# Contents

## 24-2024EPSCoR-0001
## Development of a Lagrangian Stability Analysis Framework for High-Speed Boundary Layers

**University Of Mississippi**
**Dr. Nathan Murray**

Boundary Layer Transition (BoLT) directly affects the aerodynamic heating, viscous drag, and thereby the control authority of high-speed vehicles. Conventional stability analysis techniques, namely, Linear Stability Theory (LST), N-Factor Method, and Parabolized Stability Equations (PSE) remain inadequate for non-linear transition mechanisms and complex flow configurations. In this work, we propose a novel computational Lagrangian Stability Analysis Technique (LagSAT) to investigate high-speed BoLT. Unlike the conventional stability analysis tools, which require revisiting the flow governing equations and building a separate solver for perturbations on a baseflow, the proposed LagSAT can readily extricate stability features of the baseflow embedded in Lagrangian flow maps. In this sense, LagSAT is a data-driven approach directly applicable to numerical as well as experimental flowfields comprising complex baseflow configurations. LagSAT employs a stability analysis approach that is never-done-before. It exploits unsteadiness of Eulerian steady baseflow in a Lagrangian frame of reference, leading to Lagrangian flow maps whose modal/non-modal analyses provide a comprehensive picture of the receptivity, stability and causality processes that dictate the transition phenomenon.

Accurate transition prediction remains a major technological barrier for NASA's aeronautical as well as science and space exploration missions as per the Computational Fluid Dynamics (CFD) vision 2030 study. The proposal work is directly relevant to NASA's two projects, namely, Transformational Tools and Technologies (TTT) and Hypersonic Technology (HT) under NASA's Aeronautics Research Mission Directorate (ARMD). The TTT project develops the state-of-the-art computational and experimental tools to augment ARMD's ability to advance predictive modeling and performance of future aircrafts, while the HT project develops hypersonics capabilities in close coordination with the Department of Defense. The proposed LagSAT software will complement the existing stability analysis toolkit at NASA by providing new insights into

the boundary layer stability and transition phenomena, making this effort pertinent to the NASA's objectives. The state-of-the-art BoLT prediction tools rely on empirical and simplified approaches that generally fall short in new/complex environments. LagSAT's novel and holistic approach not only addresses these shortcomings but also finds applications in fluid-thermal-structural interactions, turbulent mixing and chaos analysis. The project will enhance STEM educational infrastructure through funding and training next generation of researchers and engineers, ensuring involvement of students from underrepresented/underserved groups in STEM. The proposed project will foster future collaborations with NASA and UM on different topics including shock boundary layer interaction, jet noise, and fluid-

structure interaction, to name a few. The expertise and collaborations built during this project will help pursue future funding from National Science Foundation (NSF), Department of Defense (DOD), and Office of Naval Research (ONR).

The proposed LagSAT will be realized in three parts. First, we will establish mathematical and physical links between LagSAT and conventional stability analysis techniques by means of simpler 2D canonical flows, namely, the Blasius and Mach 5 flat plate boundary layers. Second, we will employ LagSAT on experimental flowfields, collaborating with the University of Mississippi, in a joint experimental/computational study of Mach 2 & 5 boundary layers over a flat surface. Third, the LagSAT framework will be parallelized for the memory and speed-up scalability, demonstrating its applicability to more complex/large baseflows suggested/provided by NASA collaborators, including 2D HIFiRE-1 seven-degree cone, 3D Mach 6 cone-cylinder-flare with flow separation, and 3D Mach 6 concave cone with Goertler vortex instabilities.

## 24-2024EPSCoR-0006

## Testing the functionality and performance of a large area detector for STROBE-X

**University Of Alabama**
**Dr. Lawrence Thomas**

The Spectroscopic Time-Resolving Observatory for Broadband Energy X-rays, or STROBE-X, is a next-generation time-domain X-ray probe-class mission concept that is closely aligned with the high priority recommendation of the Decadal Survey on Astronomy and Astrophysics (Astro2020). STROBE-X's capabilities will extend the reach of X-ray observations in the time-domain significantly, with expected advances over a wide range of areas - from understanding the precursors of gravitational wave (GW) sources, to precise measurements of the spin of black holes (BHs), and constraints on the nature of dark matter. We propose to carry out a series of tests to assess the functionality and performance of the large area silicon drift detectors (SDDs) for STROBE-X that are read out by custom ASICs. Large-area, low-power, position sensitive SDDs have broad utility - from probe-class missions to CubeSats, and as such, our work will contribute to a wide range of NASA missions. This project is closely aligned with work being carried out by teams at Naval Research Laboratory (NRL), NASA Marshall (MSFC), and NASA Goddard (GSFC), and we will work closely with our collaborators at these institutions in testing the functionality of the SDDs.

We will develop an education and outreach program that is interwoven with our research program. The integration of students and faculty from Alabama A&M University (AAMU) and from University of AL, Tuscaloosa, will create a collaborative bridge across Northern Alabama (AL). We will design and carry out Science/Space Public Outreach Team "SPOT" workshops targeting underserved and underrepresented students in AL (that have greater than 50 % of students who are economically disadvantaged and fewer than 50 % of students who achieve science proficiency), as identified by the AL STEM Council Math and Science Achievement Database. By partnering with the Alabama Louis Stokes Alliance for Minority Participation (ALSAMP) and the Rocket Booster Bridge Program, we will foster a diverse research program.

