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Mobile Ultrafast High Energy Laser Facility (MU-HELFF)

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Final Report

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ABSTRACT

Ultrashort pulse laser atmospheric propagation has matured into a leading technology for long distance high intensity laser propagation and tracking due to the advances in laser design and unique guiding physics. The MU-HELFF system, partly funded under this DURIP, is a state-of-the-art unique mobile high-energy femtosecond laser-propagation facility designed and built to directly address the continuing needs of the propagation community in the fields of laser propagation, ultra-fast science, filamentation, and at-distance laser interaction studies. Combined with precision tracking ability, this mobile facility enables filamentation, meta-optics, plasma effects, remote sensing, long-range ablation and the generation of THz and RF emission and more in many different atmospheric environments.

MU-HELFF is currently based at the Air Force TISTEF laser-range located on Merritt Island, and operates as a resource for all US University and national laboratory research in ultrafast laser propagation. The DURIP funds provided the critical items to meet the design specifications of a state-of-the-art 500 mJ, sub 100 fs, 10 Hz laser system with integrated guidestar, flexible beam projection optics, and a separate laser tracking system. MU-HELFF is operational and performing propagation studies on the kilometer TISTEF range.

Defense University Research Instrumentation Program (DURIP)
DURIP AWARD
Mobile Ultrafast High Energy Laser Facility (MU-HELFL)
Final Report

1. Introduction:

This funding enabled the purchase of critical equipment for the construction of a unique laser propagation facility, the Mobile Ultrafast High Energy Laser Facility (MU-HELFL). This high intensity ultra-fast laser propagation system on a mobile platform permits long distance ultra-fast laser propagation studies on a broad range of topics in many different atmospheric environments. The MU-HELFL is comprised of three major systems; a mobile 40' ISO shipping container with integrated air-conditioned cleanroom, a state-of-the-art modular ultrafast laser, and a beam direction and propagation system that allows 2π propagation of the laser beam. Given the complexity of the design and implementation, combined with vendor issues lead to many design and budget changes that were necessary to optimize and bring MU-HELFL to fruition. By strategically choosing critical items, and fabricating many parts in house, the MU-HELFL system is operational with current performance of sub 100 fs, 500 mJ per pulse, 10 Hz output propagating 1 km on the TISTEF range. These were the original specifications for the facility.

2. Budget:

The reinterpretation of the original design lead to several changes in the budget, as the costs for the ISO shipping container cleanroom far exceeded the original estimates, as well as upon arrival the container was found to be incomplete, requiring additional time and cost before the laser could be installed. In addition, many other minor changes needed to be made that further resulted in budget changes. The majority of the budget change was shifting the funds for the projector optics to the ISO container, as this would result in a functional facility. The original budget and the final purchase details are summarized in Table 1, with additional details in later sections. The projected cost was \$701,987, with the awarded amount being \$600,000. Due to the lower award amount, several beam projection items such as the FLIR camera and the guidestar laser could not be purchased at this time.

Of the \$600,000 budget, \$556,802.23 was spent. The difference of \$43,197.77 was returned ARO through AMRDEC at the termination of the contract. We regretted this action, but had no alternative as consequence of complications with the container delivered by SeaBox Inc.. Upon delivery from them, it was found that the container was not fully built to specification. The university challenged SeaBox, Inc. even to the point of discussing legal action, to either finish the system to the designed specification or to provide a credit to the university in the amount required for it to be completed. At that point in time a majority of the funds had been spent, thus with a low balance and pending legal action the university put the remaining funds on hold as to avoid the account going negative. The process of negotiations took more than one year to be finalized, upon which a credit of \$21,243.96 was received from SeaBox Inc. However, due to the amount of time to reach settlement, the end date of the contract past prior to spending the remaining funds. The remaining funds were refunded to the Army Research Office.

The MU-HELFL system was funded through a combination of this DURIP, a MRI from

HEL-JTO/AFOSR (Contract FA95501110001 Fundamentals of Filament Interaction), and a MURI from ARO (Contract W911NF1110297 Light Filamentation Science).

