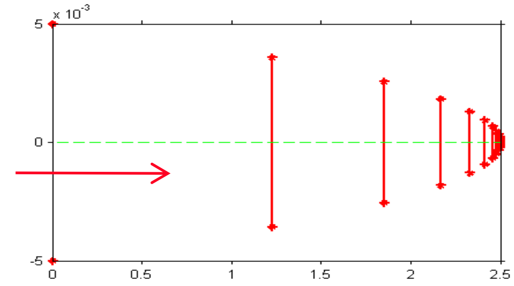
Average Intensity shows edge Fresnel ringing.

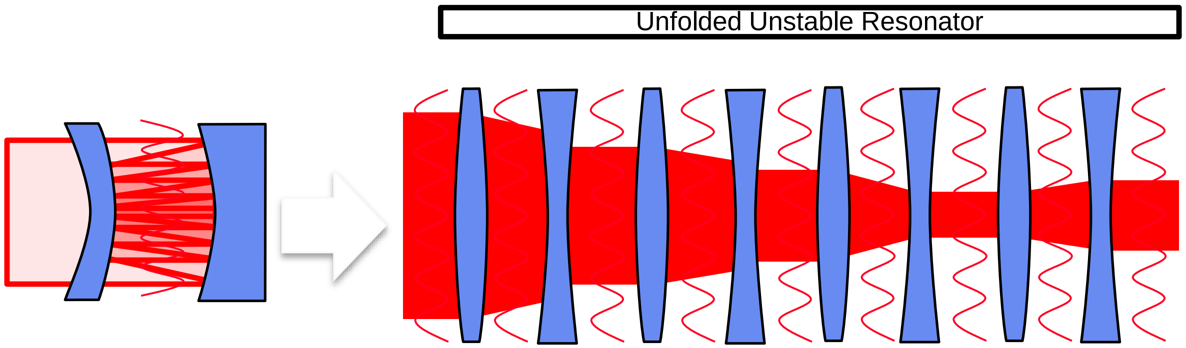


SSL Theory Developments

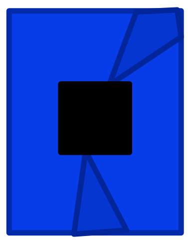
- **MZA developed an approach for mesh determination for unstable laser resonators**
  - Based on ray-optics
  - Reduces mesh size
- **Diffraction Core**
  - Radial Streaking
- **Magnify & Add**
  - Aberrations in a resonator amplify & down-sample in spatial frequency
- **Anchoring**

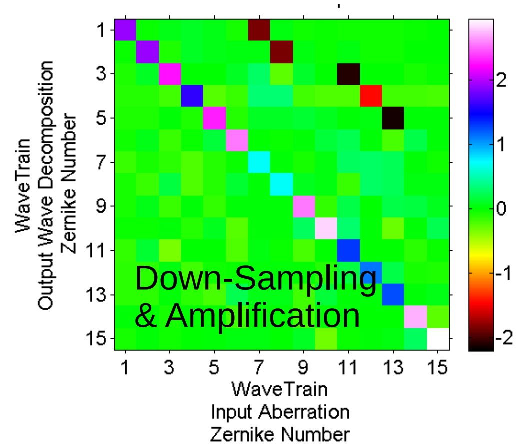
Ray-optics of a ray going backwards into an unstable resonator.