As the next planned probe-class X-ray mission (with a total estimated cost of $1B), STROBE-X will have an enormous impact on the astronomy community. Our work will enable UAH and our partner institutions in AL to have an essential role in developing one of the main instruments for STROBE-X and thereby fully participate in the science returns of this mission. This project will help to further strengthen ties between UAH and NASA MSFC, and with our partners at NRL and NASA GSFC. Access and intimate knowledge of large area SDDs that have many potential applications will give us a competitive edge in securing future grant funding. The vast scope of applications of these instrument concepts include an X-ray spectral timing and sky monitoring MIDEX mission, a time-domain X-ray and gamma ray sky monitor, as well SmallSats and CubeSats for solar X-ray monitoring and DoD and Homeland security applications. The broad range of applications of these detectors will open up a large and varied potential customer base, both in research and in applications to government/federal and aerospace industrial needs.

## 24-2024EPSCoR-0007

## Colloidal assembly: Understanding the electric field driven assembly of colloids and its applications (Science Mission Directorate)

**Louisiana State University**
**Professor Gregory Guzik**

The project's primary objective is to establish Louisiana State University (LSU), Tulane University, Louisiana Tech University (LaTech), and Baton Rouge Community College (BRCC), along with the State of Louisiana, as leaders in the field of electric field-driven soft matter research. This will be achieved through an investigation into colloidal assembly both on Earth and in microgravity environments. The ultimate goal is to provide fundamental insights into the field-driven assembly process in confinement which will form the basis to develop innovative technologies such as rapid microcrack repair. The ability to interlock colloidal assemblies developed in this proposal will provide a path to develop highly desirable microcrack repair technologies, enabling NASA to address damage sustained by space vehicles and telescopes due to micrometeoroid encounters. Additionally, two prominent companies, Advano and Intralox, have expressed interest in collaborating on this project. They aim to adapt the research to prevent thermal runaway reactions in lithium-ion batteries and create polymer/colloid composites with enhanced mechanical properties.

The research focuses on understanding, controlling, and directing the assembly of microparticles, a process governed by intricate non-equilibrium, long-range, and competing interactions. The ability to precisely manipulate these interactions in a programmable manner is pivotal for tailoring soft microstructures and developing reconfigurable materials. However, our understanding of how microgravity influences colloidal assembly remains limited, primarily due to the challenge of decoupling gravitational forces from externally applied forces (e.g., electrical or magnetic) during the assembly process. To address this knowledge gap, the collaborative team from LSU, Tulane, LaTech, BRCC, and NASA's Glenn Research Center (GRC) will work towards gaining a comprehensive understanding of the directed assembly and transport of soft colloidal particles driven by electric fields, both on Earth and in microgravity. This research aligns with NASA's priorities, as highlighted in the FY23 NASA EPSCoR Research notice of opportunity and the 2023 BPS's decadal survey, emphasizing the importance of advancing knowledge in soft condensed matter and systems far-from-equilibrium.

The project's goals are as follows:

Goal 1: Investigate the effects of confinement, electric field strength, microgravity, and particle shape on the electric-field-driven assembly of colloids into reconfigurable structures.

Goal 2: Analyze the relative impact of inter-colloidal adhesion and friction forces on the structure and dynamics of the field-directed assembly process.

Goal 3: Develop chemical strategies to interlink electric-field-assembled particles, creating mechanically stable and robust colloidal aggregates.

Goal 4: Construct laboratory-based prototypes to demonstrate the self-repairing capability of colloidal dispersions energized by electric fields.

Goal 5: Provide opportunities to students at Minority Serving Institutes by offering paid research internship in team's laboratories and supporting their visits to NASA-GRC

Systematic experiments will utilize model colloids with engineered shapes and surface-grafted polymers with tunable thermal responses. These experiments will be conducted under both gravity and within drop towers at NASA-GRC.

## 24-2024EPSCoR-0010

## SMD: Bringing gravitational-wave astronomy into the Space Age: Next-generation waveform modeling of black-hole binary coalescences for LISA data analysis

**West Virginia University**
**Dr. Melanie Page**

The Laser Interferometer Space Antenna (LISA) mission, a collaborative endeavor between NASA and the European Space Agency (ESA), represents a groundbreaking step in gravitational-wave astronomy. Aimed at detecting gravitational waves from massive black hole mergers in lower frequency ranges, LISA complements existing ground-based detectors. This research proposal seeks to extend the momentum generated by LISA Pathfinder's technical successes, by advancing waveform modeling for black-hole binary (BHB) coalescences.

Current waveform models, particularly those covering the late inspiral and merger phases of BHB events, exhibit significant limitations. This shortfall is critical because these phases contribute substantially to the signal's signal-to-noise ratio (SNR). To address this, the project underscores the necessity for models that are both efficient and accurate, especially for binaries that are spinning and eccentric, which LISA is expected to observe.

Central to the proposed work is the development of effective and precise spinning eccentric inspiral-merger-ringdown (IMR) waveforms. By leveraging recent analytical and numerical breakthroughs, the project aims to enhance the accuracy and efficiency of these models. Notably, significant focus is given to the innovative Backwards One Body (BOB) model. This pioneering approach starts from the final, merged state of a black hole binary and evolves backwards in time, promising to revolutionize the modeling of the merger and ringdown phases.

Plans to refine the BOB model include extending it to cover more of the merger phase and improving its accuracy across different modes and harmonics. In addition, the project proposes to extend quasicircular spinning models to accommodate eccentric orbits and integrate a recent merger-ringdown model for a more comprehensive approach. An innovative strategy, leveraging an analytical discovery that relates unbound and bound trajectories, is set to calibrate the enhanced eccentricity models.

