Contents

22-22EPSCoR-0003 *Metastable Oxygen Nanobubbles to Advanced Life Support Systems in Space Exploration*

Maine Space Grant Consortium

Director/PI: Dr. Terry Shehata

Science PI: Dr. Onur Apul

NASA MD: SMTD

Nanobubbles (NB) are ultrafine gas domains in liquids with nano-scale diameters that are typically smaller than 1,000 nm. They have remarkably large interfacial surface areas and unique physicochemical properties owing to their small dimensions. Recent studies have shown that they can be suspended in water for hours up to months and produce reactive oxygen species (ROS) without added catalysts. Despite these interesting observations, applications of NBs in life support systems for space exploration have not been widely explored. We believe NBs have the potential to become a key component of next generation biphasic fluids to address the essential water and oxygen supply needs of space transport, survival, and colonization. In addition, this technology has breakthrough potential for engineered terrestrial systems such as conventional water and wastewater treatment, horticulture, aquaculture, and algae cultivation. The proposed project aligns with the Space Mission Technology Directorate research areas, particularly supporting the Maine Space Complex. The objectives of the following research tasks were co- developed with Dr. John Graf technology development lead for life support systems at NASA Johnson Space Center (JSC), who linked our research activities to the priorities of his division and to Dr. Emily Matula, extravehicular activity flight controller and an expert of algae cultivation in space at NASA JSC and to Dr. Chris Matty, international space station (ISS) program integrator and expertise in crew life support in ISS at NASA JSC.

This transformative and novel research will explore the fundamental characteristics of NBs with pragmatic viewpoints to advance human spaceflight life support systems. The first phase of the project will focus on fundamental aspects of NBs including generation, stability, mass transport, interfacial interactions, and reactivity. The second phase will demonstrate their application potential for algae growth for sustainable O_2 harvesting in space. The completion of this project is also going to lead new research opportunities at subsequent technology maturation stages such as testing NB application feasibility at ISS. This proposed project is designed to build research capacity for production, characterization, and application of NBs at University of Maine (UM) and University of Southern Maine (USM). The project will stimulate competitive research in Maine and help junior faculty and their graduate/undergraduate students become national leaders in this emerging field. Our team will develop Maine's first liquid reaction platform in the form of CubeSats and participate in UM's High-Altitude Ballooning Program and collaborate with blueShift Aerospace Inc., a Maine-based aerospace company, to perform two rocket launches as technology demonstration.

The multi-institution collaboration is led by Dr. Onur Apul, an early-career faculty member at UM, who is establishing a research program in the nano-enabled water treatment field with co-investigator Dr. Ali Abedi, Associate Vice President for Research. Other collaborators include Dr. Garcia-Segura, an early-career, Hispanic faculty member at Arizona State University and Dr. Ashanthi Maxworth, an early-stage faculty member and her expertise is CubeSat flight control at USM. Investigators are active collaborators in Maine Space Grant Seed Project and co- authored several publications and currently developing a decadal survey with NASA researchers. The investigators are engaged with diverse teams of graduate and undergraduate students, including underrepresented groups in engineering, such as women and members of minority groups. At least 50% of all researchers will be selected from underrepresented groups to increase the diversity of the researcher cohort in corresponding institutions. Additionally, student training and equipment acquisition in Maine will be the two essential outcomes (50% of the total direct cost) of the proposed project.Kentucky s NASA EPSCoR jurisdiction solicited proposal responses from Kentucky university-led research teams to address the ISS flight opportunity listed in the FY2020 NASA EPSCoR International Space Station (ISS) Flight Opportunity announcement (NNH20ZHA002C). The NASA Kentucky EPSCoR program collaborated with responding faculty researchers to develop and submit a relevant proposal that will address NASA EPSCoR ISS objectives.

22-22EPSCoR-0006 *A transdisciplinary approach to assess measurements of albedo across snowy landscapes using multiple sensors at multiple scales*

Montana Space Grant Consortium

Director/PI: Dr. Angela Des Jardins

Science PI: Dr. Eric Sproles

NASA MD: SMD

This project will apply high-resolution UAV-based measurements of broadband and hyperspectral surface albedo over three varied snow-covered landscapes. These data will be used to assess and quantify the differences between calculated values of surface albedo from Landsat 8/9 (USGS & NASA) and Sentinel 2a/b/c (European Commission (EC) & European Space Agency (ESA)). Our efforts will also advance capacity to incorporate UAV-based measurements of surface albedo into operational calibration and validation products.

Our project also looks forward, addressing the goals of NASA's Terrestrial Hydrology Program's (THP) SnowEx, a five-year field campaign to address the most important gaps in snow remote sensing knowledge, and provide insights and knowledge that support a future snow-focused satellite mission.

Our research is trans-disciplinary and follows a continuum of scientific research from project testing through data curation. We will advance sensor technologies, test and optimize field methods, and collect robust datasets. Subsequent analysis and assessment of these data will be in collaboration with USGS Landsat project science and Landsat calibration/validation teams, with a focus on the newly launched Landsat 9 mission. These data will be systematically organized in accordance with FAIR practices to enable their viability for the scope of this project and as a legacy dataset with long term viability.

