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23-2023EPSCoR-0001

Advanced Diagnostic Development Facility for Space Propulsion ion

West Virginia University

Dr. Melanie Page

The recent dramatic increase in space exploration and commercial space activity has resulted in an equally expansive growth in the types of in-space propulsion systems needed. For example, deep space exploration missions have very different propulsion requirements than station keeping for a low-Earth orbit communications array. To meet this diversity of propulsion needs, researchers are developing propulsion systems that achieve high-thrust and high-specific impulse; high thrust and low-specific impulse; low thrust and high specific impulse; and even low thrust and low specific impulse. The mechanisms for creating the propellent exhaust include conventional combustion systems; electric propulsion systems including Hall thrusters, ion engines, rf thrusters, and electron cyclotron resonance thrusters; dual fuel systems in which the propellant either combusts with an oxidizer or can be ionized and accelerated electrically; solid fuel, liquid fuel, conventional pressurized gas systems; and even cold gas micro propulsion systems intended for micro and nano scale spacecraft.

A key part of the development process of in-space propulsion systems is testing and certification for flight. In a variety of facilities at NASA Centers, universities, and industry, researchers measure the thrust and specific impulse of the propulsion systems; their long-term survivability; the interactions of the exhaust plume with spacecraft materials; and their power consumption requirements. Given the wide range of fuel types and propulsion system operating conditions, there is an ongoing need to develop new diagnostic methods capable of obtaining measurements of exhaust speed, plume structure, thruster erosion, and exhaust plume composition.

We propose to build the capacity to develop new, non-perturbative diagnostics capable of measuring the exhaust velocity, interaction of the exhaust with ambient neutrals, and plume morphology for novel propellants such as solid iodine and atmospheric gasses (as would be used in air-breathing propulsion systems). Using these new diagnostic tools, we will initially address two questions regarding the performance of a specific in-space propulsion system (1) How does the thruster exhaust in a test chamber couple to the background neutral gas and how does that neutral gas subsequently interact with the thruster test system? (2) How does the exhaust velocity and plume structure of an iodine fueled resistojet vary with resistojet temperature and nozzle geometry? A key feature of the proposed measurements is that they will be accomplished with sub-mm spatial resolution and non-invasively, i.e., completely through optical measurements.

Space research in WV has been undergoing rapid expansion. Five new faculty in space research have been hired at West Virginia University (WVU) in the last four years (two in Aerospace Engineering and three in Physics and Astronomy). In 2019, a collaboration involving WVU, the local NASA Katherine Johnson facility, and regional industrial partners launched the first spacecraft designed and built in WV (STF-1, the Simulation-To-Flight mission). And in 2022, researchers at WVU received over $900K in funding from the National EDA to develop the WV Small Satellite Center of Excellence. These recent developments, plus WVU's long-standing expertise in spectroscopic measurement of flows in plasmas, have laid the foundation for a robust research program in spacecraft propulsion at WVU. This project will develop the infrastructure necessary to be competitive for future funding opportunities (for individual research programs and center-level research programs), will create a strong environment for recruiting and training students, and will support the burgeoning space-related capabilities in the state of West Virginia.

23-2023EPSCoR-0003

Nevada Multi-Messenger Astrophysics

Nevada System of Higher Education

Dr. Lynn Fenstermaker

"The last decade ushered in the multi-messenger era of astrophysics. In addition to the electromagnetic signals astronomers have been using for centuries, newly detected gravitational waves and high-energy neutrinos have opened new windows to study the universe. We propose to conduct a comprehensive multi-messenger, multi-wavelength study of several of the most energetic high-energy transient phenomena in the universe, including coalescences of binary compact objects (black holes [BHs] and neutron stars [NSs]), gamma-ray bursts (GRBs), active galactic nuclei (AGNs) and supermassive black holes, and black hole X-ray binaries in the Milky Way Galaxy. The project will make use of broad-band electromagnetic data from telescopes in all wavelengths, including three current and upcoming NASA missions, Swift, Fermi/GBM, and StarBurst, as well as the gravitational wave data from the LIGO/Virgo/KAGRA (LVK) detectors and the neutrino data from the IceCube Neutrino Observatory. To meet project goals, we will combine data analysis, theoretical modeling and numerical simulations to address several fundamental questions in contemporary astrophysics: 1. How do black holes of various scales form and what are the formation channels of gravitational wave sources? 2. How do black holes of various scales launch relativistic jets, accelerate particles and radiate energetic photons and neutrinos? 3. How do black holes of various scales interact with surrounding matter through accretion and outflows? 4. How do multi-messenger data probe fundamental physics? Specifically, we will carry out following five tasks:

1. We propose to perform timely observations and theoretical modeling of interesting compact binary coalescence events detected during the 4th LVK observing run, especially potential new NS-NS or BH-NS merger systems with associated electromagnetic counterparts (GRBs and kilonovae), aiming to understand the growth of black holes and how neutron star merger systems launch relativistic jets and power kilonovae through nucleosynthesis processes that generate heavy elements in the universe.
2. We propose to perform timely observations and theoretical modeling of special GRBs, especially nearby events with multi-messenger information, aiming to understand the formation of black holes, the launch of relativistic jets from new-born black holes, as well as particle acceleration and radiation processes from the jets.
3. We propose to perform comprehensive multi-wavelength, multi-messenger observations and in-depth theoretical modeling and numerical simulations of various types of AGNs, aiming to understand

the growth of supermassive black holes, how supermassive black holes interact with the environment through accretion and wind launching, as well as how AGNs accelerate particles and generate both neutrinos and high-energy and low-energy photons.

