2021 NASA EPSCOR Rapid Response Research (R3) Proposal Abstracts

Contents

21-EPSCoR R3-0001

Appendix A: Cooperative Energy-aware Navigation of Hybrid Airships in the Atmosphere of Venus

NASA WV Space Grant Consortium

Dr. Majid Jaridi

Although the severity of the environment on Venussurface presents an enormous challenge for exploration rovers, in altitudes that range from 50km to 65km, the temperatures of the Venusian atmosphere are below 77 degrees Celsius, thus allowing the presence of flying robots, also known as aerobots. Among the initial concepts for aerial exploration are the hybrid airships, which rely on both buoyancy and aerodynamic lift to control their altitude and lateral position. This design allows the vehicle to use solar energy during the day to power a set of propellers and rise to altitudes close to 60km, while at night it is unpowered and may sink to 50km. The vehicle may be lost if it drops below this altitude, where the high temperatures can damage its electronic circuits. In this project, we will address two important navigation problems to be encountered by groups of aerobots performing scientific missions in Venus: motion planning and localization. Motion planning is important from the scientific point of view, allowing the mission control to position the vehicles in specific latitudes, altitudes, and spatial distribution, and is fundamental to allow extended mission times, keeping the vehicles in a safe region (in terms of temperature and pressure) of the atmosphere. We propose an approach based on an online motion planner that will exploit the natural winds of the atmosphere and the vehiclesaerodynamics to control their altitudes using minimum power. Besides aiming at a smaller altitude variance, which would also reduce the temperature variance on the aerobot, using a combination of gliding, soaring, and powered flight, the planner would allow the vehicles to save energy during the day and use it during the night while meeting the science objectives. Thus, even without solar power, the vehicles would be able to react to situations of potential altitude loss caused by unpredicted turbulences, which would increase their robustness to adverse atmospheric conditions and consequently, their lifetime. As our second goal, we will use the cooperation of multiple aerobots for precise localization of each vehicle in Venusatmosphere. Within this approach, each aerobot will measure the relative inter-platform ranges and share other navigation data with nearby aerobots. Additionally, global intensity information (e.g., gravity anomaly or magnetic anomaly) previously mapped with an orbiter would provide an important information source for aerobot localization. Due to the limitation of communication ranges, the overall aerobot team will be considered as multiple subgroups with each aerobot as the information center of a sub-group. In each subgroup, a centralized cooperative localization estimation is performed to estimate each aerobots global pose (i.e., position and orientation) with the corresponding covariance matrices to represent pose uncertainties. We will consider motion planning and localization as complementary problems. While a group of aerobots can be used to cooperatively estimate the natural wind flow of the atmosphere, thus allowing the execution of more intelligent motion plans for each vehicle, actively controlled aerobot motions may be used to drive down localization uncertainties during an extended mission duration. We will evaluate the developed algorithms through a series of simulations that will consider a variety of mission requirements and approximate models for the aerobots and Venusatmosphere.

21-EPSCoR-R3-0002

Enhanced weldability of next-generation refractory high entropy alloys (for Appendix I)

New Mexico State University

Dr. Paulo Oemig

Metals and alloys joining through welding is a critical dimension to consider for high-performance structural applications such as aerospace, power generation, and military. Although the refractory metal and alloys have shown favorable benefits for high-temperature applications in aerospace and nuclear, the challenges associated with conventional welding limits its applications. The conventional refractory alloys, due to well-marked ductile to brittle transition temperature (DBT), and high chemical activity towards the impurity element, particularly oxygen, yield the physical and metallurgical defects, therefore, exhibit limited weldability. A novel alloy with reduced sensitivity for the oxygen and a favorable welding approach is required to enhance the weldability of the refractory alloys.

The proposed research is focused on the manufacturing of refractory high entropy alloys (RHEAs) based on molybdenum (Mo), niobium (Nb), tantalum (Ta), and tungsten (W). The study focuses on achieving high yield strength for structural integrity at high temperatures, increasing the room temperature (RT) ductility for ease of manufacturing, and reducing the sensitivity for the oxygen to increase weldability. This study aims at designing the grain boundaries (GBs) characteristics to minimize the concentration of the interstitial element of RHEAs to increase the toughness and ductility. A study indicates that the addition of titanium (Ti) and vanadium (V) in equimolar composition in the base alloy (MoNbTaW) might increase the ductility. Ti has been widely used as a getter element for interstitial elements. It is expected that Ti in the RHEAs matrix reduces the interstitial elements in the alloys. The getter elements selectively form carbide, nitride, and oxide in the presence of C, N, and O interstitial elements. These compounds will be distributed in the RHEAs matrix, which will increase high-temperature strength, ductility, and weldability.

Based on the equimolar composition of the Mo, Nb, Ta, W, V, and Ti, RHEAs will be developed. The RHEAs will be manufactured by powder metallurgy (PM) manufacturing technique. After achieving the bulk RHEAs with the desired composition, the bulk samples will be subjected to a range of characterization tools, including X-ray diffraction, scanning electron microscope, and electron backscattered diffraction, for the microstructure and phase analysis. Following the microstructure analysis, tensile testing will be conducted to determine the strength and ductility of the novel RHEAs. A novel solid-state low temperature friction stir welding (LTFSW) will be performed on the PM RHEAs in a controlled atmosphere to determine the weldability of the alloy. The low-temperature welding ensures that no deleterious phases are being formed during the welding process. The post-welding characterization and mechanical testings of the welded RHEAs will be done to determine the characteristics of the welding of RHEAs. Based on the results obtained, the PIs will provide a recommendation to NASA on the novel refractory alloy development with enhanced weldability.

21-EPSCoR-R3-0003

Conceptual Design and Analysis of Aerobot for Long-Endurance Mission on Venus (for appendix A)

New Mexico State University

Dr. Paulo Oemig

The harsh conditions on the Venus surface and the considerable uncertainty with regard to the atmospheric composition, chemistry, and physics provide motivation for the development of flight vehicles that can carry scientific instrumentation across different altitudes and latitudes. A wide variety of flight platforms such as fixed and variable altitude balloons, solar aircraft, and hybrid airships are being considered. While each platform has its merits and advantages depending on the mission scenario, this proposal is concerned with a hybrid vehicle (i.e. aerobot) that exploits both buoyancy and aerodynamic forces for good horizontal and vertical mobility while cutting down on power requirements and allowing for a robust and fail-safe operation. The vehicle will fly above the clouds, where the sulphuric acid content is lower and the direct and reflected solar irradiance can be tapped to recharge batteries, as well as inside and below the clouds. The vertical mobility will be achieved by adjusting the vehicles buoyancy. This one-year effort is concerned with the conceptual design (aerodynamic, propulsion, buoyancy and thermal analysis) and the vehicle optimization for relevant notional mission scenarios. Follow-up phases of the project will expand upon this initial effort by addressing other important aspects such as detailed design and testing, localization and control, and corrosion resistance.

Above the clouds, where the wind velocities can top 100 m/s and strong wind shear and turbulence are possible, vehicles with high aerodynamic efficiency and directional control are at an advantage. In the lower denser atmosphere, the buoyancy forces are larger and floating without power consumption becomes possible. The main objective of the proposed one-year initial effort is the conceptual design of a hybrid flight vehicle that can take advantage of both operating regimes. When deflated, the vehicle is to fit into a planetary entry shell. When inflated, the vehicle will have a shape with high aerodynamic efficiency that will allow it to efficiently change its latitude while providing sufficient agility to counter wind shear and turbulence. The buoyancy of the vehicle will be adjustable to allow for vertical mobility.

A two-pronged approach of theoretical and numerical analysis will be taken. The outer aerodynamic shape of the aerobot will be drafted on the computer. Computational fluid dynamics such as vortex lattice methods will be employed to investigate the vehicle aerodynamics. The differential gas pressure, which is limited by the material properties of the outer skin, and the vehicle weight and volume determine the buoyancy force. The buoyancy and propulsion requirements as well as the thermal balance for flight on the day and night side of Venus will be analyzed and optimized for relevant mission scenarios. For the analysis of the mission scenario, a parametric model of the Venus atmosphere will be integrated into an existing point-mass model simulation environment. The model will be expanded to include the vehicle power and thermal balance as well as the buoyancy force. The conceptual design will be optimized over several iterations.

The project will support two graduate students and strengthen aerospace and space exploration research in New Mexico which is an EPSCoR state. One of the graduate students will focus more on the conceptual design while the other student will mainly work on the simulation environment. The

expected outcome are a conceptual design and substantiated data sets that will provide the basis for a detailed design and eventually the development of a prototype."

21-EPSCoR-R3-0005

Appendix I - Machine Learning Accelerated Discovery, Testing, and Characterization of Light-weight Refractory High Entropy Alloys for Space Application

University of Alabama in Huntsville

Dr. Lawrence Thomas

The goal of this proposal is to accelerate the discovery of light-weight refractory high entropy alloys (RHEAs) with enhanced mechanical performances by integrating first-principles material simulations, data-driven machine learning (ML) models, and experimental validation. Advanced metals and alloys with superior mechanical properties at elevated temperatures remain in high demand for aeronautical applications. Recently, a new category of RHEAs has shown great promise as the potential materials for the high-temperature structural application. The RHEAs usually contain four or five elements from the nine elements in Group IV (Ti, Zr, and Hf), Group V (V, Nb, and Ta), and Group VI (Cr, Mo, and W) with the additions of non-refractory elements such as Al, Si, Co, or Ni. The refractory elements allow the RHEAs to function as load-bearing components at a temperature even higher than that for Ni-based superalloys. However, the traditional RHEAs suffer from limited room-temperature ductility and heavyweight, significantly hindering their manufacturing and applications. To design lightweight RHEAs with balanced specific strength and ductility is of urgency and yet poses remarkable challenges in the complex multicomponent system. Firstly, considering the potentially vast number of alloys with the complexity of compositional space, the typically used sequential trial-and-error experiments are daunting. Secondly, the feasibility of the empirical or semi-empirical rules developed for dilute alloys confronts fundamental issues due to unknown physics coming from many-body interaction.

The proposed project will employ a computationally aided materials discovery (CAMDIS) approach, and deploy multiscale ML models to data-mine the connection between electronic and thermodynamic properties of multicomponent alloys with their mechanical properties for the rapid design of light-weight RHEAs. Specifically, we will explore the compositional space of Group IV, V, and VI multicomponent alloys using first-principles based density functional theory (DFT) calculations to compute the defect energetics and identify the alloy compositions that process intrinsic ductile propensity. Multiscale neural network ML models will be developed to integrate heterogeneous simulation and experimental data and learn features and representation in the scale of relevance. The parameters of ML models will be optimized to uncover physical-based mechanisms thus enabling decision-making capabilities in precision experimentation planning. The predicted alloys will be synthesized using high-throughput magnetron co-sputtering, and then characterized to obtain structural, chemical, thermal, and mechanical properties. The new experimental data will be supplied into the dataset to train next-generation ML models for accuracy improvement. ML approaches are well suited to this problem because they can (1) operate with an incomplete understanding of the underlying physics in the novel HEA alloys but still take chemical, physical, and thermodynamic parameters to accelerate learning; and (2) find patterns in observed data, making it possible to model relationships that are unavailable in theory.

We envision the proposed ML approaches will significantly accelerate the search of multiphase multi-principal component alloys, providing novel alloy systems to tailor the mechanical performance. The created dataset and the developed ML will allow the promising alloy composition for future computational and experimental investigation towards the design of novel RHEAs for aeronautical applications.

21-EPSCoR-R3-0009

Nano-based Ceramic-metal Composites to Support Planetary Agrosystems (Appendix D: Crop Plant Stress Tolerance for Space Exploration)

Louisiana State University

Prof. T. Gregory Guzik

This proposal is in response to the FY2021 NASA EPSCoR Rapid Response Research Opportunity Appendix D: NASA SMD Biologicala and Physical Science: Crop Plant Stress Tolerance for Space Exploration.

MicroRNAs (miRNAs) are small single-stranded RNAs with low protein-coding potential. miRNAs act as negative post-transcription regulators of their messenger RNA (mRNA) targets via mRNA degradation and translational repression. Although plant miRNAs target only a small number of mRNAs, these play a critical role in many plant developmental processes. Biotic and abiotic stresses result in tissue-specific changes in miRNAs' expression. Plant response to two different abiotic stresses is unique and different from stresses applied individually. Tolerance to a combination of other stress conditions, particularly those that mimic the field environment, is the focus of this research project. Metal nanoparticles (mNPs) can enhance crop production and mitigate the impacts of plant stressors. Ceramic-metal nanoparticles (cerametals), composites of mNPs, and halloysite nanotubes offer many advantages, including high surface area, stability, and biocompatibility. We propose that cerametals affect many aspects of leafy greens or tomato plant growth and enhance these plants' tolerance to many plant stressors.