Another crucial element of this research leverages the citizen science project BlackHoles@Home (BH@H), which employs distributed computing to generate extensive gravitational-wave catalogs of eccentric and hyperbolic BHBs. This unique resource will be instrumental in calibrating and validating the proposed waveform models, with a particular focus on systems with large eccentricities and precessing spins.

The project directly aligns with the LISA Consortium's identified needs, aiming to produce models that are both highly accurate and computationally efficient. This alignment extends to NASA's broader goals in advancing gravitational-wave astrophysics, setting a solid foundation for the upcoming LISA mission.

Additionally, the initiative emphasizes capacity building, particularly in West Virginia and Idaho, by focusing on training graduate students and enhancing research capabilities in these regions.

In summary, this research represents a transformative effort in gravitational-wave astronomy. By developing advanced waveform models tailored for the LISA mission, the project not only contributes to the scientific objectives of NASA but also plays a crucial role in laying the groundwork for the future of gravitational wave astronomy. The outcomes of this research are expected to significantly enhance our understanding of black holes, the nature of gravity, and the fabric of spacetime itself, marking a new epoch in the exploration of the most energetic events in the universe.

## 24-2024EPSCoR-0012

## NASA EPSCoR: STMD/JPL: Advancing High-Energy, Cycle-Stable Sulfur-Based Batteries for NASA Space Missions: An Integrated Framework of Density Functional Theory, Machine Learning, and Materials Innovation

**University Of Puerto Rico**
**Dr. Gerardo Morell**

The overarching goal of this project is to develop high-energy and long-cycling sulfur-based batteries for energy storage in NASA missions, wherein advanced "adsorbents", sulfur materials, and electrolytes will be developed to mitigate the notorious polysulfide shuttling issue.

Sulfur is considered as one of the most promising cathode materials in the battery context, due to its predominantly high theoretical capacity of 1675 mAh/g resulting from its two-electron S0/S2- transfer reaction and light molar mass (32 g/mol). Besides, its extremely high abundance and wide availability points to a superior low battery cost. Therefore, pairing the sulfur cathode with the high-capacity and low-potential lithium/sodium metal anodes into Li/Na-S batteries represents a promising approach to develop high-energy battery systems. Unfortunately, when sulfur is electrochemically reduced, it forms lithium/sodium polysulfides that are readily soluble in the ether-based electrolytes. These polysulfides will further migrate to the metal anode, leading to self-reduction and metal anode corrosion. These reduced polysulfides will diffuse to the cathode again and get further oxidized, thus forming a reaction loop. Consequently, polysulfide shuttling issues lead to active material loss, fast capacity fading, and poor Coulombic efficiency.

This project will leverage the research expertise from the PIs and propose innovative approaches to suppress the undesirable polysulfide shuttling issue. Two major strategies will be utilized to develop high-energy and cycle-stable Li/Na-S batteries. Firstly, we will take advantage of the unique physicochemical properties of ferroelectric nanoparticles to trap these soluble polysulfides. Because ferroelectric nanoparticles can exert an internally macroscopic electric field inside the Li/Na-S batteries, these polysulfides will be electrically attracted or "absorbed" by these ferroelectric materials, thus being confined on the cathode region. These ferroelectric nanoparticles will be physically mixed with the sulfur active materials or be coated uniformly on the separator. The second approach is to develop polysulfide-free Li/Na-S batteries by using solid-state electrolytes. Because there is no liquid solvent in the entire battery system, the sulfur will be converted to its metal sulfides in a single-step solid-solid conversion reaction, thus fundamentally eliminating the polysulfide shuttling issue. However, many technical challenges need to be solved, such as increasing the electronic conductivity by introducing transition metal sulfides and developing novel electrolytes for low-stack-pressure operation. We propose a data driven novel machine learning (ML) and deep learning (DL) approach to battery design, specifically, a DFT-based training of neural network model. We will build a physically inspired deep learning model based on the Born-Oppenheimer approximation, incorporating DFT computations.

This project will further enhance the education and research capability at the University of Puerto Rico. We expect to support four students in their Ph.D. studies, and we will foster an even stronger collaboration with the NASA scientists by mutual visits and scientific publications. This project will also help the professional development of an involved junior faculty. The scientific research activities will encourage more underrepresented minorities in Puerto Rico to choose a STEM-based career, especially at NASA centers and laboratories.

## 24-2024EPSCoR-0016

## ARC: Prospecting and Pre-Colonization of the Moon and Mars using Autonomous Robots with Human-in-the-Loop

**Nevada System of Higher Education**
**Dr. Eric Wilcox**

Deep space exploration and colonization are humankind's next great endeavor as we lift off into the 21st century. Relevant progress has enabled early-stage characterization of potential resources and environmental challenges on different planets, identifying a prospective path among the stars under NASA's Moon-to-Mars mission. Establishing permanent presence on the Lunar and subsequently the Martian surface will require a novel generation of Space-Worker Robots armed with multiple capabilities. First, energy-aware autonomous environmental sampling in order to simultaneously achieve exploration, resources and volatiles mapping, potential hazard characterization including chemical compounds and regolith grain size, and broadly remote worksite analysis to facilitate informed decisions to deploy infrastructure. Secondly, the ability to conduct Surface Engineering (SE), including rock-clearing or potential surface treatment for dust suppression, in preparation for human colony establishment. This project addresses necessary components of the Blueprint Vision that will facilitate efficient human cognition-driven supervision and coordination of the off-planetary prospecting and site clearing efforts to sustain and support future human missions, by proposing a realistic framework which is cognizant to the inherent severe communication constraints.