We also place a considerable emphasis on graduate education and training by supporting a simultaneous and co-mentored cohort of two PhD students (one in Earth Sciences and one in Electrical Engineering, PhD), in addition to an undergraduate researcher(s) throughout the project.

Dr. Christopher Crawford (Collaborator, USGS) a Research Physical Scientist and the Landsat Project Scientist for the USGS is a collaborator on this project, with a research focus on remote sensing of the cryosphere. Dr. Crawford works directly with colleagues at NASA and the European Space Agency to further efforts to harmonize space observations from the Landsat and Sentinel-2 missions. His USGS research is focuses on remote sensing of the cryosphere.

Dr. Carrie Vuyovich, will serve as Technical Monitor for this project. Dr. Vuyovich is a physical scientist in the Hydrological Sciences Laboratory at NASA Goddard Space Flight Center, and lead snow scientist for the NASA Terrestrial Hydrology Program and NASA SnowEx. Additionally, Dr. Charles Gatebe, Chief of the Atmospheric Sciences Branch at NASA Ames, will provide scientific counsel on this project, especially as it relates to the Terrestrial Hydrology Program's (THP) Snow Albedo Test Bed Scoping Studies.

The areas of expertise for this proposal require a combination of snow hydrology, UAV-based measurements, optical and electrical sensors, and earth data informatics.

22-22EPSCoR-0007 *Femtosecond Laser Functionalized Surfaces for Cryogenic Fluid Management*

University of Nebraska at Omaha

Director/PI: Dr. Tarry Shehata

Science PI: Dr. Craig Zuhlke

NASA MD: HEOMD, SMD, STMD

NASA's Artemis program is focused on returning astronauts to the Moon and paving the way for human missions to Mars. To support this program and related space exploration, NASA relies on cryogenic propulsion systems and associated technologies, including those involved in storing, transferring, and controlling the pressure of cryogenic fluids. Collectively, these technologies are referred to as Cryogenic Fluid Management (CFM). The need to advance CFM technology has been accelerated with the launch of the Artemis program, which will use liquid oxygen and liquid methane as propellants. Propellant management devices (PMDs), specifically liquid acquisition devices (LADs), are critical to the function of fuel and storage tanks in microgravity. LADs are structures within the tanks that direct fluid to the output. In microgravity, surface tension is the most significant driver of fluid behavior, as opposed to the gravity field on a planet. Therefore, in microgravity, the wetting property of a surface—that is, the ability of a liquid to maintain contact with a solid surface—becomes an important factor in controlling the location and flow of fluids in fuel and storage tanks.

LADs can be improved by altering the wetting properties of the LAD surfaces to attract fluids (supercryophilic) and by ensuring that surfaces in other parts of the tank repel fluids (cryophobic).

The Center for Electro-optics and Functionalized Surfaces (CEFS), co-Directed by Dr. Craig Zuhlke (Sc-I) and Dr. George Gogos (Co-I) at the University of Nebraska-Lincoln (UNL), has developed techniques to tailor the surface properties of materials using femtosecond laser surface processing (FLSP). With FLSP, the properties of materials are altered by creating self-organized micro- and nano-scale surface structures combined with surface and subsurface chemical and microstructure changes using finely controlled ultra-short light-matter interactions. In short, FLSP directly modifies the original material. This results in a durable surface that can withstand high and low temperatures and is suitable for use in demanding environments, including space. FLSP is superior to paints or coatings because it directly alters the metallic surface micro-layer, which, therefore, will not delaminate over time. Furthermore, with FLSP, surface properties are modified without the added weight, hazard of toxicity, and long curing time associated with many coatings. Using FLSP to control the wetting properties of surfaces with respect to cryogenic fluids has the potential to drastically improve CFM.

CEFS has conducted extensive research on using FLSP to alter the wetting properties of metallic surfaces. Propellant tanks are typically made of aluminum, stainless steel, or titanium, all of which have been successfully functionalized with FLSP to become superhydrophilic or superhydrophobic. However, research has not been conducted on the interaction of cryogenic fluids with FLSP surfaces. Furthermore, FLSP has not been applied to composite materials, which are being developed for use in cryogenic fuel and storage tanks. We propose to develop FLSP techniques to alter the wetting properties of metal and composite tank materials with respect to cryogenic fluids. Creating cryophobic surfaces is expected to be more difficult than cryophilic surfaces and will require advanced control of micro- and nano-structures and surface chemistry. To conduct the research, we have assembled a multidisciplinary team with a history of collaboration and expertise in the areas of femtosecond laser-matter interactions for surface functionalization, fluid mechanics, materials science, and surface chemistry. CEFS has established collaborations with NASA scientists with seed funding in this research area and has provided them with initial FLSP-modified samples for testing. However, there is a need for a multi-year dedicated effort to develop surfaces that will enable NASA to reach its space exploration goals.