Plants will be exposed to different combinations of stresses at the same time under field conditions. The relationship between cerametal addition, plant stress responses, and changes in miRNA expression will be studied. A proprietary predictive algorithm and machine learning will be used to analyze large data sets generated. In concert, the effects of stress (+/-) cerametals on plant germination, growth, propagation, plant structures, and functions will also be assessed. Improved sustainability, stress tolerance, and reducing the impact of plant pathogens is critical as we prepare for the exploration of the Moon and Mars. Nano-based ceramic-metal agrotechnology will be a cheap and efficient way to reduce water needs, use available soil, and produce plants for biogenerative life support systems in Lunar and Mars habitats.

21-EPSCoR-R3-0010

Thermophysical property characterization of aerospace alloys for modeling In-Space Manufacturing processes (Appendix I: Modeling of Manufacturing Processes in Micro and Reduced Gravity Environments)

Louisiana State University

Prof. T. Gregory Guzik

This proposal is in response to the FY2021 NASA EPSCoR Rapid Response Research Opportunity Appendix I: MSFC EPSCoR Research Areas, and Tasks: Modeling of Manufacturing Processes in Micro and Reduced Gravity Environments (EM04/Prater).

Several methods of additive manufacturing (AM) are currently under investigation for application in micro- and reduced-gravity environments including bound metal deposition (BMD), wire+arc AM, and laser-based fusion methods. All of these methods include either the generation of a melt pool or surface wetting of the metal alloy feedstock to facilitate generation of the desired geometry. The evolution of the liquid phase, in-turn, is influenced heavily by the gravitational field, with samples undergoing distortion relative to the gravitational environment. Studies of gravitational effects on liquid phase sintering of tungsten heavy alloys in microgravity (STS83 and STS94 missions) found that samples that distort in ground-based sintering also undergo distortion in microgravity, however, the samples tended to form spherical shapes. Efforts to model these manufacturing processes therefore rely heavily on available thermophysical, surface energy and interfacial energy property data. Given the availability of these difficult to measure data, the influence of the local gravitational field can then be predicted relative to: buoyancy effects; the formation of solid-liquid and liquid-vapor interfaces; microstructural segregation; particle agglomeration; and parts deformation.

The proposed project will support ISM modeling through the measurement of thermophysical (melting range, density, viscosity) and surface and interfacial energies of several aerospace alloys of interest for ISM applications, namely Al7075, Ti-6Al-4V, and SS316L. Measurements will be conducted via electrostatic levitation (ESL) and high temperature (up to 1800 C) contact angle measurements. In addition, we will use high-temperature differential scanning calorimetry (DSC)/thermal gravimetric analysis (TGA)/thermal diffusivity (Hyperflash), and dilatometry to measure specific heat, enthalpy of fusion, melting range, melting enthalpy, thermal conductivity, and thermal expansion coefficient for generation of a comprehensive data set.

21-EPSCoR-R3-0012

Wearable Sensors for Low-Power On-Demand Health Monitoring (Appendix B: Improvement of Space Suit State of Art, CSCO-2021-02)

Louisiana State University

Prof. T. Gregory Guzik

This proposal is in response to the FY2021 NASA EPSCoR Rapid Response Research Opportunity Appendix B: Improvement of Space Suit State of Art (CSCO-2021-02)

This technical proposal is submitted in response to the current call by the NASA Commercial Space Capabilities Office to improve the state of the art of space suits that improve the wearers performance, health and/or safety. The problem currently at hand is the obtrusive nature of on-suit electronics that aide assessing suited crewmembers health. The wired nature of communication between the sensors and the central suit avionics system presents challenges during don/doff, cause irritation during extra vehicular activity (EVA), and restricts the number and type of biomedical measurements. Astronauts work under tremendous stress, especially during EVA, and this can lead to head and neck injuries. Such injuries can be fatal and require serious attention for optimal performance by astronauts. Measuring head and body kinematics unobtrusively during planetary surface EVA is important in gauging ergonomics and guiding crew rehabilitation under weightlessness.

The overarching goal of this proposal is to initiate research within the EPSCoR state of Louisiana on the development of passive RFID biomedical sensors. In comparison to the sensors wired to the central suite avionics, the substantive benefit obtained using passive RFID biosensors include ability to read the sensor signal wirelessly and battery-free operation. This will allow placing the reader in the portable life support system (backpack) and applying the biosensor as a tattoo directly on the human skin. The specific objective of this proposal is to prototype a head kinematics measurement system using UHF RFID strain sensing tattoos. The proposed research builds on existing commercial UHF RFID tags, antenna, and reader, no new complex instrumentation will be developed. The proposed method builds on prior findings showing bending and rotation of a linearly polarized flexible RFID tag affects received signal strength indicator (RSSI) in horizontal and vertical planes. The proposed research will investigate application of such tags to the head-neck region and leverage ANOVA to predict the head pitch, yaw, and roll.

The innovation proposed here includes the following: a) Compared to conventional vision-aided solutions, the lack of prior work on measuring head kinematics using passive RFID shows it is a new concept. b) Unlike gyroscope-based measurements, the soft RFID tags can operate without battery, is skin conformable, and can withstand repeated mechanical bending. c) Compared to conventional method of locating tag resonant frequency for strain sensing in biomedical applications, the combination of ANOVA, RSSI and tag polarization will be relatively faster, portable and accurate. The proposed research will also systematically examine the effect of temperature, humidity, human skin contact, sweat, and antenna positioning on tag readout."

21-EPSCoR-R3-0013

APPENDIX C: SMD EARTH SCIENCES DIVISION - ASSIMILATION OF SATELLITE DATA FOR PREDICTING CYANOHABS IN KANSAS

Wichita State University

Dr. Leonard Miller

Cyanobacterial Harmful Algal Blooms (HABs) degrade water quality by producing harmful toxins and causing significant diel changes in water column pH and dissolved oxygen concentrations. The degradation of water quality caused by HABs disrupts food webs, and has negative ecological, social, recreational, and economic impacts. Given the ubiquity and impact of HABs in Kansas, there is a need for large-scale monitoring and prediction of HAB events. However, no clear indicator or predictor for HABs in Kansas has been established. In this work, we will assimilate satellite remote sensing data into a 1-D lake model in order to improve predictions of water quality and HAB events. This will be done by first identifying key relationships between satellite data and lake water quality. These relationships will then be used to do a simple assimilation of the relevant satellite data into a lake model. The assimilated state variables will then be used as initial conditions in a forecast system and will be evaluated over a number of sites across Kansas. The proposed work will provide a proof of concept for predicting lake water quality based on satellite remote sensing and will advance the current level of knowledge while providing the basis for future grant proposals and collaboration between the University of Kansas and Goddard Space Flight Center.

21-EPSCoR-R3-0014

Appendix E: KSC Exploration Systems and Development: Moon to Mars - Gas Separation Processes for High Purity Methane Production

Wichita State University

Dr. Leonard Miller

Development of extra-terrestrial propellant production processes is a requirement for NASAs Moon to Mars strategy and will rely upon the Sabatier Reaction for catalytic conversion of carbon dioxide (CO2) to methane (CH4). The current proposal will develop gas separation technologies to provide purified methane appropriate for storage in the liquid state and for utilization in propulsion systems. The cross-disciplinary team, comprising mechanical and chemical engineers, will collaborate on thermodynamic and unit operation modeling of the process, as well as, experimental work demonstrating pressure swing adsorption (PSA) technology. The proposing team will leverage prior research expertise at KU including on-going NASA-funded thermodynamic modeling of In-Situ Resource Utilization (ISRU) on Mars for propellant manufacture and expertise in conventional natural gas purification by adsorption. KU is home to the most advanced gravimetric gas adsorption equipment in the US and will deploy its latest technology, the Multicomponent Adsorption Module (MCAM), to the project. This advanced instrument developed collaboratively with Hiden Isochema as the product of an NSF MRI grant has been operational since October 2020 and will provide thermodynamic adsorption data for gas mixtures simulating the Sabatier Reaction product stream. Additionally, KU has identified preferred adsorbents for removal of

carbon dioxide and nitrogen from natural gas streams and will utilize these preferred adsorbents in the proposed research program. The team will employ project management processes to guide the research to produce: (a) a thermodynamic model characterizing the required streams and energy flows in the gas separation process, (b) a technology design for water removal from the Sabatier Reaction product stream, (c) preliminary unit operation design for heat transfer within the process, and (d) experimental demonstration of gas purification via adsorption on solid oxide adsorbents.

21-EPSCoR-R3-0016

A flash co-sintering strategy for the fabrication of LiPON-based bulk-type solid-state lithium ion battery - Appendix G

North Dakota Space Grant Consortium

Dr. Caitlin Milera

Solid-state lithium ion batteries have long been expected due to their safer operation than the traditional lithium ion batteries, which use a liquid electrolyte that is flammable and may decompose and generate gases, causing a fire and/or explosion hazard. However, the development and commercialization of solid-state lithium ion batteries have been slow, primarily because of the lack of a perfect solid-state electrolyte and/or an efficient method to produce the electrolyte or manufacture solid-state batteries. LiPON (lithium phosphorus oxynitride) is so far the only solid-state electrolyte that can effectively suppress the lithium dendrite growth a phenomenon in lithium ion batteries that causes a short circuit to the anode and cathode, but the fabrication is based on vacuum sputtering, making the solid-state lithium ion batteries with a LiPON thin film highly priced. The proposed research is to explore an ammonolysis method for the synthesis of LiPON powder and a facile and scalable method for the fabrication of bulk-type solid-state lithium ion batteries with the LiPON powder. The method for the battery fabrication involves making battery pellets by consequently pressing anode material, LiPON powder and cathode material and then heating the pellets via flash sintering. The pressing way makes the manufacturing of batteries highly efficient, while the flash sintering that heat the pellet at a sufficiently high temperature but for a very short time (< 60 s) will result in batteries with a highly dense body and ideal interfaces between the solid-state electrolyte and active materials. It is expected that these structural advantages may facilitate the diffusion of lithium ions in the electrolyte and promote the intercalation/deintercalation reactions taking place in the anode and cathode, giving rise to batteries with a high power density and excellent cyclic performance. The proposed research also involves investigating the performance of the as-developed all-ceramic solid-state lithium ion batteries when operating at elevated temperatures up to 600 �C. This is of great significance to the need of NASA for safe and durable batteries that can withstand high temperatures and harsh environment during the space exploration.

The proposed research will advance the existing body of knowledge by revealing the feasibility and scientific challenges or technical difficulties of synthesizing LiPON powder and using it to fabricate bulk-type solid-state lithium ion batteries. The propose work will also function to strengthen the general education and research at NDSU and, moreover, stimulate the establishment of a collaborative partnership between the PIs group and the NASA laboratory.

21-EPSCoR-R3-0018

Appendix D: Characterizing Stress Tolerance of Leafy Greens to CO2, Humidity, and Radiation

University of Delaware

Prof. William Matthaeus

Food crop production for space exploration depends on crop tolerance to environmental stresses unique in space, such as super-elevated CO2 levels and low relative humidity. Controlled-environment research on Earth has gained insights on crop responses to environmental factors under sole-source lighting. However, few studies have explored extreme parameter ranges typical in space or investigated how environmental stressors interact to influence growth and quality attributes of leafy greens.

The objectives of this research are to: 1) determine how the CO2 level and far-red radiation affect photosynthesis, yield, and size of red lettuce and mustard green; and 2) characterize how the CO2 level, relative humidity, and radiation spectrum influence photosynthesis, yield, size, and nutritional value of red lettuce.

For objective 1, we will grow Outrageous red lettuce and Amara mustard green in eight treatments [four CO2 levels (400, 1200, 2000, and 2800 �mol�mol1) � two radiation spectra with and without far-red radiation]. For objective 2, we will grow outrageous red lettuce in eight treatments [two CO2 levels (400 and 2800 �mol�mol1) � two relative humidity levels (40% and 70%) � two radiation spectra]. We will conduct both experiments in four plant growth chambers capable of achieving target parameter levels, including 2800 �mol�mol1 CO2 and 40% relative humidity that are typical in the International Space Station cabin environment. 28 days after seed sow, we will collect and analyze data on crop photosynthesis, yield, size, and nutritionally important secondary metabolites.

The proposed research will: 1) create baseline data of crop stress tolerance for selection and breeding of cultivars suitable in extreme space environments; and 2) generate insights on how the CO2 level, relative humidity, and radiation spectrum influence space crop yield and nutritional value. This knowledge will advance the production of fast-growing and nutritious food crops to sustain long-term human space missions.

