Directed Energy Laboratories at University of Alabama – Huntsville (UAH)

THE UNIVERSITY OF ALABAMA IN HUNTSVILLE

U.S. Army Space and Missile Defense Command

Technical Center

Posters for Display at Center for Applied Optics (CAO) - UAH and Technical Symposiums

18 Jul 2022

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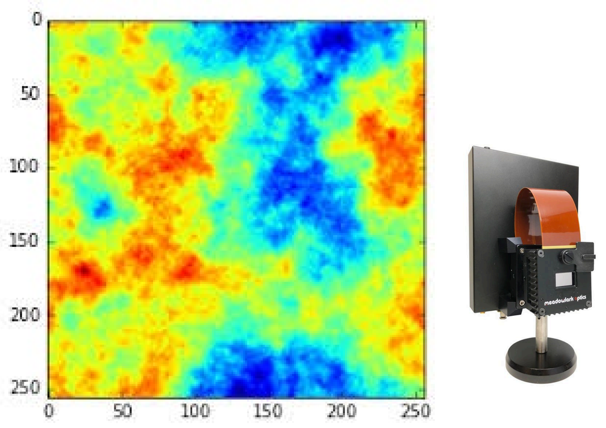
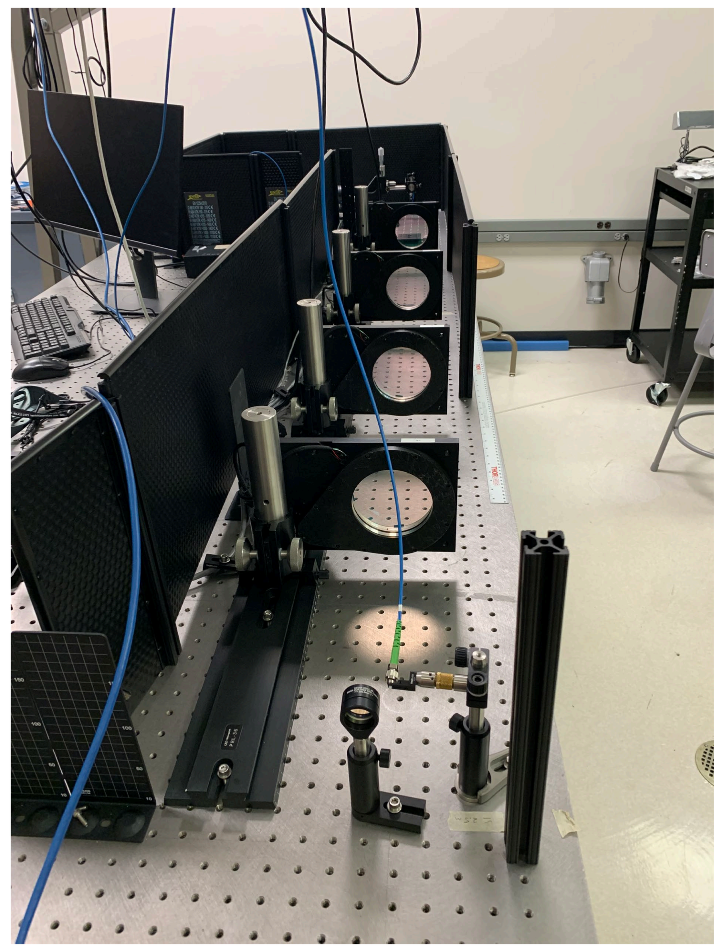
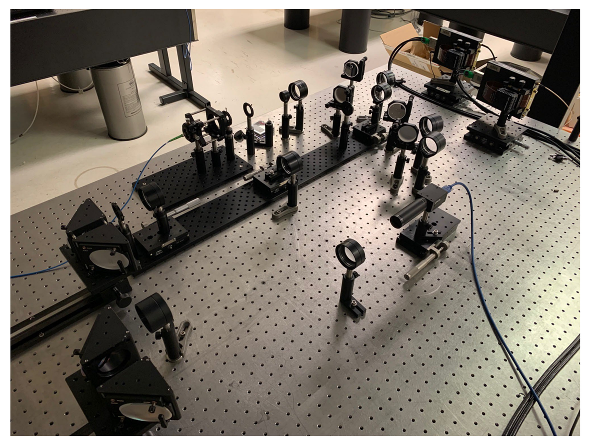
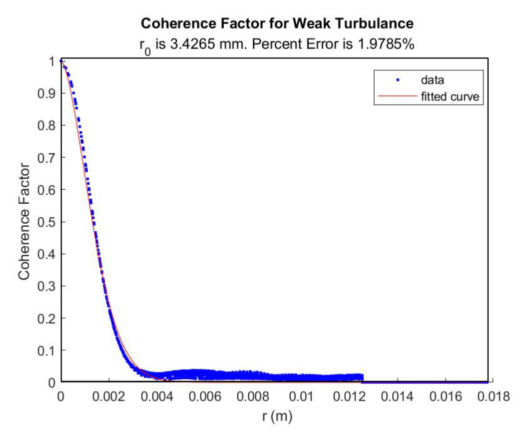
Beam Control Laboratory Overview



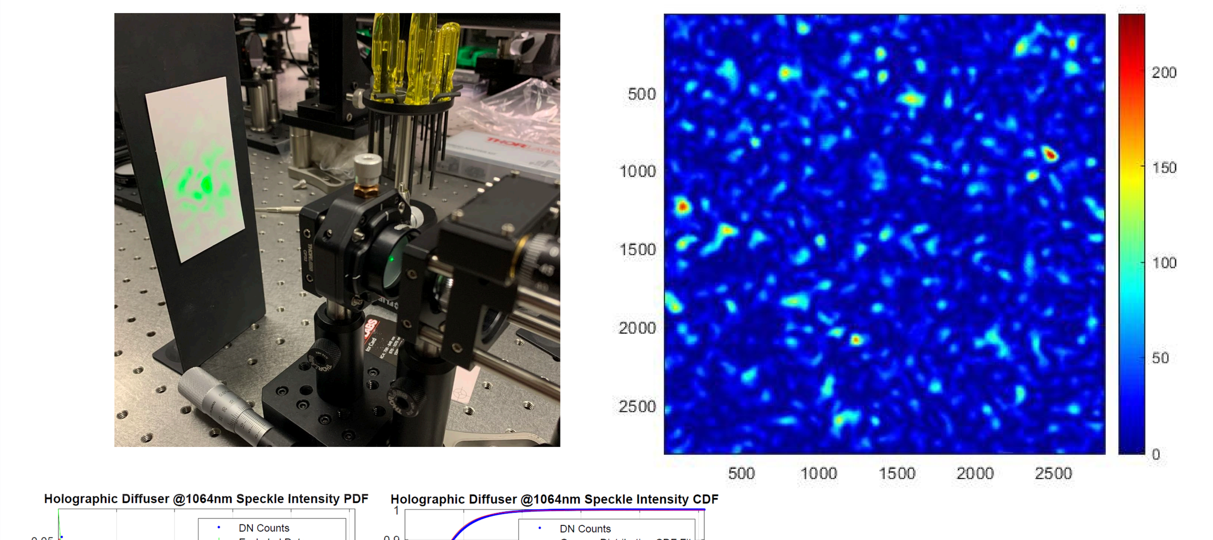


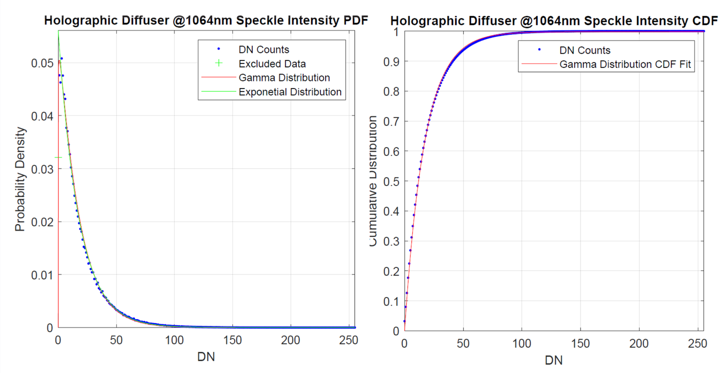


Turbulence	Theoretical r0 (mm)	Measured r0 (mm)	% error
Weak	3.36	3.42	1.98%
Moderate (isoplanatic)	1.13	1.09	3.76%
Moderate (anisoplanatic)	1.04	1.02	1.93%
Deep	0.56	0.53	5.31%



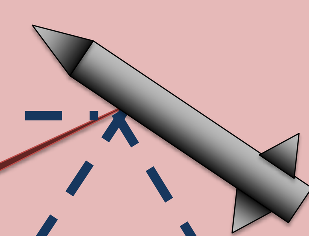
Atmospheric Turbulence Generation

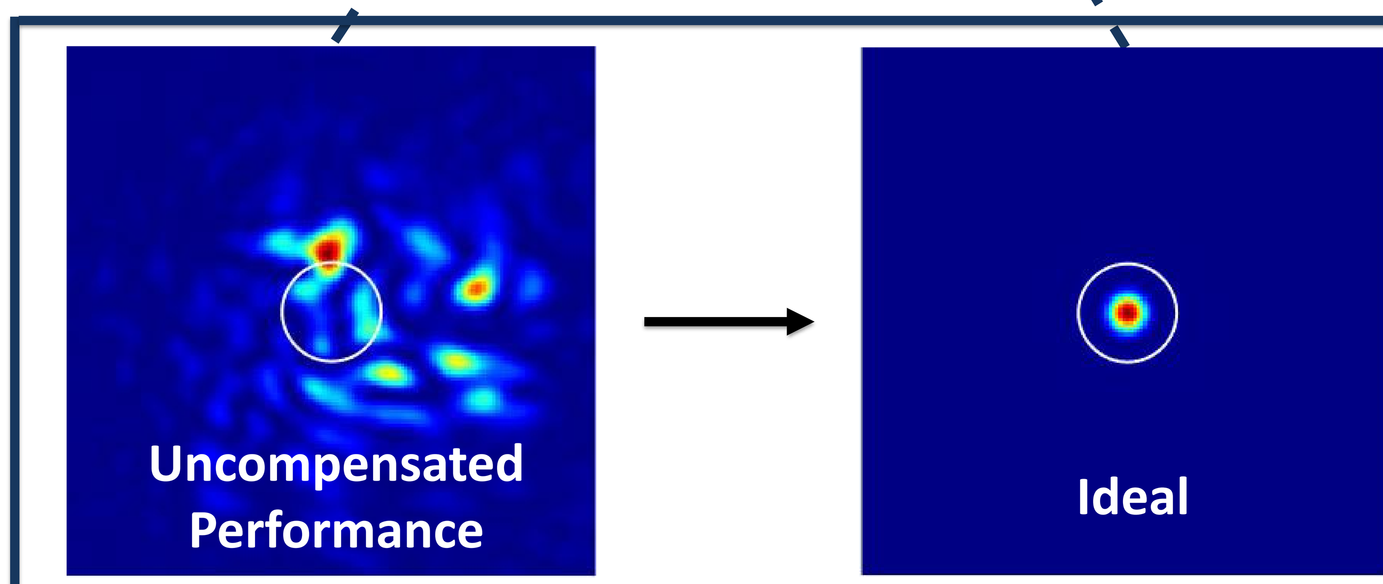




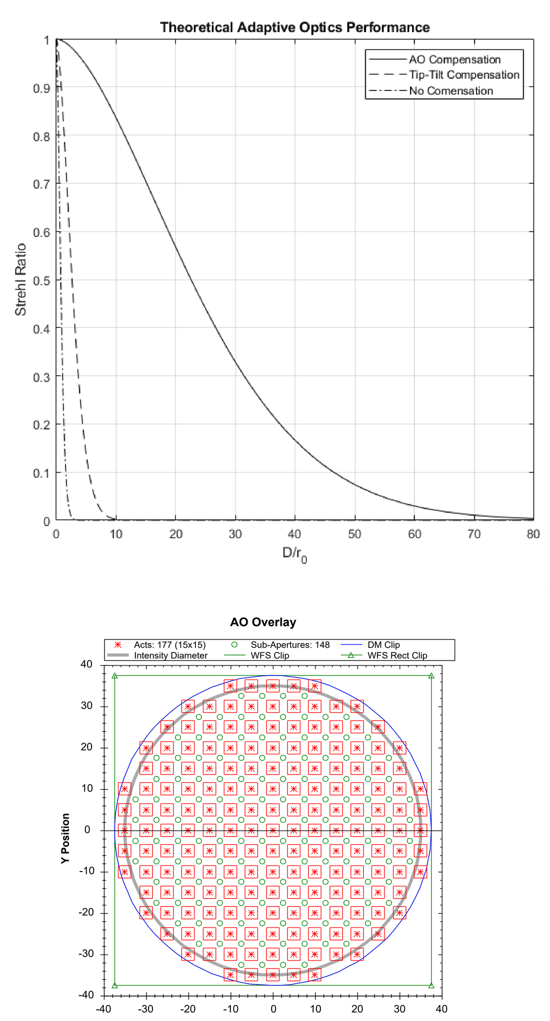
Parameter	Theoretical Value	Measured Value	Percent Error
Single Realization Average Speckle Contrast	1.00	0.996	0.4%
10 Realizations Speckle Contrast	0.316	0.323	2.2%
Mean Intensity	19.7	20.0	1.5%