22-22EPSCoR-0009 *Development of an Improved Visualization Tool for the Assessment of Climate Change Impacts on Mississippi Sound Coastal Waters using Integrated NASA Satellite and Novel Autonomous Surface Vessel Collected Field Datasets*

The University of Mississippi

Director/PI: Dr. Nathan Murray

Science PI: Dr. Padmanava Dash

NASA MD: ESD, SMD

BACKGROUND: NASA’s Ocean Color satellites provide time-series of chlorophyll a (Chl-a) data of the global ocean using which net primary productivity (NPP) can be computed. NPP is important because it is the process that forms the foundation of food webs. The satellite-derived Chl-a, however, have higher levels of uncertainty in the coastal waters due to confounding effects of multiple components present in optically complex coastal waters. Hence, the estimations of NPP and how they affect the carbon cycle at the land-sea interface are erroneous or not available. Further, water quality in the region east of the Mississippi River Delta have been poorly measured relative to the adjacent system west of the Mississippi River Delta. In fact, several studies have highlighted the frequency and spatial extent of hypoxia east of the Mississippi River Delta as an open question.

OBJECTIVES: The objective of the proposed work is to improve and develop remote sensing algorithms for Chl-a for the operational monitoring of coastal waters of the Mississippi Sound and implement the algorithms to advance an in-house visualization tool, which can be used to assess the climate change impacts on NPP of coastal waters.

METHODS: The proposed research will leverage the interactive map-based water quality visualization tool developed by the Sc-I (https://water.geosci.msstate.edu/), and a recently acquired solar powered autonomous surface vessel (ASV) at MSU, which is greatly enhancing in-situ data sampling capabilities and producing data from thousands of sites per deployment. The proposed research will measure water quality parameters from the Mississippi Sound using the ASV to directly address the limitations of satellite products in coastal waters. The use of the spatially rich dataset from the ASV together with NASA's satellite data will help develop robust remote sensing algorithms, using which more accurate Chl-a time-series maps will be generated. The updated Chl-a maps will help accurate calculation of NPP in the Mississippi Sound. A time-series of NPP maps will be used to determine the impacts of climate change and land use and land cover (LULC) change on productivity of the Mississippi Sound. The objectives will be met by an interdisciplinary team of researchers from three universities within the Mississippi NASA EPSCoR jurisdiction (including an HBCU) with complimentary expertise in remote sensing of water quality (Dash-MSU), machine-learning (Bhushan-MSU), agricultural and biological engineering (Chesser-MSU), geo-informatics (Easson-UM), and remote sensing of vegetation productivity (Kulawardhana-JSU). The team will carry out outreach activities with local K-12 schools to raise awareness about the impact of climate change on local and global ecosystems, and the Mississippi Dept. of Marine Resources and the Mississippi Dept. of Environmental Quality.

RELEVANCE TO NASA PRIORITIES: The proposed research is aligned with the NASA Earth Science Division's mission to "…develop a scientific understanding of Earth as a system ... to enable better assessment and management of water quality and quantity [and] accurately predict how the global water cycle evolves in response to climate change." NASA's Ocean Color satellites play a vital role in predicting global change to assist policy makers in making sound decisions concerning the protection of our environment. The proposed research will enhance the NASA satellite data based NPP estimates using in-situ measurements. It will primarily focus on the Mississippi Sound, which is backbone of Mississippi's economy. The research will help in assessment of the effect of climate and LULC changes on the coastal waters and may provide guideline for the policymakers for better resource management. Further, the Visualization tool developed in this study will be open-source, and can be easily extended to other coastal ecosystems, and thus has the potential to impact climate change studies beyond this project.

22-22EPSCoR-0013 *High performance W-band GaN power amplifiers for cloud Doppler radar arrays*

University Of Delaware

Director/PI: Dr. William Matthaeus

Science PI: Dr. Yuping Zeng

NASA MD: AETD, SMD

Needs: One of the NASA aerosol-cloud-ecosystems missions is to reduce the uncertainty about climate forcing in aerosol-cloud interactions and ocean ecosystem CO2 uptake in order to provide precise predictions of local climate change, including changes in rainfall. To provide more precise climate predictions, a simultaneous measurement of aerosol and cloud properties is required. However, current space borne radars do not address cloud particle size and phase information, and they do not provide cross-track imaging, limiting the capabilities of observing low-level clouds, mid/high-latitude precipitation and convection. Advances in radar technology are needed. In particular, a cross-track scanning cloud radar that can measure cloud droplet size, glaciation height, and cloud height, with channels at 94GHz (W-band) and possibly 34GHz (Ka-band) should be implemented.

Objectives: Conventional radars rely on tube-based high peak power transmitters which are heavy and bulky, requiring high voltage power supplies leading to increased cost and reliability issues. Solid-state power amplifiers can be potentially used to mitigate these challenges. Among the semiconductors (Si, GaAs, InP, GaN) for solid-state power amplifiers, gallium nitride (GaN) devices offer high Johnson's figure of merit, enabling the high performance in terms of speed and power. Additionally, they are immune to performance degradation at higher temperatures and ionizing radiation in the space environment. We propose to develop high performance W-band GaN power amplifiers for cloud Doppler radar arrays using Sci-I Zeng's group recently developed high performance GaN high electron mobility transistors (HEMTs), which leverage the superior performance of GaN. Because of the low-cost silicon substrate and its scalability, we choose to develop the power amplifiers with GaN-on-Si HEMT technology. This is based on Zeng's group's recently demonstrated GaN-on-Si transistors with record high performance, which has been highlighted by "Semiconductor-Today" and other news media. Co-I Saxena has demonstrated expertise in high-speed CMOS and BiCMOS analog/RF integrated circuit design for fiber optic transmitters and receivers.