21-EPSCoR-R3-0021

Appendix A - An Aerial Platform to Navigate the Troposphere of Venus Enabled by New Cellular Materials - Gross

College of Charleston

Dr. Cassandra Runyon

Project Summary: Exploration of Venus may provide important insights regarding the future of Earth and the habitability of exoplanets. As a result, there is great interest to operate a long duration mobile platform on or near the surface of Venus. This would allow for a number of investigations identified as essential to reach NASAs objectives and goals for Venus exploration, such as identification of surface chemistry and mineralogy, exploration of chemical processes in the deep atmosphere, and measurement of seismic activity. The extreme environmental conditions at the surface of Venus make long duration missions difficult, especially for missions that include instruments like camera systems, which cannot tolerate high temperatures and pressures. Floating vehicles have been identified as a promising option for these future missions, and here a vacuum airship is proposed as a synergistic solution to shield critical instrumentation from the harsh Venusian environment for long duration operation.

A vacuum airship is a theoretically possible, yet never realized alternative to buoyant gas filled balloons. Instead of being filled with a lifting gas, like helium, which is less dense than the surrounding atmosphere, a vacuum airship makes use of an envelope that is evacuated of gas to generate buoyancy. This concept has critical advantages over gas filled balloons, especially for operation near the surface of Venus. The vacuum envelope is an ideal location to house instrumentation that requires environmental protection. This dramatically reduces power and refrigeration requirements, which have remained major obstacles for missions to the surface of Venus. A vacuum airship can also operate for longer lengths of time since a reserve supply of lifting gas is not required and vacuum can be regenerated on an as needed with an electric pump. The pump also allows for nearly inexhaustible altitude control by managing a ballast of atmospheric gas. This enables the vehicle to ascend, travel with the wind, and descend to distant locations on the surface without large energy requirements or additional equipment for mobility. Long duration, high altitude ascents can be used for solar power generation and environmentally assisted cooling.

Despite these remarkable advantages, the development of a vacuum airship has not progressed because an envelope that is both lighter than the gas it displaces and strong enough to resist collapse against the external pressure of that gas has never been constructed. Past attempts to realize such an envelope have been hampered by approaching it as a structural design problem, whereas this buoyant platform can more readily be realized by seeking cellular materials that can support a thin film envelope against external pressure. With this perspective, the challenge of designing a buoyant vehicle from an evacuated envelop is inversely proportional to the density of the fluid that the vehicle operates in. This is because the net external pressure that must be supported by the envelope and its allowable mass have a linear relationship with each other, yet the mechanical efficiency of cellular materials has a nonlinear relationship with its mass. This nonlinear relationship favors designs with higher mass, and is naturally compatible with the dense lower atmosphere of Venus.

The goal of the proposed work is to design, fabricate, and test cellular materials that enable the construction of a vacuum airship to operate near the surface of Venus. Computational optimization will be used to minimize the mass of these materials. The optimized materials will be fabricated from alumina and sealed in a thin wall titanium envelope. The envelopes will be evacuated and tested in the Glenn Extreme Environments Rig to assess their performance in the lower atmosphere of Venus.

21-EPSCoR-R3-0022

Appendix D: Impacts of Gravity and Surfactants on Drainage Flow and Rheology of Wet Foams - Z.Li

College of Charleston

Dr. Cassandra Runyon

The objective of the proposed research is to investigate the dynamic and morphological evolution of wet liquid foams affected by the variations of surface tension and gravity. Foams comprised of polyhedral bubbles separated by thin films are widely used in many important industrial and commercial applications including cosmetics, dermal drug delivery, food industry, sealing and firefighting products. Liquid foams are intrinsically unstable because of their large interfacial energy, especially when the films connecting bubbles become thinner under the influence of the Earths gravity. Because most of the liquid in a foam is confined to the edges of polyhedral bubbles and connecting thin films, both the surface tension and the gravity play an import role in the formation of foam and its subsequent evolution or aging. Although the evolution of wet foams in microgravity has been recently studied by a FOAM-C experiment in the International Space Station (ISS), critical knowledge on multiscale features of foams is missing that would allow a full understanding of the foam evolution and stability, where the major challenge exists in how to best connect the multiple length scales coupling nanoscale thin films, mesoscale polyhedral structures, and bulk rheology of foams. We hypothesize that the evolution and aging of foams are induced by the drainage flow of confined liquid in the foam, which can be resolved by stabilizing the liquid films and reducing the fluid diffusion across the films between bubbles. We aim to use wet foams made of closely packed gas bubbles in a liquid, typically water with surfactant additives, to quantify the impacts of gravity and surfactants on drainage flow and foam rheology.

A better understanding of the relationships between nanoscale fluid dynamics of thin films and the evolution of mesoscale polyhedral structures would have a crucial impact on connecting nano-to-meso scale features in wet foams, and this research thrust (RT) is listed as RT-1. Another scientific challenge for wet foams is to build the connection between the mesoscale polyhedral structures and macroscale rheology of foams, which is listed as RT-2. Based on the PIs preliminary innovation work on multiscale modeling of complex fluids and mesoscopic numerical methods, the PI will adopt multi-phase dissipative particle dynamics (DPD) models with different level of resolutions (different fidelity) to characterize the multiscale features of flow physics in wet foams. Specifically, high-resolution DPD models will be employed for RT-1 to investigate the impacts of surfactants and gravity on the rupture of thin films and aging of foams induced by drainage and gas diffusion. Low-resolution DPD models and a data-driven neural network approach will be used for RT-2 to study how foamsmicrostructure changes the bulk rheology properties of wet foams, where computed DPD results will be taken as training data for a deep operator network (DeepONet) model to learn the effective viscoelastic equations of wet foams.

The proposed multi-fidelity framework can naturally incorporate the select-scale fluid physics into the multiphase models with consideration of intrinsic thermal fluctuations. Using this framework that tightly couples multiscale physics with state-of-the-art computational techniques, end-users of this modeling framework will be able to efficiently bridge the gap between nanoscale physics in thin films and bulk foam rheology, which will improve our fundamental understanding of the multiscale features in wet foams and help us create better foam microstructures for improved stability and lifetime of foam products. The multi-fidelity computational models for wet foams developed in this project will be

compatible for integration into NASAs ImMAC software design suite and will lead to new complex fluids applications to fulfill NASA missions.

21-EPSCoR-R3-0023

Appendix E: Supercritical combustion reactor for water oxidation and recycling of non-edible biomass for long duration space flights - Farouk

College of Charleston

Dr. Cassandra Runyon

A fundamental understanding of the dynamics and chemical kinetics of supercritical oxidation process will provide the foundational knowledge base which is currently limited. The fundamental knowledge base on this topic is also immensely important to understand supercritical water oxidation processes to advance solid waste treatment and or wastewater recovery and management, as well as allow recycling of non-edible biomass to value added chemicals for long duration space flights and advanced space exploration system. NASA's 2020 technology roadmaps include a wide range of pathways to advance the nation's current capabilities in space. Of the different space technology areas, Human Health, Life Support and Habitation Systems emphasizes development of technologies for waste water recovery and management. This multi PI team at the University of South Carolina aims to augment NASAs effort in this area in ground-based experiments and allow the development of the scientific understanding for future ground-based microgravity and/or International Space Station (ISS) investigations on supercritical oxidation. The proposed methodologies will provide fundamental and scientific understanding through developing the bench scale, ground-based experiments with advanced diagnostics and complementary hi-fidelity multi-physics modeling. Also, the overall effort will allow the development of a prototype compact supercritical reactor.

The scientific goals of this one-year project are:

1) characterization of phase change and transport processes associated with injection of subcritical fluid into an environment in which it is supercritical,

2) characterization of ignition process and the conversion of hydrocarbon and oxygenated fuels/materials at supercritical water conditions, and

3) analyses of experimental results using coupled multi-physics mathematical modeling frameworks.

The fuels to be investigated will encompass test fuels that are miscible (i.e. methanol) and immiscible (i.e. n-heptane) in water and/or additional fuels/materials (to be tested) in discussion with Glenn Research Center (GRC) and Kennedy Space Center (KSC) scientists which might be part of future NASA test matrix and target studies. Advanced diagnostic techniques, such as backlight and planar laser induced fluorescence imaging as well as high-speed imaging will be applied to characterize the trans-critical/supercritical mixing as well as ignition of hydrocarbon/oxygenated fuels at supercritical water conditions. The proposed research thus will provide insights into the physicochemical dynamics of supercritical oxidation. The visualized and quantified experimental results will be used as benchmarks to further refine/validate models. The acquired fundamental knowledge of supercritical oxidation will provide guidelines for NASA in developing technology for solid waste management, wastewater recovery and recycling of non-edible biomass for long duration space flights and advanced exploration systems."

21-EPSCoR-R3-0025

Appendix G: Rapid Laser Reactive Sintering of High-Performance Electrolytes for Additive Manufacturing of Solid State Batteries

College of Charleston

Dr. Cassandra Runyon

State-of-the-art solid state battery (SSB) processing technique based on tape-casting and co-firing techniques limits the further improvement of energy density and power density because the single cells need thick component layers to provide mechanical strength. Furthermore, each component layer's different heat processing conditions make it impossible to manufacture the high-density high-compact multilayer (HCML) SSB using the rapid additive manufacturing (RAM) technique. Therefore, the project is to develop a new processing method for fabricating SSB electrolyte thin films with well-controlled composition, crystal structure, microstructure, and thickness to achieve high-performance battery electrolytes to enable the RAM of HCML-SSBs.

The project's overarching goal is to improve the battery's essential properties of energy density, power, packaging design, safety, and scalability to help NASA's all-electric vertical take-off and landing vehicles (eVTOL) technology. The project is to serve as a bridge to establish a partnership between NASA LaRC and Clemson University based on the research area of Appendix G: NASA ARMD Electric Aircraft Batteries & Crash Safety Research-Materials and Processes for All-Solid-State Batteries for Electric Aircraft. The project technical objective is to develop a rapid laser reactive sintering method for fabricating fully dense SSB electrolyte (e.g., doped Li7La3Zr2O12) thin films with well-controlled thickness, composition, crystal structure, and microstructure to achieve high-performance SSB electrolytes, providing a prerequisite knowledge for rapid additive manufacturing of practical HCML-SSBs.

By leveraging our RLRS method for the controllable-processing of protonic ceramics, we designed the RLRS experiment for processing doped LLZO thin films with the desired properties. The RLRS method consists of three steps: 1) preparation of paste/slurry, 2) 3D printing of thin green films, and 3) CO2 laser scanning to achieve final films. The printable pastes or slurries of doped LLZO precursors can come from the cost-effective raw materials of oxides and carbonates through conventional ball-milling and vacuum-mixing. The 3D printing techniques based on microextrusion (ME) and ultrasonic spray coating (USC) can deposit doped LLZO green films with designed thickness. The CO2 laser scanning on the top of the electrolyte precursor green films can achieve the final electrolyte thin films on the pre-selected substrates. The optimization of organic additives and sintering aid to electrolyte precursor mixture and the optimization of laser sintering parameters allow us to achieve electrolyte thin films with the desired thickness, crystal structure, microstructure, and complete density. The additional thermodynamic driving force of the chemical reaction and the liquid sintering due to proper sintering aids are the two factors that ensure crack-free electrolytes and complete dense film with the desired microstructure.

The proposed technology has several advantages. 1) To start from raw materials of oxides and carbonates decreases the materials cost and simplifies the processing. 2) The ME and USC-based 3D printing can manufacture thin green layers with the desired thickness, and geometry complexity can directly contribute to the RAM of SSBs. 3) The rapid and facile laser scanning combines phase formation, chemical reaction, densification, microstructure control, and geometry adjustment in one facile laser scan step. 4) The selective laser sintering processes green films with precise in-plane (X-Y) and out-of-

plane (Z) position to achieve well-distributed structures. 5) The rapid in-situ consolidation of green ceramic layers makes it possible for rapid additive manufacturing of SSBs. 6) The large adjustment window of material additives and laser processing parameters allows the control of the ceramic oxide relative density and morphology, extending the application to the porous electrode for SSB manufacturing.

21-EPSCoR-R3-0026

Appendix H: Characterization of the Intracranial Venous System following Spaceflight - Roberts

College of Charleston

Dr. Cassandra Runyon

We have previously shown that astronauts of long-duration missions aboard the International Space Station (ISS) experience an upward shift of the brain, compression of cortical veins, and crowding of eloquent brain tissue at the vertex along the superior sagittal sinus (SSS). We hypothesize these anatomical changes may impede venous outflow from the cranium resulting in decreased blood flow through the internal jugular veins (IJVs.) Supporting this hypothesis, there have been recent reports of astronauts experiencing abnormal venous outflow from the head and in at least one case, an astronaut was found to have asymptomatic IJV thrombosis.