These components include:

a) The novel concept of a Self-Deployable Cable-Driven Parallel Robot (SD-CDPR) system-of-systems, which will be capable of offering flight-less 3D actuation of the remote worksite, addressing applications such as persistent overhead monitoring, object transport including assembly component placement, and even vertical extrusion-based fabrication. Due to its re-deployability, such as system will be capable of actuating different worksites as required.

b) Ground-based Space Worker Robots (SWRs) with the ability to pick up generically-shaped large/heavy objects over desert-like grainy soil and cooperatively transport them, by relying on simple mechanisms and principles.

c) Resource-prospecting SWRs, armed with soil sampling capabilities, intelligent energy-aware information-driven adaptive sampling algorithms that optimize for simultaneous exploration and spatial statistics-based characterization of the Lunar/Martian environment, with respect to a quantity of interest (ice, perchlorate, grain size, etc.).

d) A framework that allows human cognition to drive the initial colonization tasks at the high level, since even the current state-of-the-art in robotic autonomy is inadequate to fully tackle the decision-making complexity required for such missions. The delayed teleoperation paradigm is not viable at inter-planetary

distances; thus, an Earth-side Interactive Digital Worksite Twin (IDWT) will be developed. This will encompass manually-selected digital interactable entities (associated to segmented Digital Twin parts), additionally annotated with semantic information such as mechanical motion relationships. Such entities will correspond to objects with which the remote SWR can interact/manipulate. The goal is to allow human operators to perform "gamified'" interaction with the graphics-engine IDWT environment to virtually perform physical tasks, and then the resulting environment configuration can be represented as a task plan and a semantically-augmented final goal state, and subsequently forwarded off-planet. This will facilitate low-bandwidth mission commanding through goal-states and symbolic plans; as a sideproduct, scientists will retain a Digital Twin of the colony environment for situational assessment. Additionally, retaining a Digital Twin of each robot's model and its algorithms will allow to preview the expected way that a plan will be executed by the SWR's autonomy pipeline, allowing vetting before transmitting it.

The project will conduct field testing in Lunar/Martian analogues in N and S Nevada, as well as NASA testing facilities.

## 24-2024EPSCoR-0019

## A.7.4.2 Biosignature Detection of Solar System Ocean Worlds using Science-Guided Machine Learning (SGML)

**Oklahoma State University**
**Dr. Andrew Arena Jr.**

Understanding evidence for the habitability of icy ocean worlds in our solar system and exploring the potential existence of microbial life within their ice shells or liquid oceans is key to elucidating the origins and evolution of life on Earth. Ocean worlds like Europa and Enceladus have all the necessary ingredients for extremophile microbial life, but the direct visualization of such posited lifeforms (unambiguous evidence of life) will not be possible for some time. Currently and for near-future missions, we will rely on in situ measurements from instruments like orbiter and fly-by mass-spectrometry (MS) to sample the chemical and isotopic compositions of ocean world atmospheres, exospheres and plume volatiles. Large isotopic fractionations can indicate a biological source; however, some abiotic processes can mimic biotic fractionation, thereby increasing the probability of a false detection of life. Thus, the interpretability of machine learning (ML) models is paramount for predicting an outcome with such far-reaching implications as extraterrestrial biosignatures on ocean worlds, since such hypotheses require extraordinary evidence and confidence in our models.

ML methods predict complex outcomes using data-driven algorithms without the need for theory. That is, under most circumstances, ML does not require a mechanistic/scientific model to make highly accurate predictions. However, the lack of a mechanistic model for data-driven black-box ML or deep learning algorithms makes it difficult to explain or justify a complex prediction, and indeed, to diagnose whether a false prediction has occurred. Furthermore, certain geochemical or biological phenomena might not be feasible to learn by ML or deep learning due to limited availability or applicability of training data. On the other hand, some of these biogeochemical phenomena are modeled efficiently using first-principle mechanisms. For extraterrestrial biosignature prediction, these mechanistic computational methods need kinetic parameters from experimental data that are consistent with the target ocean world geochemistry and environmental conditions (e.g., ocean compositions, temperatures, and pressures) that may be very different than those found on Earth. This proposal will combine scientific/mechanistic modeling and novel experimental data with ML into a Science-Guided Machine Learning (SGML) approach for solar system biosignature detection and for modeling ocean world geochemistry in the presence and absence of microbial life.

Using benchmark Isotope Ratio Mass Spectrometry (IRMS) data from our NASA collaborators, we developed an ML model that classifies abiotic versus biotic-containing ocean world analogue seawater samples with high accuracy and interpretability. However, this proof-of-principle benchmark data and ML modeling have important limitations. Specifically, additional experimental data and computational methods are needed to reduce confounding of biosignature predictions due to differences in geochemical environments, non-biogenic carbon, and assumptions of earth-based origins of life. We propose to experimentally and computationally investigate a variety of complex geochemical ocean world analogue environments, such as non-Earth temperatures and pressures for both abiotic samples and extremophile biotic samples. To achieve these experimental and computational goals and create an SGML tool, our team will bring together broad interdisciplinary expertise in geochemistry, microbiology, astrobiology, planetary science, bioinformatics, computational modeling and ML from institutions across Oklahoma including The University of Tulsa (TU), The University of Oklahoma (OU), Oklahoma State University (OSU) and Northeastern Oklahoma (NEO) A&M as well as NASA Goddard Space Flight Center.