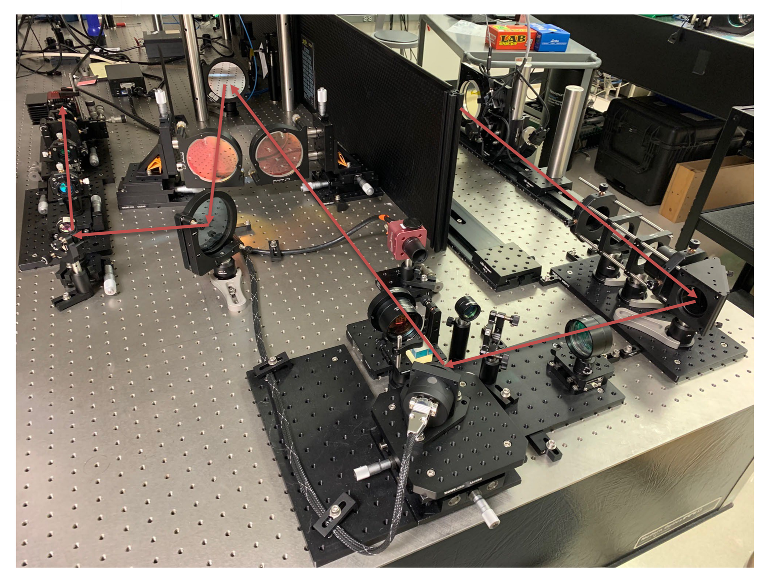
Extended Target





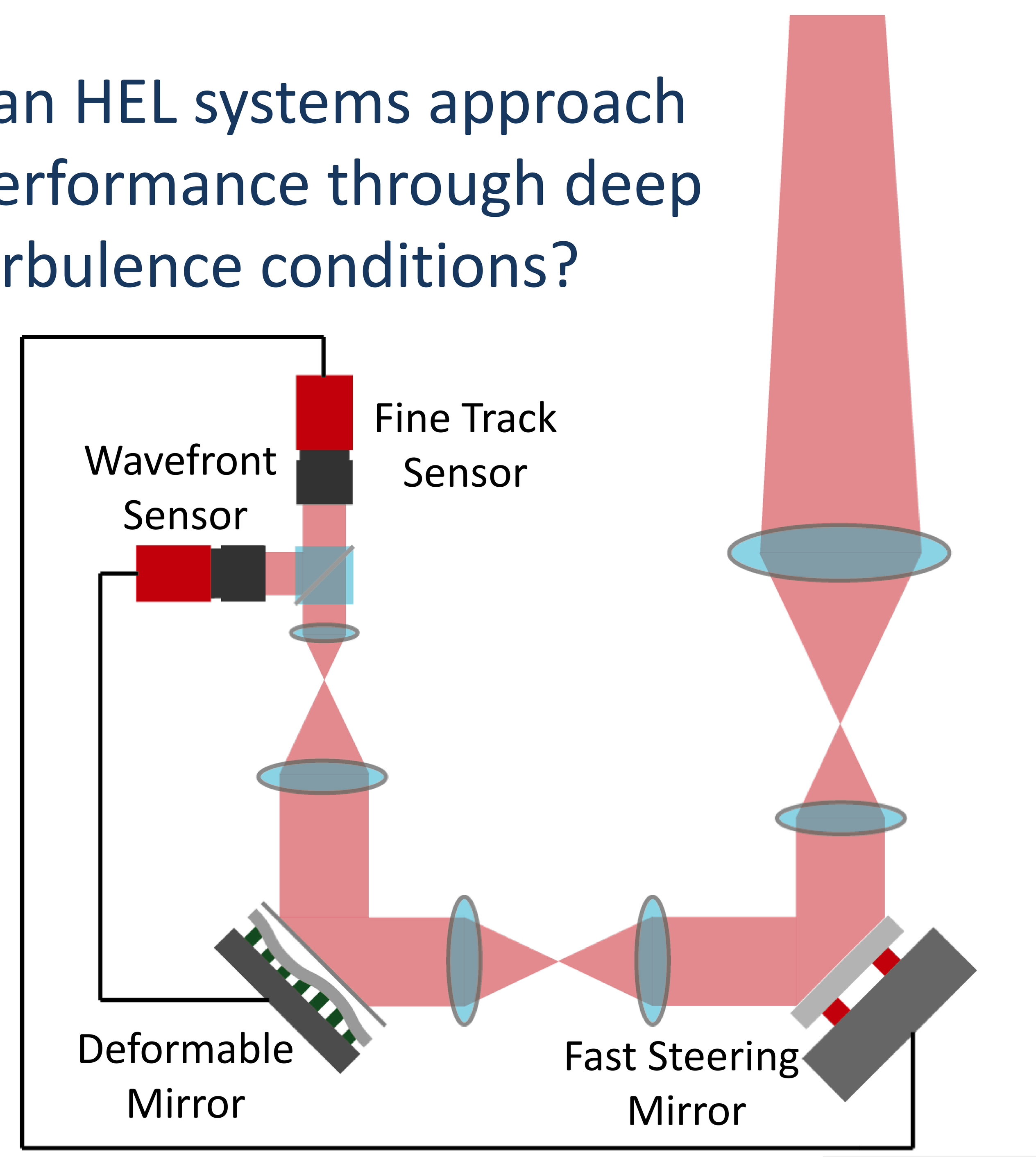
How can HEL systems approach ideal performance through deep turbulence conditions?





Main Research Areas

- Advanced Wavefront Sensor Studies
- Advanced Adaptive Optics Algorithm Studies
- Extended Target Studies



Adaptive Optics System

Turbulence Mitigation With Adaptive Optics

Lab Personnel:

- Wesley Barnes - USASMDC
- Eric Mitchell - USASMDC
- Hongrok Chang - UAH CAO
- Tony Lopé

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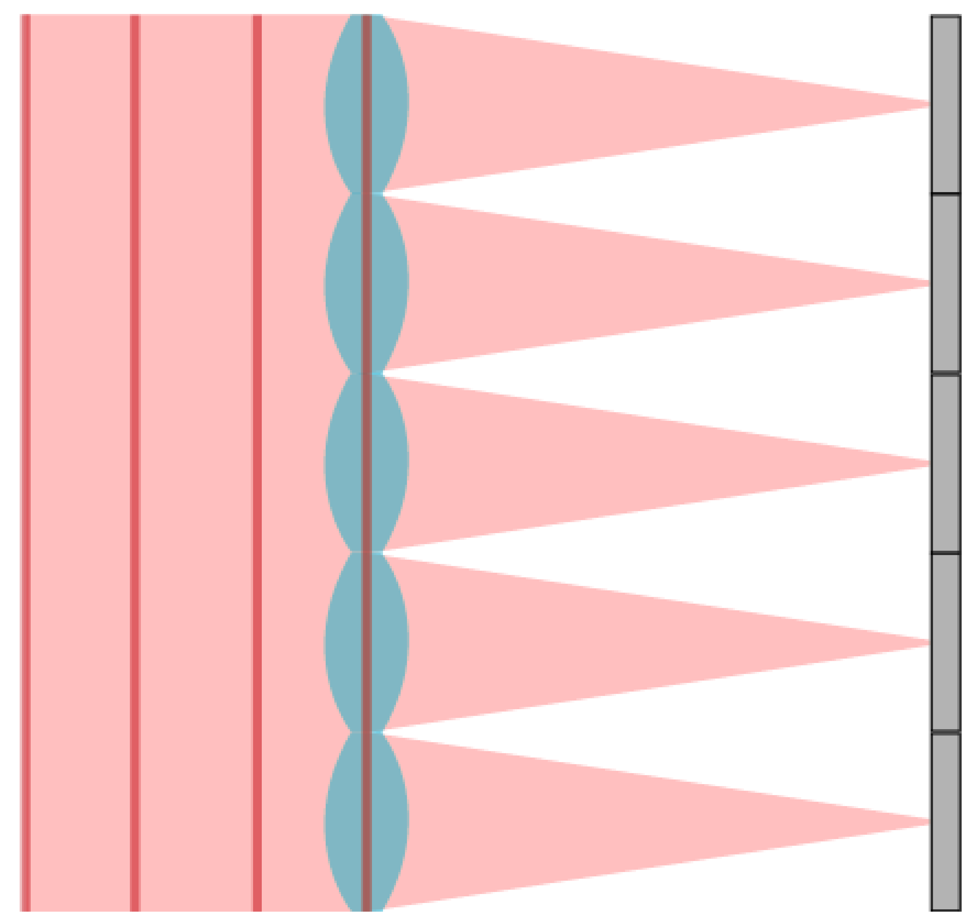
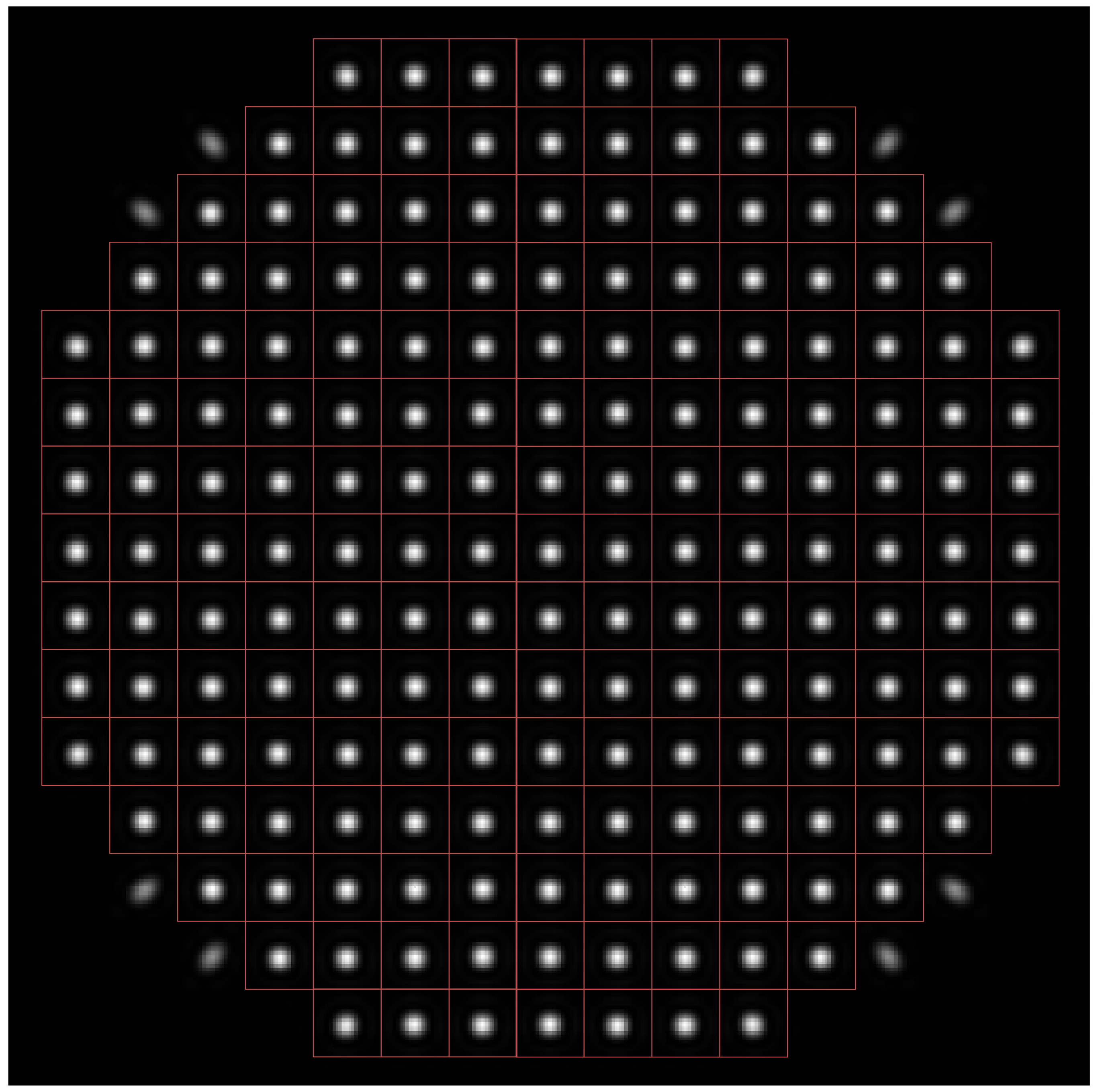
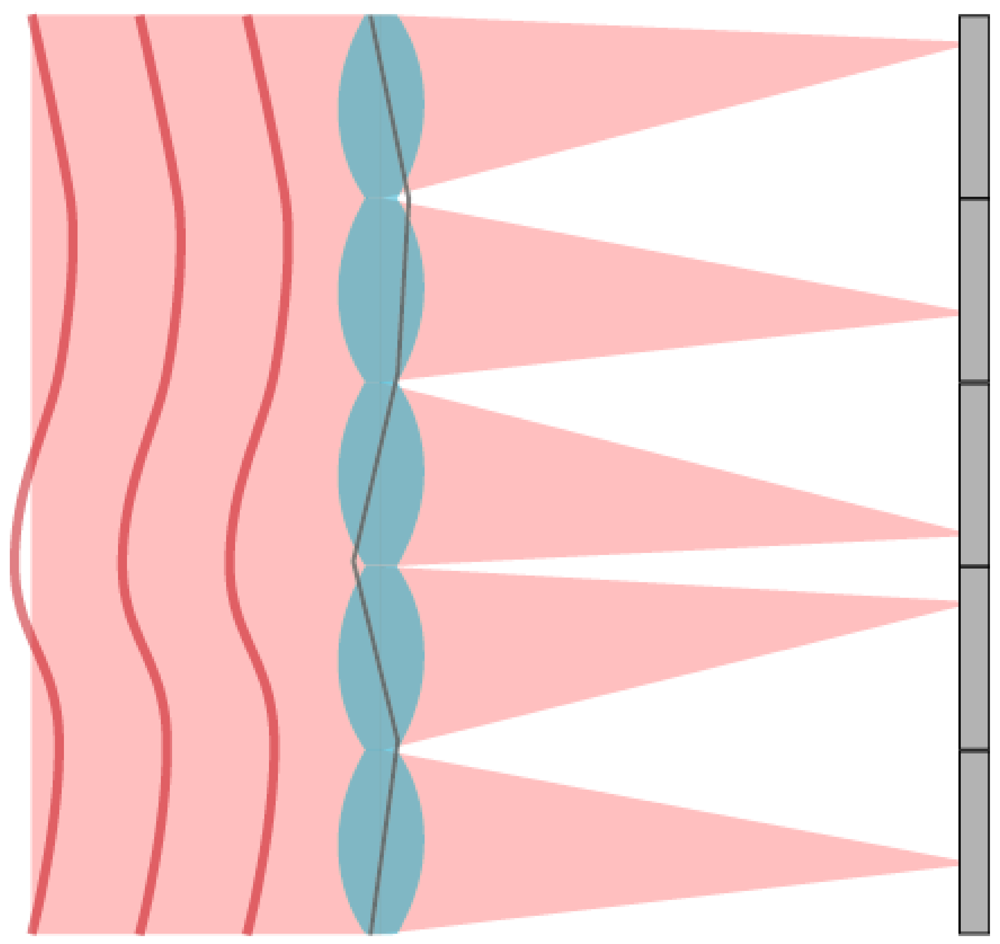
Shack Hartmann Wavefront Sensor