In addition, increased intracranial pressure (ICP) and papilledema have also been documented in NASA astronauts following long-term missions aboard the ISS months to years after spaceflight which NASA has named the Spaceflight Associated Neuro-ocular Syndrome (SANS). Some researchers have hypothesized that venous outflow obstruction may play a role in the development of SANS.

Here, we aim to characterize the response of the intracranial venous system to spaceflight, evaluate for any evidence of venous congestion or brain edema post-flight, and correlate those findings to intracranial pressure at spinal tap in astronauts with and without SANS. The study will include a total of 12 astronauts: (1.) six astronauts with documented signs of SANS, and (2.) 6 astronauts without signs of SANS matched for gender, approximate age, and approximate mission duration will serve as controls.

This proposed study directly addresses a significant health risk that was recently identified in ISS astronauts (abnormal venous blood flow and IJV thrombosis). This study will also provide evidence concerning the role intracranial venous physiology may play in the develop of SANS in susceptible astronauts.

21-EPSCoR-R3-0027

Appendix I: Advanced Machine and Process Architecture for Refractories via Laser Powder Bed Fusion Additive Manufacturing

College of Charleston

Dr. Cassandra Runyon

Refractory metals and alloys, e.g., tungsten and its alloys, have exceptionally intrinsic properties, including ultra-high melting temperature, low thermal expansion, high thermal conductivity, low sensitivity to hydrogen and low neutron yield. These properties make them top candidates for a wide range of high-temperature applications. Enabled by additive manufacturing (AM), the design innovation, and ability to integrate systems, coupled with the potential to circumvent time-consuming powder metallurgy and subtractive machining processes, will promote disruptive technologies such as fusion-powered spacecraft and advanced thermal management systems to advance NASAs space exploration initiatives.

Laser powder bed fusion additive manufacturing (LPBFAM) process is one of the preferred AM technologies to produce tungsten parts with fine feature resolution. To date, approximately 98.5% of theoretical density has been achieved in LPBFAM for tungsten. However, microcracks are consistently observed as a result of the high ductile-to-brittle transition temperature and the high residual stress during fabrication. In this project, the University of South Carolina (UofSC) proposes to explore an ultrasound-assisted machine and process architecture based on LPBFAM to increase the printability of tungsten. This project will integrate unique capabilities of a customized open-architecture LPBFAM machine, established multiscale computational models, and advanced ultrasound technologies at UofSC to: 1) Pioneer a customized LPBFAM process that incorporates in-situ ultrasound processing with applications of advanced laser scanning strategies; and 2) Initiate an integrated numerical solution that optimizes local thermal history and global residual stress for defect-free microstructure of tungsten. The impact of ultrasound on rapid solidification and the defect formation will be investigated via printing of single tracks and cubic samples. Thin wall structures will be demonstrated at the end of this project to identify potential challenges and pathways to further improve the current technology.

This study will pioneer an architecture of in-situ ultrasound processing in LPBFAM. Continuing the current research, a comprehensive process-structure-property relationship can be investigated towards manufacturing large and complex geometries with fine features for refractory metals and alloys. The system and methodology developed here are expected to be applicable to other refractories and other difficult-to-process alloys in AM, such as high-strength Al alloys and Ni-based superalloys. The successful development will not only enable a novel method to increase the printability of materials, but it will also induce potential fine/fully equiaxed grains for superior homogeneous mechanical properties. This will further extend the applications of AM and materials selection for NASAs diverse applications.

21-EPSCoR-R3-0029

Appendix I: Cryogenic Solid Particle Erosion of Advanced Materials for Lunar Mission Applications

University of Alaska Fairbanks

Dr. Denise Thorsen

NASA is developing new generation of advanced structural materials, coatings, and adhesives (hereafter materials) for construction of spacecraft and vehicles for lunar mission applications. These materials will be subjected to the extreme temperatures that range from boiling hot to freezing cold, depending on the Moons position relative to the sun. In addition to fluctuating temperatures, these materials are subjected to a wear and degradation through a process known as solid particle erosion (SPE). Solid particle erosion is a dynamic wear process in which material is removed from a target surface due to impingement of high-speed solid particles. This wear process causes surface degradation and reduction in functional life of a structure/component of spacecrafts and vehicles made of these materials. Rocket nozzles during landing and takeoff, Lunar Rover Vehicles (LRVs), photovoltaic (PV) modules deployed on the Moon are subject to SPE wear under these fluctuating temperature conditions. Information and data on SPE wear of structures/components at elevated temperatures is available. However, information and data on the cold temperature SPE is almost non-existent. Our aim is to predict how structures/components made of these newly developed materials degrade when they are subjected to SPE under cryogenic temperature conditions. Therefore, both experimental and theoretical studies of material degradation due to SPE under cryogenic temperature conditions will be performed. We will design and construct experimental setup to conduct experiments of solid particle erosion (SPE) under cryogenic temperatures. In order to facilitate cryogenic temperature, the experimental setup will provide a liquid nitrogen (LN2) stream that is injected into particles jet and as well as floods and cools the target. The temperature at the surface will be regulated by regulating the LN2 flow rate. The temperature within the LN2-cooled jet at the surface of the target will be monitored. We will identify the dominant mechanism through which materials degrade due to cryogenic SPE. We will identify whether the material degradation under cryogenic SPE is due to large scale deformation, fracture, cutting, or a combination of these. This will help in the development of new cryogenic SPE wear resistant materials in the future.

The project is significant because it will generate new data and knowledge on the cryogenic SPE wear of materials used in the construction of spacecraft, vehicles, and PV modules. The data generated will be useful in ranking and selecting cryogenic SPE wear resistant materials suitable for lunar mission applications.

Appendix I: MSFC EPSCoR Research Area - Lunar Surface Sustainability Through Dust Resistance Materials

21-EPSCoR-R3-0030

Appendix D - Improved drought tolerance of mustard green with atmospheric pressure plasmas

University of Alabama in Huntsville

Dr. Lawrence Thomas

"As NASA advances human space exploration, crop plants will play an important role in sustained human presence in space, on the moon, and on Mars. Crop plants such as leafy greens and fresh vegetables provide nutrients, varied texture, and flavor, and contribute to astronautsmental health. However, growing plants in the engineered environment of space habitats can introduce multiple abiotic stresses that can impact the plants growth and nutritional value. Drought stress is one of the important abiotic stresses. This project aims to study drought stress on Amaramustard greens and if and how treatment with atmospheric pressure plasma (APP) can improve the plants drought tolerance.

In plants, water deficiency can impair seed germination, crop yield, and the resulting nutritional content. Plants can naturally produce antioxidants and enzymes to combat the oxidative stress caused by drought. Research has shown that plasma treatment can further increase a plants production of enzymes and proteins associated with combatting oxidative stress. This project seeks to study the effect of room-temperature APP on Amaramustard greensdrought tolerance and nutrition. This project will be a collaboration among investigators at University of Alabama in Huntsville (UAH), Alabama A&M University (AAMU), and Alabama State University (ASU). The team combines expertise and lab capabilities in plasma science and technology (UAH), agriculture (AAMU), and microbiology and genetics (ASU). The project is relevant to NASAs Space Biology Program and Human Exploration Program.

The research will use a low temperature APP to treat Amara mustard green seeds at different exposure times and different plasma gases. The longer exposures result in more plasma produced reactive species on the seeds, and the different gases (He and Ar) produce different amounts of reactive species. The treated seeds will then be observed for germination rate under drought and no-drought conditions to determine if the plasma affects the drought tolerance of the seed. After germination, the seeds will be plants and the resulting plant growth under drought and no-drought conditions will be studied. Physical and nutritional analyses including color, texture, nutrients such as ascorbic acid and carotenoids, antioxidant activity, and lipid oxidation will be done. Genetic analysis will be done to understand how the plasma changed the plant to produce different characteristics and nutrients. RNA will be extracted from the roots and shoot of the plant and processed to determine the gene expression of the control and treated plants.

21-EPSCoR-R3-0032

Appendix E: KSC Partnerships Office: Design and Manufacturing of a Seed Planter and Germination System for Space Crop Production

Iowa State University - Iowa Space Grant Consortium

Dr. Tomas Gonzalez-Torres

Crop growth will be important for supplementing packed food during future long-duration human exploration missions. Various supporting technologies on the ground and on the International Space Station (ISS) have been tested at NASA Kennedy Space Center (KSC). There is a critical need for the development of seed handling technologies, approaches, and increased knowledge to advance the development of future crop production systems. NASA has identified gaps in the area of seed handling to support space crop production for future long-term exploration missions. Growing plants in the ISS to provide diversified, balanced, and healthy diets to crewmember is a common vision. The complex challenges for crop production in space include: 1) It is tedious and time consuming for maintenance of seed germination system and transplant of germinated seed after nursery in space. 2) The germination rate is relatively low when planting in space under microgravity and radiation. 3) The types of plants and crops are limited, because they must thrive under the harsh conditions of microgravity while providing various food and psychological benefits at the same time. To our understanding, controlling the orientation of seed using a customized seed container with a microgravity compatible design has the potential to improve the germination rate. In this study, we propose to use a 3D printed sacrificial seed tray coupled with an automated seed planter to improve germination rate with less labor involved during the nursery process.

In this proposal, we are responding to the NASA Cooperative Agreement Notice (CAN) EPSCoR R3 announcement NNH21ZHA002C, focusing on the research project of Seed Handling Approaches for Space Crop Production. Our team has been in communication with Drs. Raymond Wheeler, Ralph F. Fritsche, and Gioia Massa from NASA KSC for technical guidance. Our goal is to fill in the gaps of seed handling to support space crop production for future long-term exploration missions. The objective of this study is to fabricate sacrificing seed containers for different crops using additive manufacturing technology to fit the need of controlling germination orientation in international space stations. The specific aims are: 1) select the food safe, biodegradable hydrogels that can be 3D printed into sacrificial array tray to provide hydration, anchorage, and nutrients for seed nursery; 2) fabricate the germination array tray with customized array patterns using 3D printing technology to fit the need of guiding the orientation of selected seeds, i.e., lettuce, tomato, alfalfa, and soybeans; 3) investigate the effect of hydrogel firmness, hollow size, and pattern of the array tray on the seed orientation and germination rate/time using automated image analysis under microgravity environment.

The Sc-I Dr. Hantang Qin has a long track record in 3D printing process control, process optimization, and new material characterization. Previously, he has led two NASA projects to develop an in-space 3D printer. He has successfully customized the lab-built 3D printer for fused deposition modeling (FDM) and extrusion-based 3D printing. He will carry out Task #2 and Task#3 to implement 3D printing to manufacture seed planters and germination trays. The Co-I Dr. Xiaolei Shi has expertise in food production, bio-material development and 3D printing of biodegradable materials. Her work has been published in several journals ranging from material science to food and pharmaceutical applications. She has also held a US patent of Cellulose Derivative Based Sacrificial Support Structures for 3D Printing. She will supervise Task #1 and Task #3 in the proposed research. The PhD students will be co-advised by Dr. Qin and Dr. Shi. The NASA PI Tomas Gonzalez-Torres will supervise and ensure the progress of the project. He will also promote the idea with other NASA colleagues. Our team will continue the collaboration with NASA KSC for this study if funded.

21-EPSCoR-R3-0033

NASA EPSCoR R3 Appendix D (BPS): Comparison of stress-inducible sesquiterpene lactone profiles of lettuce cultivars grown on the ISS and on earth

University of Kentucky

Prof. Alexandre Martin

Kentuckys NASA EPSCoR jurisdiction solicited proposals from university-led research teams in Kentucky to address NASA research needs listed as tasks for the FY2021 NASA EPSCoR Rapid Response Research (R3) announcement (NNH21ZHA002C). The NASA Kentucky EPSCoR program collaborated with responding faculty researchers to develop and submit relevant proposals that address R3 task objectives. The proposed work is in response to the task of Crop Plant Stress Tolerance for Space Exploration in R3 Appendix D, NASA SMD Biological and Physical Sciences (BPS).