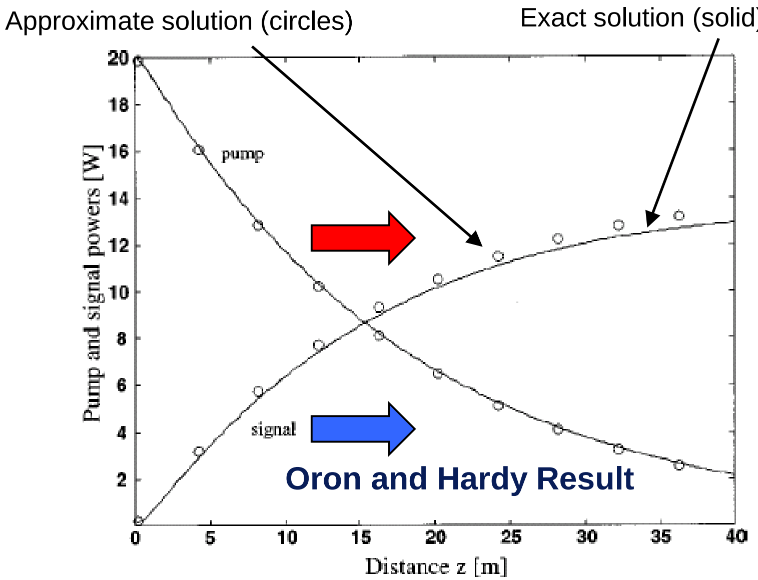
Intensity Radial Streaking

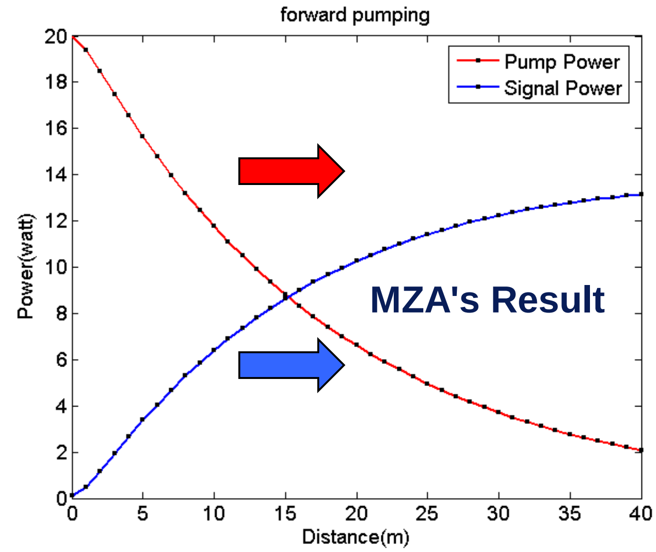




Fiber Laser Modeling

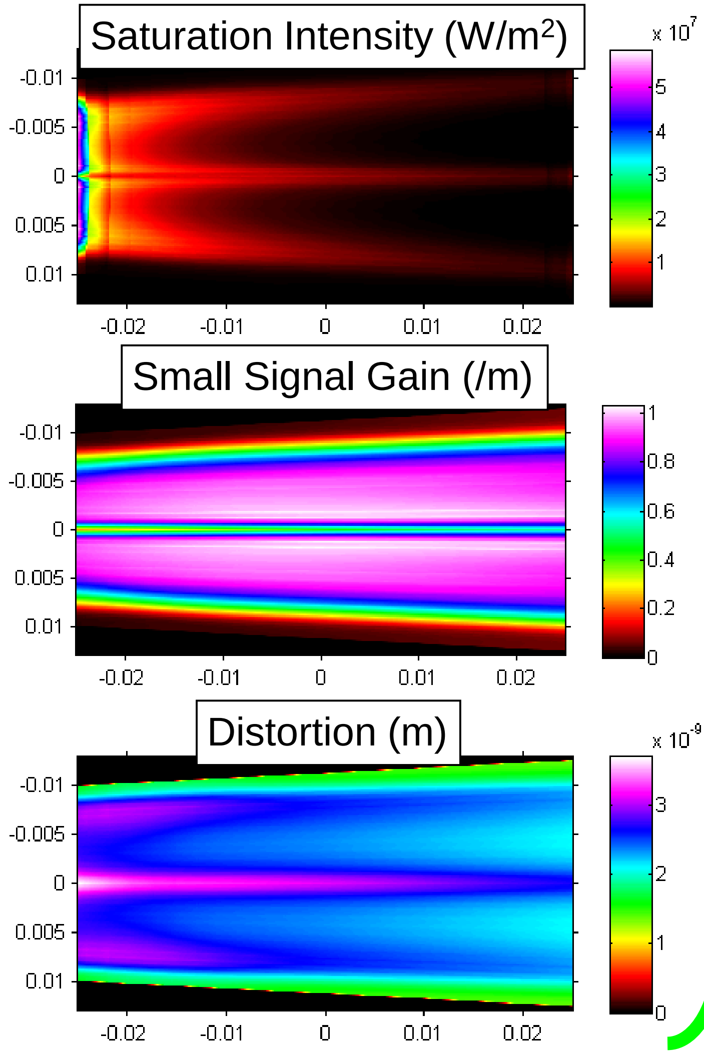
- **Fiber Laser Amplifier Modeling including**
  - Rate Equation Gain
  - Amplified Spontaneous Emission (ASE)
  - Rayleigh Back-Scattering
  - Stimulated Brillouin Scattering (SBS)