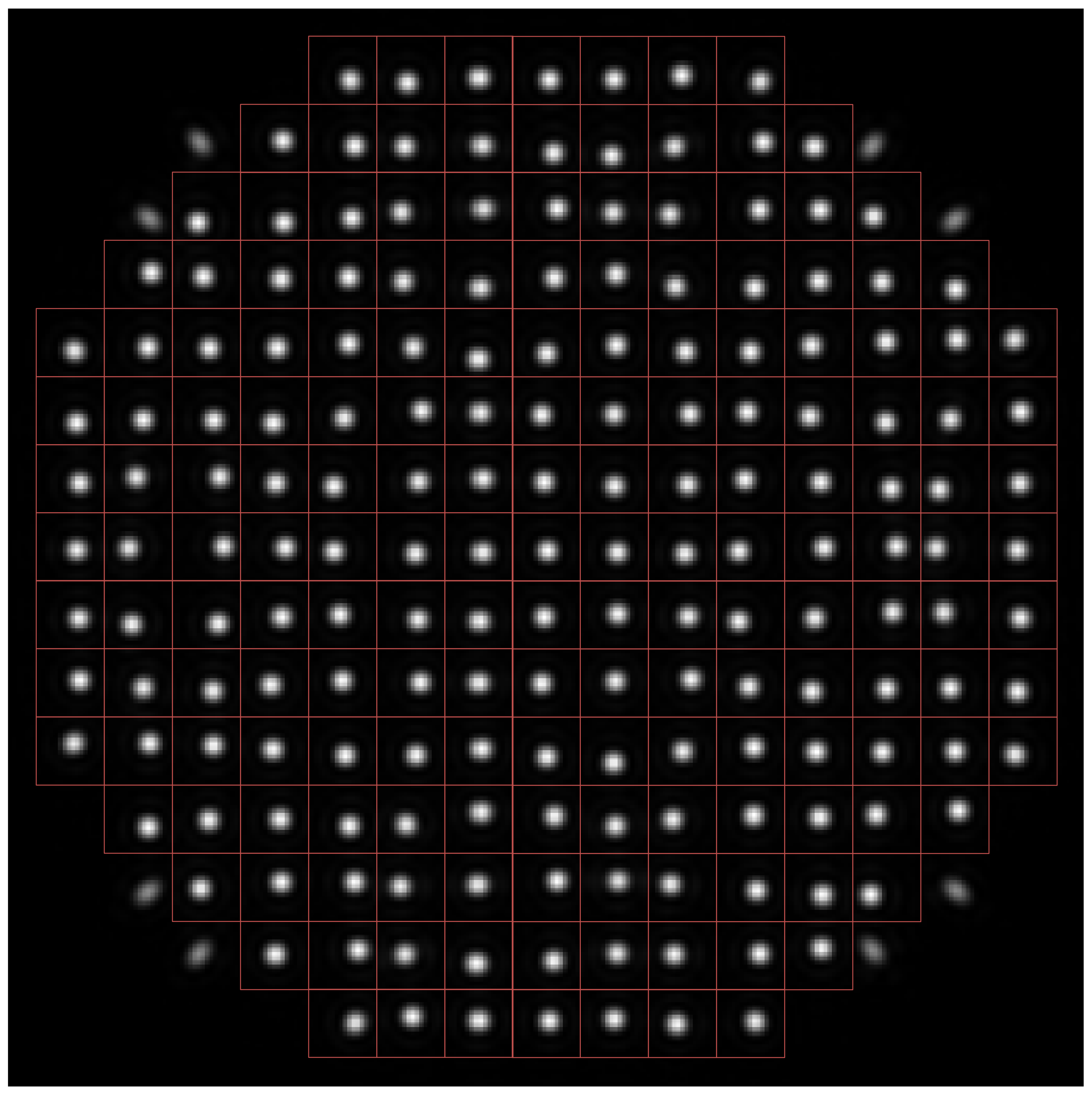
Flat Wavefront



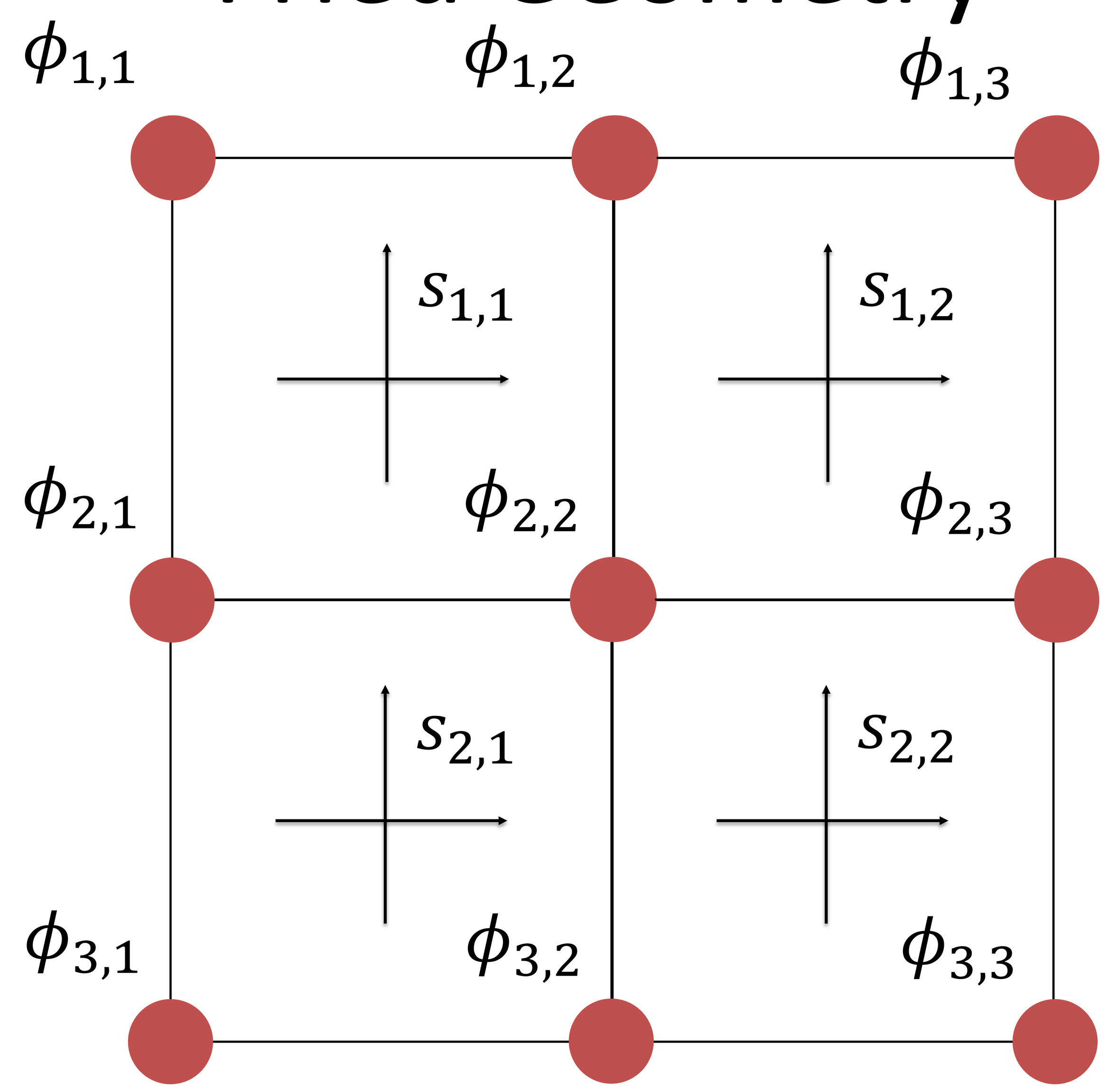


Aberrated Wavefront





Fried Geometry



$$s^{x}_{m,n} = \frac{1}{2}\left[(\phi_{m,n+1} - \phi_{m,n}) + (\phi_{m+1,n+1} - \phi_{m+1,n})\right]$$

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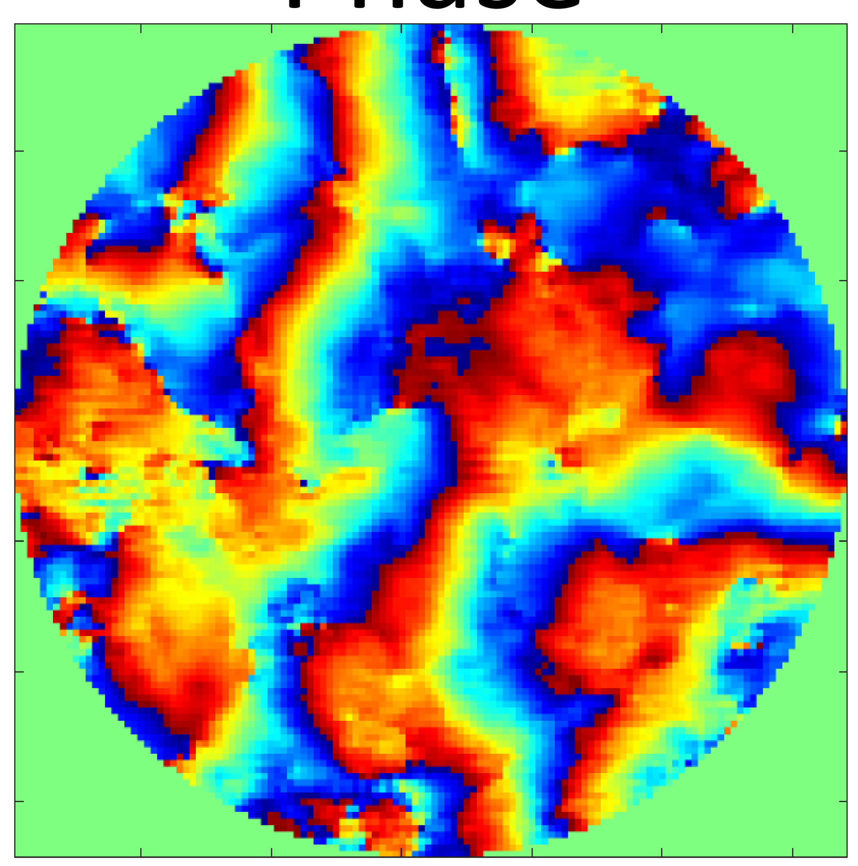
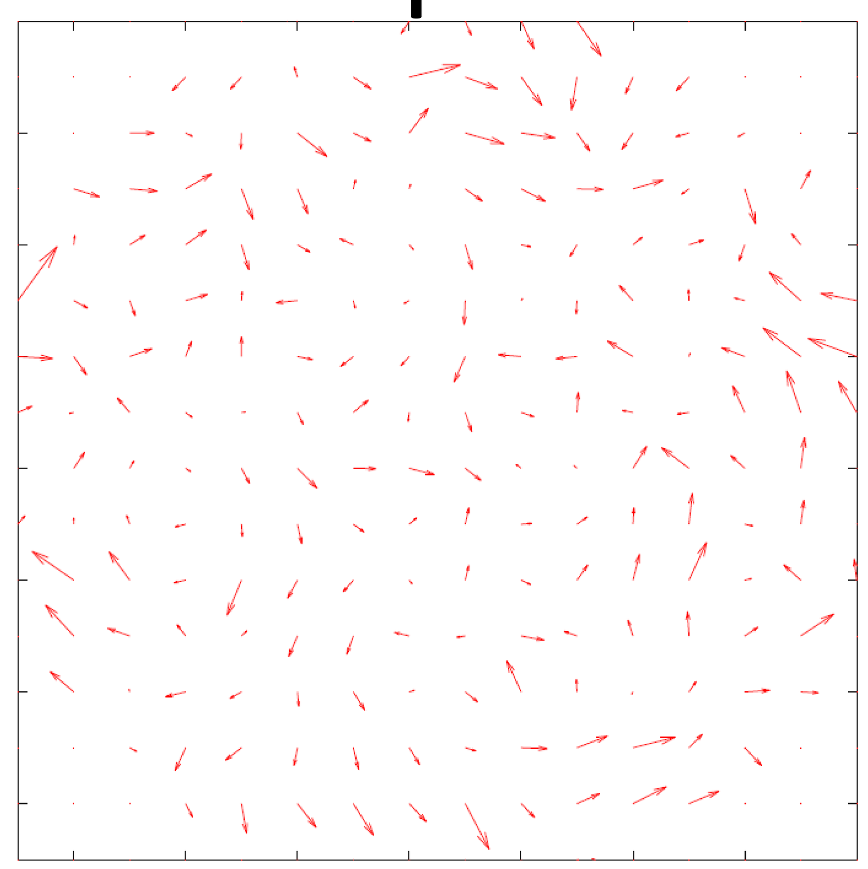
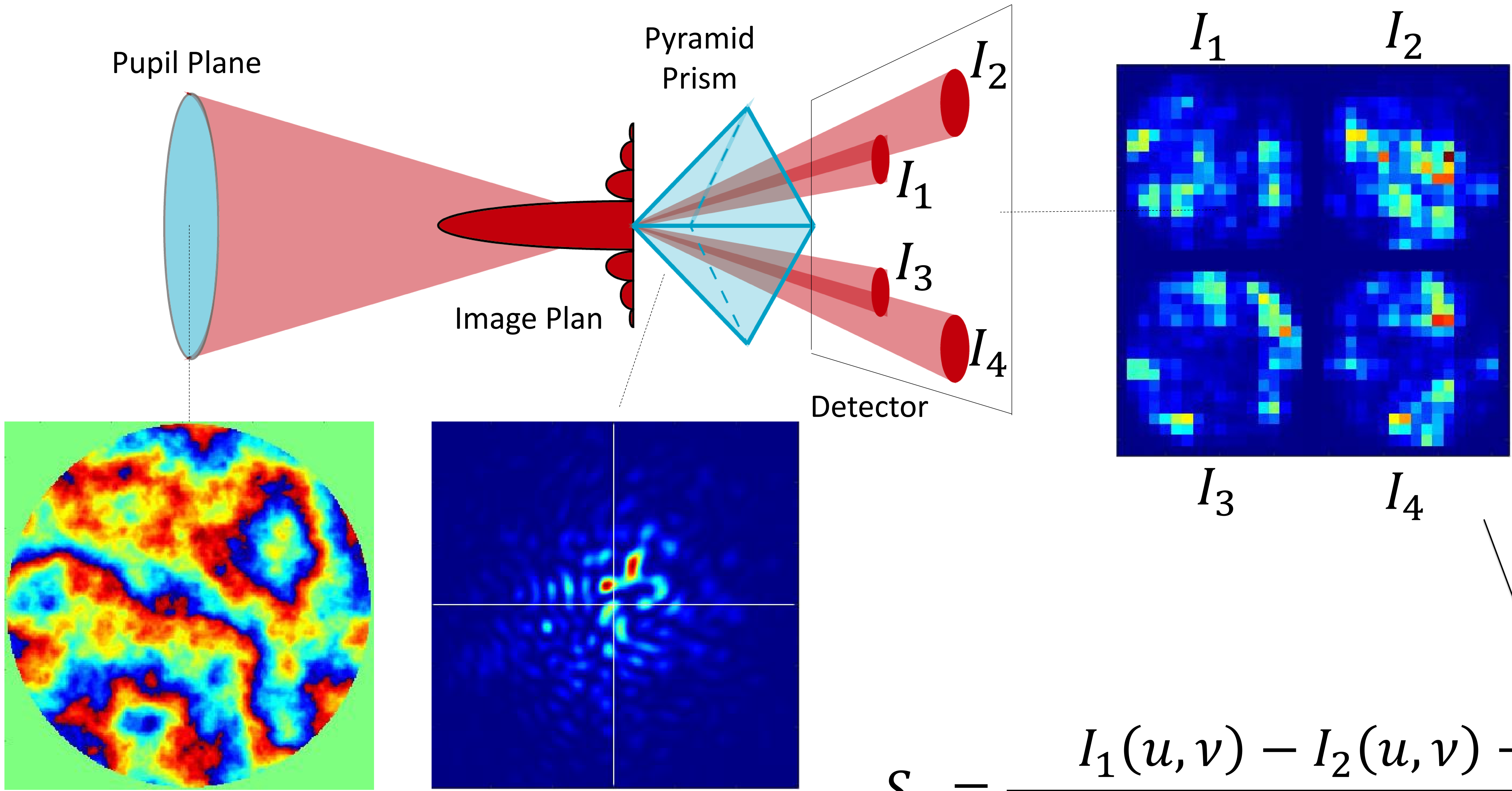
Phase