The Biological and Physical Sciences division within the Science Mission Directorate of NASA has identified the need for a better understanding of the sustainability and durability of plant propagation as a part of NASAs Artemis and Gateway missions in anticipation of long duration human space travel to Mars. As described in appendix D of funding announcement NNH21ZHA002C, NASA is requesting proposals addressing crop plant responses to space travel exposure that include changes in their innate chemical composition. The extensive efforts of NASA Kennedy Space Center plant biology scientists in developing and deploying hardware (Veggie chambers) for growth of crop plants aboard the International Space Station, ISS, has now led to successful missions focused on documenting the growth of lettuce species, identification and quantitation of the bacteria and fungi associated with these ISS-grown plants, and an assessment of their contents associated with oxidative stress. These developments have resulted in unprecedented opportunities to explore more broadly the stress responses of ISS-grown lettuces, which will have significant implications for the reliable deployment of plants for the human nutritional needs necessary for long-term space exploration and extraterrestrial colonization. The primary objectives of the current application will be to establish a standardized protocol for qualitative and quantitative assessment of stress-inducible sesquiterpene lactones, which will then be applied to profiling the sesquiterpene lactones in lettuces grown on the ISS in comparison to matched earth-grown samples. The data generated will provide NASA with information essential to fully assess the biological safety of plants grown during space exploration and extraterrestrial colonization for human consumption. And, if new sesquiterpene lactone chemical entities are identified, opportunities for future therapeutical applications and screens will be availed. The team assembled for this project represents expertise in metabolomic profiling of plant natural products engaged with very experienced NASA Kennedy Space Center scientists addressing high priority objectives in pursuit of NASA missions for supporting long-term human space travel and exploration.

21-EPSCoR-R3-0035

Appendix G: (NASA ARMD Electric Aircraft Batteries & Crash Safety): Composite Materials Mechanical Property Characterization for LS-DYNA MAT213 Model

Iowa State University - Iowa Space Grant Consortium

Dr. Tomas Gonzalez-Torres

A university-NASA partnership is being developed to provide technical and experimental support for the development of numerical predictive models for the design and analysis of advanced polymer-matrix composite materials under extreme loading conditions. The mechanical behavior of composite material structure is not easily predicted because of the great complexity of the failure mechanisms that occur within the material, and is further complicated with the geometric structure details.

The scope of this work is to perform a full experimental calibration of a hybrid weave composite material for implementation into LS-DYNA MAT213, focusing on the deformation module calibration. Three objectives are targeted in this work. First, we will provide the experimentally required stress-strain curves and the associated material constants for the calibration of the MAT-213 material model. Full-field displacement measurements by digital image correlations (DIC) and global coordinate axial strains measurements by non-contact video extensometer will be employed in all mechanical tests. Mode-I and Mode-II fracture experiments will be carried out for interlaminar characterization of failure modes. The proposed experimental protocol will facilitate large sample set testing, data collection and statistical analysis of the needed material parameters. The experimental framework will accelerate the testing protocol and might facilitate the study of one or more material systems.

Second, we propose to utilize the measured incremental plastic strain field in the calibration/verification of the modeling framework, represent on the reduced Moher strain-plane. This is a comprehensive way to relate the full-field incremental strain measurement by DIC to a numerically estimated strain-field derived around a stress concentration feature (e.g. 2D indentation or offset double-notched tensile (ODNT) configuration). We will interactively assess the experimentally observed deformation and plastic flow characteristics, and the incremental strain trajectories against those predicted by the numerical framework, and thereby provide a comprehensive model calibration and verifications for the examined hybrid composite system.

Third, in collaboration with the project manager, Dr. Goldberg, NASA Glenn, we will employ simplified 2D cylindrical indentation which is amenable to provide strain rates in the range of (0.001 to 10 /S) and ODNT configuration. The merit of these loading configurations are in providing (i) a stable deformation path for in situ monitoring of the microscopic evolution and propagation of a highly heterogeneous deformation field, and (ii) a well characterized stress state to examine individual events of increased plastic strain increment within localized deformation band(s) after reaching the peak stress; a precursor for transverse-shearing and lamina-bending failure modes. The proposed methodology is expected to overcome current limitation in the numerical framework of MAT213, by providing detailed mechanistic view of post-peak stress degradation response.

The EPSCoR-R3 funding will nourish the university-NASA Glenn and Langley partnership to develop the supporting experimental framework for further development of the composite material models and their implementation into computational frameworks. Dr. Bastawros and two Aerospace Engineering graduate students will execute the experimental testing and analysis plan to calibrate the model parameters for the NASA-provided hybrid weave composite panels. The established partnership with

NASA will enable the development of the future workforce through educating young engineers and scientist, with further global impact on reliability of transportation systems by ground, sea, air, and beyond, while influencing the environmental and industrial practices.

21-EPSCoR-R3-0040

Appendix EIII: Optimizing the bioconversion and recycling of inedible plant waste using mixed microbial cultures for long-term human habitation in space

Montana Space Grant Consortium

Dr. Angela Des Jardins

Plants play a crucial role in bioregenerative life support systems (BLSSs) for long-term human habitation in space, due to their potential to revitalize the atmosphere (e.g., O2 production and CO2 removal) while producing edible biomass. Plant cultivation in BLSSs will require a continuous supply of nutrients and will result in the production of inedible plant wastes that still contain valuable nutrients and carbon that could be reused, recycled, or upcycled for other purposes. In this funding announcement, Appendix EIII (Spaceflight-compatible Recycling of non-edible Biomass, Space Crop Production Gap 1.D.1.0.1), NASA recognizes the need for alternatives to improve processes that can convert plant waste (lignocellulosic biomass, LCB), into value-added materials and recycle resources to achieve a higher degree of self-sustainability in BLSSs. The microbial conversion of LCB into value-added products is a natural process suitable for long-term human habitation in space and a promising alternative to existing physicochemical methods. Typically, LCB bioconversion is performed using pure cultures or communities of either fungi or bacteria; however, the use of mixed microbial communities, particularly fungal-bacterial cultures (e.g., biofilms), has not been widely explored. In nature, LCB degradation is performed by communities of diverse microbes that metabolize LCB in a synergistic, dynamic, and time-dependent fashion. Importantly, mixed cultures typically display improved adaptability and substrate utilization compared to monocultures. Thus, we hypothesize that mixed microbial communities will be more efficient at utilizing and converting LCB into useful products. Based on our hypothesis and experience establishing mixed fungal-bacterial biofilms, we are proposing to use and engineer (through culture conditions) mixed cultures of LCB-degrading organisms (Phanerochaete chrysosporium, Pleurotus ostreatus, Trametes versicolor, Pseudomonas putida, Bacillus subtilis) to improve LCB bioconversion to further close the plant/food production loop in BLSSs. Specifically, we aim to use mixed cultures (e.g., biofilms) to transform plant waste (lettuce, tomato) to value-added products (e.g., nutrients, ethanol, fungal-derived bioplastics for 3D-printing), and even fungal biomass that could be used as an alternative food source. We aim to do this by optimizing the microbial growth, interactions, substrate utilization, and enzyme production in LCB-degrading mixed cultures to promote microbial synergisms and improve LCB bioconversion. The specific tasks proposed are: (1) establishing LCB-degrading mixed cultures and characterizing their potential synergistic interactions; (2) optimizing culture conditions to establish mixed cultures for LCB bioconversion; and (3) developing bioreactor designs that can provide the required growth conditions to maintain mixed cultures and enhance LCB bioconversion. The completion of this study will provide foundational knowledge and reactor designs for converting LCB into value-added products and recover & recycle resources from LCB to close the plant/food production loop in BLSSs (addresses Appendix EIII), while decreasing the costs and dependency on resupplying resources from Earth. This project is synergistic with current efforts on LCB waste transformation (i.e.

physicochemical pretreatment) by NASAs Kennedy Space Center, and could be relevant to Human Health, Life Support and Habitation Systems Technology Areas. We have had conversations with NASAs scientists Aubrie O'Rourke and Ralph Fritsche at Kennedy Space Center, who have expressed their excitement regarding our project proposal and their willingness to guide our overall efforts. Moreover, optimizing the LCB bioconversion can help achieve a more sustainable agriculture system, which could also be relevant to other agencies (e.g., recently signed -Dec 2020- NASA-USDA agreement to improve Agricultural, Earth Science Research) and the general public.

21-EPSCoR-R3-0042

Appendix I In-Situ X-Ray and Thermal Monitoring of the Laser-Powder Bed Fusion Process: Determining Fusion Signatures Indicative of Part Quality

Wichita State University

Dr. Leonard Miller

A NASA EPSCoR Rapid Response Research Project is being proposed by Kansas State University (KSU; the Offeror located in an EPSCoR state) in response to Research Request Number EM21 AM In-Situ Monitoring Data Analysis and Correlation for NDE of Part Qualityfrom NASAs Marshall Spaceflight Center (MSFC). The proposed research will aid the MSFC by providing valuable experimental data representative of quality fusion signaturesobtained via in-situ X-ray imaging and thermal monitoring of the laser-powder bed fusion (L-PBF) additive manufacturing (AM) of a high-priority/program-aligning material. Quality fusion signatures are a key part to qualification and certification of L-PBF processes as dictated by NASA MSFC-STD-3716/17; thus, this Project focuses on correlating direct and salient thermal responses of the L-PBF melt pool and/or heat affected zone (HAZ) with successful fusion (i.e. no lack of fusion or pore generation). The experiment is unique in that it will be performed at the Stanford Synchrotron Radiation Lightsource (SSRL), a division of the SLAC National Accelerator Laboratory, using a custom-designed L-PBF system with an infrared (IR) camera, two-color pyrometer and high-speed visual camera. Various specimens will be built within the X-ray hutch at SSRLcollecting various images detailing melt pool formation and solidification along with pore-generating phenomena such as vapor recoil (keyholing) and spatter ejection. The X-ray data will be labeled for position and time and then correlated with IR/pyrometer image data. The goal is to predict the type and amount of porosity based on measured temperature response characteristics. This will be accomplished via deep learning and leveraging an L-PBF thermal process model. A Post-Doctoral Associate will be hired to solely work on the proposed project to ensure its success. Due to the novelty of the proposed experiments, at least two high-impact journal publications are planned.

21-EPSCoR-R3-0043

Appendix G -- Materials and Processes for All Solid-State Batteries for Electric Aircraft: Multi-Dimensional Networked Antiperovskite Electrolytes for All Solid-State Batteries for Electric Aircraft

South Dakota School of Mines and Technology

Dr. Edward Duke

High-performance solid-state batteries are highly demanded for the practical application of all electric vertical take-off and landing vehicles (eVTOL). Recent studies have reported different solid-state electrolyte (SSE) such as garnet, lithium phosphorus oxynitride, etc. However, those existing SSEs have still suffered from their own limitations such as instability with alkali electrodes and severe decay of the performance due to moisture sensitivity. Herein, the overarching goal of this project, for the first time, is to develop a new SSE based on multi-dimensional networked antiperovskite (AP) with unprecedented functions. A novel and scalable liquid-phase method will be used to break the thermodynamical metastability and fabricate the advanced SSE by manipulating the building blocks. To further improve the performance of AP based SSE, a nonflammable electrolyte will be designed and synthesized as a surface wetting agent in combination with the SSE. By assembling the full cells with the novel SSE, advanced anode, and cathode, it is expected to meet the requirement by eVTOL of the five key properties including safety, energy density, power, packaging design, and scalability. The proposed project is also aligned well with the research interests of NASA research centers, such as Glenn Research Center. We plan to leverage this project to strengthen the collaboration with research scientists at NASA to improve research infrastructure and capability in South Dakota. By conducting the research activities in this proposed project, it also has the potential to develop local workforce and boost technology transfer in the field by collaborating with local companies and/or startups.

21-EPSCoR-R3-0046

Appendix F: NASA SMD Computational and Information Sciences and Technology Office (CISTO): A Meta-Learning Framework for Characterizing and Accessing Training Data for GLOBE Observer Mosquito and Land Cover Protocols

University of Wyoming

Dr. Shawna McBride

This proposal is in response to NASA EPSCoR Rapid Response Research (R3) Solicitation that is related to Appendix F: NASA SMD Computational and Information Sciences and Technology Office (CISTO) under the research titled Assessing and Qualifying Citizen Science Labeling for Training Data for GLOBE Observer Mosquito and Land Cover Protocols Improving Data Quality within the GLOBE Observer Community. An exponentially increasing number of geo-tagged field photos are being collected and shared with the public community, providing the exciting potential for human and environmental studies across different scales. However, labeling and featuring those labels is time-consuming and might be biased for scientific re-use. In this project, based on GLOBE Observer (GO) unique sampling protocols, we proposed to develop a meta-learning framework to label and qualify GO Land Cover and

Mosquito Habitat Mapper, and access the label qualities based on remote sensing imagery. This work will start to answer in which way we can use citizen science derived data for research purposes and how we should use those photos with extensive Computer Science and Geography knowledge to reestablish a solid citizen science field photo processing pipeline that can be used for other use cases.

The proposed work seeks to grow a research area crossing frontiers in citizen science, geography, spatial literacy, and machine learning and AI. Focusing on labeling, qualifying, and accessing the GO field photos for which few studies and literature exist, the work has the potential to advance knowledge and understanding across several related disciplines. Furthermore, this proposed work provides an opportunity to translate decades of traditional ways of experts collecting field data into the digital framework that can foster innovation in re-using citizen science data.