4. We propose to perform multi-wavelength campaigns and theoretical modeling of BH X-ray binaries, to understand the physical origins of different accretion phases, the interplay between accretion and outflows, and jet launching.
5. We propose several novel tests or constraints on fundamental physics making use of the multi-messenger data collected during the next three years.

Our research team includes 12 scientists from 3 institutions of the Nevada System of Higher Education and 3 NASA scientists from 2 NASA Centers. The proposed investigations directly address the broad questions in NASA’s strategic objective in astrophysics, “How does the universe work?” and “How did we get here?” The study will probe the origin and destiny of the universe including the nature of black holes and gravity, the standard model of particle physics and beyond. The effort will contribute to the Nevada Science and Technology Plan and the state’s Economic Development Plan through workforce training, developing digital technologies, as well as applying scientific methodology to solve Nevada water-related problems."

23-2023EPSCoR-0006

Mechanistic Determination of the Electrochemical and Thermomechanical Effects of Freeze-Thaw Cycles on Li-ion Batteries

Iowa 4-H Youth Development

Dr. Sara Nelson

Electrochemical and thermomechanical phenomena in lithium-ion batteries are of critical importance to NASA and others because of their influence on operational characteristics and safety, especially in extreme thermal conditions (e.g., extreme cold). Specifically, the role of time-varying thermal conditions—some so severe they subject the electrolyte to freeze-thaw cycles—on Li-ion characteristics is of interest to NASA because they are often encountered in lunar/Martian platforms. However, the underlying electrochemical and thermomechanical mechanisms of battery degradation and failure during such freeze-thaw cycles remain unknown.

The goal of this project is to identify and quantify the electrochemical and thermomechanical effects and underlying mechanisms for Li-ion cells subjected to freeze-thaw cycles encountered by lunar/Martian spacecraft, and establish the first shared research-scale pilot battery fabrication and testing facility within the Iowa NASA EPSCoR (INE) jurisdiction. We will attain this goal by quantifying the cell-level effects of thermal/freeze-thaw cycles on Li-ion batteries (Objective 1), determining the corresponding subcell-level mechanisms (Objective 2), and establishing a state-of-the-art battery fabrication and testing facility that is available to scientists and engineers within the INE jurisdiction.

To accomplish Objective 1, we will diagnose the failure and degradation of Li-ion batteries exposed to different (constant) temperatures (Task 1.1), during and after thermal and/or freeze-thaw cycling (Tasks 1.2 and 1.3), under ultra-high vacuum conditions (Task 1.4), and using accelerating rate calorimetry (Task 1.5). Objective 2 will be focused on understanding the mechanistic origins of degradation and failure on electrodes, electrolytes, and interfaces within the battery using in-operando analysis (Task 2.1), in-situ studies (Task 2.2), accelerating rate calorimetry (Task 2.3), and ex-situ characterization techniques (Task 2.4). This will provide a comprehensive understanding of battery performance and safety and its mechanistic origins under thermal conditions related to those in lunar/Martian platforms. Finally, Objective 3 will be realized by procuring new and consolidating existing battery fabrication and testing equipment into a state-of-the-art shared battery facility at Iowa State University (Task 3.1) and providing scientists and engineers across the INE jurisdiction with shared access to the battery facility (Task 3.2).

Upon completion of the proposed work, we will have, for the first time, a first-principles understanding and quantitative link between the electrochemical and thermomechanical effects of subjecting Li-ion batteries to thermal/freeze-thaw cycles and the mechanistic underpinnings. Moreover, we will have established the first shared research-scale pilot battery fabrication and testing facility within the INE jurisdiction that is open to all INE scientists and engineers. These contributions will be significant for several reasons. First, they will have a significant impact and dramatic improvements on current and future NASA missions—specifically spacecraft and power hibernation technologies—and several of NASA's Mission Directorates (e.g., STMD, SMD, and ESDMD). Moreover, they will significantly impact the state of Iowa by providing INE battery researchers with the critical infrastructure needed for Li-ion battery fabrication and subsequent testing and a platform for interdisciplinary collaborations.

23-2023EPSCoR-0007

Self-Powered Health Monitoring Wearable for Non-Invasive Diagnosis of Health Disorders of NASA Astronauts during Space Exploration

New Mexico State University

Dr. Paulo Oemig

"The proposed project aims at providing non-invasive and self-learning health monitoring solutions for early diagnosis of health disorders of NASA astronauts during space exploration by detecting subtle changes in the astronauts' daily behavioral and sleep patterns. It is essential to keep the NASA astronauts informed about their fitness and health in space by minimally invasive and intrusive means. The health monitoring wearable is considered the most promising solution for accomplishing this goal.

State-of-the-art health monitoring wearables are not well suited for monitoring astronauts' health during space mission operations due to batteries needing to be recharged regularly and extreme conditions of space. The Science Investigator, Dr. Donghyeon Ryu, and the co-investigators propose to innovate the health monitoring wearables by developing a self-powered sensing fiber and a machine-learning (M-L)-based health diagnosis platform. In the previous awarded NASA EPSCoR CAN project, Dr. Ryu invented the multifunctional mechano-luminescenceoptoelectronic (MLO) composites, The MLO was shown to generate direct current (DC) when subjected to external mechanical stimuli through the mechanical-radiant-electrical (MRE) energy conversion mechanism. The MRE energy conversion is enabled by the two functional building blocks (i.e., the mechano-luminescent composites generating the light under the strain and the mechano-optoelectronic thin films generating the electricity using the light) integrated in the MLO design platform. The DC generated from the MLO was shown to vary in magnitude with the applied strain. In addition, the generated DC can be used as an electrical energy source.