Slopes



Pyramid Wavefront Sensor



$$I = |FFT\{FFT\{U_s\}P\}|^2$$

Where U_s is the aberrated field to be measured and P is the Pyramid

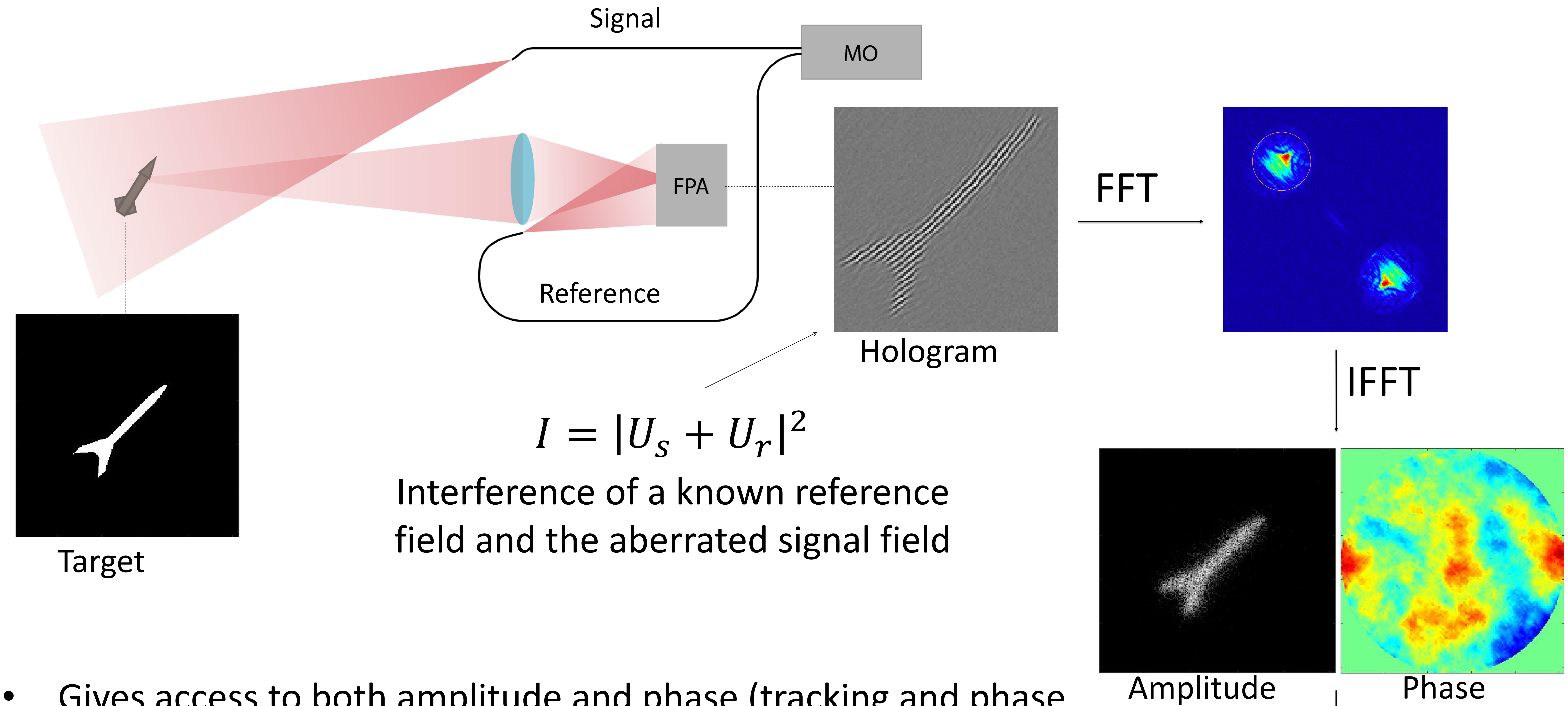
Convert to slopes

$$S_x = \frac{I_1(u,v) - I_2(u,v) + I_3(u,v) - I_4(u,v)}{\frac{1}{N}\Sigma_{u,v} I_1(u,v) + I_2(u,v) + I_3(u,v) + I_4(u,v)}$$

$$S_y = \frac{I_1(u,v) + I_2(u,v) - I_3(u,v) - I_4(u,v)}{\frac{1}{N}\Sigma_{u,v} I_1(u,v) + I_2(u,v) + I_3(u,v) + I_4(u,v)}$$

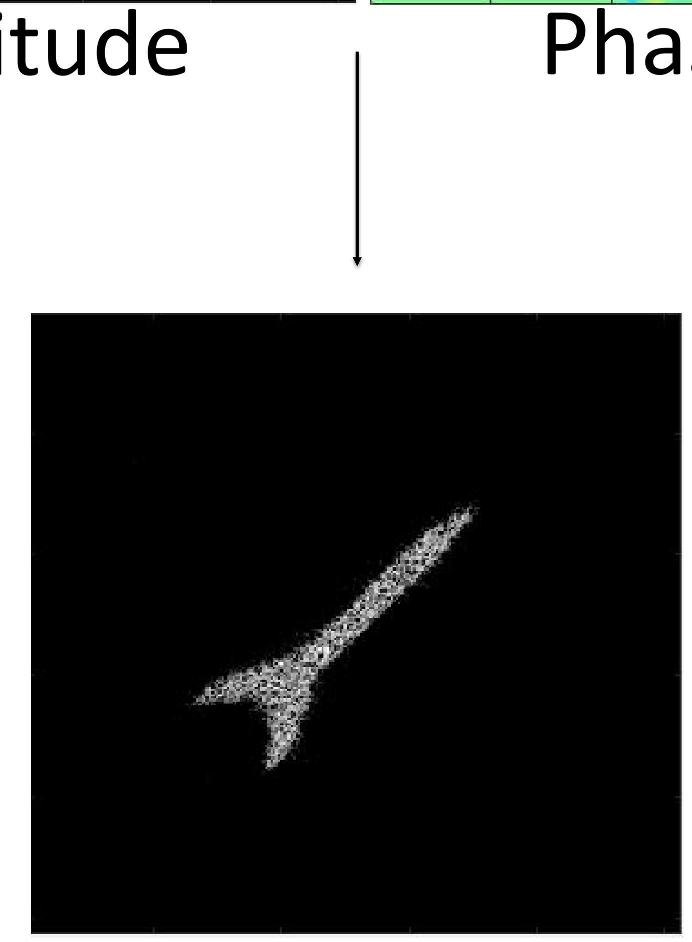
- Higher sensitivity than SHWS
- Higher resolution than SHWS
- Modulation of the pyramid enables adjustable dynamic range

Digital Holographic Wavefront Sensor



$$I = |U_s + U_r|^2$$

Interference of a known reference field and the aberrated signal field


Phase Corrected Image

- Gives access to both amplitude and phase (tracking and phase compensation from one sensor)
- Less illuminator power required compared with traditional methods

1. Mark F. Spencer, Robert A. Raynor, Matthias T. Banet, Dan K. Marker, "Deep-turbulence wavefront sensing using digital-holographic detection in the off-axis image plane recording geometry," Opt. Eng. 56(3) 031213

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Pulsed Laser Lab (PuLL)

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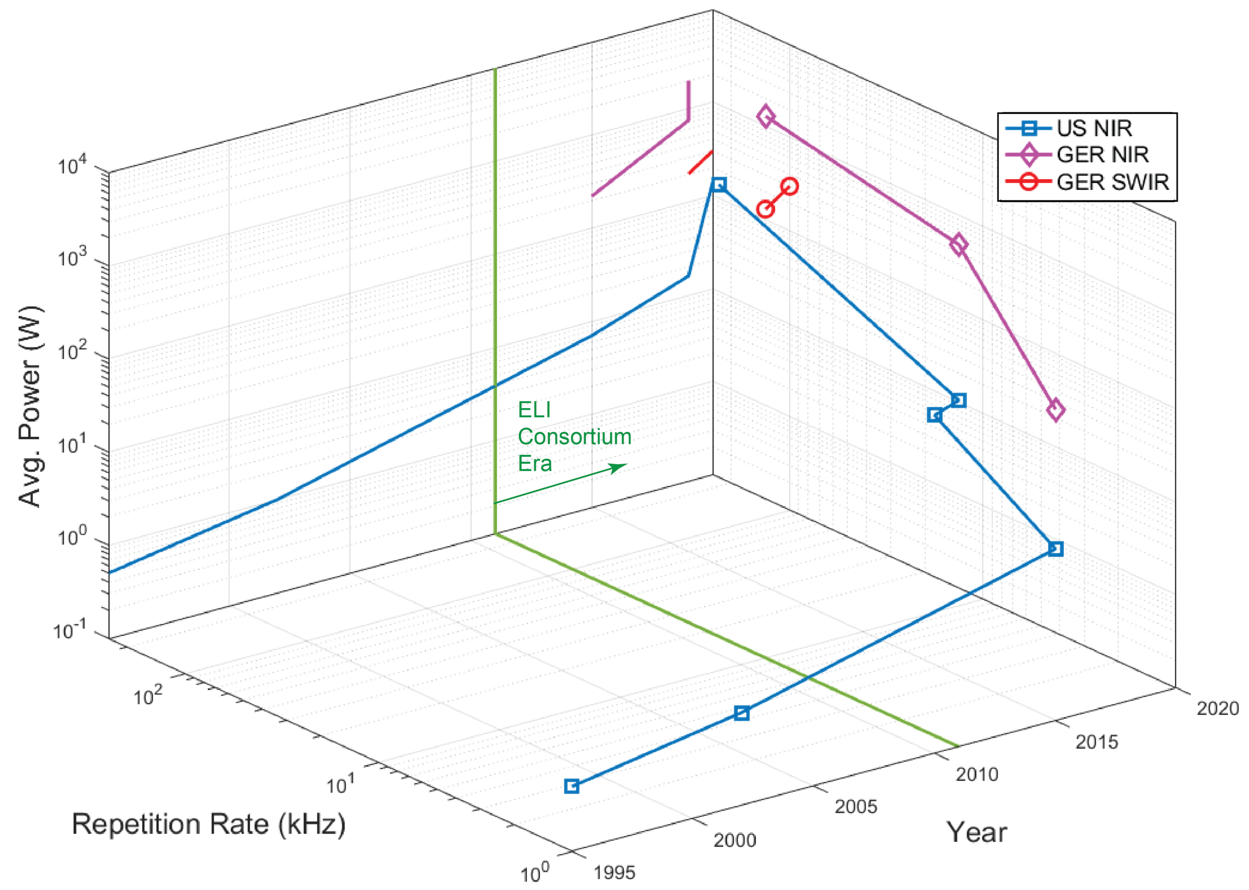
Personnel: Dr. Tony Valenzuela – SMDC; Dr. Charles Ballmann – UAH; Joey Harrington - TAMU

Illuminating the pathway for the future of laser directed energy weapons



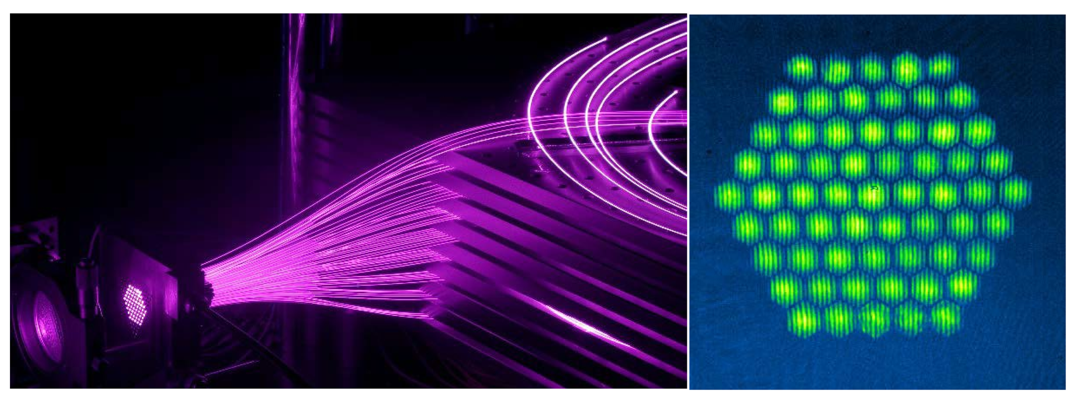
2-3 orders of magnitude improvement in USPL average power and SWaP metrics since 2015

- Advanced ultrashort pulse laser (USPL) source with multifunction burst and burst-in-burst modes will bring novel capabilities to the Army and DoD research environment
- Leverage SMDC and UAH expertise in laser systems to identify USPL technology gaps
- Partner with Clemson and other Academic partners to extend the reach and capabilities for nonlinear optics research
- Work with DoD and DOE colleagues by providing unique and complementary experimental capabilities
- Explore unique ultrafast phenomenon while providing a cutting-edge facility for the education of the future workforce

New UAH USPL system featuring unique burst mode capabilities

Explore and Quantify Novel Nonlinear Effects by Harnessing the Latest Advancements in Ultrashort Pulse Lasers for **Better Propagation** and **Wider Range Of Target Effects**

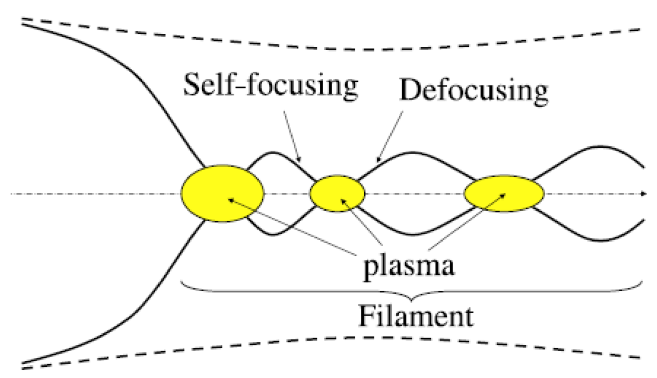
Advanced Laser Sources



XCAN, J.-C. Chanteloup, et al. Proc. SPIE 11665, 11665H (2021)