The PI believes that the proposed work has far-reaching implications on science, education, and technology that will benefit citizen scientists, researchers, and the community. The broader impacts include: 1) Promote geospatial literacy and call for citizen science participation in the State of Wyoming, where has the least population but tourism is the primary driver of the local and regional economy. 2) Advances in cutting edge toolsapplications on citizen science data. 3) Linking local citizens, researchers, government agencies (NASA GO) together to improve science communications.

21-EPSCoR-R3-0047

Appendix D: All-metal-oxide p-n photovoltaic junctions fabricated using materials abundant in the Martian regolith

Montana Space Grant Consortium

Dr. Angela Des Jardins

We propose fabricating all-metal-oxide photovoltaic devices using materials that are abundant in the Martian regolith. We are applying under Appendix D: NASA SMD Biological and Physical Sciences (BPS). Specifically, the hypothesis motivating this proposal falls under the research focus section c. Studies of the extracted material to determine its properties or to investigate novel ways of utilizing it to support NASAs exploration goals. The long-range goal of this investigation is to develop a method for fabricating photovoltaic devices using minimally-processed in-situ resources available on Mars and fabrication techniques amenable to the Martian environment to support NASAs mission goals. To achieve our long-range goal, we will fabricate and characterize p-n homojunction photovoltaic devices using hematite (�-Fe_2O_3) as the n-type semiconductor substrate and a recently discovered $Fe_{0.84}Cr_{1.0}Al_{0.16}O_3$ metal-oxide alloy as the p-type semiconductor substrate. Hematite and the elements Fe, Cr, and Al are all abundant in the Martian regolith and will serve as the light-absorbing layers in the p-n homojunction photovoltaic devices.

The objective of this proposal is to characterize the n-type �-Fe_2O_3 and p-type $Fe_{0.84}$ $Cr_{1.0}$ $Al_{0.16}$ O_3 materials and photovoltaic devices made from them. Specifically, we will quantify: optical properties, donor density, flat band potential, current-voltage characteristics, and incident photon conversion efficiency (IPCE). Our central hypothesis is that, once the properties of the individual metal oxides are known, p-n photovoltaic device architectures can be designed and fabricated to circumvent the undesirable characteristics often encountered in all-metal-oxide photovoltaic devices such as: short carrier diffusion lengths, short excited state lifetimes, and the resulting low IPCE values.

Our preliminary data shows that solution-processed all-metal-oxide photovoltaics of n-type �-Fe2O3/p-type Fe0.84 Cr1.0 Al0.16 O3 do generate a photocurrent under white light illumination. Our proposal is focused on answering fundamental questions to provide insight into strategies for improving the efficiency of these photovoltaic devices and addressing the challenge of using minimally-processed Martian resources as the feedstock for fabricating these devices."

21-EPSCoR-R3-0049

Appendix F: Assessing Citizen Science Labeling to Improve Training Data Quality for Land Cover Protocols within the GLOBE Observer Community

University of Vermont

Prof. Bernard Cole

The proposed project aims to use hackathons as the enabling platform to label images collected through the Land Cover tool in the NASA GLOBE Observer app, the citizen science app of the GLOBE Program. The labeled images would be used to train, validate, and test machine learning algorithms in NASA Earth Science missions. GLOBE Observer has cataloged over 15,800 entries (up to 6 photos per entry) but only 40% of entries are labeled, rendering their use and applications to be limited compared to their potential. The work efficiency will be maximized by leveraging the existing Land Cover Type classification systems for labeling scheme design and leveraging already labeled images for ground truth label generation. Labels will be structured in a modularized hierarchy, initially using Carbon Monitoring System as the application but extensible to other applications. Hackathon will run throughout the performance period marked by four meetings. Trainees will be recruited inclusively from diverse groups, and trained via computing platforms centered on Microsoft Teams at the University of Vermont and leveraging Amazon SageMaker services geared for efficient labeling of ground truth images. The quality of image labels generated through hackathon will be assessed using a direct measure (comparing with the ground truth labels) and an indirect measure (comparing the outputs from using multiple image classification models); and, additionally, image labelers will be assessed as well in conjunction with the quality of image labels they produce. Successful completion of this work requires multidisciplinary expertise spanning from data management, machine learning and data science to land-cover and land-use to workforce training and community development. The project team collectively covers all necessary expertise. The project outcome will include not only high-quality image labels but also assessment metrics for the quality of image labels and labelers. A success of this project would enable a longer-term vision to build a comprehensive, compact land-cover labeling system encompassing heterogeneous applications. Another vision would be to let the data deficiency identified during the hackathon engage citizen scientists to contribute data better customized to meet the need namely "hackathon-in-the-loop".

21-EPSCoR-R3-0051

Appendix D: Elucidation of stress resilience of sweet potato (Ipomoea batatas (L.) Lam) on Mars-like soil

NASA WV Space Grant Consortium

Dr. Majid Jaridi

Elucidation of stress resilience of sweet potato (Ipomoea batatas (L.) Lam) for Mars-regolith.
PROJECT SUMMARY: The recent advancement in space science and technology is one of the primary drivers of human exploration and exploitation of Mars. Several international space agencies have announced a crewed exploration of Mars in the near future. The innate ability of plants to consume carbon dioxide and release oxygen and recycle organic waste and water attributes them as a plausible part of a bio-regenerative life-support system for human life and facilitate the colonization of the red planet. However, plants will encounter hostile Martian environments and suffer severe abiotic stress-induced by several factors, including low-gravity, high radiations, high CO2 and low oxygen levels, low temperature, limited sunlight, and mainly unfavorable soil properties to support the plant life. The Martian soil contains mostly lots of minerals and chlorine in the form of perchlorates. Chlorine is toxic to plants directly affects plant growth and development. Moreover, the produce on the Mars soil will not be edible due to the accumulation of toxic metals such as Aluminum, Chromium, and possibly Arsenic, Lead, and Cadmium. The proposed research involves elucidating the physiological, biochemical, and molecular mechanisms underlying plant adaptation to simulated Mars-like environments and developing transgenic plants that selectively extrude toxic heavy metals to produce edible food. Understanding the molecular mechanisms of plant adaptability to the simulated extraterrestrial environment will help space biology researchers to develop and design solutions for the plant growth management system.
Sweet potato (Ipomoea batatas (L.) Lam), which shows considerable abiotic stress tolerance, low water requirement, and a relatively short life cycle, is one of the crop plants considered as a model plant for space biology research. This project will investigate sweet potato's efficacy and adaptability as a potential Mars-crop to generate the food crop habitable in the harsh extraterrestrial environment. The proposed research's overall objectives are to perform physiological and biochemical characterization of the sweet potato plants under a simulated Mars-like environment and thoroughly evaluate the major traits such as development, biomass production, photosynthesis (oxygen emission capacity), tuber quality, and abiotic stress tolerance. Additionally, the functional genomics approach will be employed to identify novel genes regulating the physiological and biochemical functions, followed by validating their role in sweet potato adaption to the simulated Mars-like growth conditions. We will analyze the profiles and content of heavy metals in leaves, stem, and tuber tissues to understand the uptake and accumulation of toxic metals in sweet potato grown on Mars soil simulant.
Further, the data will help develop transgenic stress-tolerant sweet potato plants in the future that selectively prevent heavy metal uptake. The proposed research project's outcomes will have broad societal relevance. The proposed project's long-term goal is to develop a sweet potato crop physiology program to generate cultivars plausibly habitable in harsh growth conditions. Our proposal's equally important objective is to educate, encourage, and engage the HBCU students in participating in NASA-related space biology research activities. The teaching modules will be developed to train undergraduate and graduate students in the research program.

21-EPSCoR-R3-0052

Appendix F (CISTO): Fault Diagnosis for Safety-Critical Autonomous Systems using Reinforcement Learning

NASA WV Space Grant Consortium

Dr. Majid Jaridi

The overarching objective of the proposed research is to create and validate a principled and general framework for fault diagnosis of an autonomous system operating in a high-dimensional state/action space. The proposed research will frame the fault diagnosis problem of an autonomous system as a sequential decision-making problem in a reinforcement learning setting where the ultimate goal is to find a policy that maps states to those disturbances causing the system to fail. To identify the most likely failure paths in a simulated environment, the fundamental method developed in this research will be applied to a small satellite in a simulated suite developed by NASA. If successful, the proposed research will accelerate the safety verification of complex autonomous systems that minimizes the number of required computationally expensive validation experiments, while reliably reveals the most likely failure events.

The proposed research integrates with educational and training activities with a goal of exposing underrepresented communities in the mid-Atlantic region to the problems important to NASA and facilitate future collaborations with NASA scientists. The participants will learn about the proposed solution of reinforcement learning and explore novel solutions to the problem-space. We will use webinars and Hackweek events to introduce and engage the underrepresented communities to the problem of Fault Diagnosis in Autonomous system, thereby increasing their competitiveness for future NASA opportunities.

21-EPSCoR-R3-0055

NASA EPSCoR Rapid Response Research: BDNN Hackathon: Uncertainty Aware Few Shot Learning from Citizen Science Data and Bayesian Deep Neural Network for Land Cover Image Classification

University of Puerto Rico

Dr. Gerardo Morell

The goal of this proposal is to apply Machine Learning (ML) and Artificial Intelligence (AI) paradigms for quantifying uncertainty in the Citizen Science image data, and train a Bayesian Deep Neural Network (BDNN) with few shot learning for prediction of classes and labeling of the images in the GLOBE database. The GLOBE database of color (RGB) images are taken by people worldwide, with different camera settings, lighting, acquisition parameters leading to uncertainty in predicting land cover classes and thereby labeling the images. A robust method that can account for the uncertainty in the mixed pixels found in the edges and corners of neighboring classes in the image is necessary for accurate prediction of land cover classes and labeling of the Citizen Science database of images. The other goal of this project is to organize a year-long multievent hackathon for capability building in ML and AI in underrepresented minorities. The objectives for this NASA Rapid Response Project are:

1) Quantify uncertainty due to edge and boundary pixels in Citizen Science image data using uncertainty aware few shot learning method.
2) Develop a Bayesian Deep Neural Network (BDNN) with regularization of uncertainty for land cover classification of Citizen Science images.
3) Organize a year-long multi-event BDNN Hackathon for education and training in developing ML and AI approaches for land use classification of GLOBE images.

The edge and boundary data points will be identified by checking for optimality of the estimated class boundary known as Bayes boundary-ness, which will be quantized using Shannon entropy. We will implement self-trained few shot learning that selects instances from the unlabeled pool of these data points for uncertainty awareness. The uncertainty estimates will be added to the objective function of the BDNN which will be solved to output predictions of land cover classes and generating labels for the images. We will characterize images from homogeneous regions to more complex heterogeneous regions using region, shape and texture based descriptors, to improve land cover class predictions. The final labeling of the image will be done by majority voting. We will apply the BDNN tool for assessing the impact of hurricanes in the country. An interdisciplinary year-long multi-event virtual BDNN Hackathon will be organized and conducted by the PI and Co-I. Collaborators of the PI and CO-I from UPR and other educational institutions will contribute to the ML and AI training and learning modules. Dr. Roberto Rivera and Dr. Fernando Vega leading faculty in ML and AI in UPRM will be providing education modules for the hackathon. It is expected that atleast one hundred students from UPR campuses and high school students will participate in the hackathon. The hackathon will provide a hands-on learning experience for students with the tools developed in this project. Dr. Peder Nelson, Science lead for the land cover tool in GLOBE will be collaborating on this project. He will provide guidance, and feedback during the Land Cover Classification (LCC). The year-long virtual BDNN hackathon will be directed towards education and training of underrepresented minority students to gain expertise in learning ML and AI methods and applying them to NASA datasets. The hackathon will be organized in UPR-Mayaguez, a Hispanic minority serving institution with 99% Hispanic students who will gain knowledge in the fields of satellite remote sensing, airborne hyperspectral imaging and Python ML and AI tool development through the Hackathon. The BDNN hackathon will also enable Hispanic minority students to take up internships with NASA, and add to the workforce development for future NASA missions.