In order to accomplish the development of the non-invasive and self-learning health monitoring wearables using the self-powered MLO sensing fibers, the team will focus on three research tasks to: 1) develop the hybrid manufacturing technique for the MLO fiber, 2) design microstructures of the functional building blocks to optimize the sensing capability, 3) create a non-invasive and self-learning health monitoring platform."

23-2023EPSCoR-0008

"Global to Regional: Origins of Water Stress (GROWS)"

University of Wyoming

Dr. Shawna McBride

"The Global to Regional: Origins of Water Stress (GROWS) project aims to bring the global origin of water to regional relevance in the western US. Water availability and stress can have profound regional consequences to the state outlook for agriculture, tourism, and quality of life. However, the role of the atmosphere in distributing water encompasses the globe and requires a wholistic approach to understand and constrain how water moves and how error propagates in our understanding of these processes. Linking the origins of regional water stress to global precursors offers a unique avenue for research infrastructure development that will serve to grow Wyoming's prominence globally. This will create new research connections and provide a framework that can be used to demonstrate to students and stakeholders alike, how global changes impact their own backyard.

Water availability is critical to the future of the western US. The global atmospheric circulation carries moisture from warm, tropical regions and deposits it as precipitation far from its source. Changes in evaporative fluxes and atmospheric circulation can either bring deluges or drought. We must rely on Global Climate Models (GCMs) to predict how these moisture fluxes will change on the scale of decades to centuries. Here, we propose to utilize the E3 GCM, being developed by NASA-GISS, to provide robust ensemble forecasts of moisture convergence in the US West on decadal time scales. GISS-E3 is unique because it has structured its development around a perturbed physics ensemble (PPE) where model uncertainty is systematically explored by randomly varying model parameters within their probable range. The GISS-E3 PPE can be confronted with observations of the current atmosphere to objectively select the model configuration that is most consistent with the real world. Here, we will develop a suite of observational metrics that act to constrain moisture convergence (and ultimately precipitation) into the US West. This work will enable us to identify global origins of seasonal moisture trends and provide future predictions. We will do this utilizing back trajectory modelling to link source regions of enhanced moisture in future scenarios. This will yield physical understanding of linkages between global circulation and US West precipitation.

This work will create a framework for NASA and the University of Wyoming (UWyo) to offer predictions of future moisture convergence for the western US. The framework will be designed in a flexible way so that it can be applied to other regions around the globe. This will place UWyo in collaboration with NASA as a center of hydroclimate modelling with global impact. One direct impact on UWyo will be to provide an ensemble of future forecasts of moisture flux for downscaling in synergy with the Wyoming Anticipating Climate Transitions (WYACT) initiative at the UWyo. This proposal supports two Assistant Professor-level faculty, the development of their respective research groups, and leverages their expertise in global modeling, remote sensing, and observational data. Funding from this grant will support a student and a postdoctoral scholar, who will, with their faculty advisors, develop this framework. Specific collaboration-building activities are planned."

23-2023EPSCoR-0009

Response of Coupled Magnetosphere-Ionosphere-Thermosphere (MIT) System to Changing Levels of Geomagnetic Activity

University of Alaska Fairbanks

Dr. Denise Thorsen

"Background/Significance: During space weather events, called geomagnetic storms here on Earth, the energy deposited at high latitudes into the Earth's upper atmosphere can increase by 10- to 20-fold, leading to thermospheric heating and expansion and neutral composition changes. Heating and expansion of the thermosphere drives high-velocity disturbed neutral winds from the polar regions toward the equator. Within minutes of storm commencement, high-latitude electric fields penetrate to low latitudes. The plasmasphere, an inner part of Earth's magnetosphere, erodes. All of these processes catalyze plasma flows along geomagnetic field lines, coupling the nearly collision-less magnetosphere to the highly collisional ionosphere and thermosphere.

Knowledge of the electron and ion number densities along geomagnetic field lines is required to understand processes such as plasmasphere erosion and refilling, ionospheric outflows, magnetospheric particle precipitation, wave-particle interactions that regulate the response of the coupled magnetosphere-ionosphere-thermosphere (MIT) system and plasmasphere dynamics. Whistler mode waves propagate close to geomagnetic field lines. Therefore, WM radio-sounding method permits field-aligned electron and ion densities measurements [Sonwalkar et al., 2011a; 2011b]. These measurements, combined with advanced physics-based model simulations, provide a powerful new approach [Reddy et al., 2018] to determine the underlying processes that play a role in the storm-time dynamics of the highly-coupled MIT system.

Goals and Objectives: We propose a three-year research program to determine the response of the Earth's upper atmosphere to changing levels of geomagnetic activity through a combination of physics-based model simulations and analysis of whistler mode (WM) radio-sounding data from the IMAGE and DSX satellites. We will complement WM sounding measurements by those from other satellites (e.g., DMSP and CHAMP), ground-based ionosonde stations, and other indicators of geomagnetic activity, such as visible and radar aurora. The main objectives are: (1) Determine the evolution of field-aligned electron and ion densities profiles at low-, mid-, and high-latitudes as a function of geomagnetic storm activity using WM radio sounding data from IMAGE and DSX. (2) Simulate the evolution of observed field-aligned electron and ion densities profiles using physics-based models (e.g., SAMI2, SAMI3). (3) Use observation-simulation results to investigate the physical processes leading to storm time variations in field-aligned electron and ion densities and understand the response of the coupled MIT system to geomagnetic storms. (4) Use the proposed work as a springboard to launch a nationally competitive UAF space-weather research program using plasma waves. The proposed research program provides a graduate student with exposure to space weather research.