## 24-2024EPSCoR-0024

## JSC, ARC: Non-GPS Navigation System Using Dual Star/Planetary Cameras for Lunar and Deep-Space CubeSat Missions

**Iowa State University**
**Dr. Sara Nelson**

CubeSat is a very attractive solution for space research of universities and research institutes due to its cost-effectiveness in conducting experimental missions. Further expansion of CubeSat into deep space will require highly accurate position knowledge and precision. However, applying CubeSats to deep-space or cislunar missions poses challenges in acquiring precise navigation information because these missions cannot use Global Positioning Systems (GPS).For a typical satellite, the Doppler effect from the Deep Space Network (DSN) is exploited for deep-space navigation, but future space mission considers the concurrent operation of tens to hundreds of smaller spacecraft, which will significantly stress or exceed DSN's current capacity. Moreover, DSN-based navigation might not be viable for fleet missions that require simultaneous connection to the ground station and can be obstructed by challenging weather environments or geographic circumstances. Additionally, frequent communication may be impossible for smaller missions like CubeSat due to the limited antenna gain and available electric power, so upcoming CubeSat missions must independently ascertain and relay relative and absolute orbital states without relying on GPS. These capabilities are imperative for standalone or distributed missions beyond Earth, so CubeSat researchers with narrow electives were getting interested in the extensive application of star cameras for navigation purposes. Consequently, research on automated navigation technology based on Optical Line of Sight (LoS) has become crucial, so several research institutes are actively exploring this research field. Similar researches are performed by European and Chinese engineers but focused on a theoretical perspective. Some European scientists suggest an approach with a Hardware-in-the-loop testbed with only one camera designed for deep-space asteroid exploration. This proposal suggests an approach to obtain non-GPS inertial navigation information by tracking solar system planets through dual star trackers with a CMOS sensor commonly used in CubeSats. To simultaneously achieve navigation and attitude determination, we plan to install two camera modules with orthogonal configuration, which will also enable CubeSat to observe a broader star/planet field of view (FOV) for acquiring necessary planetary observation information.

The research also includes (1)(2) the construction of a virtual night-sky and a cameras-in-the-loop simulation (CILS) testbed for navigation performance evaluation, (3) the development of advanced calibration techniques considering chromatic aberration and a centroiding model, and (4) a robust navigation filter with angles-only measurements with (5) geometric analysis of angles-only measurements of planets. (6) All products will be integrated and verified using the developed CILS testbed and onsite night sky experiments.

The proposed research also encompasses the development of onboard image processing and data processing for fully automated navigation. Furthermore, our research endeavors to expand and align with

cislunar positioning and navigation capabilities in accordance with the White House's National Cislunar Science and Technology Strategy.

## 24-2024EPSCoR-0025

## GRC: The Alaska--Venus analog: synthesizing seismic ground motion and wind noise in extreme environments

**University Of Alaska, Fairbanks**
**Dr. Denise Thorsen**

Due to the similarity in size and overall surface age between the two planets, Earth and Venus are referred to as twins. Despite these similarities, Venus seems to have a different interior structure and has clearly experienced a different surface evolution. The Magellan mission to Venus revealed that the planet's surface does not exhibit plate tectonics, notwithstanding evidence of crustal movement and surface deformation. To understand the origins of these differences, we turn to seismology, a preeminent geophysical tool for understanding tectonic activity and the interior structure of a planet. However, the major challenge for a seismometer deployed on the Venusian surface is the extreme environment: its temperatures reach 460 C, its pressure can be over 90 bar, and its reactive atmospheric chemistry is primarily composed of supercritical $CO_2$ with sulfur species and other reactive elements.

Advances in the technology of high-temperature electronics, led by research conducted at the NASA Glenn Research Center (GRC), are expected to make it possible to deploy a seismometer on the surface of Venus within the next decade. A battery-powered Venus seismometer could monitor seismic events for 120 Earth days. However, due to power constraints, less than ten hours of data could be transmitted to an orbiter over the mission period. Consequently, the onboard seismometer should be equipped with intelligent operation strategies that distinguish seismic signal from noise, which requires thorough and accurate prediction of Venusian seismograms. University of Alaska (UA) faculty on the proposing team have conducted initial research on this topic under a partnership with GRC, and these initial efforts have revealed significant gaps in knowledge that we aim to fill with the proposed work.

Our overall goal for this project is to develop and assess Venus seismometer operation strategies, based on what a deployed Venus seismometer will observe. This research will use synthetic seismograms generated by combining synthetic Venus ground motions with synthetic Venusian surface wind waveforms. First, we will synthesize realistic ground motions for Venus based on our current understanding of the Venusian interior and various hypothesized geodynamic states. Second, we will create a realistic model of wind noise on Venus; wind is expected to be the primary source of seismic noise, and presents a modeling challenge due to extreme atmospheric conditions on Venus with respect to Earth. Third, we will measure seismograms at Venus-analog sites in Alaska and Hawaii to develop, test, and validate our modeling work. Finally, we will use our cumulative knowledge to develop effective Venus seismometer operation strategies under the constraints given by expected instrument capabilities and possible mission plans.