Table 1: Purchasing

Proposed Item	Projected Cost	Final Specs	Final Cost	Vendor
TRAILER – 53’ Trailer	\$98,000	40’ ISO Shipping Container	\$392,719.60	SeaBox Inc.
		Refund	-\$21,243.96	SeaBox Inc.
		Tripp Lite UPS	\$9,421.12	Grubber Industries
		Chiller	\$30,189	Carrier
		Machining	\$950	UCF Machine Shop
		Misc Parts	\$14,415.52	Various
		Pulse Gratings	\$9,423	Optigrate
CLEANROOM – Portable cleanroom	\$10,073	Integrated into Container	Included Above	Seabox Inc.
Optical Table	\$35,326	Optical Table	\$18,566.43	Newport
Last Amplifier Pump laser	\$146,125	Quanta-Ray	Not Purchased	Spectra- Physics
Last Amplifier crystal and mount	\$7,500		Not Purchased	
Final amplifier compressor	\$17,595	Horiba Jobin Grating pair	\$27,311.52	HORIBA Instruments
SWIR Camera	\$60,720		Not Purchased	
MIR Camera	\$94,525		Not Purchased	
Telescope	\$9,999		Not Purchased	
Targeting Guidance System	\$35,999	Beam Director + Controllers	\$75,050	Vision Engineering
Interaction Laser	\$146,125		Not Purchased	
Guidestar laser	\$40,000		Not Purchased	
Proposed TOTAL	\$701,987			
Awarded TOTAL	\$600,000	Total Spent	\$556,802.23	
		Total Refunded	\$43,197.77	
		Net Balance	\$0	

3. Description of Equipment:

The following provides additional details on the equipment purchased as well as further details explaining the modifications from the original budget.

a. Mobile Unit – ISO Container + Cleanroom

The original proposal called for using a mobile large air-conditioned enclosed semi-trailer, similar to that built for the NASA Langley Mobile Lidar facility. In the design process, it was found that this layout was not an optimal arrangement for the laser system and associated subsystems. Upon design review, a standard 40' ISO shipping container was found to provide much more adaptability, increased internal space, higher stability, while still providing for ease of transport. Additionally, this arrangement could be outfitted such that the entire container could be a clean room with raised floors and drop through table legs providing the increased level of stability, a significant improvement over the cleanroom in a semi-trailer concept. The final design layout is illustrated in Figure 1 below.

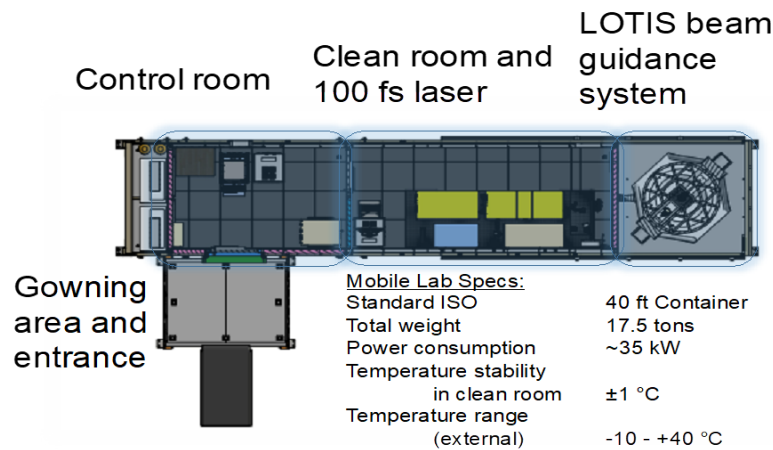


Figure 1: The ISO 40' shipping container layout

The layout consists of four separate sections, the entry gowning area, the main control room, the laser bay, and the LOTIS beam guidance bay. The LOTIS bay incorporates a retractable roof to provide 2π beam propagation.

