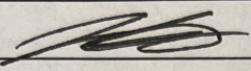
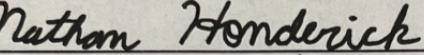
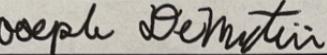
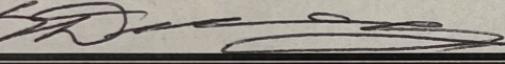
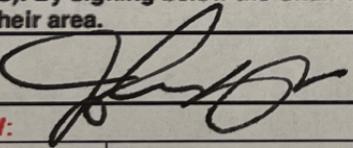


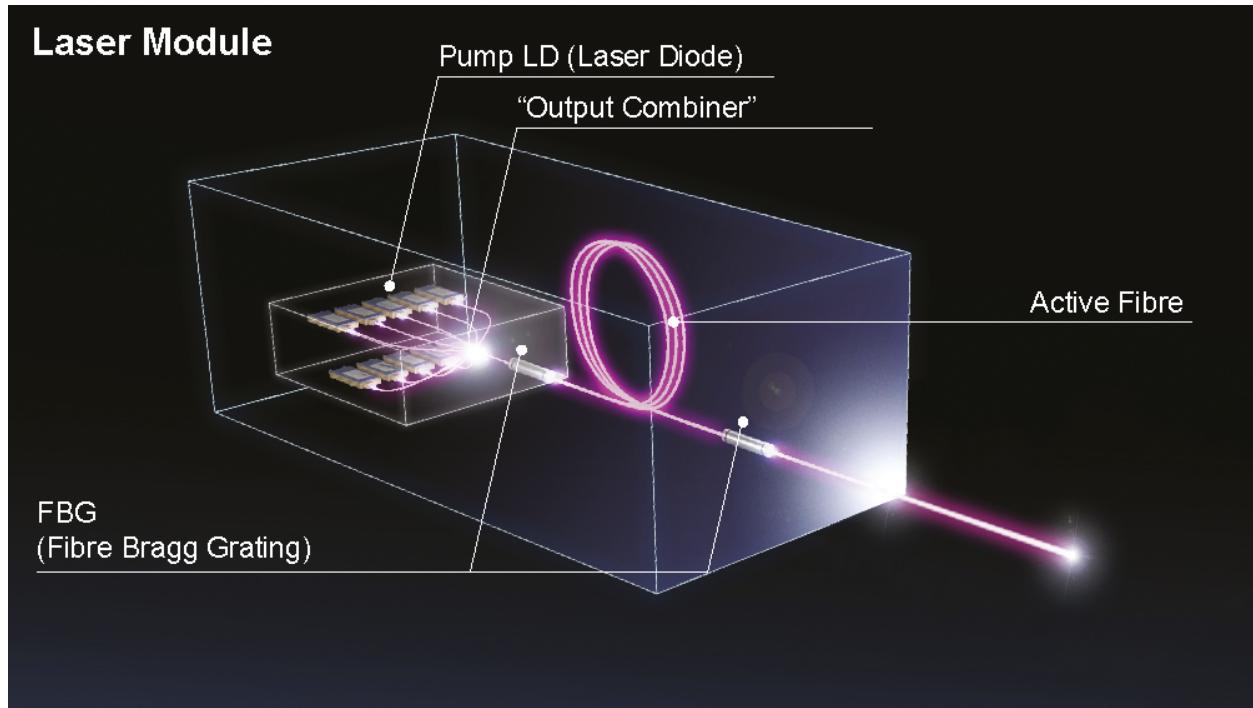
PROPOSAL COVER PAGE / REVIEW AND APPROVAL
Ignite Co-Curricular Research Project Grant
2023-2024