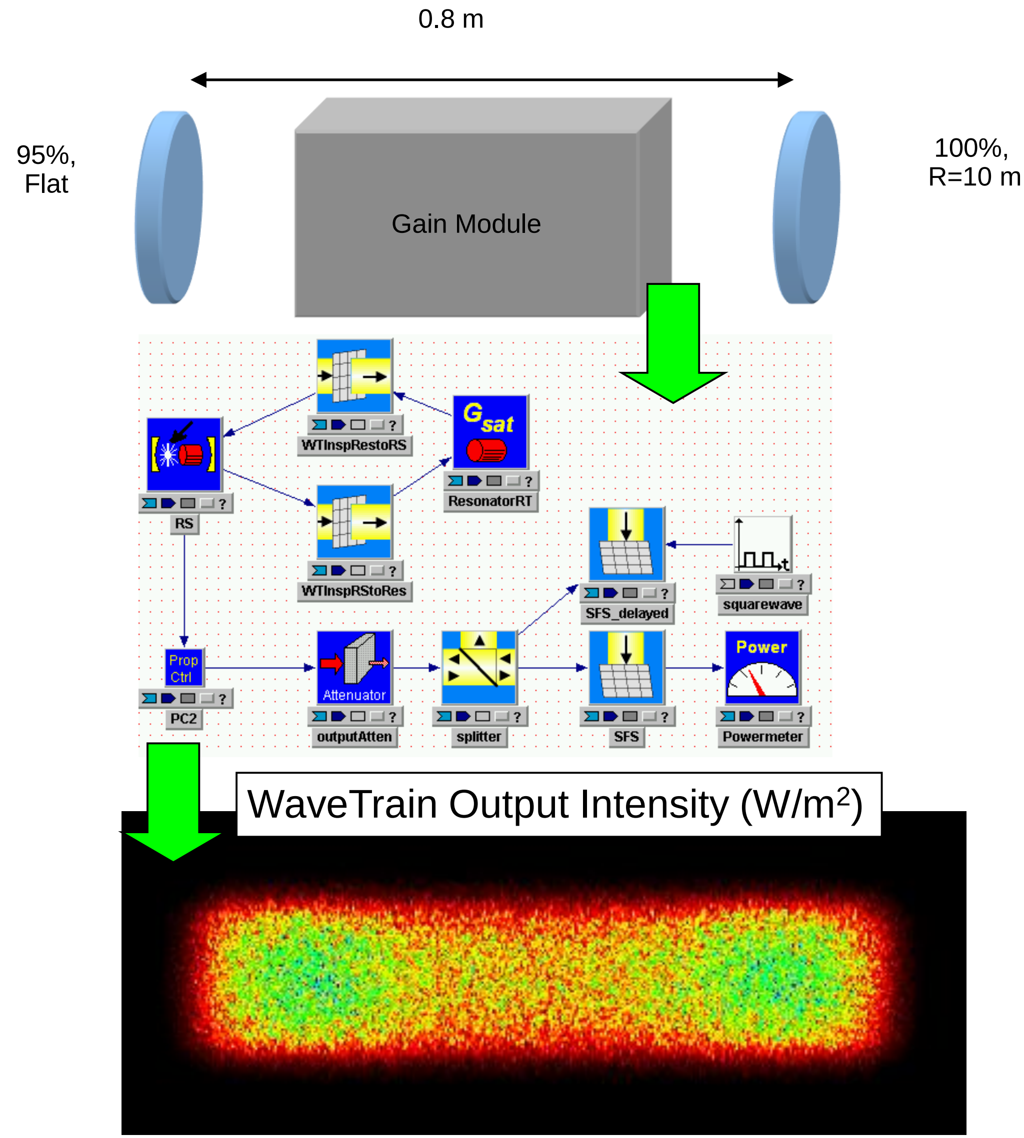




RADICL Stable Resonator Modeling with GASP CFD

GASP Inputs

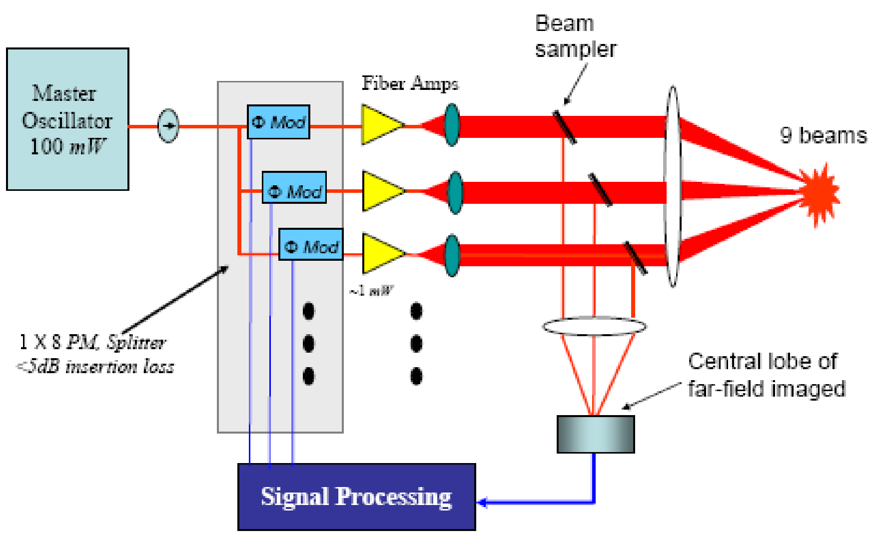




LOCSET Fiber Phasing Concept

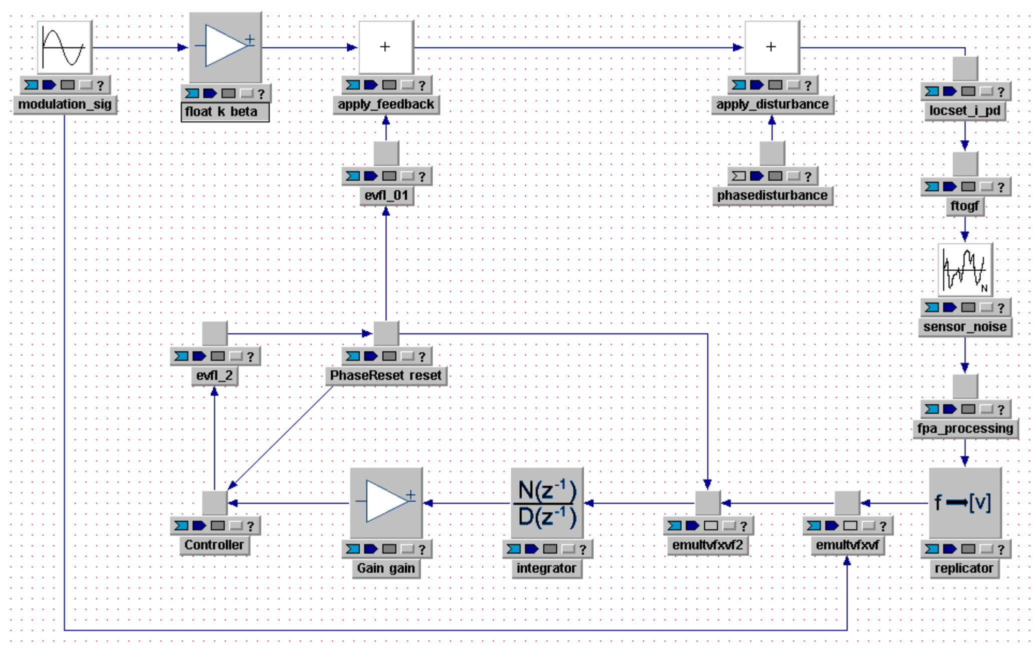
First Experimental Demonstration of Self-Synchronous Locking of Optical Coherence by Single-detector Electronic-frequency Tagging of Fiber Amplifiers

T. M. Shay[a], Vincent Benham[b], J. T. Baker[c], Capt. Benjamin Ward[a], Anthony D. Sanchez[a], Mark A. Culpepper[a], Sgt. D. Pilkington[a], Lt. Justin Spring[a], Lt. Douglas J. Nelson[a], and Lt. Chunte A. Lu[a]