The original proposed design using a semi-trailer costing \$98,000 would have been limiting to the functionality, thus the decision was made to re-design in order to overcome these limitations. The shipping container outfitted with full cleanroom and power was purchased for \$371,475.64 from SeaBox industries, accounting for a majority of the change to the proposed budget. The SeaBox built MU-HELFF container is shown installed on the TISTEF range in Figure 2. The final buildout of various subsystems for laser cooling and data cabling was completed in-house, accounting for the \$950 in machining and \$14,415.52 in various vendor parts. These various vendor parts and supplies were to finish out the container to specification as detailed in section 2.



Figure 2: MU-HELF installed on the TISTEF Range

b. CLEANROOM – Portable cleanroom

Utilizing the ISO container allowed the container integrate the cleanroom, thereby eliminating the need for a portable installed unit. The proposed cost of \$10,073 is absorbed into the ISO container cost.

c. Optical Table

The design change from semi-trailer to shipping container allowed for a more stable table configuration whereby the table legs can pass through the container to sit directly on the foundation, thus eliminating any vibrations due to personnel and HVAC systems. The optical table originally quoted for the laser system as designed provided stability in a mobile trailer using Newport table legs, whereas with the design changes the legs were now integrated into the table lifting system along with custom designed legs that would be provided by SeaBox, and thus their cost was integrated into the container. The originally quoted table cost of \$35,326 incorporated the legs, and the final cost of \$18,566.43 was the table alone. A photo of the table installed in the cleanroom is shown in the figure below.



Figure 3: The optical table as installed in the MU-HELF cleanroom. Photo taken upon container delivery, thus packing materials are still visible on the walls.

Initial range data from MU-HELF shows extremely high stability when measured at 1 km, validating our table design changes.

d. Laser Amplification – Amplifier Pumps – Horiba Jobin Grating Pair

The original DURIP proposal budget included the 2J amplifier, the last amplifier crystal, and the compressor gratings, which were necessary given the home built laser design proposed. Along with the changes to the overall facility, it was decided that for reliability and compactness the regenerative pump and final amplifiers would be purchased from Amplitude Technologies in France. Separate MURI funds paid for the Amplitude laser system. The design change to a commercial system, along with a fiberized front end provides a state-of-the-art turnkey system.

With these changes, the laser crystal originally budgeted for was not needed, and the 2J pump was paid for by a separate proposal. The originally gratings quoted at \$17,595 ended up costing \$27,311.52 due to additional design changes in the compressor. To provide for future upgrades, the gratings were increased in dimension to provide higher energy throughput, thus also increasing the cost. Given the long projected lifespan of the system, having the compressor pre-designed for higher powers will keep the system relevant to the state-of-the-art laser systems, without the need for additional expensive replacement upgrades. A photo of one of the compression gratings is shown in figure 4 below.

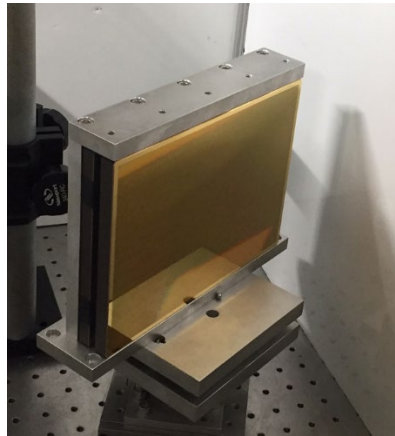


Figure 4: The optical compression grating pair (one shown) as installed in the MU-HELF.

e. Beam Projection – Cameras – MIR camera – Telescope – Target guidance – interaction laser - guidestar

Upon review of the budget after the purchase of the SeaBox container, many of the non-critical to functioning items proposed were not purchased. With the goal of a fully functional system, it was realized that we could re-utilize an existing target tracking and guidance system available at TISTEF, by paying for it to be refurbished. The local company, Vision Engineering, are specialists in these mounts and they were contracted for the refurbishment totaling \$75,050. The mount was re-named Laser Optics Turret and Instrumentation System (LOTIS) and is shown in Figure 5. This decision provided a

higher stability and resolution beam projection system than that originally proposed using the Meade Instruments target guiding system (\$35,999). As not being critical for operation, the FLIR camera (\$94,525) and Meade Instruments Telescope (\$9,999) were not purchased.