Relevance to NASA and Jurisdiction: In Priority 1 of the 2020 NASA Science Plan, Strategy 1.4 pertains directly to space weather. The proposed work relates directly to NASA's Science Mission Directorate

(Heliophysics Research) and the NASA/Goddard Space Flight Center goal 1: """"Expand Human Knowledge Through New Scientific Discoveries"""" and Objective 1.1: """"Understand the Sun, Earth, Solar System, and Universe."""" The proposed work significantly contributes to addressing NASA's Heliophysics decadal survey goal: """"Determine the dynamics and coupling of Earth's magnetosphere, ionosphere, and atmosphere and their response to solar and terrestrial inputs."""" This work aligns with Alaska NASA EPSCoR's goal, """"Increase Alaska's ability to respond to research and technology development needs of NASA."""""

23-2023EPSCoR-0013

Human Factor Analysis of Space Crop Cultivation Methods and Interactions

North Dakota Space Grant Consortium

Dr. Caitlin Milera

"Space crop cultivation has the potential to be utilized as a countermeasure for stress and anxiety that results from long term space habitation while also supplementing crew diets. It is assumed that crews on long duration space missions will be working in close proximity, if not directly interacting with, space crop production systems in their habitats. To date, there is a lack of scientific/validated behavioral health data beyond anecdotal evidence regarding the effects of crop cultivation on crews during both analogue and spaceflight missions, and thus has been identified as a key gap in enabling crop cultivation in long-term space missions. This study proposes a human factors analysis of interactions with crop production systems during analogue space missions.

The objective of this study is to produce a baseline dataset of human factors associated with space crop cultivation during analogue space missions. These data are meant to contribute to future NASA space crop production initiatives while also increasing the fidelity of analogue space missions.
By leveraging the resources available through the use of the Inflatable Lunar Martian Analogue Habitat (ILMAH); the University of North Dakota’s Space Studies Department, in collaboration with NASA Johnson Space Center’s Behavioral Health and Performance Laboratory, seek to achieve the following objectives through the proposed project.

Goal I: Assess the behavioral health and performance impacts of working with analogue space crop production systems in a space mission analogue environment.

Goal II: Inform behavioral-cost benefit trades for plant growth systems in space analogue missions.

Goal III: Inform human factor design of plant growth systems in spaceflight analogue missions.

Over the span of ten analogue missions, crew members will cultivate crops using systems and methods analogous to the VEGGIE system aboard the ISS. Throughout each mission, crew members will submit various survey tools associated with behavioral performance, stress, interpersonal interactions, and crop acceptability. This study proposes a novel approach of combining the aforementioned qualitative measures with quantitative stress hormone sampling. Salivary cortisol has been identified as an effective method of measuring stress biomarkers due its ease of collection and wide scope for application. Cortisol samples will be collected three times a day during each mission in order to quantify stress hormone fluctuations. This approach seeks to identify the relationship between variables associated with self-reported behavioral health and performance assessments and stress hormone fluctuation as a result of space crop cultivation system interactions. The parameters, research methods, and research tools in the proposed study were developed through consultation from both NASA KSC Space Crop Production team and JSC BHP Laboratory.

This project is strongly supported by NASA Kennedy Space Center's Space Crop Production team as well as the NASA JSC BHP Laboratory.. This study falls under the NASA Technology Taxonomy areas of TX06.3.3 Behavioral Health and Performance, TX06.3.5 Food Production, Processing, and Preservation, and TX06.3.6 Long Duration Health. The work proposed aims to quantify human factors associated with behavioral health, systems interactions and acceptance while operating crop production systems in space analogue missions. The assessments in this project seek to inform the development of future space crop production system in space habitats based on a mixed method analysis of human factors as they relate to crop production and consumption in space analogue missions. These goals are also in alignment with the NASA Strategic Technology Investment Plan areas of Human Health, Life Support, and Habitat Systems 6.3.3 Behavioral Health/6.3.4 Human Factors as well as Destination Systems 7.2.4 Food Production, Processing and Preservation."

23-2023EPSCoR-0015

Focused Elastodynamic Morphing for deployment of Metamaterial Spaceborne Antennas and Lattice Structures for Aerospace Application

University of Vermont

Prof. Bernard Cole

"The goal is to strengthen the research infrastructure in Vermont by researching a novel and potentially highly reliable method of deploying and controlling the shape of space structures and antennas, exploiting these shape changes to enhance the performance of antennas, and to combine deployment and structural control techniques to create feasible designs for large km-scale space structures and sensing systems.

The deployment technique uses an innovative elastodynamic method that focuses and localizes elastodynamic energy to expand individual truss elements in a sequential manner. The method uses frangible flexure and elastic snap joints that release and expand the structure when elastic waves focus on an individual cell. This technique potentially avoids many of the sticking and jamming problems associated with conventional mechanical linkage deployment. Elastodynamic focusing exploits the periodic nature of compressed and deployed truss structures to create elastic metamaterials with robust wave propagation and robust topologically protected asymmetry. Focused vibration also replaces the heavy electro-mechanical actuation systems of conventional truss deployment with lighter vibratory systems that exert remote actuation. Furthermore, the initially folded truss structure may be more resilient to the highly dynamic conditions of launch and require significantly less supporting hardware.