Fiber Phasing Schematic

WaveTrain Model



Summary of Laser Source Modeling

- Wave-optics Models of Laser Resonators
  - ABL COIL Modeling (for ABL SPO)
  - RADICL Modeling (for AFRL)
  - SSL Modeling (for Textron JHPSSL & HELLADS)
  - Integration with GASP (for AFRL)
  - Fiber Laser Illuminator Modeling (for AFRL)
- Engineering Models
  - LADERA JHPSSL Specifications (for HEL JTO)
  - LADERA SSL System Weight Model (for AFRL)
- Fiber Physics and Control Modeling
  - Detailed Fiber Amplifier Modeling (for AFRL)
  - LOCSET Fiber Phasing Control Algorithm (for AFRL)

Overview
of
Adaptive Optics and Wavefront Compensation
for
High Energy Laser Weapons Systems
(HELWS)
and
Optical Surveillance Systems

Adaptive Optics Systems Make HELWS More Lethal and Cost Effective

- **High Energy Laser Weapons Systems must…**
  - employ a Laser Source of sufficient power to be lethal, and
  - be projected from a Beam Director of sufficient diameter.

- **The Laser Source and the Beam Director make up nearly all of the Size, Weight, and Power required by a HELWS**
  - The logistical footprint of a HELWS can become significant.

- **The addition of Adaptive Optics to a HELWS allows…**
  - A lower power Laser Source to achieve the same lethality as that of a system with a lower laser power source.
  - A smaller Beam Director to achieve the same lethality and better surveillance capabilities as that of a system with a larger Beam Director.

- **The most cost effective High Energy Laser Weapons Systems will employ Adaptive Optics.**

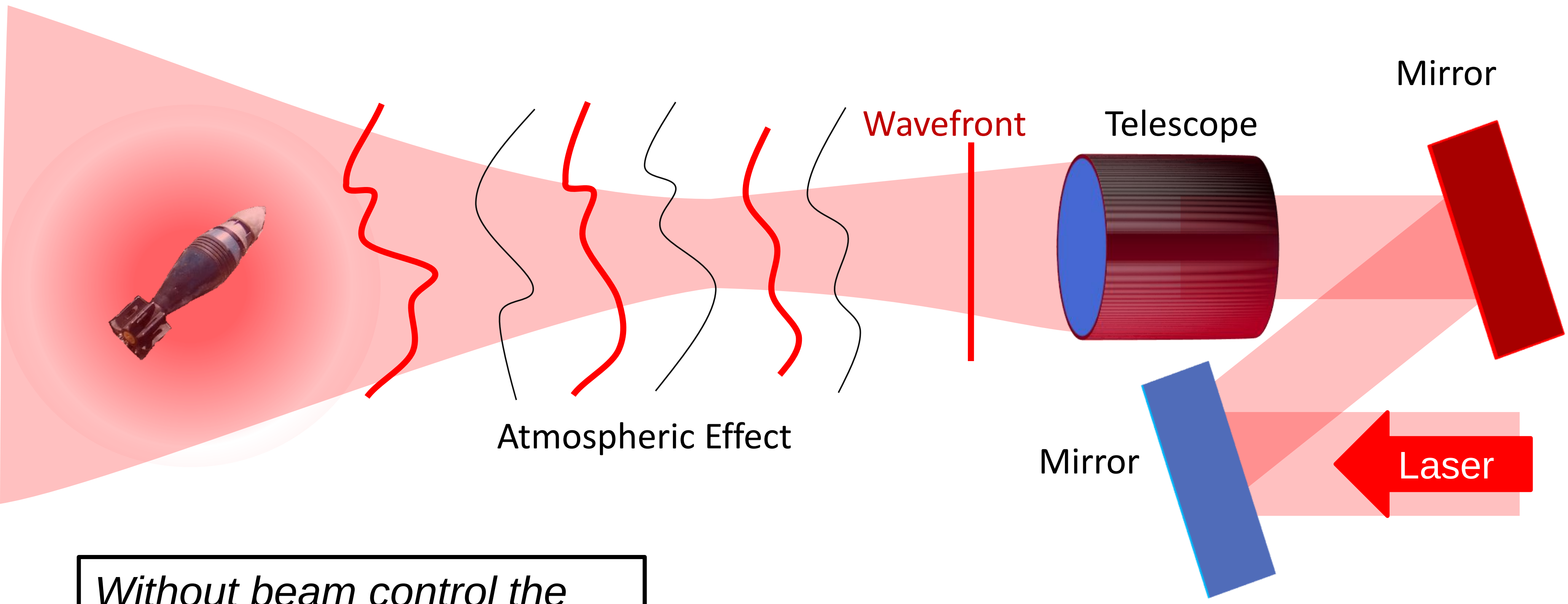
What Does Adaptive Optics do for High Energy Laser Weapons Systems?

- **Extend the range**
  - Adaptive Optics Wavefront Compensation delivers more power to a target vulnerable region at longer ranges.
- **Reduce the time-to-kill**
  - More power on the target vulnerable region means that it takes less time to kill the target
  - This allows greater margin in the system and possibly increases the number of defeated targets in a salvo.
- **Reduce the total number of systems in an area defense**
  - Increased range and decreased time means that fewer total weapons system might be used to defend the same area.
- **Increase system robustness**
  - The presence of an adaptive optics system potentially increases the range of environmental conditions under which the system can be effective.
- **Improve surveillance range and quality**
  - Adaptive optics improves image quality when the system is used for surveillance purposes.