Figure 5: The LOTIS optical tracker installed in the MU-HELF.

The 2J interaction laser (\$146,125) proposed was not purchased due to the budget constraints. The Coherent Verdi (\$40,000) proposed to be used as the guidestar was not purchased, instead an inexpensive low power diode system is being used currently with plans for a replacement in the future.

4. Status of the MU-HELF facility:

During the course of the MU-HELF project, many major design revisions to the original proposed plan were made, necessitating large changes to the budgets and purchases. However, the results of this hard work produced an ultrafast laser facility that is significantly more versatile and will likely have an operational lifespan exceeding the original estimates. Currently the MU-HELF facility is operational and propagating ultrafast beams on the 1 km range.

The final design of the laser system utilizing a fiberized front end has truly made this system a turnkey design, with minimal warm up times and high stability through the day and day-to-day as well. The system currently produces sub 100 fs, 10 Hz, >500 mJ per pulse output. The laser temporal profile is roughly super Gaussian with a relatively clean spatial flat top beam profile, as shown in Figure 6.

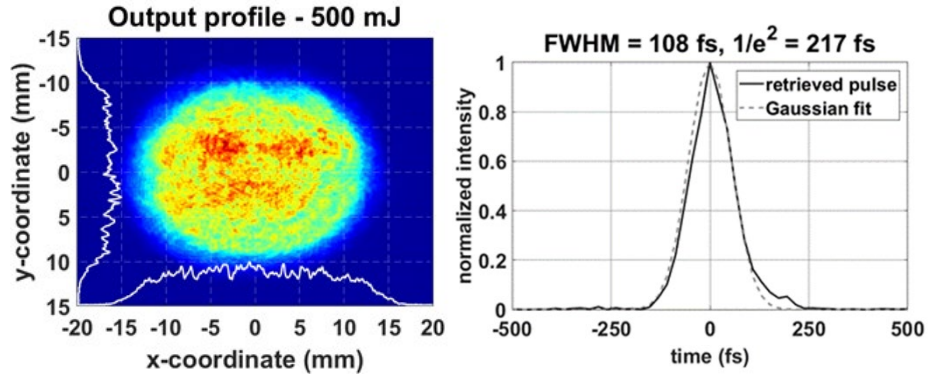
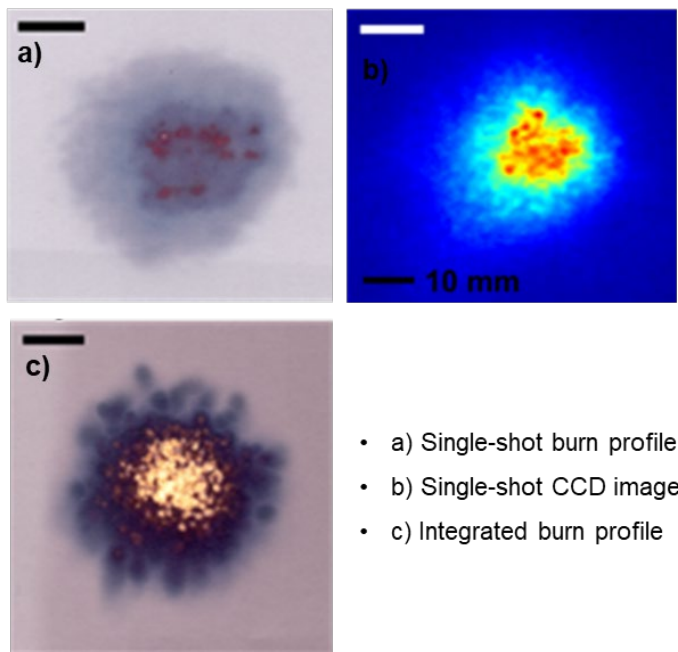


Figure 6: MU-HELFLaser output profile and temporal shape.