21-EPSCoR-R3-0056

NASA EPSCoR Rapid Response Research: Multispectral and Hyperspectral Data Representation using Deep Autoencoders and Transfer Learning of BERT for Improved Detection of Harmful Algal Blooms

University of Puerto Rico

Dr. Gerardo Morell

The goal of this proposal is to apply artificial intelligence paradigms for developing a knowledge base of drivers of Harmful Algal Blooms (HABs) from multispectral and hyperspectral images, and train a Bidirectional Encoder Representation of Transformers by transfer learning to improve detection of HAB in Lake Erie.   There has been drinking water risk due to the presence of Cyanobacteria Microcystis in Lake Erie, which is also affecting tourism, recreation, and fishing. The algal blooms show inherent optical properties that have a high variability in spatial and temporal scales. Hence, satellite, and airborne remote sensing offers a viable solution to monitoring cyanobacteria HAB. In this project, we will develop and apply unsupervised data representation using autoencoders to accurately estimate the diverse bloom composition with variable absorption and backscatter properties. We will also process multispectral Satellite Image Time Series (SITS) using the trained BERT model to predict the class distributions of HAB constituents. The objectives for this NASA Rapid Response Project are:

1) Multispectral and hyperspectral image data representation of drivers of HABs by unsupervised learning using deep Autoencoders (AE) and creation of a knowledge-base of HAB drivers.
2) Train a deep Bidirectional Encoder Representation of Transformers (BERT) by transfer learning of the knowledge-base of drivers of HABs to improve their detection.

Multispectral images from NASAs Earth observing satellites such as Landsat 8, MODIS, and Sentinel 3 will be used in this project. Airborne Hyperspectral Imager (HSI 3.2) images with a meter spatial resolution and spectral bands ranging from 400 to 900nm will be provided by Glenn Research Center (GRC). Deep AE will be used for unsupervised feature extraction from these images to create a knowledge-base of novel drivers of HABs. The hidden layers of the AE will identify intrinsic structures in the image datasets, as well as produce a compressed representation of the multi-sensor image datasets. The BERT model consists of layers for pixel embedding, and self-attention feedforward sequence, and will be trained with the knowledge-base by transfer learning. The learnt BERT model will be used for improving predictions of HAB class distributions, and estimating fractional abundances of HABs in the hyperspectral images. The BERT trained model will be useful for supporting operational forecasting systems, and water quality management in Lake Erie. Eng. Roger Tokars, optics Engineer, GRC, NASA will collaborate in this project, giving important information on the pre-processing, and corrections done on the HSI 3.2 hyperspectral images. Dr. Jeffrey Luvall, GRC, NASA will also be collaborating in this project, and will provide guidance on the use of Ecostress and Desis images. The NASA collaborators will provide other available datasets and field measurements for validation of the results for quantifying drivers of HABs in Lake Erie and other aquatic regions. This project will be conducted at the Laboratory for Applied Remote Sensing, Imaging, and Photonics (LARSIP), ECE, UPRM. This project is conducted in a Hispanic minority serving institution with 99% Hispanic students who will gain knowledge in the fields of satellite remote sensing, multispectral and hyperspectral image processing and Python tool development. This project will directly support two graduate students in Earth science research, and involve many undergraduate students through course work and workshops. The PI will use the material from this project in the Remote Sensing, and Image Processing courses taught at ECE, UPRM. The students will be exposed to NASA Earth science related research. This project will also enable Hispanic minority students to take up internships with NASA, and add to the workforce development for future NASA missions.

21-EPSCoR-R3-0058

Hack the land out of them: Obtaining land cover classifications from GLOBE Observer photographs (for Appendix F).

New Mexico State University

Dr. Paulo Oemig

A picture can be worth a thousand words and this describes the data necessary to identify and track global land cover change. Citizen science apps and social media are generating enormous amounts of data in the form of photographs uploaded to the cloud. Photographs submitted via the Globe Observer app provide the link between space and Earth, fostering an understanding of Earths physical processes and natural phenomenon. The volume of photographs is outpacing human ability to organize, characterize, evaluate and classify data for search, comparison, change detection, and prediction.

This is where the hack comes in. We propose a year of activities to explore and create machine learning (ML) tools to segment, characterize, classify, and label components of land cover photographs from the GLOBE Observer (GO) land cover app. We propose to recruit a broad diversity of participants of New Mexican, American and international students, satellite images are already capable of being processed to classification standards by ML tools, providing the opportunity to prove the concept that similar approaches can be developed for photographs. In contrast to imagery analysts processing data on a computer, our approach includes outdoor observation and sampling of landscapes in situ, making the connection between the land, the human observers and machine learning palpable.

Designing a series of simultaneous virtual learning workshops will collate participants into teams, and facilitate engagement by introducing the shared languages of photos, land interpretation and code (-), to outline approaches and targets of the hackathon (1). Recruitment will focus on participants from across the Southwest. Targeted recruiting of female and Hispanic participants from New Mexico State University and the tribal colleges in New Mexico, in addition to programs associated with AmericaView will result in teams from locations across America. The online platform (Website) will allow participation from any location without time restraints. Packaging the invitation to those who embrace a sense of Earth stewardship will foster the creation and establishment of local service projects to perpetuate the networking and collaboration established in the hack environment.

Data preparation chooses image replicates from the Globe Observer data set (e.g., download images, identify locations in close proximity over a range of ecosystems). Preparation of workshops includes designing outreach and application materials, and completing the IRB training. Designing workshops starts with preparing data and other resources for collaboration, practicing GO activities, recording video and creating homework assignments. Organizing data and sample locations will involve collaboration through Jupyter notebooks. Design of social components for daily schedules includes meet-and-greet, physical exercise, breaks, games, and meals.

21-EPSCoR-R3-0062

NASA EPSCoR R3 Appendix A (SMD): Material response of woven heat shield material in Venusian atmosphere

University of Kentucky

Prof. Alexandre Martin

Kentucky s NASA EPSCoR jurisdiction solicited proposals from university-led research teams in Kentucky to address NASA research needs listed as tasks for the FY2021 NASA EPSCoR Rapid Response Research (R3) announcement (NNH21ZHA002C). The NASA Kentucky EPSCoR program collaborated with responding faculty researchers to develop and submit relevant proposals that address R3 task objectives. The proposed work addresses problems listed in the solicitation under Appendix A: NASA SMD Planetary Division, Extreme Environments Applicable to Venus, Io, Earth volcanoes. and deep sea vents.

The proposed work will build on previous work supported under the R3 program and shift focus to the development of reliable gas-surface interaction models for Venus atmospheric entry. The model development will be specifically designed for Thermal Protection Systems made of woven carbon preform. The effect of the TPS structure with the high-pressure high-temperature effects of the atmosphere will be studied, including the effects of radiation penetration, due to the expected presence of CN gas in the post-shock region.

21-EPSCoR-R3-0064

Stability and Distribution of Methane Clathrate Hydrates and Clathrasils on the Surface of Mars - Appendix B - Renewal 80NSSC19M017

University Of Arkansas at Little Rock

Dr. Mitchell Hudson

Methane has been first identified in the atmosphere of Mars by the Planetary Fourier spectrometer onboard Mars Express (Formisano et al., 2004). It was then confirmed by ground-based observations (Mumma et al., 2009) and later in situ by the Mars Science Laboratory s SAM instrument (Webster et al., 2018). Methane is a potentially significant resource for future human exploration of Mars, provided we can identify its sources, locations, and abundances. According to our current knowledge of the surface and subsurface environment of Mars, one of the main sources should be clathrates hydrates, a structure composed of water molecules cages entrapping other gas molecules, especially methane.

21-EPSCoR-R3-0065

Study of Performance for Commercial Extravehicular Space Suit - Appendix B

North Dakota Space Grant Consortium

Dr. Caitlin Milera

In response to NASA EPSCoR Opportunity: FY 2021 Cooperative Agreement Notice (CAN) Rapid Response Research (R3), and within the scope of the Commercial Space Capabilities Office Appendix B. Commercial Space Research Request Number CSCO-2021-02, the following research; Study of Performance for Commercial Extravehicular Space Suit is proposed.

With the proliferation of commercial spaceflight, commercial activities beyond tourism are set to become a normative utilization of space. These activities will require the use of similar risk mitigations that non-commercial space entities currently require, to include Extravehicular Activity (EVA) space suits. These suits are a complex system of systems which provide the wearer with a semi-flexible enclosure and a self-contained life support system allowing them to perform tasks in a microgravity or other inhospitable environments such as a non-Earth planetary surface. The research proposed herein looks to ascertain the usability aspects of the Final Frontier Design (FFD) commercially designed EVA space suit through the utilization of human-centered usability methods and techniques to include Humans-in-the-Loop (HITL) testing. Anthropomorphic work envelope data collection will be performed within two conditions; human research subject without the pressurized outer garment, and human research subject with the pressurized outer garment with a Delta P of 3.5psid. In both conditions, the subject will be in a standing position equivalent to tasks performed in microgravity. Further data collection will include the use of an Activity Board device, which includes various connections, switches, and other activities equivalent to tasks performed within microgravity to supplement work envelope data with that of actual tasks and include dexterity of the EVA space suit gloves as part of the usability of the suit. This research is being conducted at a standard atmosphere and 1-g environment and will utilize a three-dimension full body motion capture system to measure and compare the data between both conditions while the research subject is performing the Activity Board tasks. Research subjects will be selected within the range of allowable operator height and weight of the FFD EVA space suit and within the 5th and 95th percentile for stature as required by NASA Man-systems integration standards Volume 1 Section 3 (NASA-STD-3000). The research proposed herein will also utilize UND Human Spaceflight Lab (HSL) standards and processes (including Internal Institutional Review Board) for testing with human subjects as well as any NASA testing procedures that its standards and processes reference, such as NASA STD-3001 NASA Space Flight Human-System Standard and those of other U.S. Agencies such as the FDA and NIH.

21-EPSCoR-R3-0066

NASA EPSCoR R3 Appendix G (ARMD): Composite Solid Electrolytes for High Safety Lithium Metal Batteries

University of Kentucky

Prof. Alexandre Martin

Kentucky s NASA EPSCoR jurisdiction solicited proposals from university-led research teams in Kentucky to address NASA research needs listed as tasks for the FY2021 NASA EPSCoR Rapid Response Research (R3) announcement (NNH21ZHA002C). The NASA Kentucky EPSCoR program collaborated with responding faculty researchers to develop and submit relevant proposals that address R3 task objectives.
The proposed work is in response to R3 Appendix G (ARMD) related to Electric Aircraft Batteries & Crash Safety. Batteries for electric aircraft are required to meet five key properties: safety, energy density, power, packaging design and scalability. Achieving high safety and energy density are challenging for state-of-the-art Li-ion batteries that contain flammable liquid electrolytes and graphite anode. In this work, we propose to develop inorganic-polymer composite solid electrolytes (CSEs) for solid-state Li metal batteries (SSLMBs) to achieve enhanced safety and increased energy density. The developed CSEs will combine the merits of high ionic conductivity of inorganic sulfides (lithium argyrodites) and flexibility/stability of polymer electrolytes. Using such CSEs, the fabricated solid-state Li metal batteries are able to achieve outstanding cycling performance on both energy density and C-rates. Solid-state Li metal batteries from this proposed work will advance the development of safe and powerful energy storage systems for electric aircrafts to meet NASA s specific needs. In addition, this project will establish a sustainable collaboration between University of Louisville in Kentucky (an EPSCoR state) with NASA research centers (i.e. Glenn Research Center and Langley Research Center).

21-EPSCoR-R3-0069

INE Proposal in Response to NASA EPSCOR Rapid Research Response Appendix A: High-Temperature 3-D SiC Integrated Circuit Chip Packaging for Venus Surface Exploration

University of Idaho

Dr. Matthew Bernards

The objective of this project is to investigate the three-dimensional (3-D) packaging of silicon carbide (SiC) integrated circuits (ICs) for high temperatures of about 465�C and high pressure of about 9.6MPa for Venus surface explorations, specifically to explore the SiC die attach, wirebonding, flip chip, microbump and through-substrate-via (TSV) formation materials and process technologies for 2.5-D chip packaging and 3-D SiC die stacks and integration to withstand the extreme environment on Venus surface. We propose to use 3-D IC stacks and integration to package significantly more SiC dies and GaN sensors in one package to save the already precious ceramic printed circuit board (PCB) space and improve electrical and mechanical performance of the chips and package. The developed 3-D SiC IC package will be subjected to a simulated Venus surface atmospheric environment to verify the thermal and structural integrity. A thermal cycling test up to 500�C will be performed for electrical and mechanical failure analysis of the 3-D package including die shear test and wire pull test.

Current Venus landers can only operate on the planet s surface for a few hours because the commercial electronics fail to work in the extreme Venus surface environment. NASA Glenn Research Center has recently demonstrated that a SiC integrated circuit with more than 100 transistors withstood the simulated Venus surface atmosphere environment for 521 hours. To successfully implement the data collection and telemetry tasks, the SiC integrated circuits need to be carefully packaged to be integrated to the Venus lander. Some preliminary research has been done for basic 2-D packaging of SiC chips including basic die attach and wirebonding. In comparison to millions to billions of transistors in a silicon integrated circuit, a SiC integrated circuit with only several hundreds of transistors need to be densely packed in order to save the precious PCB footprint and improve the electrical and mechanical performance. On the other hand, current advanced 3-D electronic packages are developed for working temperature less than 300�C. The widely used polymer materials in these 3-D package technologies will be burned to ashes on Venus surface. To make the 3-D packed chips and sensors work for an extended time (months), different, even new, materials together with new processes must be developed to build the 3-D packages to meet the needs of Venus surface exploration requirements.