| | | | | |
|---|---|------------------------|----------------------------------|---|
| STUDENT ORGANIZATION: | Engineering Physics Propulsion Lab | | ORGANIZATION CONTACT: | drakunov@erau.edu |
| DEPARTMENT: | Physical Sciences | | COLLEGE: | College of Arts and Sciences |
| PROPOSAL TITLE: | Advanced LASER Mining Array | | | |
| AMOUNT REQUESTED: | \$7,000 → \$7,571.78 | PERIOD OF PERFORMANCE: | Start: July 2023 / End: May 2024 | |
| SIGNATURES: Student Principal Investigator and Team Members: Type names and include signatures | | | | |
| Jacob Romeo |  | | DATE: | 02/28/2023 |
| Phoebe Fleshman |  | | DATE: | 2/28/2023 |
| Nathan Honderick |  | | DATE: | 2/28/2023 |
| Joseph DeMartini |  | | DATE: | 2/28/2023 |
| | | | DATE: | |
| STUDENT ORGANIZATION FACULTY MENTOR: | | | DATE: | 2/28/2023 |
| Vikas Sudesh. | | | DATE: |  |
|  | | | DATE: | 3/1/2023 |
| Add additional Team Members on SECOND PAGE, PLEASE HAVE ALL DEPARTMENT CHAIRS ADDED TO THE ENDORSEMENT SECTION BELOW. | | | | |
| SIGNATURES FOR ENDORSEMENT: (Chairs can provide written evaluative judgments of the project as part of the SUPPORTING DOCUMENTS). By signing below the Chair verifies their support and that adequate physical space is available (if applicable) in their area. | | | | |
| DEPARTMENT CHAIR: |  | | DATE: | 02/28/23 |
| SIGNATURES FOR REVIEW: | | | | |
| Director, Undergraduate Research: Ronnie Mack, Ed.D. | Ronnie Mack | | DATE: | 3/3/2023 |

Proof of Design for the Advanced LASER Mining Array (ALMA)

Principal Investigator: Jacob Romeo
Student Team: Joseph DeMartini, Phoebe Fleshman,
and Nathan Honderick
Supervisor: Dr. Sergey V. Drakunov

January 28, 2023



Nomenclature

$\mu = 10^{-6}$

C – Type = Carbonaceous chondrites

EPPL = Engineering Physics Propulsion Lab

Er = Erbium

FBG = Fiber Grating

FBL = Fiber LASER

K = Kelvin

LASER = Light Amplification by Stimulated Emission of Radiation

nd : YAG = neodymium-doped:Yttrium Aluminium Garnet

NEO's = Near earth objects

PPE = Personal Protective Equipment

SOP = Standardized Operating Procedure

Tm = Thulium

Yb = Ytterbium

1 Abstract

The goal of the ALMA project is to design and create an apparatus to test the ability of a FBL to mine water ice in space. This includes ice on the moon, NEO's, and asteroids in the asteroid and Kuiper belt (which mainly consist of C-types and comets) [3]. ALMA is a down-sized version of the full LASER, being able to melt smaller chunks of ice. The reason for using a FBL versus a nd:YAG or CO₂ gas LASER is to make use of the efficiency and accessibility of the FBL. The FBL is a more cost effective, and energy efficient laser, while also more compact than its counterparts [5]. The simpler design, allows it to be both reliable and maintenance-free during use [1]. Most high powered FBL's have a recorded 30% - 50% power efficiency, much greater than other options [4]. Because of this the FBL was found to be the best option.

The basic design of a FBL utilizes: coupled diodes, a combiner, a Yb doped fiber cable, FBG (one of higher polarization on the input and another of low polarization on the output), and a FBG to protect the inside of the cable (*Fig. 1*). Due to the fact this project is researching means of mining in space, where the resting temperature is approximately 2.7K, there would be no use for cooling. More likely a means to find ways to shield the FBL from the space environment will need to be developed, because temperatures do not remain consistent once on the surface of the moon and other bodies in space. Because of this, the components will need to be changed based on the FBL based on its environment it is mining.

To complete the project and its goals, there will be a safety plan implemented as follows. The downsized model will have a system of precaution, including PPE, a safe and isolated environment for testing, and documentation with information disclosing safety measures.