To realize the goal, we will: (we will: (1) optimize the material epilayer structure by TCAD simulation for enhanced DC and RF performance (Zeng); (2) develop the HEMT device and on-chip passives fabrication process (Zeng); (3) develop amplifiers: build transistor simulation models using Keysight's Advanced Design System (ADS) software (Zeng); Using the GaN-on-Si HEMT models and on-chip passives and transmission line data, design and layout W-band PA circuits for the targeted spaceborne Radar specifications (Saxena); fabricate PA ICs using the GaN-on-Si process (Zeng); Characterize the fabricated power amplifiers using W-band experimental setup (Saxena and Zeng).

Significance: Our proposed work will enable the state-of-the-art GaN-on-Si high electron mobility transistors performances; it will provide high frequency GaN power amplifiers for W-band cloud radar applications with power gain >12dB, peak output power >30dBm. This will enable a radar instrument with high power efficiency, temperature robustness, radiation hardness and reduced size and weight, allowing for the simultaneous measurement of aerosol and cloud properties to provide more precise predictions of local climate change. 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 high speed electronic devices and IC technology for reduced size, weight and power components of small spacecraft with high bandwidth communications, aligning well to the NASA missions and strengthening STEM education goal. It will help to develop partnerships research centers (i.e. GSFC, etc.) and expand the Delaware research infrastructure, science and technology capabilities.

22-22ESPCoR-0014 *On-Demand Manufacturing of Smart Systems for Structural Health Monitoring*

University of Idaho

Director/PI: Dr. Matthew Bernards

Science PI: Dr. Zhangxian Deng

NASA MD: HEOMD

Inflatable reentry vehicles and habitats are attractive for NASA's Moon to Mars Exploration campaign and the next-generation space station, because of their high volume-to-mass ratio and packaging efficiency. Since inflatable structures are usually thin-walled, ionizing radiation and micro-meteoroid orbital debris pose considerable threats to their integrity. Consequently, there is a critical need for reliable and integrated structural health monitoring (SHM) systems that can detect or predict structural damages in inflatable structures. NASA has a long history of using traditional SHM sensors based on passive materials, such as resistive strain gauges, capacitive strain gauges, and optical fibers. While these sensors are well-established for rigid structures, their applications in soft inflatable habitats are challenging due to difficulties in installation, data transfer, power distribution, and maintenance.

Smart materials have much to offer over other passive materials, since their properties vary significantly in response to stress, temperature, electrical or magnetic fields, or other external stimuli. The project goal is to combine smart materials development and On-Demand Manufacturing of Electronics (ODME) techniques to deliver a wireless, flexible, self-sustaining, and multifunctional SHM system aiming at achieving a technology readiness level of 5. We will investigate four types of smart materials: (1) piezoelectric materials that build up surface electrical charges when stressed, (2) magnetostrictive materials that demonstrate magnetic property variation when subjected to mechanical loadings, (3) magnetoelectric materials that output electricity when driven by a magnetic field, and (4) shape memory polymers that exhibit visible and repeatable deformation during heating. We will focus on two promising ODME techniques that align with NASA's ongoing efforts, have been proven to work in microgravity via parabolic flight testing, and are currently available at Boise State: direct ink writing and plasma jet printing. To accelerate ink development and lower the risk of this project, we will also use aerosol jet printing as an initial step to validate plasma jet inks.

Our interdisciplinary team consists of material scientists, electrical engineers, mechanical engineers, and Science, Technology, Engineering, and Math (STEM) educational specialists. We will leverage and bring together the multiphysics modeling and characterization expertise, nanofabrication and additive manufacturing expertise, and device prototyping expertise. In collaboration with NASA Marshall Space Flight Center, NASA Ames Research Center, and NASA Johnson Space Center, we will focus on three specific objectives:

a) Synthesize smart material inks—We will merge top-down nanofabrication techniques with ink synthesis. The anticipated outcomes are a versatile laser ablation technique enabling in-space ink customization and material recycling along with novel smart nanoparticle colloid inks and composite pastes ready for ODME.

b) Print and characterize smart thin films—We will optimize printer settings and investigate low-temperature material post-processing methods to produce smart material thin films for SHM applications. The anticipated outcome is an unprecedented database correlating material fabrication procedure with the resulting material properties.

c) Prototype a smart system for structural health monitoring—By printing the proposed smart material inks together with commercial inks, we will prototype smart devices suitable for in-space applications, including force sensors, strain gauges, energy harvesters, and morphing antennas. We will also merge individual smart devices with customized and commercial integrated circuits to form an all-in-one SHM system. The anticipated outcome is a flexible, self-sustaining, wireless, and multifunctional smart system enabling large-scale, non-destructive, and distributed SHM.

22-22ESPCoR-0015 *Surface States and Doping in Aluminum Prototypes for NASA Detector Development*

West Virginia University

Director/PI: Dr. Melanie Page

Science PI: Dr. Mikel Holcomb

NASA MD: SMD

In NASA astrophysics missions, particularly at long wavelengths in the far infrared to microwave, extremely sensitive detectors are required to measure the faint signals from astronomical sources. In order to avoid thermal fluctuation noise, the detectors typically need to operate at sub-Kelvin temperatures, in which case superconducting detectors can be used to achieve high sensitivity even for low energy photons. We will focus this proposal on two types of superconducting photon detectors: microwave kinetic inductance detectors (MKID) and transition-edge sensors (TES). Both detector technologies are used in current NASA missions, and NASA is working to improve both technologies for instruments in future missions, such as the Origins Space Telescope. Aluminum is an important low temperature detector material because of its well understood superconducting properties. However, there are a few scientific challenges that are problematic to repeatable control of these systems, which can be answered by the team at West Virginia University. Holcomb, Johnson, Romero and Bristow form the ideal team for this work based on their expertise and already established research experience together and with NASA's Detector Development Lab.