Adaptive Optics Systems Increase the Resolution and Quality of ISR Systems

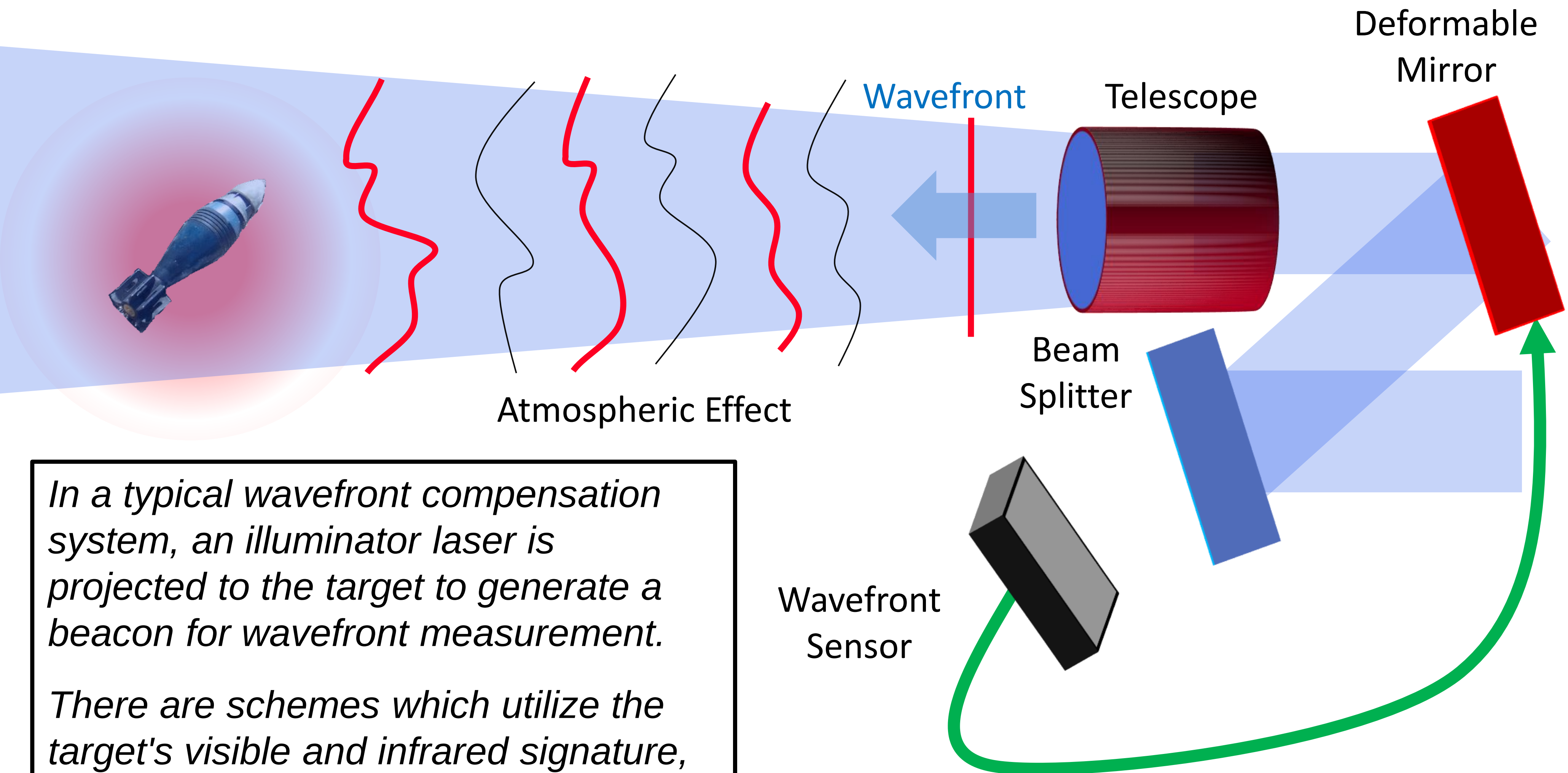
- **Optical surveillance systems must…**
  - contend with intervening atmospheric distortions,
  - and operate under a range of vibration and thermal conditions.
- **The typical approach to improving such systems is to…**
  - increase the aperture diameter,
  - constrain the operational environment, and
  - employ more expensive sensors.
- **These approaches all increase the cost, complexity, and logistical footprint.**
- **The addition of Adaptive Optics to such systems allows…**
  - the same aperture diameter to achieve greater effective resolution, and
  - increase the signal-to-noise ratio on the optical sensors.
- **The most capable future ISR systems will employ Adaptive Optics.**

The Need for Wavefront Compensation



Without beam control the weapons beam spreads and less power reaches the target vulnerable region.