The proposed work will significantly benefit future Venus missions deploying seismometers on the surface or using other techniques such as infrasound to explore Venus seismicity. The resulting tools developed in this work will also enhance the ability of seismologists and earthquake engineers in the Alaska EPSCoR jurisdiction to understand Alaska's subsurface and near-surface. This also presents an opportunity to develop and reinforce partnerships between engineering efforts at UA Anchorage and UA Fairbanks that focus on mitigating seismic hazards in manmade structures, as well as research seismologists at the Geophysical Institute, UA Fairbanks, and engineers at GRC.

## 24-2024EPSCoR-0027

## UVI's Etelman Observatory in the Era of Time Domain and MultiMessenger Astronomy: Preparing for a New Era of Science Productivity

**University of The Virgin Islands**
**Dr. Tyler Smith**

SMD/HQ; SMD/GSFC: UVI's Etelman Observatory in the Era of Time Domain and MultiMessenger Astronomy: Preparing for a New Era of Science Productivity

Project Summary
The field of astrophysics is at the dawn of a new and exciting era of research, known as Time Domain and Multi-Messenger (TDAMM) astronomy. Ushered in by the 2017 discoveries of electromagnetic emission simultaneous to gravitational wave emission from a merging binary neutron star (Abbott et al. 2017) and the detection of neutrinos from an active galaxy undergoing gamma-ray flaring activity (IceCube-Collaboration 2018), together with the greater availability of transient survey instruments like the Zwicky Transient Facility (Bellm 2019), and the Swift Gamma-Ray Burst Observatory (Gehrels 2004), this new subfield of astrophysics was highlighted in the National Academy of Science, Engineering, and Medicine's Decadal Survey of Astronomy and Astrophysics (NASEM, Pathways to Discovery in Astronomy and Astrophysics 2021; Astro2020) as one of the highest priority areas of support for federal funding to the astrophysics community. The science return of cutting-edge, federally-funded research facilities can only be fully realized if they are supported by a global network of ground-based telescopes, designed to perform long-term, dedicated follow-up of TDAMM sources. The Etelman Observatory (EO) was renovated in the early 2000s to support gamma-ray burst follow-up of Swift Gamma-Ray Burst Observatory discoveries. As the field of TDAMM astronomy has matured and grown in the past 20 years, so has the research capacity of the EO. Through this EPSCoR project, we will grow the research capacity of EO to support the growing field of TDAMM astronomy and, in so doing, will greatly increase EO's science productivity, will institutionalize our sustainable science workforce training model, and will prepare EO to contribute to groundbreaking science in the TDAMM community for decades to come.

EO has been transformed over the past 10 years from a dormant facility with a non-operational telescope, into the cornerstone of a vibrant research program in GRB astrophysics at the University of the Virgin Islands (UVI). EO regularly publishes transient follow-up reports to the international Gamma-Ray-Coordinates Network (GCN), which is the premier international system used by TDAMM astronomers to publish their research results in near-real-time so that the community can respond to discoveries which often are only visible for minutes-to-hours before fading (events like Gamma-Ray Bursts, Fast-Radio Bursts, and supernovae, for example). In the past 7 years, UVI faculty and student researchers have published 5 peer-reviewed papers, 16 conference presentations, and 27 publications to the Gamma-Ray Coordinates Network (GCN) related to EO. The revitalization of UVI's EO for research, training, and workforce development, was initiated in 2013 by a NASA EPSCoR award (NNX13AD95A); we will leverage

this past work to make a new leap forward in science productivity at EO that will establish a sustainable operations model.

We will upgrade EO information technology (IT) infrastructure, physical research infrastructure, and staffing and will improve transient detection and reporting times through improved data processing pipelines, will make upgrades to instrumentation to reduce maintenance-related or anomaly-related downtime, and will train UVI students and graduates in EO operations and TDAMM science to augment our current staffing level and allow the facility to operate during all weather-permitting nights (from approximately 3-4 nights a week at current staffing levels) to respond to transient alerts and to perform studies of late-time variability in GRBs. We will also provide the administration and management support critical to grow EO's research capacity and competitiveness in TDAMM astronomy.

## 24-2024EPSCoR-0028

## Cubesats for Climate Change Detection of Transient Greenhouse Gas Emissions

**University of Hawaii**
**Dr. Luke Flynn**

This project will advance technology--originated at the University of Hawaii--enabling of two overarching science goals of importance to NASA and the State of Hawaii: Climate change induced by human activities (a major area of scientific research for NASA), and natural and climate change-enhanced hazards of particular importance to the State of Hawaii. The project will improve infrared remote sensing technology from space to facilitate detection and characterization of the greenhouse gases carbon dioxide and methane, and to aid characterization and mitigation of wildfires, the natural hazards posed by volcanic activity and the climate effects of volcanic sulfur dioxide. Climate change due to human produced greenhouse gases is among the most challenging problems facing this and future generations, and addressing this issue is a compelling goal for many pro-active young people world-wide and in the State of Hawaii. Wildfires are a critical problem for the State of Hawaii as tragically demonstrated by the complete loss of the historical town of Lahaina on the island of Maui, and is an extreme hazard nationally and internationally (Tedim et al. 2020). Volcanic activity in Hawaii is a persistent hazard, causing disruption of lives and major loss in property, while having very high cultural significance among native Hawaiians, and the entire population of the State of Hawaii. Additionally, $SO_2$ emissions from volcanoes are an important natural process that affects characterization of global warming through production of reflective sulfuric acid aerosols that alter the heat budget of the Earth. The project will not directly conduct measurements relative to addressing these problems, but instead carry forward the technical achievements necessary to achieve these goals under non-EPSCoR funding sought by the University of Hawaii following completion of this project.