One of these challenges is the formation of various phases of oxides and fluorides on the superconducting metal surfaces and nearby dielectric surfaces during detector fabrication. Two Level System (TLS) defects in those disordered dielectrics add noise and reduce the responsivity of MKIDS. The oxides and fluorides formed can be studied and characterized in new ways through x-ray photoemission, x-ray absorption and ultrafast optics. Initial work demonstrates high sensitivity to these phases. Another challenge is that you would like to be able to tune (i.e., engineer) the superconducting transition temperature (Tc) of the material used in these photon detectors so that the sensitivity can approach the photon noise background limit for the range of optical load powers and optical frequencies encountered in a particular space mission application. Lowering the Tc of a TES bolometer helps optimize it for lower optical powers and lower photon energies. Lowering the Tc of an MKID lowers the minimum photon frequency to which it responds. Adding a dilute solution of manganese atoms to pure aluminum is known to decrease its Tc, without unfavorably broadening the shape of the resistivity versus temperature curve, and this effect has been used in both MKID and TES detectors. However, testing has demonstrated that sometimes the resulting transition temperature can change upon annealing. It is hypothesized that the Mn upon annealing may be clustering, which could be determined spectroscopically through x-ray absorption and ultrafast optics.

To address these challenges, the proposed program will identify the alternative phases on these Al devices, determine the effect of annealing and film thickness on Mn ordering in doped systems, reveal the underlying physics by means of ultrafast optical characterization, and utilize theoretical methods (such as density of states, band structure and vibrational spectroscopy) to identify the lowest energy states and the nature of the Mn clustering. All objective findings will be correlated to device performance. By understanding the alternative phases and Mn ordering in these systems, the detectors can be better engineered, allowing reliable, high resolution astrophysics measurements.

Relevant NASA MD: Science Mission Directorate

Relevant NASA Center: NASA Goddard Space Flight Center

22-22ESPCoR-0016 *Multi-scale data-driven modeling of radiative transport through thermal protection systems*

University of Kentucky

Director/PI: Dr. Alexandre Martin

Science PI: Dr. Savio Poovathingal

NASA MD: STMD, SACD

The NASA Kentucky EPSCoR Program’s mission is to enhance 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. With this motivation, and entry, descent, and landing (EDL) technologies being a key NASA priority, we propose to partner with three NASA centers to fundamentally transform the current state-of-the-art approach in modeling the degradation and failure of thermal protection system (TPS) materials used on space capsules. Specifically, we aim to improve the understanding of the penetration of flowfield (shock-layer and wake flow) radiative emissions into the TPS material, its coupling with other thermochemical processes, and the potential degradation and failure of the TPS material. These advancements will benefit the New Frontiers Dragonfly mission, and missions under development such as the Mars Sample Return (MSR), Venus Entry, and potential Discovery class missions to the gas and ice giants. It will also aid the analysis of MEDLI2 data from the Mars 2020 mission.

The proposed effort that blends modeling tools with rigorous experimental validation is aimed at reducing the uncertainties associated with the effect of flowfield radiation on TPS materials. Advancements will be made to reveal insights on radiative physics at the microscale by explicitly accounting for the microstructure of the TPS material and simulating the transport of photons through the material microstructure. The modeling will be validated through novel spectral measurements, where effective transmission and scattering functions for thin TPS small samples will be obtained. Investigation of radiative transfer (transport) through the entire TPS material will be performed through the expansion of the current state-of-the-art material response solver developed at the University of Kentucky, the only U.S. University with such capability. The macroscale modeling through the entire TPS material will be performed in conjunction with a custom variant of Knowledge Distillation, a machine learning technique, to reduce the errors and uncertainties associated with the underlying assumptions in the macroscale approach required for radiative transport modeling. The machine learning technique will be trained against the microscale data, which will contain all of the relevant physics at the highest fidelity. Modeling efforts at the macroscale will be compared against innovative effective radiative conductivity measurements that will precisely validate the energy transport mechanism in each mode of heating. Finally, custom-designed experiments will be performed in the Hypersonic Materials Environmental Test System (HYMETS) arc-jet facility at NASA Langley Research Center (LaRC) to demonstrate the reliability of the models and tools developed in this research effort. The modeling approach, coupled with the unique experiments is the first-of-its-kind collaborative effort, with the goal of creating an entirely new modeling paradigm for the design of TPS materials.