The proposed research will make a significant contribution toward the high-performance 3-D packaging of SiC chips and sensors for high temperature, high pressure Venus surface exploration missions.

21-EPSCoR-R3-0071

INE Proposal in Response to NASA EPSCoR Rapid Response Research Appendix D: NASA SMD Biological and Physical Sciences - Crop Plant Stress Tolerance for Space Exploration - Water Delivery and Gas Exchange Crop Stress Analysis for Space Exploration

University of Idaho

Dr. Matthew Bernards

Growing plants in reduced gravity is essential for future long-term missions. Although plant growth modules for microgravity have been developed and tested for more than 40 years (Wheeler, 2017), creating optimal water-saturation conditions for plant growth in reduced gravity remains a significant obstacle (e.g., Hoehn et al., 2000; Zabel et al., 2016; Anderson et al., 2017). With the shift to capillary-dominated fluid behavior, managing water, gas exchange, and the delivery of nutrients is challenging (Jones and Or, 1999; Steinberg et al., 2005). The discrepancy is mainly attributed to unexpected fluid distributions where the hysteresis in the soil-water retention properties appear to play an enhanced role compared to Earth which increases the risk of hypoxia and disruptions in water and nutrient supply to plant roots (Heinse et al., 2009, 2015b). The goal of this work is to enable productive space agriculture during spaceflight and lunar and planetary habitats by reducing these root-zone crop stresses.

This proposal is responsive to determining how interrelated stress factors caused by challenges in providing balanced water, air, and nutrient delivery in reduced gravity impact plant production. We will (1) analyze existing root-zone data collected during the Advanced Plant Habitat (APH) PH-01 mission (soil and crop water balance, soil water and oxygen) comparing water and nutrient delivery between ground-based and microgravity experiments, and (2) use numerical forward and inverse modeling in Hydrus 3D to frame an optimization problem leading to candidate management strategies that minimize crop stress by providing balanced root resource fluxes and promote uniform root distributions. For the optimization, we will consider effective diffusivities, allowing a more accurate description of root-experienced fluxes combined with root- and microbial requirements (similar to Heinse et al., 2009; Jones et al., 2012) considering amongst others the proposed plant pillow architecture for the VEGGIE missions (Massa et al., 2013, 2020; Morrow et al., 2016). The investigations into root-zone stress tolerances are essential for providing the root-zone management and design characteristics that are critical for reliable and up-scalable plant space agriculture.

The research described in this proposal will yield new knowledge and understanding about watering crops in reduced gravity. The combination of analyzing root zone data between 1g and microgravity together with numerical modeling of root zone performance allows us to better understand crop stress caused by water and nutrient delivery deficits and root zone hypoxia. Improving this understanding is crucial for predicting the efficacy of water and nutrient delivery systems in spaceflight, and lunar and planetary habitats. Thus, our work will contribute to how plant stress may be reduced during each growth stage by evaluating management set points and delivery strategies. The proposed application of media characterization, data analysis and modeling leading to the formulation of an optimization problem is innovative, and our focus on root-zone stressors caused by inadequate water delivery has been identified as a key limitation to plant-growth successes in space.

This project represents a training opportunity for an undergraduate student. The undergraduate student will be involved in the data analysis and laboratory experiments and is expected to complete a small independent project that will be presented at a subsequent conference. The student will also be encouraged to participate in scholarly publications as a co-author or potentially as a lead author. This project is of particular interest to the PI because it helps foster collaboration with NASA scientists, and harbors a vision of long-term contributions to successful bioregenerative life support systems in space.

21-EPSCoR-R3-0074

Appendix B. Renewal of Life on Mars Algae Cultivation for Long-term Food and Oxygen Production

Nevada System of Higher Education

Dr. Lynn Fenstermaker

Here we are proposing a renewal of our current grant entitled Life on Mars: Algae cultivation for long-term food and oxygen production. Long-term human exploration of Mars will require significant amounts of both oxygen and food, and the ability to grow photosynthetic organisms on Mars would contribute significantly to both of these needs. Algae, which produce much of the oxygen on Earth, have also adapted to extreme terrestrial environments. Some species of algae are also edible, and are increasingly utilized as food sources. Growth of such extremophilic and edible algae species, therefore, has the potential to provide both oxygen and nutrients for long-term Mars exploration.

As stated in the call for the original funding, Low pressure is being sought to reduce mass and volume of structures that would enclose the plant growth area and potentially enable use of transparent materials to utilize ambient light . However, other than our ongoing work, no prior studies have examined snow algae growth under low atmospheric pressure conditions relevant to growth on Mars. Our promising initial results show growth of algae under low pressure conditions (80 � 5 mbar). Despite these promising results, however, significant questions remain. These include the lower limits of atmospheric pressure under which algae growth will occur, the impact of lowered light levels such as are expected on Mars, as well as the impact of Mars regolith.

We therefore propose a renewal to test additional relevant conditions. We will use a proposed new low pressure chamber to test algae growth at lower pressures of 30 mbar and 17 mbar. We will also examine light conditions relevant to Mars, which include a 50% decrease in light levels corresponding to levels on Mars, as well as introducing dark periods relevant to dust storms on Mars. We anticipate that snow algae, in particular, may be resilient to both lowered light levels, as well as periods of time with no light due to their life cycle, which includes a period of time in the soil beneath the snowpack. We will also test the impact of nutrient supply from Mars regolith on algae growth. We will both grow the algae in medium generated by reacting Mars regolith simulants with liquid water to determine whether adequate nutrients can be supplied, as well as testing the levels at which regolith become toxic by directly inoculating cultures with Mars regolith simulant. Our preliminary experiments show some successful growth on the Mars regolith simulant, but more work is needed to assess the constraints of using Mars regolith as a nutrient source. For each growth condition, we will measure cell counts, optical density by UV-VIS, and oxygen production using GC-MS. Finally, we will identify the genetic basis of adaptations in the algae species by differential gene expression studies.

We propose that our current team will continue working on this project, including UNLV postdoc Dr. Leena Cycil, Science PI Dr. Elisabeth Hausrath, NASA Scientist Dr. Doug Ming, who has extensive experience in Life Support, and consultant Dr. James Raymond, who is a snow algae expert. The proposed work has been discussed with Dr. Warren Ruemmele, and will fill important knowledge gaps in the production of oxygen and nutrients on Mars. The proposed work pursuing in situ production of oxygen and food on Mars would be an important step forward in the exciting field of human exploration of Mars.

21-EPSCoR-R3-0075

Appendix D: Biomimicry of the Growth of a Desert Plant as an Approach for Extractions of Phosphorus and Minerals from Martian Regolith

Nevada System of Higher Education

Dr. Lynn Fenstermaker

Robotic or human space missions are extremely costly. The cost associated with exploration of space missions can be curtailed by reducing the launch mass. This is possible by utilizing in-situ resources. Martian regolith is composed of iron, magnesium, aluminum, calcium, potassium, silicon, chromium, manganese, sulfur, phosphorus, and sodium, and has the potential to be an excellent in-situ source of minerals and nutrients to support human lives and activities. However, these elements exist in the forms of stable oxides and/or complexes rather than their elemental form. The processing of oxides and complexes to recover high purity elements is economically and technically challenging. Several desert plants, such as paloverde, grow on rocks in Nevada with limited water, similar to the conditions on Mars. This means that these plants are able to extract nutrients and minerals from desert rocks such as basalt. These plants survive by extending their roots deep, up to a few meters into basalt fractures. Being legumes, their nitrogen comes from nitrogen gas fixing bacteria living symbiotically in their root nodules. It is hypothesized that these plants have unique mechanisms for the extraction of phosphorus and minerals. For example, they likely release biomaterials from their roots (acidic exudates) for the solubilization of phosphorus and minerals. The goal of this project is to deliver a safe and economical approach to extract phosphorus and minerals from Mars regolith via biomimicry of the growth of paloverde.

The main objectives of this proposed research are to: 1. Investigate phosphorus and mineral extraction biomechanisms utilized by paloverde to grow on basalt and Martian regolith simulant; and 2. Characterize biomaterials and their sources and rhizosphere microbial communities and their roles. We expect that the identified biomechanisms can be mimicked for the extractions of phosphorus and minerals from Martian regolith. We will conduct a detailed investigation on these extraction biomechanisms in a greenhouse using crushed basalt and Martian regolith like material (Mars Global Simulants) with no nutrient and mineral supplements.

We will monitor minerals and phosphorus released by basalt and the simulant and uptaken by the plant. The investigation will elucidate the involvements of rhizosphere microorganisms and plant exudates in phosphorus and mineral dissolutions through several advanced analytical and molecular biology techniques. For example, we will examine the microbial community of the rhizobacteria using high throughput sequencing. We will chemically characterize the plant exudates by Fourier transform infrared spectroscopy, nuclear magnetic resonance spectroscopy, and chromatography and mass spectrometry. The vision of the project is not to grow paloverde on Mars but to characterize the biomaterials and biomechanisms which could potentially be adapted through biomimicry for the extraction of resources from Martian regolith and/or adopted through genetic engineering for growing other plants on Mars.

Our investigator team, which consists an interdisciplinary team of qualified engineer and scientist, will collaborate with a well-respected NASA planetary scientist with expertise astrobiology and terraforming. Research results will lead to the developments of two main project deliveries: 1. A verified biobased approach (biomechanism) to extract phosphorus and minerals from Martian regolith and 2. Biobased material(s) for the extraction.

Research findings will generate a peer reviewed article in a respectable journal (impact factor > 5) and one or more proposals to major federal funding programs. The proposed project aligns with the goal of the NASA Physical Sciences Program research emphasis to develop and increase understanding of extraction techniques to generate useful materials from Lunar or Martian regolith.

21-EPSCoR-R3-0078

Appendix E: Thermophilic Biomass Recycling by Novel Chloroflexi to Support NASA Spaceflights

Nevada System of Higher Education

Dr. Lynn Fenstermaker

Lignocellulose is the structurally complex building block of all plants and would be the dominant waste from crop materials during spaceflight missions. NASA recognizes the complex and highly mission dependent nature of both the quality and quantity of lignocellulose wastes. As such, technologies for degradation of diverse lignocellulose waste streams depend on diverse organisms and enzymes regardless of the downstream application (e.g., soil formation, biofuels, specialty chemicals, etc.). To address this need, we propose to explore the ability of the novel bacterium, Kallotenue papyrolyticum, and its purified glycoside hydrolase (GH) enzymes to degrade a variety of polysaccharides under the broad hypothesis that this organism could be useful to degrade lignocellulose wastes during spaceflights. The proposal has two objectives.

Objective 1 is to determine the functions of K. papyrolyticum GH enzymes. Codon-optimized genes will be synthesized, expressed in E. coli, and screened for activity against both defined and complex polymers. Enzyme kinetic parameters of promising GHs will be determined, particularly primary cellulases. The functional properties of individual GHs are foundational for understanding polysaccharide degradation and to establish the potential contributions of K. papyrolyticum enzymes to lignocellulose depolymerization during spaceflights.

Objective 2 is to determine the broader substrate range and degradation products of K. papyrolyticum. K. papyrolyticum will be screened for growth against a broad group of polymers. For a few polysaccharides, metabolic products will be quantified by untargeted gas chromatography/tandem mass spectrometry. Additionally, gas chromatography with flame ionization detection will be used to quantify volatile fatty acids and alcohols through time courses and to assess the effects of terminal electron acceptor availability (i.e., low or no oxygen) and simulated microgravity on production of chemicals of potential utility. Knowledge of the broader substrate range and products of polysaccharide degradation would be critical to assess biodegradation potential and direct production of biofuels or specialty chemicals.

This work directly addresses the R3 research objective defined in Appendix E under Research Project III: Spaceflight-compatible recycling of non-edible biomass. Although a variety of cellulolytic microorganisms have been described, the current cache of organisms and enzymes is insufficient to degrade the diverse and recalcitrant crop wastes necessary for long-term space flight and colonization. K. papyrolyticum is a member of the bacterial phylum Chloroflexi and is therefore unrelated to other well-described cellulolytic bacteria. By focusing on a highly cellulolytic organism from a poorly explored branch on the tree of life, this project has a strong potential to add to existing cellulolytic organisms and enzymes to address NASA s spaceflight needs and also provide a template to study other cellulolytic Chloroflexi.