The project will 1) produce extremely low mass and power infrared spectrometer prototypes compatible with extremely small satellites (CubeSats) with sufficient performance to achieve the science goals; 2) integrate these spectrometers into low cost CubeSat kits produced by the Hawaii Space Flight Laboratory; 3) conduct a study to determine the characteristics of a satellite constellation and its component satellites to achieve the science goals; 4) Execute a "capstone" project deploying the project-produced cubesats on crewed aircraft and a meteorologic balloon to raise technical readiness of the instruments. and provide data as a proof-of-concept demonstration for future proposals.

## 24-2024EPSCoR-0029

## SMD/GSFC: Improving global dryland streamflow modeling by better characterizing vegetation use of deep water resources using NASA's GRACE/GRACE-FO, SWOT, and LIS

**University Of Idaho**
**Dr. Matthew Bernards**

Global drylands span over 40% of the Earth's terrestrial surface and support approximately 2.5 billion inhabitants, half of whom live under the poverty line set by the United Nations and are heavily reliant on river water. Yet, with climate change accelerating, accurate streamflow prediction in these regions is proving difficult, particularly as process-based models often fall short in dryland environments. Research by Science Investigator Dr. Zhao has shown that these models' deficiencies stem from a lack of clarity on ecosystem water use of deep water resources (such as deep soil moisture, rock moisture, and groundwater) that usually feed baseflow. Particularly, land surface models do not account for moisture in deep weathered bedrock, which is a substantial source of plant-available water, especially in dryland environments. Additionally, current stream gauging stations are located disproportionately in large, perennial rivers in wetter regions, limiting the evaluation and improvement of streamflow modeling for drylands. This lack of accurate streamflow modeling for drylands makes it more difficult for dryland countries to prepare for, respond to, and recover from climate threats, contributing to economic and social inequality for the people living in drylands.

This research addresses these gaps by leveraging NASA's GRACE/GRACE-FO and SWOT satellites to improve dryland streamflow prediction. By capturing changes in total terrestrial water storage anomalies, GRACE/GRACE-FO will provide insights into vegetation's access to deep water resources. NASA's SWOT will provide discharge estimates on a global scale, which will significantly boost available streamflow observations in drylands. By combining these NASA measurements with NASA's Land Information System (LIS), we propose to evaluate a novel approach to improve dryland streamflow modeling accuracy. This approach accounts for the ability of vegetation to grow roots into the bedrock and extract water stored in weathered bedrock.

The primary objectives of this study include:

1. Understanding the relationship between streamflow and vegetation activities under varying climatic, hydrologic, and geological conditions;
2. Investigating the role of shallow versus deep water resources in this relationship; and
3. Assessing the value of modeling plant access to rock moisture for improving dryland streamflow simulation accuracy.

These project objectives will be achieved via close multi-institutional partnerships among the University of Idaho, Boise State University, NASA Goddard Space Flight Center, and Pacific Northwest National

Laboratory. By achieving these objectives, the research will enhance the predictability of streamflow, particularly in dryland areas, including Idaho. The research can also improve the representation of vegetation use of deep water resources in NASA's LIS, increasing the efficacy of LIS in assimilating total terrestrial water storage from GRACE/GRACE-FO and satellite vegetation data. The project will further enhance the modeling and data assimilation infrastructure of the State of Idaho by making NASA's LIS accessible on Idaho's supercomputer and usable by state-wide public universities and research institutes. The project will also support two workshops to train Idahoan researchers to use NASA's LIS, with an intended outcome of increasing Idaho researchers' competitiveness in the nation. These activities directly relate to the Idaho NASA EPSCoR Strategic Plan that aims to "promote the development of research expertise and infrastructure that will allow Idaho researchers to compete nationally in areas of strategic interest to NASA."

## 24-2024EPSCoR-0030
## AR- III-Nitride Ultraviolet Laser Diodes for Harsh Environments, Space Based Communications, and Remote Sensing (STMD)

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**Dr. Constance Meadors**

The last few years have seen a dramatic increase in interest in laser based communications replacing standard radio bands for satellite to ground and satellite to satellite information transfer. This offers many improvements such as lower noise and wider bandwidth with potentially orders of magnitude higher data transmission rates. Whereas radio spans from transmission rates of on the order of kbps up to the most advanced technologies at nearly Gbps, the initial attempts at demonstrating satellite communications using laser modulation have already demonstrated rates of several Gbps.

Back on Earth, solid state, semiconductor, vertical-cavity surface-emitting lasers (VCSELs) have been used for fiber communications since their first demonstration at infrared (IR) wavelengths using GaInAsP/InP semiconductors in 1979. As a result, semiconductor laser diodes (LDs) have been developed heavily in this near IR range in order to optimize transmission through fiber optic cables. This has resulted in a recent world record fiber data transfer rate of 319 Tbps, i.e., 3.19 1014 bps using laser light with wavelengths spanning from 1487.8 nm to 1608.33 nm.

Nearly another order of magnitude increase could be gained by going to shorter wavelengths on the order of 300 nm in the ultraviolet (UV) range. However, the UV band of light, being more energetic, is heavily absorbed in most media. However, this is not a limitation for freespace, satellite to satellite or deep space communication, where it could facilitate nearly real-time video rate data transmissions. Additionally, most UV bands are strongly absorbed by gasses, therefore bright and directed UV light sources will also facilitate, scientific explorations to other planets (including Earth based observations) which require lasers for spectroscopy and remote sensing. Generally, the higher the energy, the wider range of physics and chemistry can be probed.