2 Background

After Albert Einstein discovered the math that describes lasers in 1917, work stagnated until the 1950s with the first successful design in 1960. It wasn't until 1963 when Elias Snitzer demonstrated a FBL [6]. This work was evolved to create lasers that are used to cut precious metals or in communication systems. In recent years the most common point of discussion is for mining, as it is the most rewarding possibility for FBLs to be used.

The function of a FBL works by using a diode coupled to a doped fiber optic cable, with amplification by stimulation. Some dopants for the amplification process are the elements Yb, Er, and Tm [6]. This process is called population inversion, defined as the redistribution of energy levels by collisional excitation of the electrons in the atom [7]. When electrons collide with a photon, from the pump source, it becomes energized and jumps to a higher energy level (*Fig. 3*). This process can be mathematically described by the elementary equation: $E_2 - E_1 = \Delta E = hf$, where h is Plank's Constant and f is the frequency of light. Once the electron goes back to the ground state and re-emits the photon, it gets reflected from the high reflective FBG, thus exciting more electrons and emitting more photons. From this quantum phenomena, a single photon can start a domino effect and amplify the input significantly and quickly.

The cladding of the fiber cable, surrounding the doped core, allows the light to have total internal reflection (*Fig. 2*) allowing minimal energy loss and scattering. This effect comes from Snell's law: $\sin(\theta_c) = \frac{n_{clad}}{n_{core}}$, where n is the refractive index. For this to work and there to be total internal reflection: $n_{clad} < n_{core}$. There can be some scattering loss due to bending of the cable, which can be calculated and accounted for. The FBG on each end of the fiber filter the photons so that it can be reflected and energized to the correct wavelength (λ). For the current setup, ALMA will have $\lambda \approx 1070\text{nm}$. The input grating has a larger reflectivity, thus no light can re-enter the diode and it is reflected to be amplified. Once the photon has reached the max wavelength (1070 nm), it is transmitted through the low reflectivity FBG.

3 Methodology

ALMA will be a down-scaled version of the theoretical FBL at about 1.2 Watts of peak output power, giving a pulse energy of $.24\mu\text{J}$ at a pulse width of $20\mu\text{s}$. There will be a control board with the diode soldered on, giving us the ability to change the pulse-width parameters and input/output power. Within the lab, we plan on building a test cell made from 80/20 linear rails, the laser will be contained in the cell. Around this test cell will be a polarization screen, explained in section **Safety Precautions**. The apparatus will show mining techniques and collect spectra data from ice. This spectra data will be used when compiling the simulations, deriving the power needed to complete this task in different environments. The goal is to see how applicable this idea is with current technology. If not at all, the simulations can tell us why and what we need for it to come to fruition. It is also a lot more inconvenient and expensive to do tests with a higher powered FBL. Thus with the smaller version, ALMA is still able to experimentally derive the necessary processes that the simulations will be sourced from.

Currently, there is no precise value for the absorbance of ice, which is the lowest power requirement to melt ice. The basic definition of the absorbance, stated as the Beer-Lambert Law: *An absorbance of 0 corresponds to a transmittance of 100% and an absorbance of 1 corresponds to 10% transmittance* [11]. This comes from: $A = \alpha cl$ and $\alpha = \frac{4\pi k}{\lambda}$, where A is absorbance, α is absorption coefficient, c is molar concentration, l is optical path length, k is extinction coefficient, and λ is wavelength. The absorption coefficient is defined: *How far into a material light of a particular wavelength can penetrate before it is absorbed* [12] and the extinction coefficient: *How efficiently light is absorbed or reflected from a material* [12]. Because of this, we will need to experimentally derive k and α to solve for A . This is important because without these values λ for the system is essentially an educated guess, which is what we are currently doing. Thus in the future, ALMA will need to incorporate different FBG, testing with different λ s to derive the best absorbance value for the system.