- Disk Laser
- Coherent Fiber Combination
- "Digital" laser beam structuring

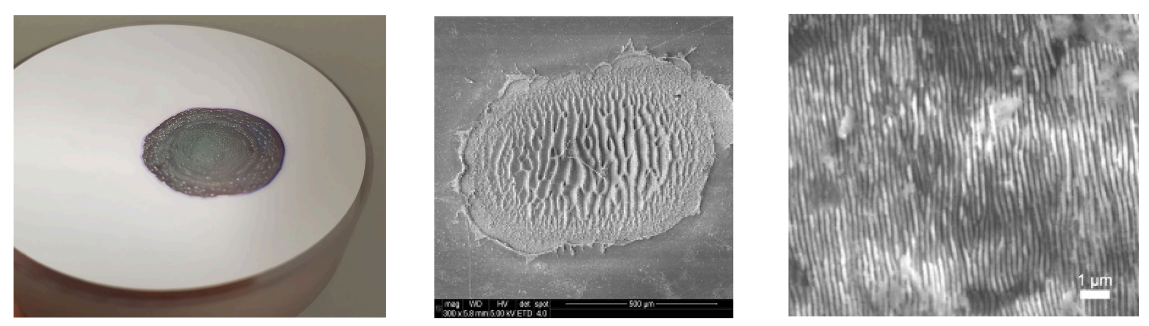
Nonlinear Propagation



A. Couairon and A. Mysyrowicz, Phys. Rep. 441, 47-189 (2007)

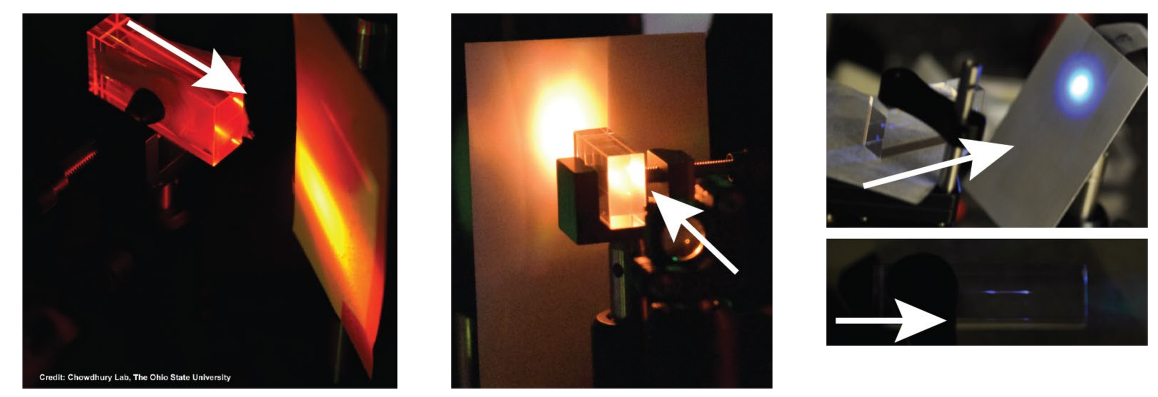
- Self-focusing, filamentation
- Lower susceptibility to turbulence

Wider range of target effects



- Surface patterning
- Near-ubiquitous laser damage
- Localized EM generation

Nonlinear Frequency Conversion



- Broad spectral coverage
- Remote THz generation

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Ultrashort Pulse Laser Lab

KEY TERMS

P	T	G	M	μ	n	p	f	a
Peta	Tera	Giga	Mega	Micro	Nano	Pico	Femto	atto
10^{15}	10^{12}	10^{9}	10^{6}	10^{-6}	10^{-9}	10^{-12}	10^{-15}	10^{-18}