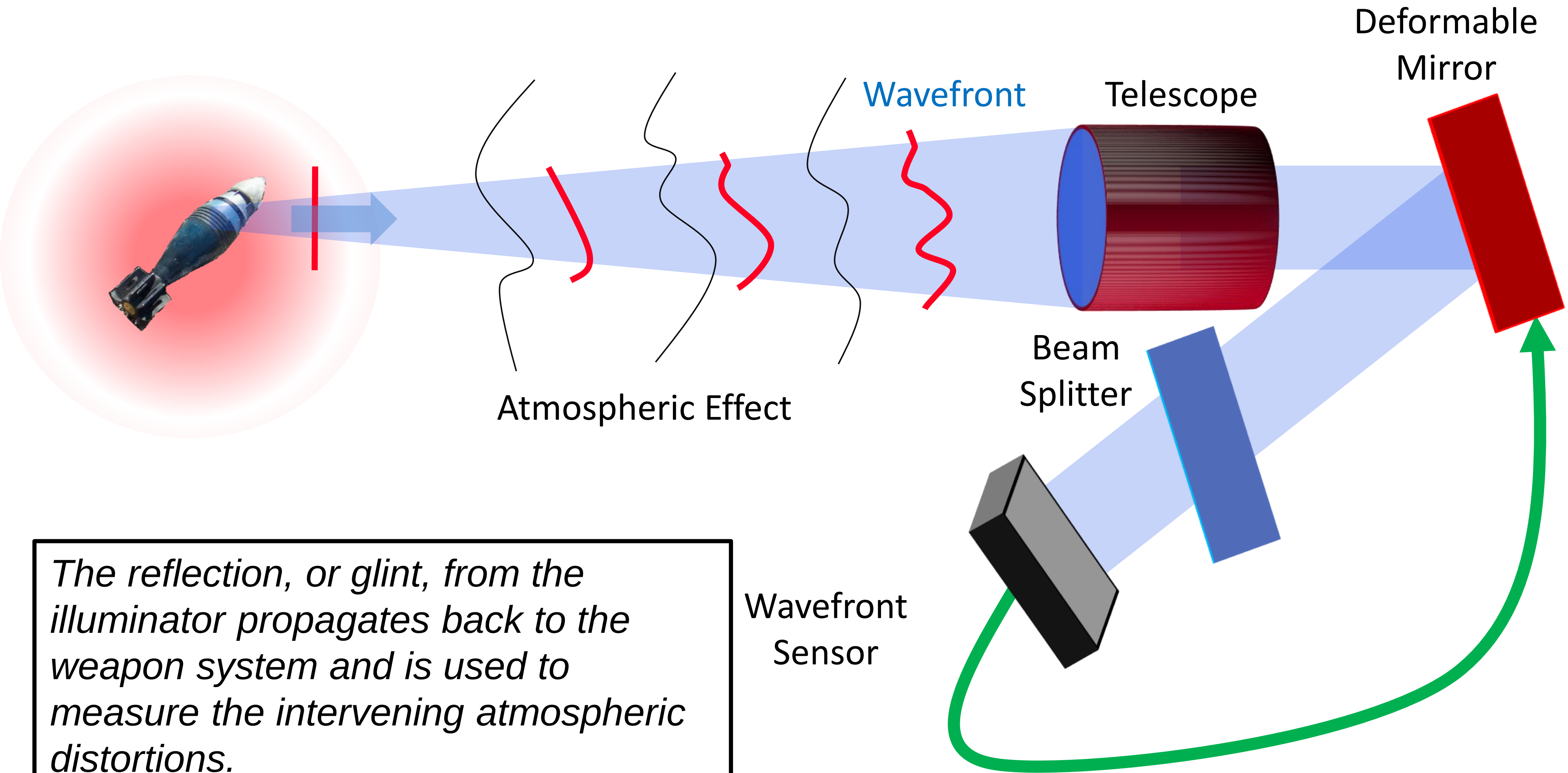
Target Illumination



In a typical wavefront compensation system, an illuminator laser is projected to the target to generate a beacon for wavefront measurement.

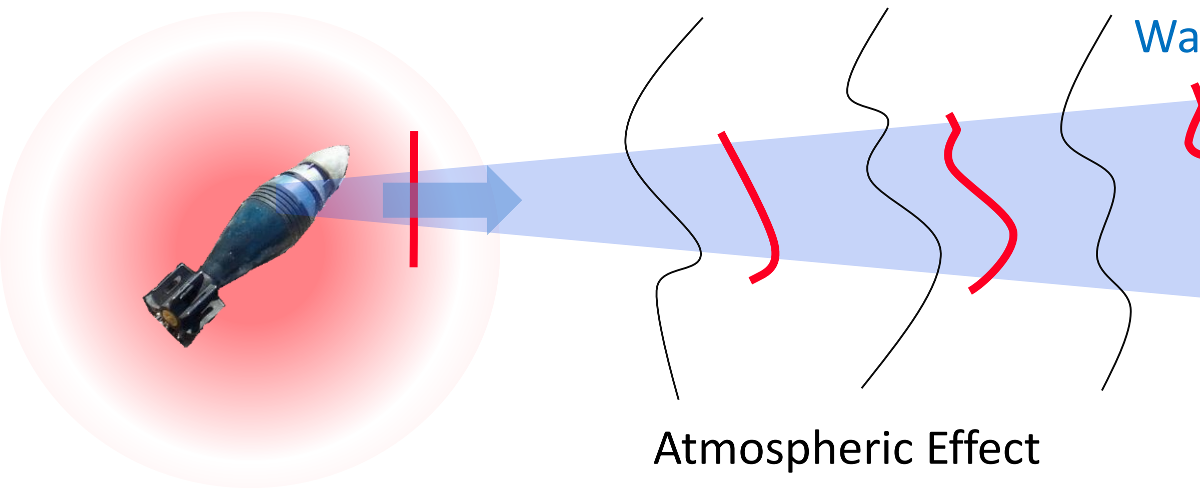
There are schemes which utilize the target's visible and infrared signature, rather than an active illuminator, to obtain this measurement.