The same set of metamaterial elastodynamic techniques enables controlling shape of deployed antennas in dynamic manners that make for innovative electromagnetic sensing methods. Possible electromagnetic metamaterial antenna applications include small aperture antennas; antennas capable of sending and receiving structured beams, such as dichroic chirality, orbital angular momentum, self-healing Bessel beams, and accelerating Airy beams; and antennas built from arrays of active elements, such as metamaterial circulators.

Combining these deployment and structural control techniques opens the door for creating large km-scale scale structures, antennas and scientific instruments – a topic of high interest to future NASA plans.

The research plan includes mathematical simulations of focused deployment, proof-of-concept experiments with 1D and then 2D structures, morphing antennas, and conceptual designs and simulations of km-scale space structures. Uncertainty of the results will be quantified with repeated experiments and sensitivity analysis.

The potential impact of this research for NASA can be substantial with the implementation of improved and more reliable methods of deploying and controlling large space structures, antennas and enabling km-scale sensing systems. We plan to collaborate with NASA Ames on structures, and NASA Goddard on antennas to receive technical guidance and advice on NASA relevance.

This research will build on existing research infrastructure in Vermont in dynamics, electromagnetics, metamaterials, and structures. The project will raise the research infrastructure within Vermont on space structures and metamaterials to a higher level by involving senior and junior faculty members, and three graduate students in a collaborative multidisciplinary project of significant relevance to the NASA and other operators of systems in space. The acquisition of test equipment will enable the development of sophisticated test apparatus and procedures that will be of relevance in future research efforts. The project will have a direct impact on economic development in Vermont with the education of highly trained engineers at the graduate level and the potential for creation of intellectual property with benefit to the space industry."

23-2023EPSCoR-0016

Scalable, High Energy Density Lithium-Sulfur Batteries (SD-LSB)

South Dakota School of Mines and Technology

Dr. Edward Duke

"Rechargeable lithium-ion (Li-ion) batteries offer performance advantages over lead-acid and nickel-cadmium batteries. Li-ion batteries, however, are approaching an asymptotic limit of specific energy that is unable to meet NASA future space mission needs. The South Dakota School of Mines and Technology and the University of South Dakota propose to research and develop an advanced, beyond Li-ion, lithium-sulfur (Li-S) battery technology through this project titled Scalable, High Energy Density Lithium-Sulfur Batteries (SD-LSB). Together with our partners, including NASA Jet Propulsion Laboratory (JPL) and Glenn Research Center (GRC), we will pursue five objectives:

1. Advance battery material science and engineering to render a Li-S battery with high energy density (greater than or equal to 450 Wh/kg), long cycle life (greater than or equal to 500 cycles), safe operation (Li anode protection, nonflammable electrolyte), and wide temperature range (-40 degrees C to +60 degrees C).

2. Apply computational approaches, including machine learning, to guide product development and to understand battery performance improvement from a mechanistic standpoint.

3. Improve institutional infrastructure and foster collaborations within the state to advance new research on energy storage and increase competitiveness for future federal, state, and private research support.

4. Engage researchers from JPL and GRC and industries for follow-on technology transfer and commercialization.

5. Support STEM education and training and workforce development with a special emphasis on Native American communities.

Li-S battery technology is identified as a strategic priority for future aerospace missions. However, Li-S batteries face substantial technical challenges including: (1) low practical specific capacity and fast performance decay due to formation, migration, and shuttling of intermediate lithium polysulfides (PSs); (2) poor power capability due to inherently slow electron transfer kinetics of sulfur/sulfide redox chemistry; (3) intrinsically large volume change of the sulfur cathode leading to battery degradation; (4) safety concerns due to dendrite growth of metallic Li anodes; and (5) limited operational temperature range and flammability issues of the electrolytes. These technical hurdles must be overcome before Li-S batteries can be deployed. In a recent work, our team has discovered a new type of PS-trapping material, nanolayer polymer [poly(4-vinylpyridine), P4VP] coated high surface area carbons (NPC). We found that when thin films of NPC were coated on sulfur cathodes, the resultant Li-S battery cells demonstrated a discharge specific capacity of ~1,600 mAh/g, approaching the theoretical value. The weight of the nanoscale NPC thin film on sulfur cathodes is negligible rendering a significant performance gain without sacrificing battery specific energy. Our approach is simple, effective, low-cost, and scalable. Leveraging this finding, SD-LSB proposes to further research and develop this novel approach through three technical thrusts: (1) Develop a free-standing, 3D nanostructured, highly conductive, and NPC-enabled PS trapping capable sulfur cathode. This effort will eliminate the dead-weight of the metal substrate, afford high sulfur content, high power capability, and tolerance to large volume change while effectively trapping PSs to inhibit PS dissolution. (2) Develop a fluorinated nonflammable electrolyte to provide robust protection to the Li anode to suppress dendrite growth and improved safety. (3) Integrate battery materials developed in Thrusts (1) and (2) into batteries and characterize Li-S battery performance. Throughout these R&D efforts, we will carry out fundamental, mechanistic studies via multi-physics, multi-scale modeling including density functional theory (DFT). The proposed approach is expected to help meet NASA needs of next-generation battery energy storage for future space missions."