λ = laser wavelength

τ_P = pulse duration

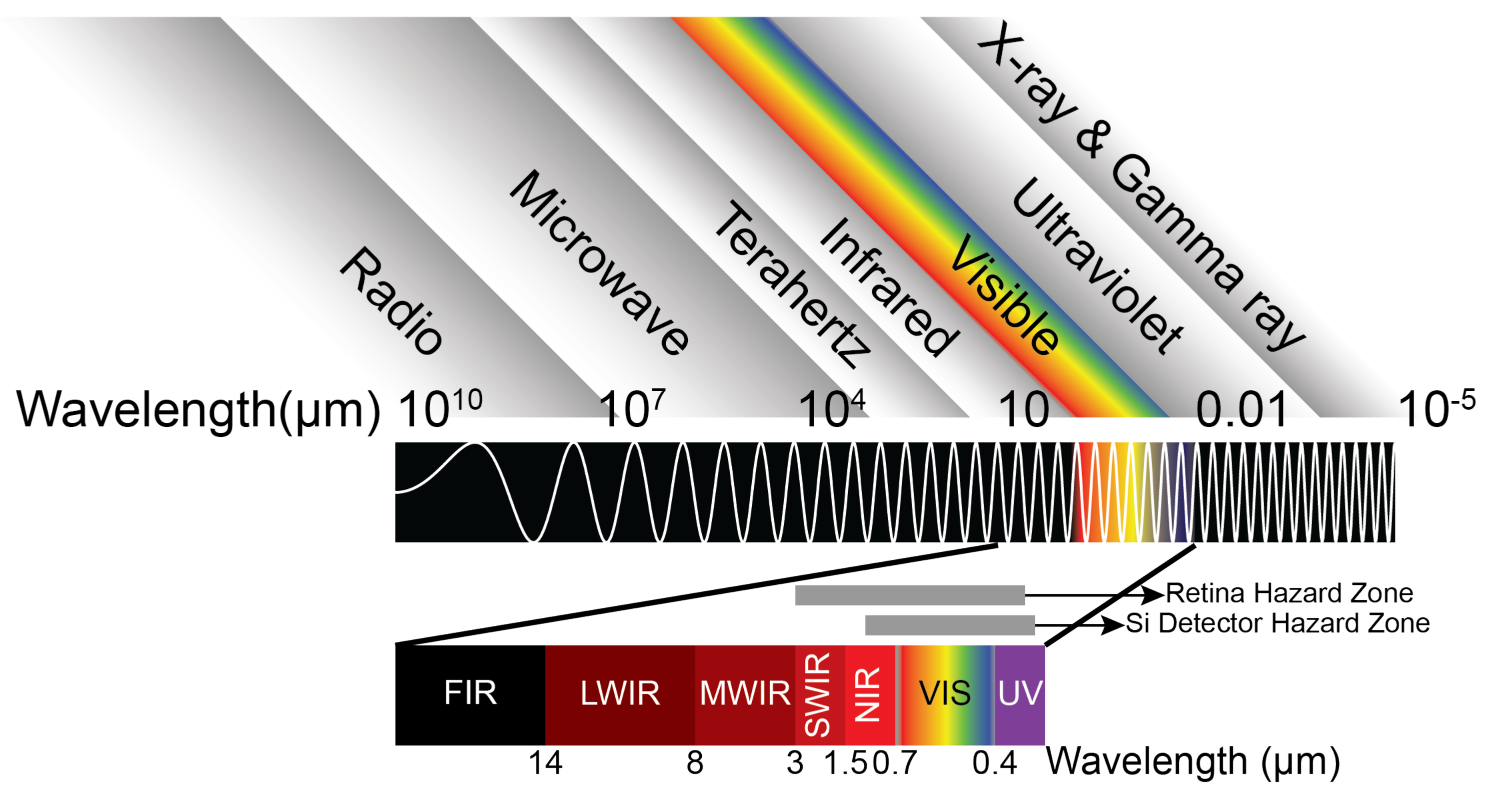
E_P = Energy per pulse

f_P = Pulse repetition rate

$P_{peak} = E_P/\tau_P$ = Peak power in a pulse

$P_{avg} = E_P \times f_P$ = Average power output from laser

ELECTROMAGNETIC SPECTRUM



VIS = Visible

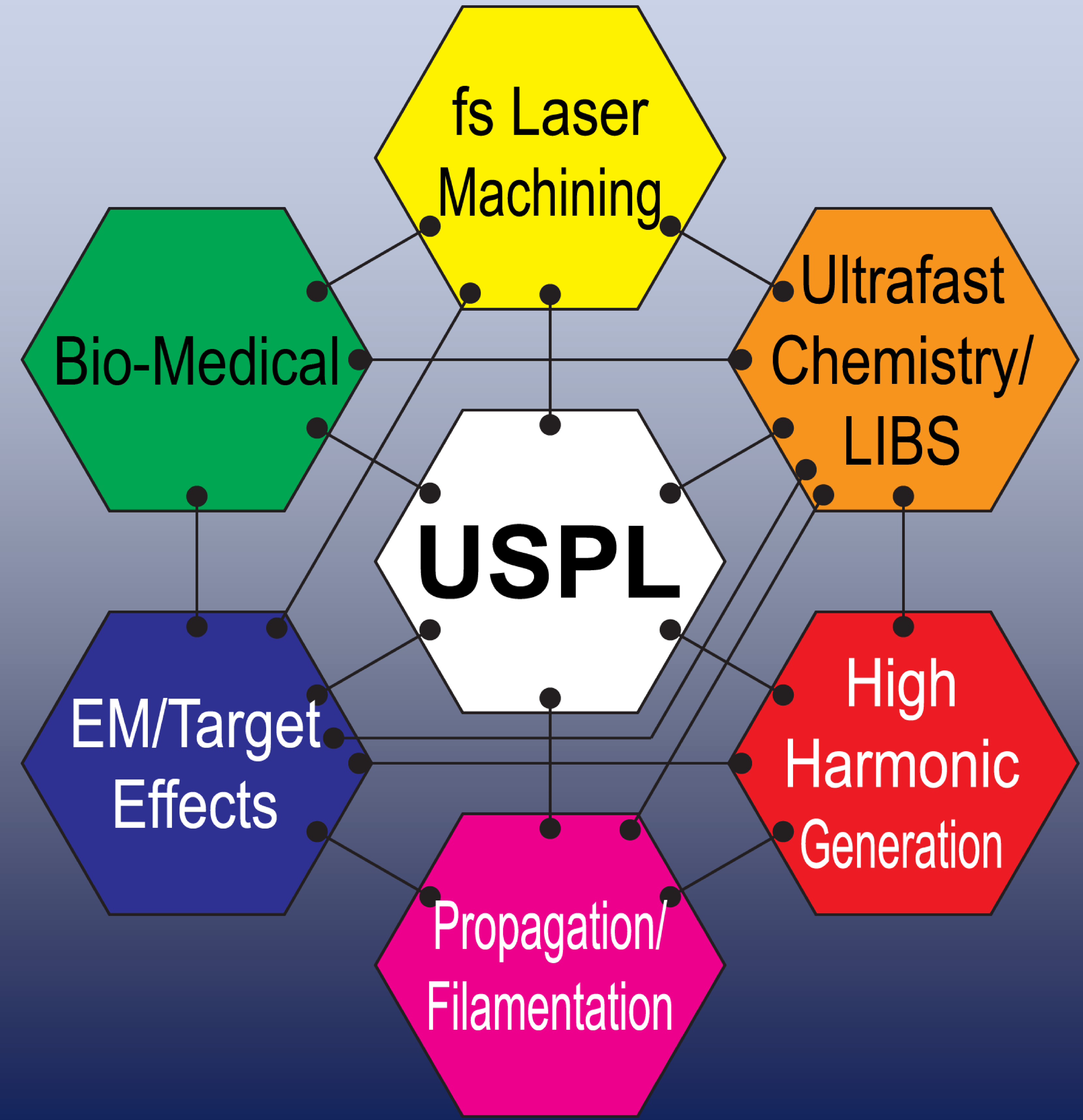
SWIR = Shortwave Infrared

LWIR = Longwave Infrared

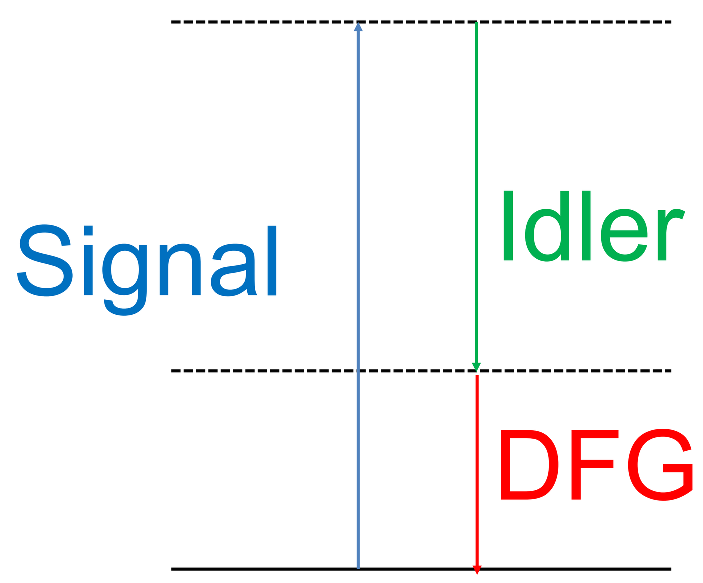
NIR = Near Infrared

MWIR = Midwave Infrared

USPL APPLICATION SPACE

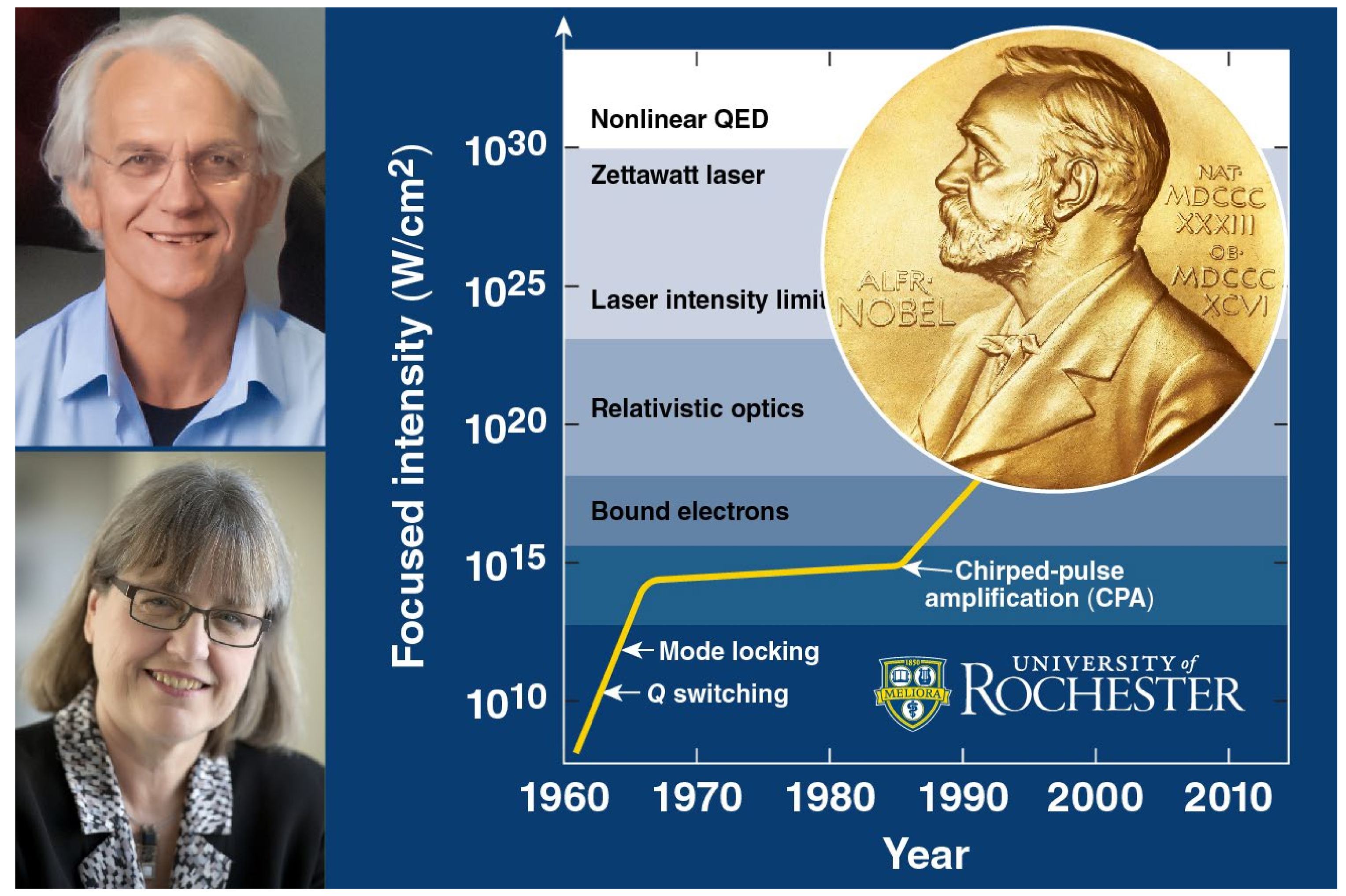


DIFFERENCE FREQUENCY GENERATION

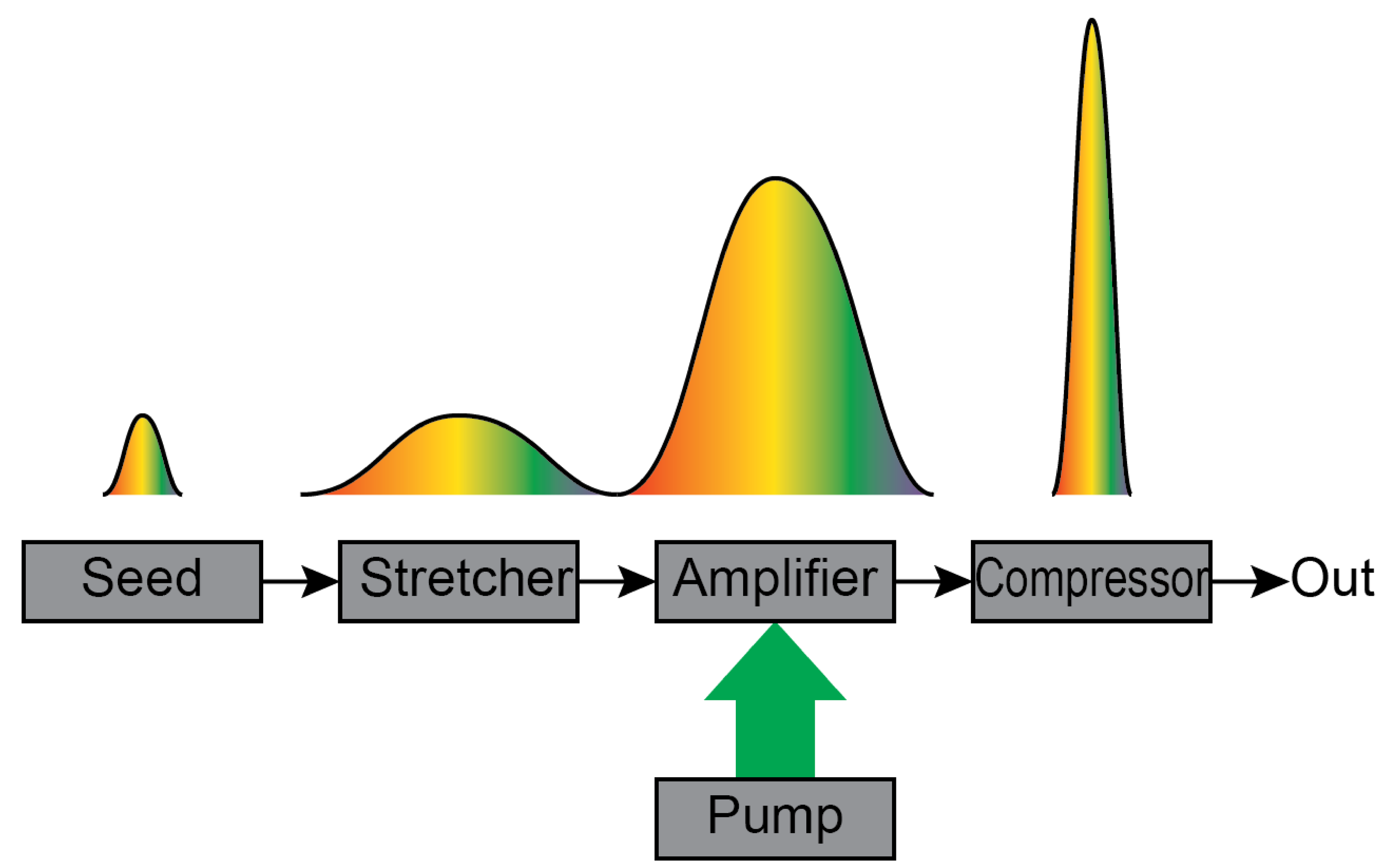


$$\lambda_{DFG}^{-1} = \lambda_{Signal}^{-1} - \lambda_{Idler}^{-1}$$

CHIRPED PULSE AMPLIFICATION



Laboratory for Laser Energetics – University of Rochester



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Direct Diode Laser Lab

Personnel: Scott Meadows – SMDC; Eric Mitchell – SMDC

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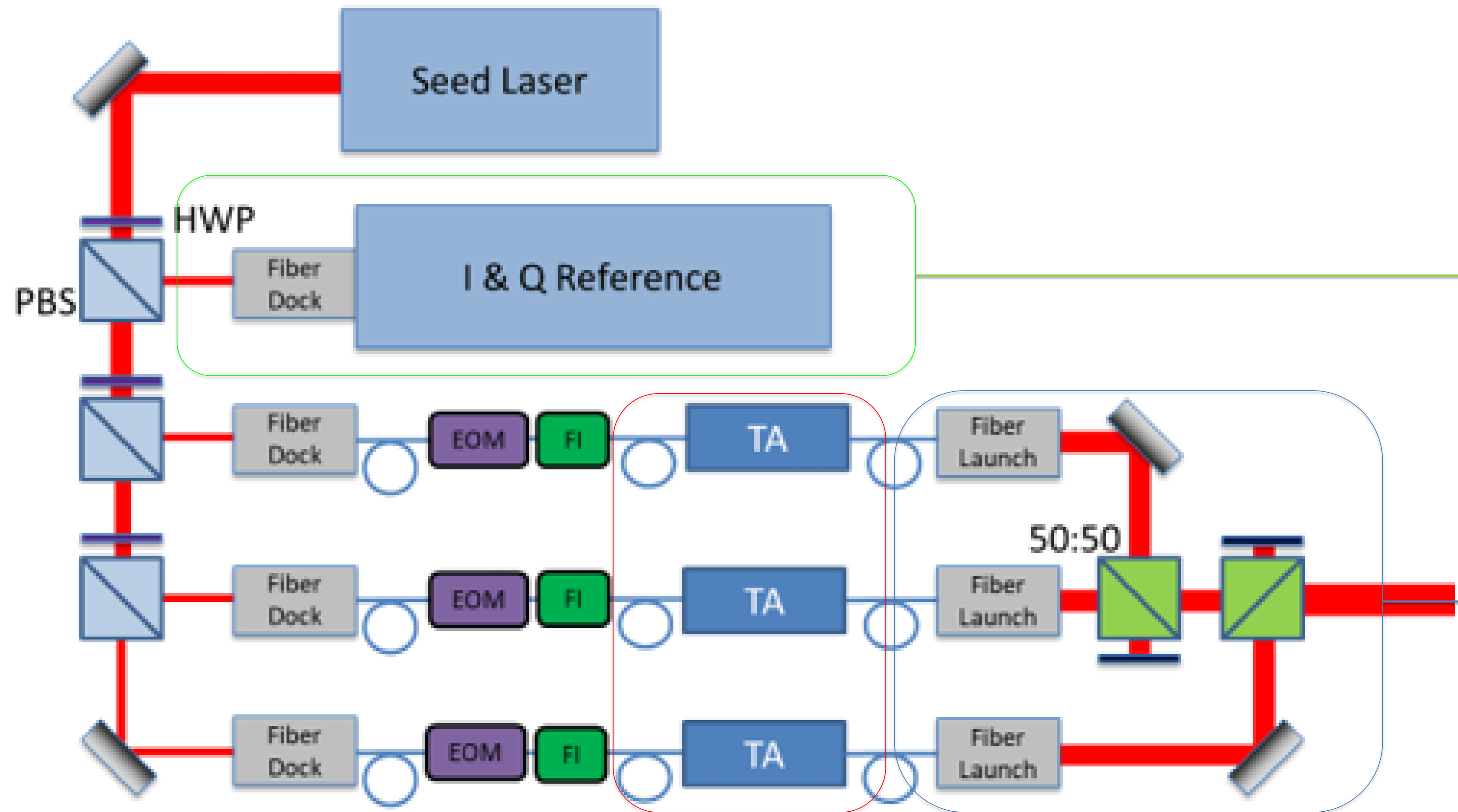
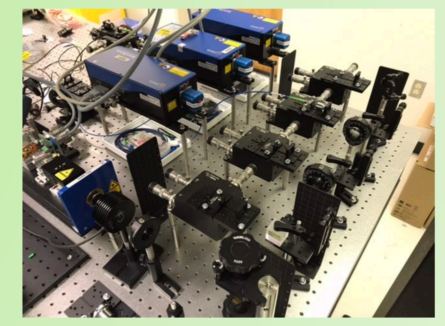
Motivation

Fiber laser technology used in today's HEL weapons is approaching it's efficiency limit of around 40%, which is a major hurdle for meeting SWaP requirements for Army platforms as we push towards a 300 kW laser weapon. Dependence on a sole technology solution: Research of novel fiber laser techniques may improve this efficiency, but the technology is still based on optical fiber amplification and a few industry partners. Fundamentally, the Direct Diode (DD) approach seeks to omit the need for optical fiber amplification to reach kW output powers, BUT this work will also benefit the fiber laser weapon because it also relies on diodes lasers to pump the fiber amplifiers. Commercial state-of-the-art diode emitters can reach Watts of output power at efficiencies greater than 60% and high beam quality. In the Direct Diode Lab at UAH, we study and implement new diode technologies to inform the army on investment decisions.



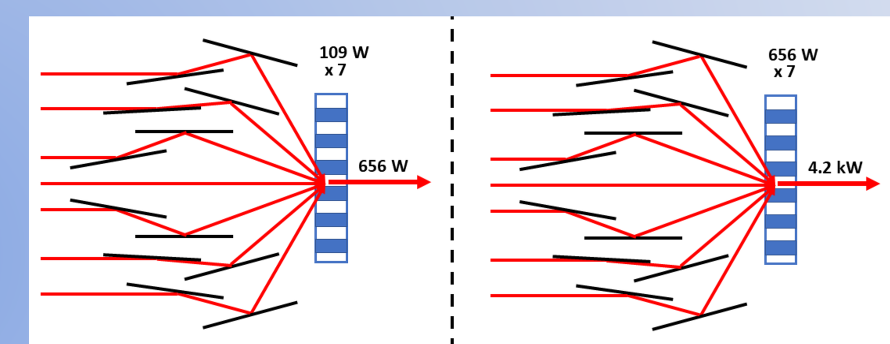
Phase Locking Methods

- IQ Modulation
- Stochastic Gradient Descent
- LOCSET
- Optical Heterodyning



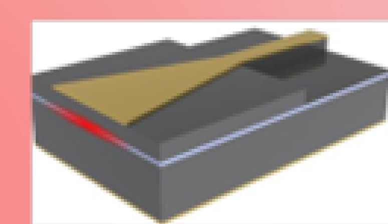
Combination Methods

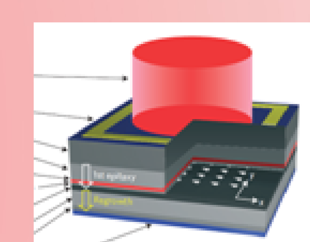
- Beam splitter cubes
- Volumetric Grating
- Talbot Cavity
- Tiled Phased Array
- Self-Fourier Cavity

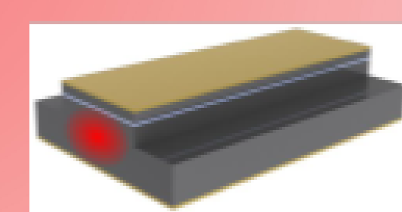


Emitter Technology

- Tapered Amplifiers
- PCSEL Arrays
- Slab coupled Optical Waveguide Lasers







Testing & Evaluation

With the ever changing world of diode technology, we have developed testing and evaluation capabilities within the labs at UAH. As our industry and academic partners develop brighter and more efficient emitters, we are positioned to study and verify the performance of these emerging technologies.

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Fiber Amplifier Laser Component Optimization (FALCO) Laboratory

Daniel J. Matyas[1], Anthony J. Eubanks[1]

Zachary C. Helton[2], Aubrey N. Beal[2]