22-22ESPCoR-0017 *High-Temperature Effective Piezoelectric Composites for Future Space Self-Powering Sensors*

University of New Hampshire

Director/PI: Dr. Antoinette Galvin

Science PI: Dr. Yan Li

NASA MD: SMD, STMD

Piezoelectric materials can transduce mechanical deformation to electrical signals and vice-versa. This reversible feature not only makes piezoelectric materials good sensors to monitor the health of an operating system, but also allows them to harvest energy for power generation when traditional battery charging is impossible/inadequate in remote locations. A fundamental challenge of implementing self-powering sensors in space application is the temperature limit of current piezoelectric materials, which usually experience significant performance drop around 120 °C and complete loss of functionalities above 250 °C. Development of high-temperature effective piezoelectric materials will provide new possibilities for NASA to monitor system stability and make preventive maintenance and troubleshooting even in harsh environments. The proposed topic aligns with NASA's strategic objective in developing advanced materials for remote sensing and energy storage. Collaboration with JPL experts in piezoelectric device design will significantly increase the university-industry-government engagement for research, education, STEM workforce training and technology transfer.

The central hypothesis of this research is that piezoceramic composites, which are processed by adding Lead Zirconate Titanate (PZT) as the filler to the preceramic polymers, can push the temperature limit of existing piezoelectric ceramic-polymer composites. Firstly, unlike conventional polymers which start rapid thermal degradation above 200 °C, preceramic polymers can be converted to ceramics upon heat treatment. The unique polymer-to-ceramic phase transition allows the final piezoceramic product to exhibit complex shapes and hierarchical architectures that are otherwise impossible to achieve through traditional ceramic processing routes. The phase transition process also provides great flexibility for property tailoring through careful control of processing parameters. Additionally, adding PZT as the filler to the preceramic polymer matrix not only alleviates the internal damage formation which results in energy loss due to friction and damping, but also significantly improves the thermal stability of the entire composites.

Four research tasks will be carried out to understand how material selection, key processing parameters and microstructure/structure architecture design will influence the mechanical and piezoelectrical behavior of the PZT-PDC composites. 1). A multiscale computational framework will be developed to simulate the polymer-to-ceramic phase transition in the PZT-PDC composites under systematically varied PZT volume fractions and processing parameters; 2). A set of computational tools will be built for microstructure/structure architecture design, characterization, and implementation to the finite element model; 3). A coupled electromechanical model will be developed to evaluate the sensing and power harvesting capabilities of each PZT-PDC composite design; and 4). Model validation will be performed based on in-situ compression-piezoelectric test, SEM (Scanning Electron Microscope) analysis and existing experiment results. The proposed research will engage a collaborative network of faculty members, NASA JPL and DOE mentors, industry members, postdoc, graduate/undergraduate students to leverage the New Hampshire community knowledge in new piezoelectric material design, property prediction, manufacturing, and energy efficiency evaluation. If successful, the developed models, algorithms, and knowledge base from the research activities can be implemented into design decisions, which are not only important for new space material design and manufacturing, but also useful for training and educating a diverse future workforce in space engineering.

22-22ESPCoR-0018 *Translating hibernation for space torpor and remote emergency medicine*

University of Alaska Fairbanks

Director/PI: Dr. Denise Thorsen

Science PI: Dr. Kelly Drew

NASA MD: HEOMD

How to protect human life in the event of a medical emergency during near-earth spaceflight, and how to protect against loss of muscle and cognitive function during deep space exploration are challenges that must be overcome to enable a human presence in space. Towards that goal, we have used mammalian hibernation as a discovery platform, and revealed processes in two model, hibernating species, the small, arctic ground squirrel, and the human sized, black bear, that have potential to protect and repair muscle and brain from damaging insults. Hibernation protects vital organs from injury by hunkering down in a dormant state. Hibernation then repairs vital organs by rebuilding new or damaged cells. We have developed a therapeutic known as BCP-191 to induce a hibernation-like state that we call “synthetic” torpor. BCP-191 is a cocktail of three small molecules. One molecule induces synthetic torpor, while the other molecules minimize side effects. For example, the molecule in BCP-191 that induces synthetic torpor also causes hypotension, a life-threading side effect which limits safety. The other molecules block hypotension, but we do not yet know the optimal proportion of these components or the effects of BCP-191 on processes known to rebuild muscle and brain during hibernation. There is therefore a critical need to define ratios of components in BCP 191 to optimize safety and to minimize side effects.

Central Objective. Our primary objective is to reduce to practice, a therapeutic to induce a hibernation-like state in humans. This therapeutic (BCP-191) will protect astronauts from injury caused by an acute medical emergency, such as cardiac arrest or stroke or injury caused by exposure to high dose ionizing radiation. It will also protect astronauts from chronic loss of muscle or brain function caused by prolonged disuse or exposure to ionizing radiation. By reducing BCP-191 to practice we will answer NASA’s quest to reduce risk of medical emergencies during near-earth exploration and to reduce risk of loss of muscle and cognitive function during deep space exploration.

Objective 1. During the first 18 months, we will advance the technology readiness of BCP-191 from proof of concept to a defined formulation ready to move into investigational new drug (IND) enabling studies by administering escalating doses and measuring metabolic rate and blood pressure in rats. These experiments will establish a ratio of active components to suppress metabolism up to 60 percent of basal metabolic rate while maintaining mean arterial pressure above 60mmHg. Once completed, the ratio will be the basis for future studies to assess safety that will be used for an application to the FDA prior to testing BCP-191 in humans.