23-2023EPSCoR-0017

Vacuum thermal evaporation (VTE) processed perovskite solar cells for in space assembly

Oklahoma State University

Dr. Andrew Arena

"This project entitled, "Vacuum thermal evaporation (VTE) processed perovskite solar cells for in-space assembly" aims to develop a simple solar panel manufacturing process suitable for space, particularly the lunar surface. Direct in-space assembly of solar panels - especially on the lunar surface - could be critical for future NASA space missions. As a part of NASA's Artemis program launched in 2017, NASA plans to send human's back to Moon by the mid-2020s and develop a base-camp on the Moon for supporting longer expeditions on the lunar surface. Therefore, the planned base camp will require a robust source of power. If we could fabricate solar panels directly on the lunar surface, it would be greatly beneficial to establishing sustainable long-term exploration of the Moon. Metal halide perovskites have stimulated considerable interest recently due to their rapid increase in power conversion efficiency (> 25%), which is now at levels in excess of state-of-the-art crystalline silicon solar cells. While for terrestrial applications, the vulnerability of halide perovskite solar cells to oxygen and moisture is a major drawback this issue is largely irrelevant in space since there is no oxygen or moisture in this environment. As such, the environmental conditions limiting the implementation of perovskites terrestrially are less problematic in space. This coupled with their lightweight, the potential for low specific power and packing volume, and the potential for deployable implementation; along with the ease of processing, outstanding performance, and their remarkable radiation tolerance all suggest perovskite thin film solar cells are excellent candidates for space applications.

In this proposed research, we would like to explore fully vacuum processed thermally evaporated (VTE) halide perovskite solar cells using only solid precursors to develop a simple solar panel manufacturing process suitable for space, particularly the lunar surface. Typical solution-based perovskite solar cell fabrication that could enable cost-effective printing and manufacturing is very attractive for commercial applications terrestrially. However, the proposed solid-based VTE-processed perovskite solar cell fabrication has more advantages for direct in-space manufacturing because it offers the potential for high power generation at lower payloads. Unlike the typical solution-based perovskite solar cell process, which requires large amounts of solvents that would create additional weight and require larger volumes in spacecraft, VTE-based solar cell fabrication is inherently solvent-free using only solid precursors that would occupy minimum weight and less volume during transit. To achieve the goals of this project, a multi-disciplinary team of researchers from Engineering, Physics, Chemistry and Materials Science, comprising faculty from the three large research universities in Oklahoma (Oklahoma - OU and Tulsa - TU, and Oklahoma State University - OSU) has been assembled. Dr. Do Young Kim, who has the expertise in fabrication and characterization of halide perovskite solar cells using VTE-deposited halide perovskites, will lead the proposed NASA EPSCoR research as the Science-I. While this proposal is of strong interest to several NASA Directorates; including the SMD, the STMD, and the HEOD, it is the STMD that is charged with developing novel innovative solar cell technologies that enable current and future missions. The Photovoltaics and Electrochemical Systems Branch at NASA Glenn Research Center already shows a strong interest in this proposed research for the implementation of perovskite solar cells for future lunar missions."

23-2023EPSCoR-0019

Investigation of Material Surface Erosion and Failure due to High-Velocity Particle Impact

University of Kentucky

Prof. Alexandre Martin

"The NASA Kentucky EPSCoR Program’s mission is to enhance the research and intellectual capacity of the state’s universities and colleges through strategic investments in NASA-priority research areas and to increase researcher competitiveness for non-EPSCoR NASA funding. To that end, this project aims to significantly expand the modeling capability of the Kentucky Aerothermodynamic and Thermal-response System (KATS) by coupling with solid solver based on a novel nonlocal meshfree Lattice Particle Method (LPM) to investigate material surface erosion and failure due to high-velocity particle impact relevant to NASA missions.

Understanding and being able to accurately predict materials surface erosion and failure due to high-velocity particle impact is relevant for NASA current and future missions. In the case of planetary entry application, the thermal protection system (TPS) materials are susceptible to impact by hypervelocity particles such as dust particles suspended in the Martian atmosphere during Mars landing and sample return. Accurate assessment of surface erosion is necessary to avoid over-design of the TPS. In the case of spaceflight application, spacecraft are subject to micro-meteoroid and orbital debris (MMOD) impact damage which have the potential to degrade performance, shorten the mission, or result in catastrophic loss of the vehicle. Material surface erosion due to high-velocity impact is also relevant to the aerospace propulsion engine applications. When operating in dust-laden environments, engine components are impacted by solid erosive particles entrained in the gas flow, which results in significant material removal that can lead to deleterious effects in engine performance. All these must be carefully studied to support NASA missions.

The overarching goal of the project is investigation of materials surface erosion and failure due to high-velocity particle impact related to NASA applications including TPS, spaceflight and next-generation aerospace propulsion engine applications. To achieve this goal, a set of multiscale multiphysics computational tools capable of modeling materials pervasive failure with coupled flow effects will be developed based on LPM and KATS. High-velocity impact tests will be conducted to provide data for validation of the developed computational tools. The investigation will provide fundamental insights on the nature of material surface erosion and failure due to high-velocity particle impact. The tools developed and the knowledge gained in this project will be useful for capsule and vehicle performance modeling and simulation and materials design for TPS and aerospace propulsion engines for NASA current and future missions. As a university program, this project will also train and prepare the next generation of aerospace scientists and engineers."

23-2023EPSCoR-0020

Efficient and High Quality Space Robotic VR Teleoperation through Neural Scene and Object Reconstruction

Brown University

Dr. Ralph Milliken

"We aim to significantly improve robotic teleoperation efficiency and quality for applications in space, such as reconstruction of the lunar environment around a rover for remote controlled sorties, or robotic manipulation of objects within the lunar environment. The objective is to allow the human operator to naturally reason about the detailed 3D shape of the environment and objects around a robot, to make declarative control instructions and predict the outcome of actions within a 3D environment, and for the robot to perform more complex semi-automatic control operations from these declarative instructions. Meeting this objective will require 1) the development of core science in new methods of visual computing, AI, and human-robot interaction (HRI) called ‘neural fields’, in which the PIs are leading experts, and 2) specific consideration of how neural field methods could apply to lunar robotic teleoperation needs as part of the NASA Artemis program.