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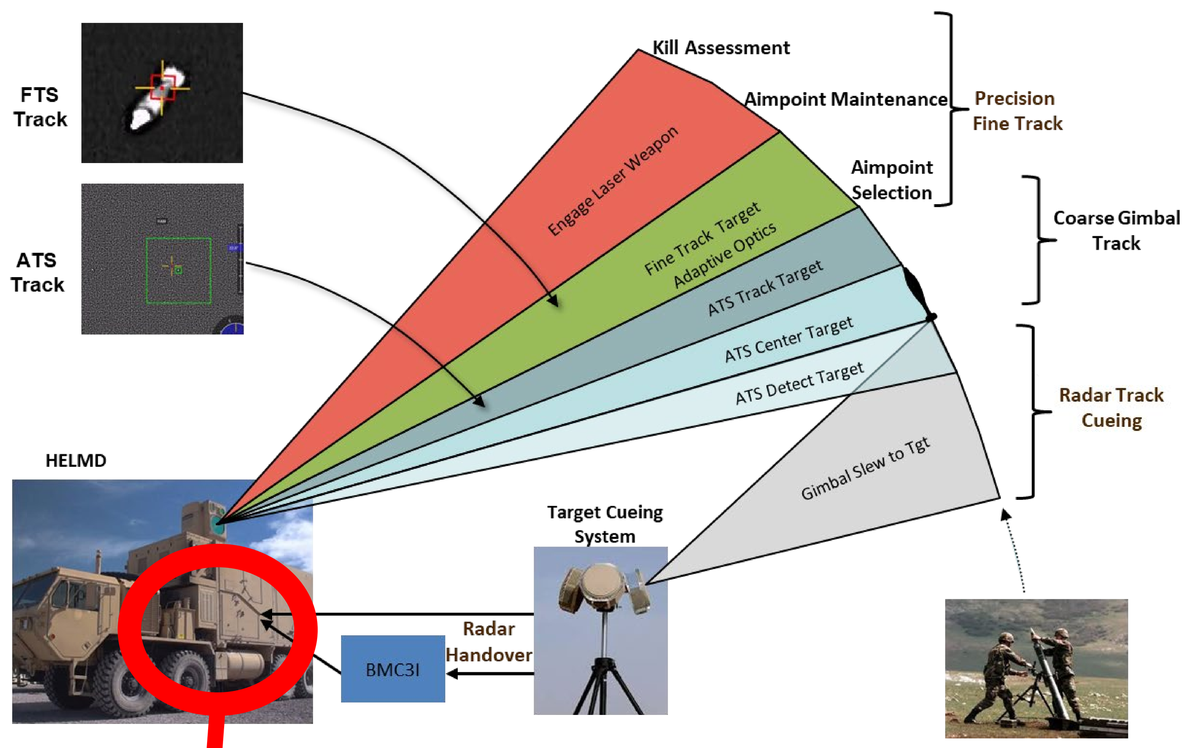
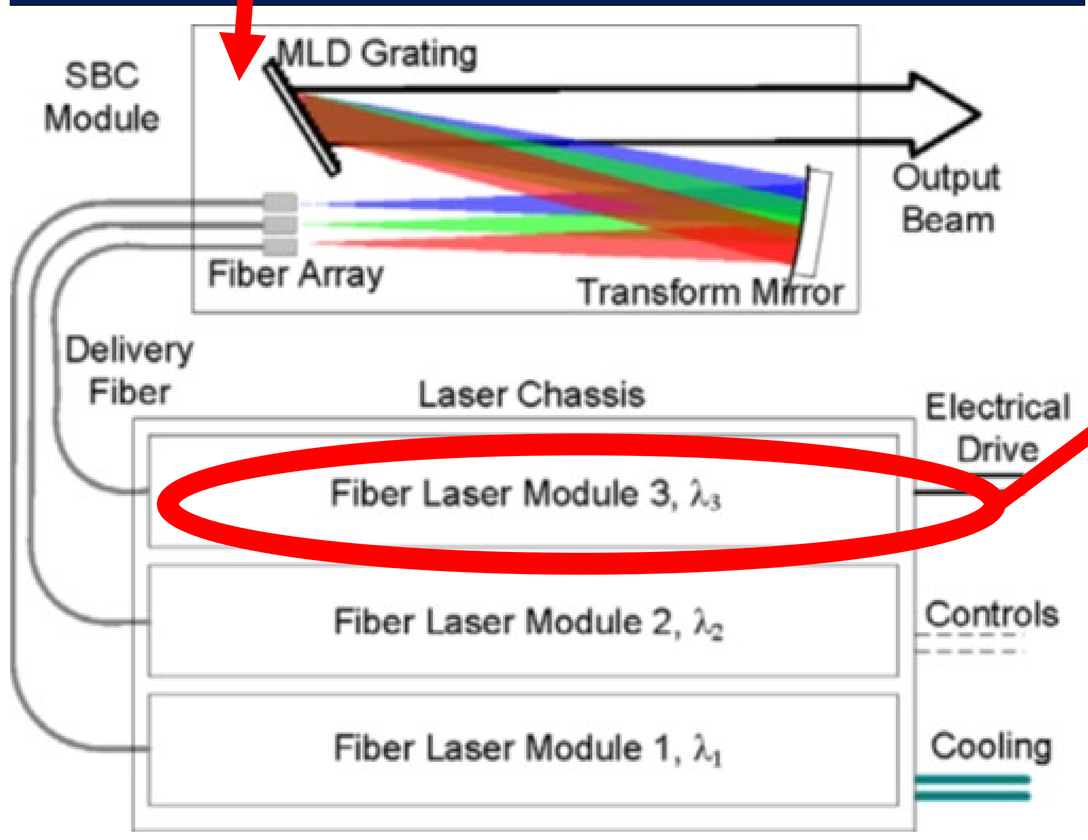
Introduction: The SMDC Technical Center's Directed Energy Directorate is leading efforts to transition kilowatt-class laser technology to be utilized on air and missile defense platforms in the upcoming years. All of these tactical laser sources are designed around a diode-pumped, fiber amplifier laser (FAL) architecture that has multiple channels strategically combined to obtain 10-100 kW power outputs. As these systems are fielded, problems will inevitably arise that require intimate technical knowledge of the laser source itself; capabilities must be available on hand to differentiate between failing amplifier channels, insufficient pump coupling, and beam quality degradation associated with non-linear effects such as stimulated Brillouin scattering (SBS) and transverse mode instability (TMI). Every High Energy Laser (HEL) developer has their own design on the laser source delivered and this laboratory aims to further our SMDC internal capability to characterize, optimize, calibrate, and compare all HEL sources in a controlled yet system relevant verification environment.

High Energy Laser Air and Missile Defense System



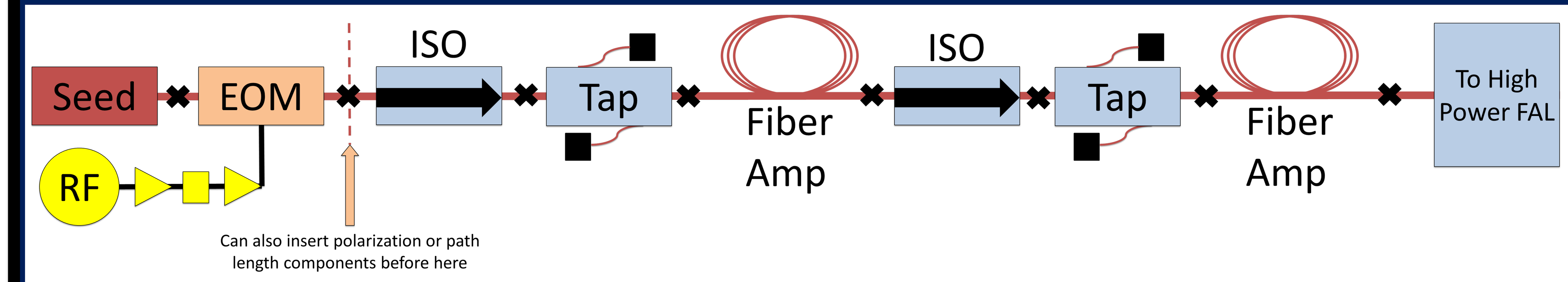
Example of air and missile defense with a HEL. Segments of note include Acquisition Tracking (radar handoff and coarse passive EO tracking), Fine Tracking (laser-illuminated tracking, aimpoint maintenance, and adaptive optics), HEL engagement with target, and confirmation of treat neutralization.

Spectral Beam Combining (SBC) Architecture

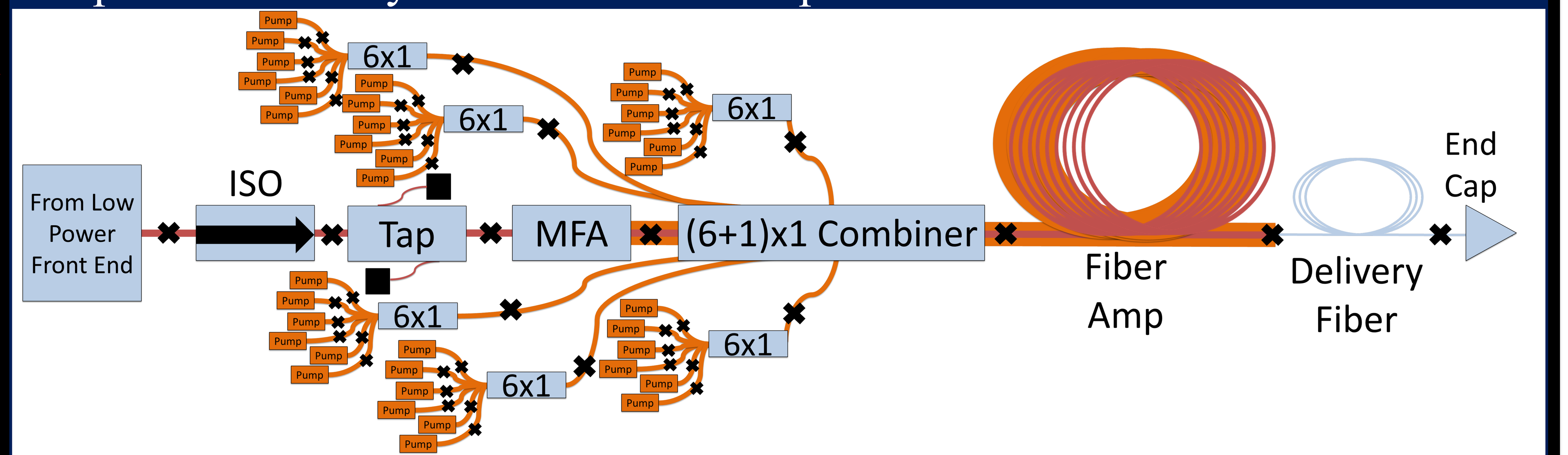


An example of spectral beam combining of Fiber Amplifier Lasers (FALs) where each FAL operates at separate wavelength that geometrically maps to a multilayer dielectric (MLD) grating. The linewidth of each FAL must be wide enough not to cause nonlinear effects but as narrow as possible to maximize total FAL channels. Alternatively, coherent beam combining (CBC) can combine FALs without a grating but requires intricate phase matching.

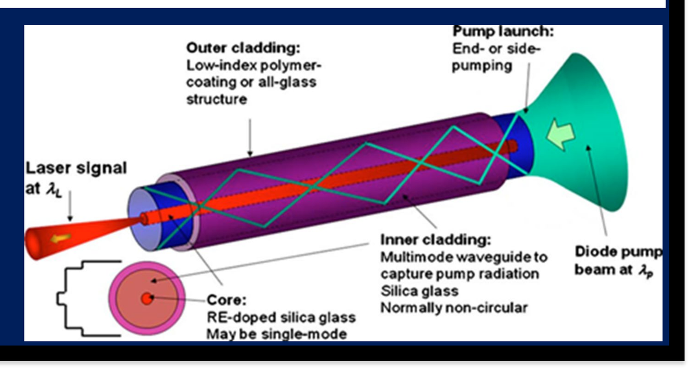
Typical DoD Kilowatt-Class Fiber Amplifier Laser



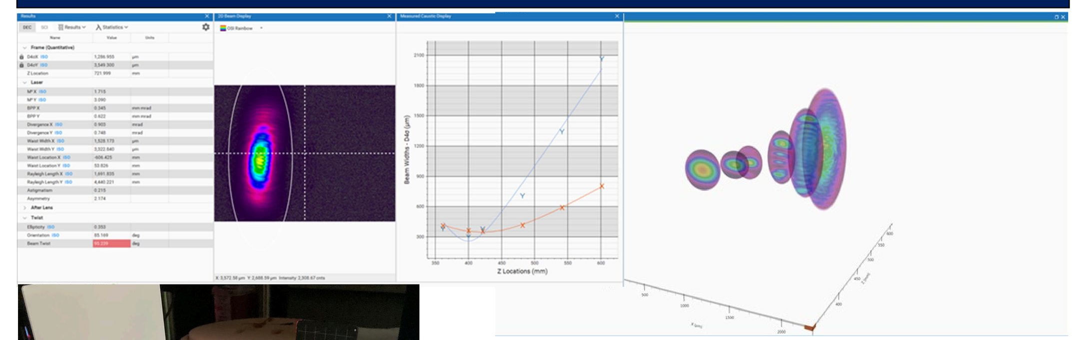
- Over 50 Components, 50 Integration Splices, and 50 Vendor Splices
- Engineering must balance power output, linewidth, and electrical-to-optical efficiency while within atmospheric transmission windows

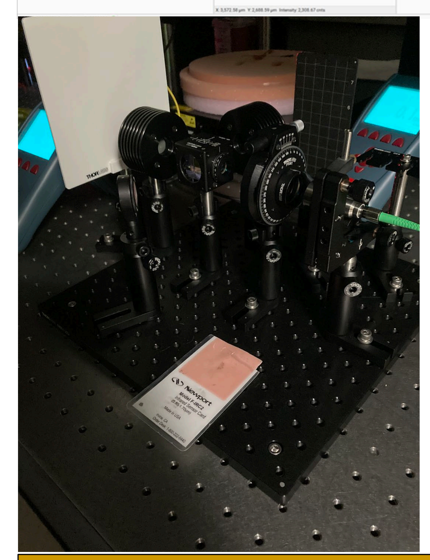


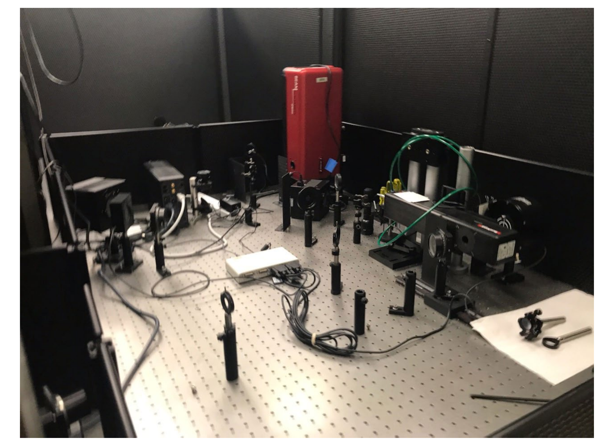
- Built around single-pass end-pumping of double clad Large Mode Area amplifiers. Next generation: counter or two-tone pumping



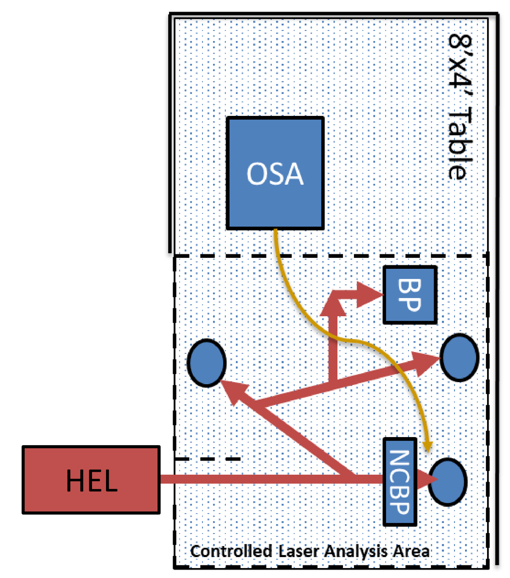
Fiber Amplifier Laser Lab Verification

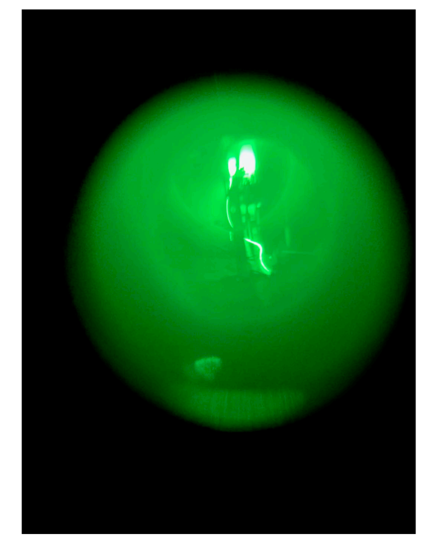






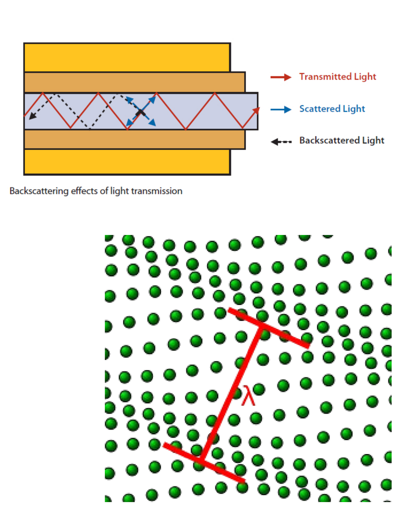
FALCO Lab has state of the art optical characterization equipment for measuring FAL key performance parameters such as: laser linewidth, optical spectrum, optical power, electro-optical efficiency, polarization, and three-dimensional beam profile