Some other examples of why testing with different FBG will help ALMA's progression include power output, beam quality, mining techniques, etc. Completing any of these experimentally will help the theoretical process and also make it more accurate for our goals.

| | TASKS | START DATE | COMPLETION DATE |
|----|--|-------------------|------------------------|
| 1 | IGNITE grant is rewarded | 07/2023 | - |
| 2 | Order components for FBL and apparatus | 07/2023 | 08/2023 |
| 3 | Make apparatus to mount FBL | 08/2023 | 08/2023 |
| 4 | Start testing FBL | 08/2023 | 08/2023 |
| 5 | Research Symposium | Fall TBA | Fall TBA |
| 6 | Collect spectra and mining data | 09/2023 | 11/2023 |
| 7 | Testing w/ more FBG(if enough \$) | 11/2023 | 01/2024 |
| 8 | Repeat 6. with other FBG | 01/2024 | 02/2024 |
| 9 | Discovery Day | Spring TBA | Spring TBA |
| 10 | Compile sim with spectra data | 03/2024 | 05/2024 |
| 11 | Publish research | 05/2024 | 05/2024 |
| 12 | Reach out for more opportunities | 05/2024 | 07/2024 |

4 Safety Precautions

The EPPL in room 123.1 of the COAS is a very secure environment to preform experiments. Storing ALL of ALMA's equipment, including PPE, the apparatus, and experimental tools. There is also a test cage in which all of the experiments will be preformed along with a protective screen that blocks all light emission. The screen is present so that if light gets scattered or reflected it will not injure any researchers or damage sensitive equipment. The researchers working on ALMA will be wearing PPE at all times, including polarized goggles and latex gloves. In the test cage, there will be designated spot for NO crossing, where the beam would be active along with a sign outside the lab door signaling the use of a LASER. Money will also be allocated to buying a downsized test cell with the ability to install polarization features, in the case the screen cannot be purchased.

4.1 Storage's SOP

Money for the FBL equipment will be allocated for secure, pelican crates for the equipment. It will be stored in a room behind a locked door, and will only be available to the PI once stored. Only 3 research interns and the supervisor have access to this door inside the lab once locked. The PPE will also be stored in pelican crates inside the test cage along with the equipment. The PPE includes polarized goggles, grounding cables, and protective gloves. Along with this, there will be NO jewelry of any kind when handling/experimenting with equipment.

4.2 Experiment's SOP

The experiments will always be conducted inside the test cage, behind the locked door, inside the lab. There will be warning lights when the FBL is active and will be warning signs on the locked lab door and test cage at all times. Inside the test cage, there will be warning tape, at all times, where the beam would cross while active. The FBL will also have a switch to turn power on/off and a shutter on the output lens to block any light coming out of the FBL, on or off. Stated above, the test cage will have polarization tint so that if the beam gets reflected towards the cage, it will not be transmitted through the cage.

5 Significance

Space mining is one of the "Big Talks" in fields of science and business alike. Once pioneered and efficient, mining in space will rid the need for ripping earth of its materials. If we continue to mine earth, we will eventually run out of resources within the millennia. Mining in space also gives humans the ability to complete space travel easier and generate new processes of wealth. This project introduces the concept of using a FBL to mine in space. From this project, the aerospace industry will have a new, optimized process of extracting water ice from space, allowing companies to make fuel from hydrogen or steam and have an oxygen supply. ALMA will also exponentially increase this team's knowledge in areas of lab competency and safety, experimental processes of LASERs, physics of LASERs, and mathematics. Feeding this team the knowledge we need to be successful in each of our fields.

6 Communication Plans

The findings of ALMA will first and foremost be shared with Embry Riddle Aeronautical University. An accumulation of the findings, data, and simulations will also be shared to multiple journals in hopes of publication regarding the project. We will also apply for more grants and reach out to companies in hopes of partnership to further the research of ALMA.

7 Adequacy of Resources

All experiments will be conducted in the EPPL, room 123.1, in the College of Arts and Sciences at Embry Riddle Aeronautical University. There is sufficient space to include all measures for storage and operation, along with adequate tools and additional resources. The EPPL comes with 10 3D printers, including a 0.6 cubic meter printer, that are available for the ALMA team to use when needed. Dr. Sudesh, who has more than 20 years of experience in conducting experiments with FBLs, solid state LASERs, and optics, will be a mentor for the team. His knowledge and industry connections will help in many ways throughout this project. Also Dr. Drakunov, who is the founder of the lab, will provide an excellent source of knowledge when applying the results to the simulations.