This science and application merits study because, in the last two years alone, neural field techniques have dramatically improved the detail and accuracy of the reconstruction of 3D geometry and appearance for real-world scenes and objects, exceeding the capabilities of classical photogrammetry and allowing photorealistic reproductions from arbitrary angles. Neural field techniques have also increased the compactness in bytes of the recovered scenes and objects, producing 3D representations that need fewer bytes than their equivalent 2D images. This makes them potentially well suited to the space teleoperation scenario: instead of transmitting image and video feeds, neural reconstruction can form compact representations of the world around a robot, transmit this, then recreate a photorealistic image for the human operator. This can be thought of as `scene compression’ rather than classical `image compression’. At the same time, both the human and the robot can exploit the knowledge of the recovered geometry for analysis and planning, leading potentially to better human awareness when making control decisions and to better execution of those control decisions by the robot. This is especially true when using immersive view and control interfaces, such as virtual reality (VR), that allow an operator to act as if they were in the same space as the robot via these neural field reconstructions.

The proposal will culminate in a teleoperation demonstration on tasks co-designed with NASA, backed by evaluation via experimental evidence through user studies. We will also evaluate the impact of the neural scene reconstruction methods in 2D and VR settings when compared to traditional image and video feeds and in their ability to accurately reconstruct scene and object representations, and their impact upon semi-autonomous control. In sum, we hypothesize that more efficient but still high-quality teleoperation can be achieved by investigating the core science and applications to space of new neural field scene and object reconstruction methods.

We will work with NASA Goddard Space Flight Center, where AR/VR and robotic teleoperation are of particular interest for the Artemis program to the Moon, via NASA engineers and scientists Marc Lupisella and Brent Garry."

23-2023EPSCoR-0021

Multifunctional Zero-standby Power Sensing and Reconfigurable Photonic Integrated Circuits

University of Delaware

Prof. William Matthaeus

"NASA's DISCOVER and EXPLORE strategic goals require a variety of types of detectors and sensors. Due to the limited capacity of satellites and space probes, miniaturized sensors with low energy consumption are of particular interest. Because NASA's missions to explore solar system, universe, and deep space require a prolong travel time before and between events to be recorded by sensors, sensors consuming near zero power until an event of interest wakes them up significantly expand their lifetime during these missions. However, the standby power of current sensors is not ideal. Motion sensors or light sensors in a conventional LED bulb consume 0.1W to 1W in standby. Electronic switches and sensors with zero-standby power are ideal for the detection of infrequent but time-critical events such as fire, projectiles, explosives, earthquakes, and reconfigurable RF photonics circuits. They are particularly suitable for long-standby-time missions, such as planetary exploration and space sensing. Sensors with zero-standby power and low operation power consumption will be the ideal loads for both laser sail and solar sail which have superiority of speed but carry small loads.

Meanwhile, photonic integrated circuits (PICs) demonstrate great potential for next generation space applications especially in the fields of communications, signal processing, and sensing. However, many components of PICs, such as optical amplifiers, modulators, and switches, consume much higher power than their electronic counterparts. Reconfigurable PICs operating at low operation power are in heavy demand.

In this project, PIs will combine their complementary expertise to demonstrate multifunctional zero-standby power sensing and reconfigurable photonic integrated circuits, providing extremely low power solutions for NASA missions:

O1: Develop scalable near zero-standby power switches. These switches can serve as event-driven power switches for electro-optical sensors, communication units, and even the main switch of a whole space probe system in a deep-space exploration mission.

O2: Develop a versatile reconfigurable photonic integrated circuits sensor system with near zero-standby power and low-operation power. By incorporating near zero-standby power switches for sensors awaken and reconfigurable components for fast and frequent signal processing, the proposed PICs sensor system significantly reduces power consumption for signal processing and for optical-to-electrical conversion by units such as detectors and optical amplifiers.

This proposed work will advance the state-of-the-art low power technology in optoelectronic switches and reconfigurable PICs. Successful completion of this work will lead to scalable near zero-standby power switches which may be used in sceneries from single waveguide, single devices, to chips and even a whole space probe system. By combining these switches and other reconfigurable components, PICs consuming very low power will be achieved and fit in ultracompact systems such as a space probe driven by laser sail or solar sail. Through our proposed efforts, we expect to bring this technology from TRL1 to TRL4.

Successful completion of this work will contribute to the development of Delaware state research capability in the area of integrated photonics and sensors technology. It attracts students in materials science and electrical engineering, enhancing the NASA mission “strengthening STEM education through inspirational missions and collaboration with the academic community”. It will also help to develop partnerships with below-mentioned research centers, providing opportunities to expand the research infrastructure, science, and technology capabilities of Delaware State."