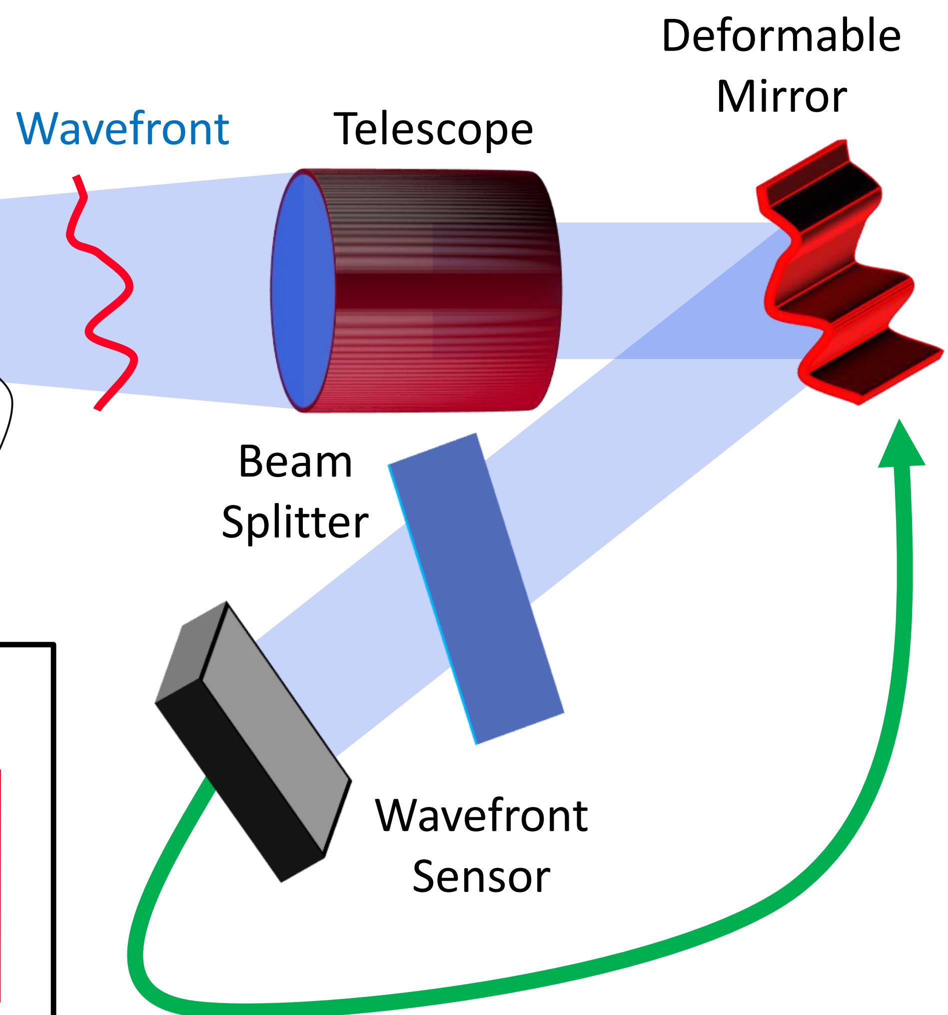
Wavefront Measurement



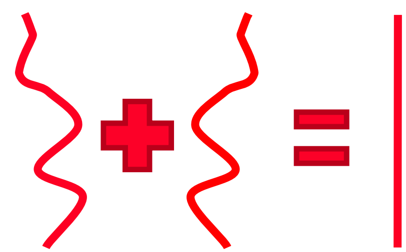
The reflection, or glint, from the illuminator propagates back to the weapon system and is used to measure the intervening atmospheric distortions.