Objective 2. During year 2, we will learn how to maximize the benefit of synthetic torpor on muscle hypertrophy and brain function. We will do this by quantifying the effect of BCP-191 on expression of genes in muscle and brain that stimulate regrowth and repair. Our working hypothesis is that synthetic torpor will stimulate expression of the same genes we have seen increase during hibernation and that these genes contribute to repair and regrowth.

Objective 3: During year 3, we will complete data analysis and prepare manuscripts to communicate our findings. We will also work with the FDA to supply additional safety data needed to seek approval to test BCP-191 in healthy humans.

The significance of the proposed work is that determination of drug ratios will define a safe and novel formulation that will offer a strong scientific framework whereby BCP-191 can be developed for remote emergency medicine. It will also provide novel insights into new drug or nutrient-based treatments to regrow brain and muscle after disuse, atrophy or injury. Once completed we will be prepared for a pre-IND meeting with the FDA which is our next step towards testing BCP-191 in healthy humans and eventually in remote emergency medicine.

22-22ESPCoR-0019 *Planetary Methane in Ultramafic Contexts: Searching for Cyclicity in Methane Emissions at a Planetary Analog Site in Northern California*

Brown University

Director/PI: Dr. Ralph Milliken

Science PI: Dr. Dawn Cardace

NASA MD: SMD, STMD

Given enduring interest in methane detections on Mars (Mumma et al., 2003; Mumma et al., 2009; Webster et al., 2018; Giuranna et al., 2019; Knutsen et al 2021) and its cachet as a "potential biosignature on Mars" (cf. Yung et al., 2018), we aim to provide crucial Earth analog setting methane flux data, as the scientific community explores patterns and constraints on Martian methane. We will: (1) quantify methane gas flux from the land surface at a weathered ultramafic landscape in northern California, USA; (2) measure concentrations of dissolved methane, acetate, and formate in related groundwaters; (3) constrain spatial differences in methane dynamics across the field area footprint through time; and (4) complete microbial membrane lipid profiling work on priority subsurface region to determine whether or not a significant biological methane 'filter' is at work in this setting. We will conduct this work in cold and warm seasons to detect seasonal variation and assess aqueous geochemical conditions that may play a role in methane escape from the deeply sourced groundwater system active at the target field locale. We will resolve methane flux and shifts in aqueous carbon species' abundances to fill a gap in the scientific understanding of methane dynamics in natural ultramafic rock systems on Earth, and make comparisons to sites of extraterrestrial serpentinization more robust.

We combine multiple strategies to quantify the methane flux at the land surface at the northern California field site, weaving together data streams from LI-COR's portable backpack trace gas analyzer (CO2, CH4), Picarro's cavity ring-down spectroscopy unit (CO2, CH4), and rich complementary data from benchtop gas chromatography units (CH4, H2). Organic acids in groundwater will be measured using industry standard ion chromatography techniques. Lipid profiling from materials obtained from scientific monitoring wells in the serpentinite-hosted subsurface aquifer will rely on a modified Bligh and Dyer extraction technique followed mainly by gas chromatography mass spectrometry.

The NASA relevance of this work rests in the high interest in investigating terrestrial gas fluxes at sites that are apt analogs for habitable extraterrestrial bedrock. Serpentinites are appropriate units for such study, made more compelling by (a) the increasingly well described experimental data and theoretical models for gas generation through serpentinization (Etiope and Sherwood Lollar, 2013; McCollom, 2016; Etiope and Whiticar, 2019), (b) continued interest in serpentine-bearing planetary environments on Mars and ocean worlds as pertinent to origin of life science (Russell and Nitschke, 2017; Vance and Daswani, 2020), and (c) healthy debate and innovative science tied to resolving methane signals in the Martian lower atmosphere and, as examples, evaluating advective pressure pumping of methane from regolith (Viúdez-Moreiras et al., 2020) and regolith adsorption/desorption processes at Gale Crater (Moores et al., 2019).

The proposed work contributes significantly to the state of knowledge in the field: ultramafic rocks host source regions and transfer pathways that transmit deeply sourced methane (reduced carbon) to the hydrosphere and atmosphere (perhaps continuously). NASA Ames Research Center researcher M.N. Parenteau is a key mentor in this work, supporting new skills development in lipid analyses.

22-22ESPCoR-0021 *Arkansas - ARKSAT-3: Toward the Development of Technologies and Science Missions for Interplanetary CubeSats Flying in Formation as Active Spectroscopy Instruments*