23-2023EPSCoR-0022

Physics-Informed-AI Enabled Smart Electrospinning of Nanofiber Membranes Towards In-Space Manufacturing

Wichita State University

Dr. Leonard Miller

"Overview: With the growing and emerging NASA interests in deep space exploration (e.g., the exciting launch of Artemis I rocket on November 16 of 2022 and subsequent Artemis missions to land humans on the Moon, as well as NASA's next-stage vision to land on Mars), In-Space Manufacturing (ISM) beyond the earth is of immediate need and is extremely essential to enable flexible on-demand manufacturing and mission sustainability. Most existing ISM techniques are rooted in Additive Manufacturing (AM), which: (1) often suffers from the impact of low/micro-gravity environments in space; and (2) mostly focuses on printing macroscale solid parts, while not being effective to print nanostructured thin parts like functional nanofiber membranes.

To overcome challenges of AM, this project pioneers a novel ISM paradigm via creating a physics-informed-AI enabled compact electrospinning (PEACE) system for sustainable and scalable production of high-performance functional nanofiber membranes (FNM), and explore/demonstrate its potential towards future ISM. Compared with AM, this electrospinning-based manufacturing paradigm: (1) is driven by electric forces and does not rely on gravity, thereby having promising potential for ISM; and (2) fabricates nanostructured thin parts like functional membranes in space, which complements AM that prints macroscale solid parts. More specifically, two fundamental research questions will be answered to demonstrate the ISM potential via PEACE: (1) how does the electrospinning system work under space conditions (i.e., low/micro-gravity); and (2) how to optimize the entire electrospinning process towards scalable and high-performance FNM fabrication under a small size of training data, since material resources in space are often limited and expensive.

The project objective will be achieved via close multi-institutional partnerships among three Kansas Universities (Wichita State University, Kansas State University, and the University of Kansas), three NASA research centers (NASA Marshall Space Flight Center that directly leads the national ISM program, NASA Ames Research Center, and NASA Glenn Research Center), two government agencies (Argonne National Laboratory, Applied Physics Laboratory), and three business/industry partners with a strong economic footprint in Kansas (Spirit AeroSystems, Meta Platforms Inc., and HCI Energy)

Impact: The proposed innovative PEACE system will facilitate NASA's manufacturing paradigm shift from "factories on earth" to "factories in space," thereby enabling a series of future complex and long-duration deep space missions that are previously impossible. This project opens up a new electrospinning-driven avenue towards future ISM, which complements the current AM pathway. Project outcomes will create immense scientific value and economic benefit to both NASA and Kansas. Specifically, (1) on the NASA side, we directly target the need of NASA's ISM program to explore technologies and economic processes that enable sustainable on-demand manufacturing for future long-duration space missions on the International Space Station (ISS), Moon and Mars; (2) on the Kansas side, Wichita has earned reputation as the "Air Capital of the World" since 1928 and has bases of multiple leading aircraft/aerospace industries. Project success will enable Wichita and Kansas to develop a new research enterprise directed toward long-term, self-sustaining, nationally-competitive aerospace research capabilities on ISM, which contributes to Kansas's aerospace economy and expand the nation's base for aerospace research and development. A broad class of research-integrated educational initiatives with a wide range of dissemination and outreach activities will attract students to pursue data science and advanced manufacturing studies, research and careers, especially female and underrepresented minority groups."

23-2023EPSCoR-0024

IDEAS: LA: Idaho Exploration And Science Lunar Analog

University of Idaho

Dr. Matthew Bernards

"Key, central objectives:
NASA's planned return to human exploration of the moon with Artemis III in the next several years and subsequent plans to continue onward to Mars are part of a paradigm shift in space exploration. While engineering applications have dominated Extravehicular Activities (EVAs) since the end of the Apollo missions in the 1970s, the Artemis mission EVAs will be driven by science questions meant to elucidate the geologic history and evolution of the planets in our solar system. The scientific success of the Artemis missions will depend on carefully designed EVA plans grounded in high-fidelity analog systems tested on Earth before they are conducted under the high-risk conditions of space. In support of that effort, we propose to conduct targeted lunar analog field studies in the eastern Snake River Plain, Idaho, that will a) provide testing grounds for high-priority lunar targets as well as b) evaluate and provide recommendations for the astronaut geolocation system currently intended for the early human lunar missions of the Artemis spaceflight era.

Methods and techniques:
The proposed research has two branches: 1) field analog investigations of high priority lunar targets using the eastern Snake River Plain volcanic field, and 2) evaluation of errors within the intended Artemis III astronaut tracking procedure, including the development of training recommendations based on our findings. In our science branch, we will: investigate the use of field-portable instruments to differentiate between primary and hydromagmatic pyroclasts; conduct 3D lidar scans of lava tubes, studying their morphology and fractal scales as well as evaluating longitudinal and vertical variation in mineralogy and geochemistry; and use high-resolution UAS data to characterize lava surface morphometry as a function of sediment infill, developing a means by which to interpret the original morphology of lunar lava flows partially buried by lunar dust. Throughout all of our field campaigns, we will collect and analyze data on the accuracy of researchers locating themselves in space using the same alphanumerically gridded map system that the Artemis III astronauts will use. Field placements using that system will be evaluated against both interpretations taken from video feeds of chest-mounted cameras on the researchers and drift-corrected GPS logs. Patterns of errors in location will enable us to

identify particular vulnerabilities of the self-location method and to create training recommendations to be used to help the Artemis astronauts mitigate such errors.

Significance:
The proposed work will provide original lunar analog data for high-interest features, as well as result in training recommendations to improve the self-location of astronauts in the absence of a beacon system. This serves the Artemis exploration program as a whole through science, and the Artemis III mission specifically from an operations perspective. The proposed work would also lay important groundwork to establish Idaho as a leader in lunar analogs and provide career training for students in space exploration, including funding summer or semester-long internships with NASA collaborators at Goddard Space Flight Center."