Deformable Mirror Shaping

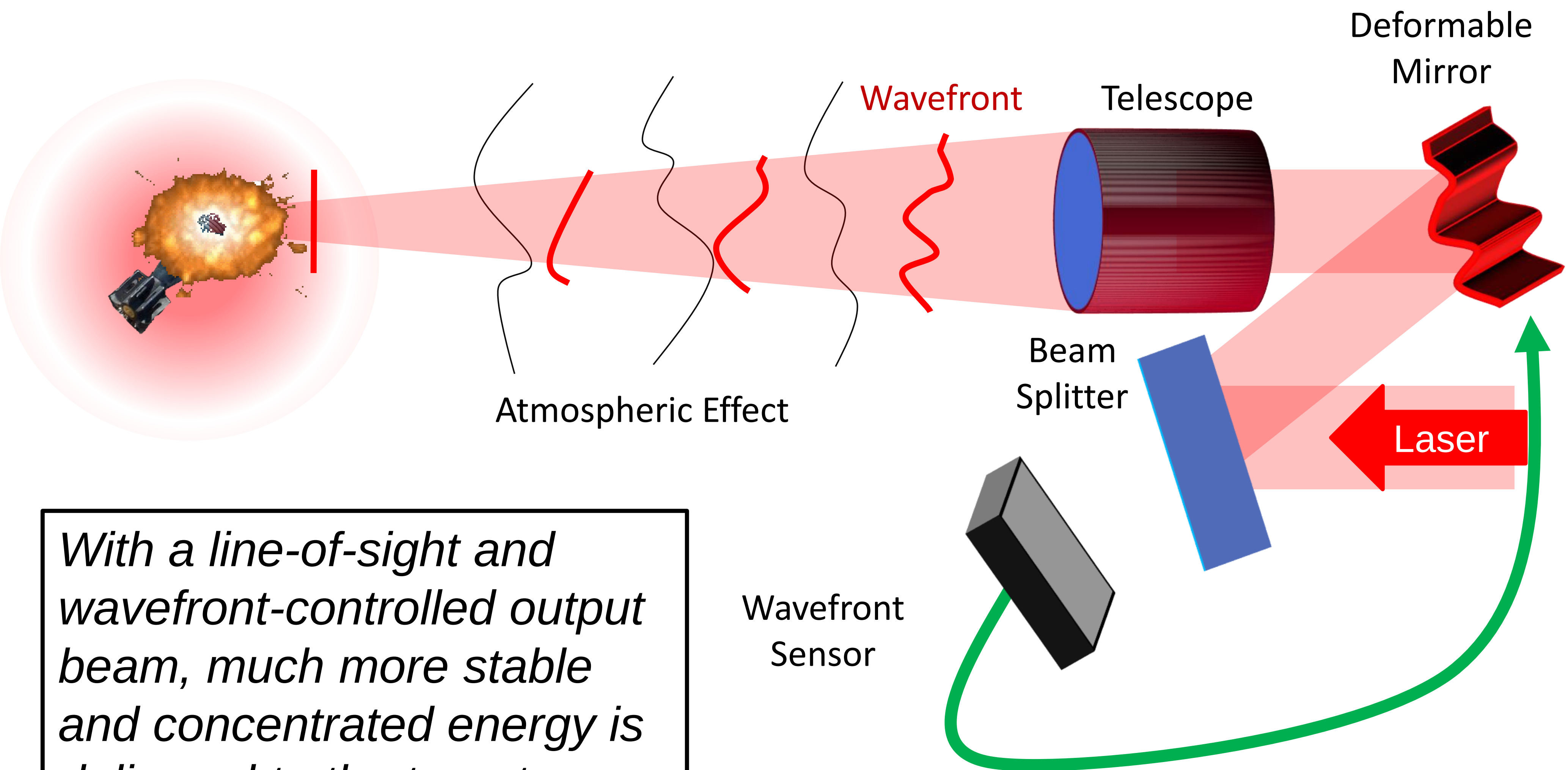




At very high speed, the wavefront controller commands a deformable mirror to warp the wave-front in the opposite shape as the measured warp.

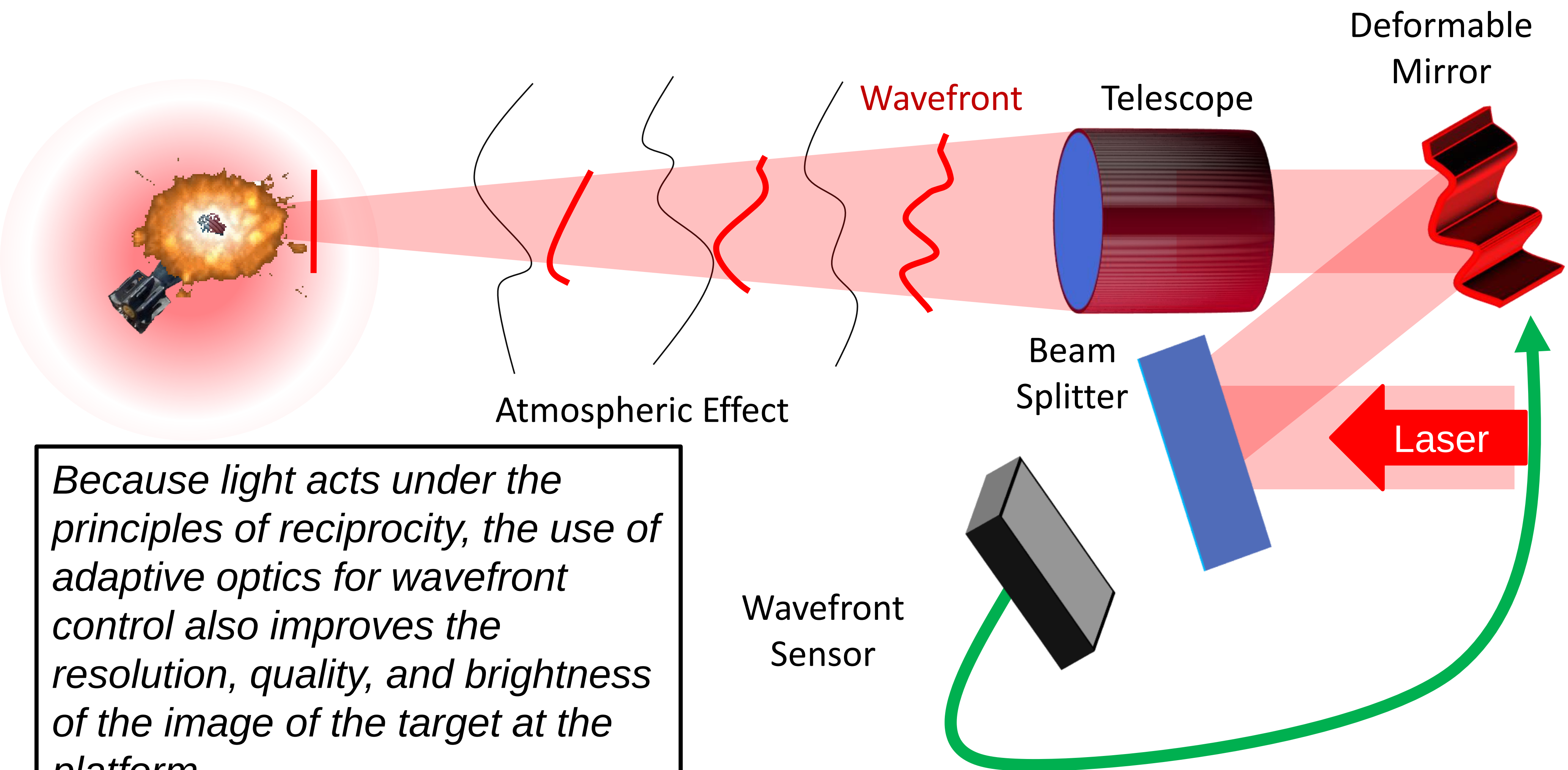


High Energy Laser Illumination



With a line-of-sight and wavefront-controlled output beam, much more stable and concentrated energy is delivered to the target.

Surveillance and Imaging



Because light acts under the principles of reciprocity, the use of adaptive optics for wavefront control also improves the resolution, quality, and brightness of the image of the target at the platform.

MZA Associates Corporation

An Employee-Owned Company

Laser Weapon & Sensing Modeling and Simulation

Laser System Testing and Integration

Adaptive-Optics Beam Control Hardware

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