8 Appendix

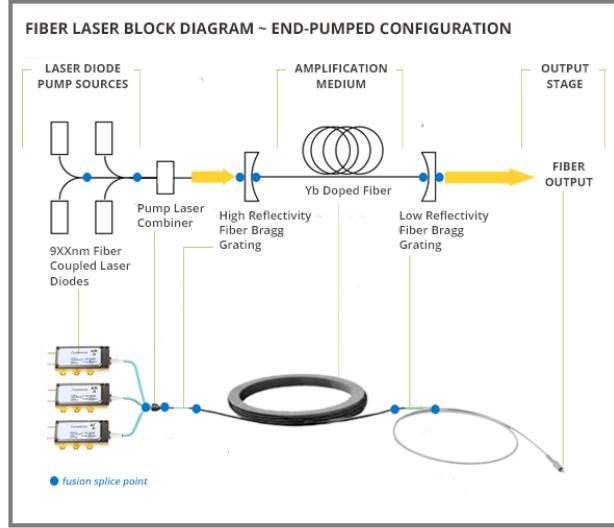


Figure 1: FBL design setup for amplification [7]

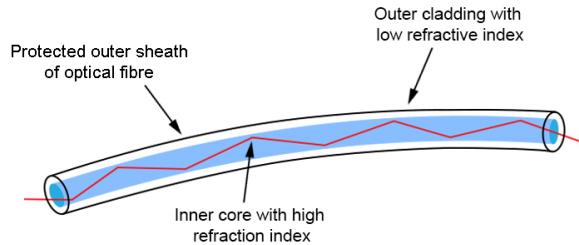


Figure 2: Example of total internal reflection in cable [8]

Stimulated emission

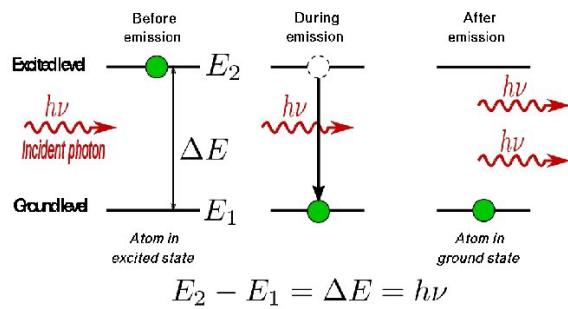


Figure 3: Population inversion cartoon example [9]

9 References

- [1] Butterfly, B. (2022, March 15). Fiber Laser: 7 advantages and differences. FindLight Blog. Retrieved October 3, 2022, from <https://www.findlight.net/blog/2022/03/15/7-advantages-of-fiber-laser/>
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- [3] Lovett, R. A. (2021, January 8). From the vault: Icy asteroids? Cosmos. Retrieved October 3, 2022, from <https://cosmosmagazine.com/space/icy-asteroids/>
- [4] Photonic frontiers: High-efficiency optical pumping: 'going green ... (n.d.). Retrieved October 3, 2022, from <https://www.laserfocusworld.com/lasers-sources/article/16547048/photonic-frontiers-highefficiency-optical-pumping-going-green-cranks-up-the-laser-power>
- [5] Laserax. (2021, September 23). Fiber Lasers: Everything You Need To Know. Laserax. Retrieved October 3, 2022, from [https://www.laserax.com/blog/fiber-laser#:~:text=1963%20%E2%80%93%20The%20first%20fiber%20laser,is%20demonstrated%20\(Elias%20Snitzer\).](https://www.laserax.com/blog/fiber-laser#:~:text=1963%20%E2%80%93%20The%20first%20fiber%20laser,is%20demonstrated%20(Elias%20Snitzer).)
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- [7] Fiber Laser Basics and design principles. Fiber Laser Basics and Design Principles (with VIDEOS). (n.d.). Retrieved October 3, 2022, from <https://www.laserlabsource.com/Solid-State-Lasers/Solid-State-Lasers/fiber-laser-basics-and-design-principles>
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- [9] Laser light amplification by stimulated emission of radiation. SlideToDoc.com.(n.d.).Retrieved October 3, 2022, from <https://slidetodoc.com/laser-light-amplification-by-stimulated-emission-of-radiation-5/>
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- [11] Granite, S. by. (2023, February 14). Beer Lambert law: Transmittance amp; Absorbance. Edinburgh Instruments. Retrieved February 24, 2023, from <https://www.edinst.com/blog/the-beer-lambert-law/>
- [12] Absorption coefficient. PVEducation. (n.d.). Retrieved February 24, 2023, from <https://www.pveducation.org/pvcdrom/pn-junctions/absorption-coefficient>