The data shown in Figure 6 was taken after the compressor, pre beam projection. Initial propagation data clearly shows filamentation throughout the 1 km range. Intra-range (sub 1 km) beam profiles are shown in Figure 7, with *a* and *c* being traditional burn paper and *b* a triggered bandpass CCD image.

Intra-range profiles



- a) Single-shot burn profile
- b) Single-shot CCD image
- c) Integrated burn profile

Figure 7: MU-HELFLaser output profile and temporal shape.

At full 500 mJ output it is observed in the above images that multiple filaments are forming. This was investigated in more detail at the end of the 1 km range. A triggered bandpass camera system was configured to record every shot in high resolution, such that individual filaments can be resolved. Figure 8 shows an example of that data.

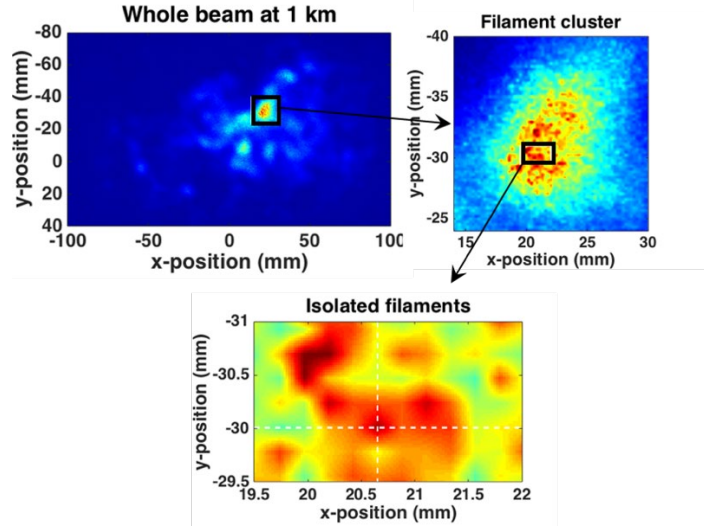


Figure 8: Clustered filaments clearly observed at 1 km while operating at 500 mJ pulses.

Given the ability to generate large clusters of filaments at 1 km, MU-HELF will be able to perform a wide range of studies on structured arrays like those originally proposed as well as new novel designs currently in development. Initial testing of structured arrays was performed using a binary vortex plate (no optimized) producing a ring of filaments at distance as shown in Figure 9.

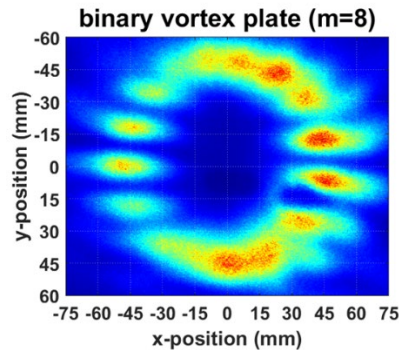


Figure 9: Initial data utilizing binary vortex plate.

4.1 Responsibilities for the completion of this project.

Drs. Lawrence Shah, Martin Richardson, and Nathan Bodnar oversaw the majority of the technical management for this DURIP. Dr. Robert Bernath led the final technical management for this program along with Dr. Nathan Bodnar. The final design and construction of the facility have involved several students, and contributed to their education:

- Daniel Thul (PhD student): is the lead student on the MU-HELF laser installation and operation. Design and implementation of high-energy systems for filamentation is the focus of his PhD research.
- Haley Kerrigan (PhD student): is the lead student on interaction effects, and has been supporting this project as part of her PhD research.
- Danielle Reyes (PhD student): is the lead student on fundamental filamentation studies, and has been supporting this project as part of her PhD research.
- Jessica Pena (PhD student): is the lead student on filamentation aerosol studies, and has been supporting this project as part of her PhD research.

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