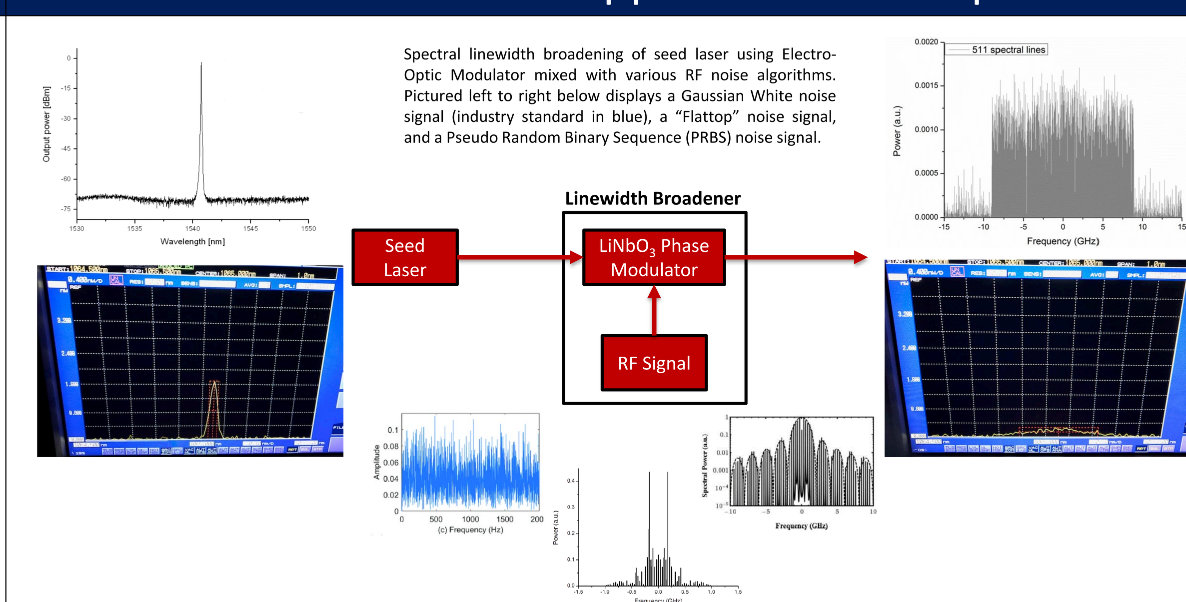


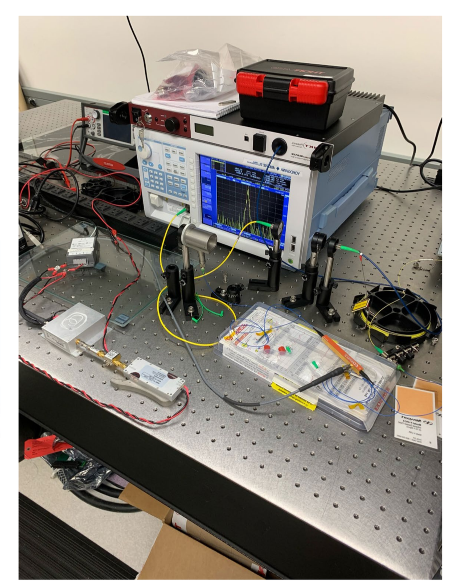
Stimulated Brillion Scattering (SBS)

SBS is a nonlinear effect that occurs in materials where light's EM fields are so strong they begin to distort the atomic lattice. This then causes a grating or vibrational phonons that can scatter light in the backwards propagating direction, potentially damaging components.



SBS Suppression Techniques for Increasing Power Per Fiber





Next generation SBS suppression techniques will be required for power scaling. These increases in power per amplifier will lead to increased lethality at a give range or capability to deliver a given power at a further range. Further scaling will require suppression of Thermal Mode Instability (TMI) as well.

Affiliations
1 – USASMDC Tech Center- Directed Energy Directorate
2- University of Alabama in Huntsville

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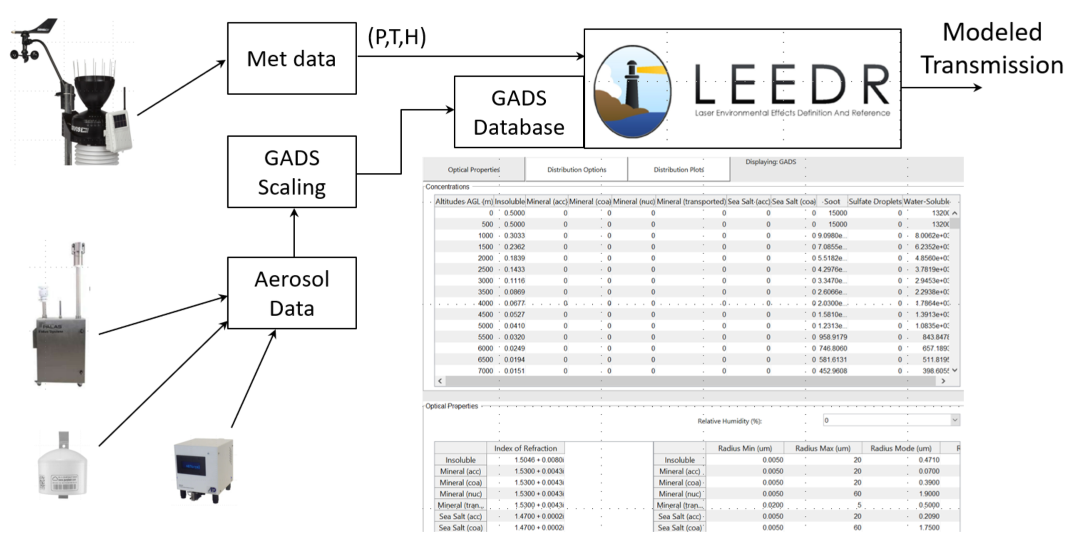
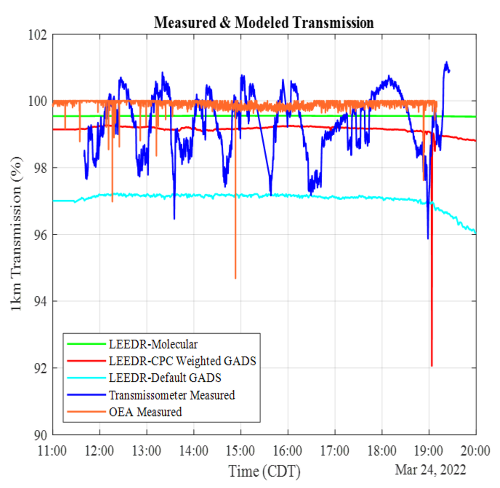
U.S.ARMY

Atmospheric Propagation Lab

THE UNIVERSITY OF ALABAMA IN HUNTSVILLE

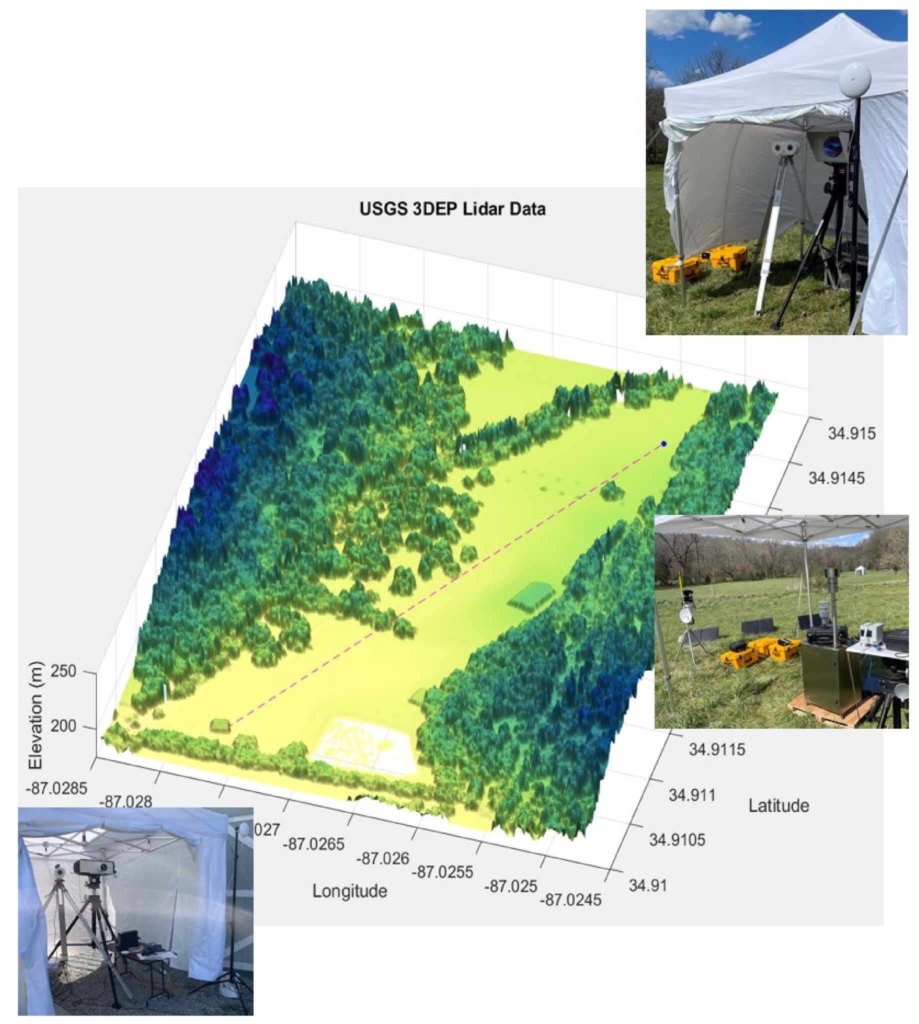
Atmospheric propagation research and modeling for high energy laser weapon systems



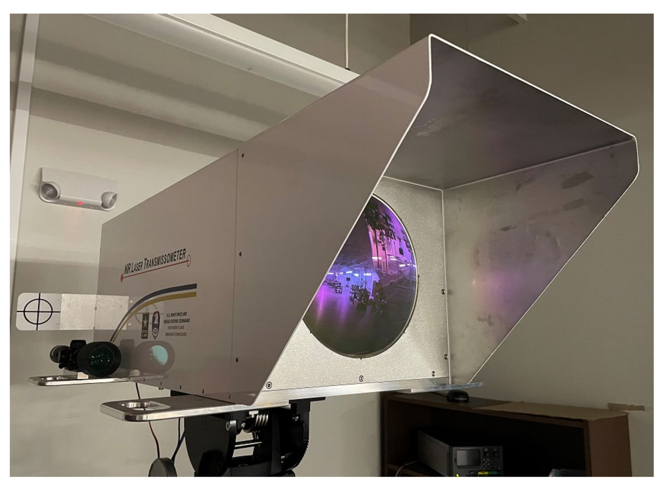


Mission

- Provide accurate Atmospheric Propagation (AP) predictions of HEL Weapon Systems (HELWS) effectiveness given real-time measurement, prediction, and forecasting of atmospheric parameters.
- Development and testing of innovative atmospheric sensing capabilities.
- Collect field test data to expand knowledge of atmospheric propagation and for HEL system model validation.
- Provide maintenance, verification, and validation for updated system level atmospheric propagation and HELWS models.
- Define the minimum required atmospheric sensor suite for tactical HELWS mission planning and deployment.
- Incubate the next generation of high energy laser development professionals.

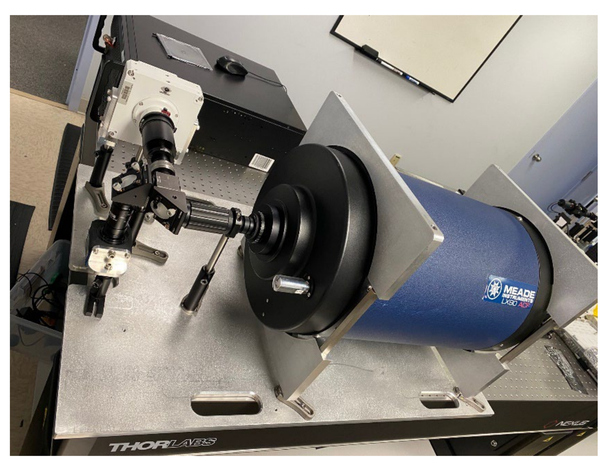


NIR Laser Transmissometer



- Direct measurement
- At HEL Wavelength
- Model validation tool

High Speed HTS

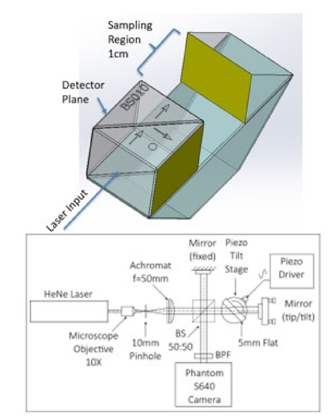


- Turbulence sensor
- High update rate
- Vertical turbulence profiling

High Speed Beam Profiling

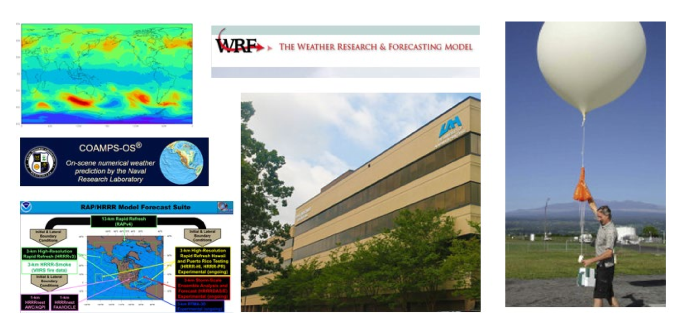
- Direct propagation measurement
- 1,000 Hz Frame rate
- Model validation tool

Interferometric Turbulence Sensor



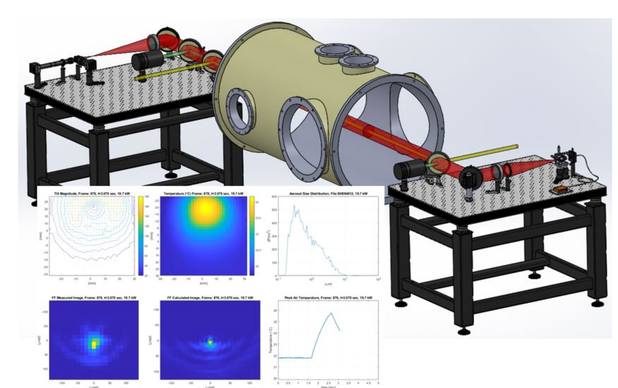
- Novel turbulence sensor
- Direct measurement of C_n^2
- Model validation tool

NWP Atmospheric Modeling



- UAH Collaboration
- Atmospheric Sciences
- Model enhancements

Aerosol Induced Thermal Blooming



- WSMR-SSLT Lab
- Direct beam heating measurement
- Thermal blooming model validation

Lab Personnel:

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