10 Student Group Resume

Jacob Romeo: A second semester junior in Astronomy and Astrophysics with research experience in applied and theoretical physics, astronomy, electrical and software engineering, and control theory. Over 4 years of experience with electronics (PCB development) and coding in python. Experienced using Fusion360 CAD software, C++ and java, and development with raspberry-Pi's and Arduino's.

Phoebe Fleshman: A second semester junior in Engineering Physics with a focus on spacecraft systems. Roughly 2 years of technical experience designing and building robots. Along with roughly 2 years of budget creation and management . Experienced using Autodesk Inventor Pro, MatLab, and CNC mills.

Joseph DeMartini: A third year Engineering Physics student with professional experience in software development and simulation. 5+ years of experience in Java, C#, and Unity3D development with an understanding of advanced software development practices. Experience in applying numerical methods and modern physics concepts to create high fidelity 3D physics simulations in optics, orbital mechanics, and electromagnetism.

Nathan Honderick: A second semester freshman in Aerospace Engineering, specializing in Astronautics. Experienced using Matlab, Onshape, Inventor, and Catia CAD software. Currently working on a CubeSat, a laser mining array, a hybrid rocket engine, and developing a patent for an eco-friendly product crafted from up-cycled beach plastic.

11 Detailed Budget

| Line # | Vendor | Item | Product # / SKU | Ordering Instructions / Notes | Link | Quantity | Est. Total for All Items Requested: \$7,600.00 | | | Actual Total: \$7,571.78 | |
|--------|----------------|--|-----------------|---|---|----------|--|--------------------|-----------------|--|----------------------|
| | | | | | | | Price Each | Est. Shipping Cost | Estimated Total | Actual Total - Inc. Shipping Fee (will be complete this) | Notes from Purchaser |
| 1 | Lumics | BTC LASER diode | LU0975M500 | | Contact for purchase | 1 | \$2,175.00 | | | \$2,175.00 | |
| 2 | Analog Modules | Seed diode Control board | Model 762 | | Contact for purchase | 1 | \$1,405.00 | | | \$1,405.00 | |
| 3 | Fibercore | Yb doped fiber cable | custom | | Contact for purchase | 1 | \$1,000.00 | | | \$1,000.00 | |
| 4 | TechJewel | High reflectivity Fiber bragg grating | custom | | Contact for purchase | 1 | \$250.00 | | | \$250.00 | |
| 5 | TechJewel | Low reflectivity Fiber bragg grating | custom | | Contact for purchase | 2 | \$300.00 | | | \$600.00 | |
| 6 | Uline | Welding screen (Also getting a small one from SPARK) | H-517958 | MAKE sure to get the 'Shade-8' color under the color specifications | https://www.uline.com/ProdH-517958 | 2 | \$150.00 | | | \$300.00 | |
| 7 | Amazon | 80/20 Linear rails | B08XXN97VN | | https://www.amazon.com/ | 1 | \$90.00 | | | \$90.00 | |
| 8 | Uline | pelican case | H-6800 | | https://www.uline.com/ProdH-6800 | 1 | \$72.00 | | | \$72.00 | |
| 9 | GO Photonics | spectrometer | USB4000-FL | | https://www.gophotonics.com/Products/USB4000-FL.aspx | 1 | \$1,500.00 | | | \$1,500.00 | |
| 10 | Ocean Insight | Fiber Cable | P200-1-Y05-NB | for the spectrometer | https://www.oceaninsight.com/Products/P200.aspx | 1 | \$144.00 | | | \$144.00 | |
| 11 | FTDI chip | UART → USB-A | TL-232R-SV | | https://ftdichip.com/product/tl-232r-sv.aspx | 1 | \$23.40 | | | \$23.40 | |
| 12 | Null | Toggle switch | B099S66XH | To toggle power of apparatus | https://www.amazon.com/ | 1 | \$12.38 | | | \$12.38 | |