University of Arkansas at Little Rock

Director/PI: Dr. Mitchell Hudson

Science PI: Dr. Po-Hao Adam Huang

NASA MD: STMD

The proposed work is focused on developing the technologies and science missions of Cube Satellites (CubeSat) equipped with active open-path spectroscopy in formation flight, enabling this terrestrial instrument in space free-flight from Technology Readiness Level (TRL) 5 at the beginning of the project to achieving TRL 7 at the end of the project. The same technology should also be capable of traditional limb sounding, occultation, and LiDAR measurement. The proposed major project goal is on flight demonstration of the developed technologies in Low Earth Orbit (LEO), proofing the Active SpecTROmeter with Small Satellites (ASTROSS) concept by performing Earth atmosphere measurements with validation using National Oceanic and Atmospheric Administration's (NOAA) Geostationary Operational Environmental Satellite (GOES) datasets. The ultimate goal is to utilize formations of ASTROSS in interplanetary missions to complement the traditional usage of highly capable and expensive but large spacecraft that can only be at one place at one time, such as missions to Venus, Mars, Titan, and other planetary bodies with atmospheres, aerosols, particles, and/or plumes; with measurement sensitivities approaching in-situ measurement techniques without their associated limitations (i.e. satellite/probes flight profile, size, power, detection speed, and sample collection). A Cube-Sat system, ARKSAT-3, will be developed to flight demonstrate the ASTROSS concept, where a light-emitting ARKSAT-3E (Emitter) is followed by a co-orbiting chaser ARKSAT-3C (Chaser). The ARKSAT-3 provides new satellite remote-sensing measurement capabilities currently non-existent within the state-of-the-art; such as the ability to sample processes related to atmospheric cooling on the ecliptic side of an orbit by using calibrated spectroscopic sources of light-emitting and laser diodes provided by -3E and spectrometers hosted on -3C. The ARKSAT-3 system is uniquely capable of controlling the integration vectors (lengths and direction) for the spectrometers, allowing temporal and spatial resolutions with rapid global coverage during planetary surveys.

The ARKSAT-3 project is a research collaboration between 3 Arkansas universities and although UA is the lead institution, all will jointly develop and build CubeSats. UA is tasked with developing the more complex ARKSAT-3C and all the engineering units, while providing expertise to HU and JBU for building their respective flight -3Es. There will be a total of 2 -3Cs (1 flight and 1 engineering model) and 3 -3Es (2 flight and 1 engineering model). NASA Marshall (MSFC) will serve the role of NASA research advisor and providing access to electric thruster test chambers, with the Center Technologist Mr. John Dankanich as the lead contact. In addition, industry will provide collaborative and technical support from 3 in-State entities: BEI Precisions Systems & Space Company (Maumelle, AR), Wolfspeed (Fayetteville, AR location), and Spire Global (represented by Mr. Robert Sproles at Little Rock, AR). These collaborations will help guide the project to

success. Ultimately, ARKSAT-3 represents the nascent but rapidly growing NASA-based education, research, and technology development capacity for the State of Arkansas, involving students, researchers, and industry partners.

22-22ESPCoR-0024 *Application of UAV and satellite based optical sensors to help preserve the coral reefs of the US Virgin Islands*

University of the Virgin Islands

Director/PI: Dr. Tyler Smith

Science PI: Dr. Tyler Smith

NASA MD: ESD

The We propose to assess uncertainties in existing data and model products and quantify relationships between in situ water quality parameters measured in coral reef environments and optical measurements of water properties obtained from high-resolution field and orbital sensors. These relationships will be tested against long-term records and targeted assessments of coral health to accurately identify potential water quality stressors on coral reef ecosystem health. This project is a continuation of the scientific partnership between the University of the Virgin Islands, College of Charleston, Kent State University, and NASA's Jet Propulsion Laboratory. Our project is aligned with NASA's Earth Science MD in areas of oceanography and Biology and is directly relevant to NASA's Strategic Goal 2 "Advance understanding of Earth and develop technologies to improve the quality of life on our home planet", and Objective 2.4 "Advance the Nation's STEM education and workforce pipeline by working collaboratively with other agencies in NASA's missions and unique assets".

The corals of the US Virgin Islands (USVI) are facing stressful levels of land-based runoff, more frequent and severe bleaching events, and unprecedented mortality due to the recent and novel stony coral tissue loss disease (SCTLD). Water quality decline from urbanization in some cases is compounding these effects and/or hindering recovery from mass bleaching events, as coral reefs have low tolerances to changes in nutrient, sediment, and phytoplankton concentrations. On the other hand, more opaque water associated with lower water quality may slow the progress of SCTLD. Current methods of water quality assessment in the USVI are based on in situ measurements. Although these measurements provide good baseline data, they are labor intensive, costly and lack the spatial and temporal coverage needed to better understand changes in such a highly dynamic environment. This makes them less useful for understanding relationships between water quality and high resolution coral reef ecological data sets.

Remote sensing (RS) is an indispensable tool for early detection and monitoring of stressors related to temperature and water quality constituents indicative of environmental impairments. The goal of the proposed project is to integrate the use of Unoccupied Aerial vehicles (UAVs) and satellite-based sensors to develop a practical approach to assess the physical environment of coral reefs rapidly and quantitatively by more accurately determining the RS signatures of various water quality parameters. This capability will enable early warning of detrimental ecosystem changes and provide inputs for management and mitigation decisions. We seek to establish the link between SCTLD refuges and water quality, and to establish RS techniques to track the spread of SCTLD within the USVI and greater Western Atlantic. Our team will use existing field data coupled with new data to be collected during this project. The specific data that will be used includes in situ optical data from targeted sampling and by deploying moored near-continuously recording optical sensors (radiance, irradiance, backscattering), satellite and UAV-based optical data, water quality data, and high resolution coral reef ecological data. We believe this data volume will greatly strengthen the modeling coefficients used to describe water optics from remotely sensed data. Information on uncertainties in retrievals carry tremendous significance from an operational standpoint, especially if management decisions are to be based on RS retrievals. We anticipate that our approach will apply to the variety of aquatic environments that are characteristic of the USVI waters.