Therefore, we propose to develop a VCSEL designed semiconductor laser using the III-nitride material system with a target wavelength of less than 300 nm. The III-nitride system will not only facilitate the short wavelength emission due to the wide bandgap of the materials, but generally nitrides have demonstrated a significant resilience to harsh environments like high/low temperatures and intense radiation. As such this material system is ideal for this purpose.

We have spent the last year studying the feasibility of this idea with funding from the Research Infrastructure Development program, through the NASA funded Arkansas Space Grant Consortium. During this time we have demonstrated through simulations the general design of the expected device, and understood the materials requirements to monolithically grow the various components including the optical emission or quantum well layer for emission at 300 nm and the high reflective layers or distributed

Bragg reflectors to complete the lasing cavity, resonant with the 300 nm emission. These simulations have led to very early growths, which demonstrate both the potential as well as a clear path for improvement.

We anticipate achieving lasing using the proposed VCSEL structure at a wavelength less than 300 nm. This device after it is demonstrated should also be capable of operating at both higher and lower temperatures than state of the art laser diodes, as well as surviving intense radiation damage. Finally, we anticipate development of a characterization methodology to analyze the material properties, as well as the performance, lifetime, and reliability of the resulting devices. Furthermore, the proposed work will lead to state-wide economic development in Arkansas and visibility in the very active field of wide and ultra-wide bandgap semiconductors, which is aligned with national needs and international industrial challenges.

## 24-2024EPSCoR-0031

## SMD: High Spatial-Temporal Resolution Soil Moisture Retrieval using Deep Learning Fusion of Multimodal Satellite Datastreams

**South Dakota School Of Mines & Technology**
**Dr. Edward Duke**

Soil moisture measurement is essential for understanding Earth's water cycle, enhancing weather forecasting, undertaking agricultural management, and contributing to our understanding of climate change, ecosystems, and biodiversity. Existing soil moisture data products (e.g., NASA Soil Moisture Active Passive (SMAP) and downscaled SMAP-Sentinel-1 products) typically have low spatial resolution (e1 km) and relatively high temporal resolution (~3-day revisit). These data cannot meet the 200-m resolution soil moisture requirement identified recently by the NASA Satellite Needs Working Group for a range of applications such as data-driven agriculture management, regional hydrological models, and drought, wildfire, and flood monitoring. This project will leverage new synthetic aperture radar (SAR) data from the soon-to-be-launched (Q1 2024) NASA-Indian Space Research Organization (ISRO) SAR Mission (NISAR) and the European Space Agency (ESA) Sentinel-1A (launched 4/2014), Sentinel-1B (04/2016), and Sentinel-1C (to be launched 2024) to derive high-resolution soil moisture that satisfies the NASA mission requirements. Optical data from Landsat 8 (launched 2/2013) and Landsat 9 (9/2021) and Sentinel-2A/B (6/2015 and 3/2017) will be used to complement SAR data.

This project will develop quasi-operational algorithms to fuse SAR data from NISAR and Sentinel-1 and harmonized optical data from Landsat and Sentinel-2 (HLS) to generate accurate, high spatial resolution (~200 m), and high temporal resolution (<2 day) soil moisture measurements. Our methods can retrieve soil moisture at any satellite data acquisition date, which advances beyond previous efforts that retrieve soil moisture only when the microwave data are contemporaneous with optical data. This innovation is achieved through a novel time series deep learning methodology developed by the South Dakota team to model the vegetation seasonal dynamics to better quantify vegetation coverage and soil moisture. We will use the International Soil Moisture Network (ISMN) in-situ soil moisture measurements as training data, augmented using the land surface reanalysis soil moisture data from the North American Land Data Assimilation System (NLDAS) and the European Centre for Medium-Range Weather Forecasts (ECMWF). Our preliminary experiment using six years of Sentinel-1 data over 178 ISMN sites showed a marked improvement over the NASA 3-km and 1-km SMAP-Sentinel-1 products.

Five tasks will be undertaken with data acquired over the ?Conterminous United States (CONUS) from 2017 to 2025: (1) Derive training samples by matching satellite data from Sentinel-1, NISAR, and HLS with ground-truth soil moisture data from ISMN; (2) Develop algorithms to derive soil moisture at SAR acquisition dates; (3) Develop algorithms to derive soil moisture for any satellite data acquisition dates; (4) Pre-train the time series retrieval model using land surface reanalysis soil moisture data; and (5)

Validate the derived soil moisture through field measurements in partnership with Oglala Lakota College, a Tribal College serving the 9,000 square kilometer Pine Ridge Reservation.

Our project is aligned with NASA fundamental science objectives by developing advanced information techniques for accurate surface soil moisture qualification, and with NASA applied science objectives by inspiring and educating underserved communities in using NASA data. This project builds new and enhances existing collaborations among South Dakota universities, the USGS Earth Resources Observation and Science (EROS) Center, Oglala Lakota College, and NASA collaborators at JPL and GSFC. The project involves local industrial partners who will use the derived soil moisture data to augment their irrigation support systems. This will impact economic growth of the agricultural industry in South Dakota, a $32.1 billion sector responsible for 30% of South Dakota GDP.