IGNITE Co-Curricular Research Project Grant Budget

Please provide as much detail as possible.

| | |
|-----------------------------------|--|
| Organization / Student PI: | Engineering Physics Propulsion Lab (EPPL)/Jacob Romeo |
| Project Title: | Proof of Design for the Advanced LASER Mining Array (ALMA) |

| | |
|--------------------------------|------------|
| Total Amount Requested: | \$7,571.78 |
|--------------------------------|------------|

| Travel | |
|--|---------------|
| Expense | Amount |
| Flight | |
| Rental Car / Other Ground Transportation | |
| Hotel | |
| Registration | |
| Total for Travel: | \$0 |

Justification:

For this research, there is no need for travel.

| General Supplies | |
|-------------------------|------------|
| Total: | \$0 |

(Gen. Supplies - small, non-reusable items)

Justification:

All supplies can and will be re-used, either for future research or donated to the physics department and the EPPL at the end of experimenting.

| General Equipment | |
|--------------------------|------------|
| Total: | \$7,571.78 |

(Gen. Equipment - large, reusable items)

Justification:

All equipment we will be purchasing is under this category, due to the need for the larger equipment pieces such as the diode, control board, bragg gratings and fiber cable, PPE and protective equipment, etc. The control board comes with software drives in the purchase of the board, thus no expense is needed for software.

| Computer Equipment | |
|---------------------------|-----|
| Total: | \$0 |

(Comp. Equipment - laptops, monitors, etc.)

Justification:

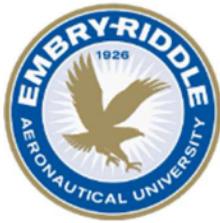
The EPPL has computers available for use and all team members have laptops. Having the ability, if necessary, for them to download software needed for the control board.

| Computer Software | |
|--------------------------|-----|
| Total: | \$0 |

(Comp. Software - Adobe, CATIA, etc.)

Justification:

As of now, there is no current need for software packages or simulations. In the future these will be needed, but that will be funded via other resources.



EMBRY-RIDDLE

Aeronautical University

DAYTONA BEACH, FLORIDA

Department of
Physical Sciences
Tel: 386-226-6709

March 2, 2023

To whom it may concern,

Re: Letter of Support for Jacob Ross Romeo (Student ID: 2544074)

It is my pleasure to strongly support Mr. Jacob Romeo's application for the Ignite grant 2023-24. I commit to be a mentor during the tenure of his research. I am a photonics/laser physicist and was actively involved in performing similar research work, and acted as a supervisor of the NSF funded REU program students in Professor Richardson's laser plasma laboratories at CREOL/UCF (2006 – 2009).

Jacob is a junior in Bachelors of Science in Astronomy and Astrophysics. I believe that he is a talented, hardworking, intelligent and honest student who is ready for any challenge. I believe that Jacob has tremendous potential as a future scientist and innovator, and he will definitely be an excellent choice for the grant.

Jacob will get an opportunity to experience first-hand top-class research work and learn several laboratory and analytical skills which will be useful in any research he does in future. This grant also opens a path for future NSF grant for undergraduate research in optics/photonics at ERAU.

Jacob will have my full mentorship, guidance and supervision during this research. I recommend him and his team very highly and without reservation.

If you have any further inquiries regarding Jacob, please feel free to contact me.

Sincerely,

Vikas Sudesh.

Vikas Sudesh, Ph. D., M. Tech., M. Sc.
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