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17-EPSCoR-ISS-0002, *Growth of Large, Perfect Protein Crystals for Neutron Crystallography*

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Superoxide dismutases (SODs) are important antioxidant enzymes that protect all living cells against toxic oxygen metabolites, also known as reactive oxygen species (ROS). SODs are the first defense against propagation of damaging oxidative reactions through elimination of superoxide. Superoxide is generated through normal metabolism and/or ionizing radiation. Each catalytic cycle dismutes two molecules of superoxide to oxygen and hydrogen peroxide via cyclic reduction and oxidation half reactions using the active site metal ion. Humans have Cu/ZnSOD in the cytosol and extracellular spaces and MnSOD in their mitochondria. Mutations in SOD lead to aging and degenerative diseases such as amyotrophic lateral sclerosis, diabetes, and cancer.

This flight proposal will provide the critical crystal samples needed for a detailed study of human SOD. Despite the biological and medical importance of SOD, the complete enzymatic mechanism is still unknown. Precise structural data are needed. The binding sites of the diatomic substrate and product as well as the source of the protons in the reaction have been studied, but their exact identification has not been possible. This detailed information can only be determined by neutron diffraction. Complexes of human MnSOD including structural intermediates and mutants will be the targets for large volume crystal (≥ 1mm3) growth for structure determination by neutron macromolecular crystallography (NMC). The quiescent environment afforded by microgravity is known to grow crystals large enough for neutron studies; not only are they large but their quality approaches perfection. In 2001, the Borgstahl laboratory successfully grew large crystals of SOD using microgravity conditions on the International Space Station (ISS). With NASA's renewed interest in implementing the microgravity environment on the ISS for protein crystal growth we would like to move forward with these exciting early microgravity crystallization results for SOD. Existing crystallization hardware that uses the Granada Crystallization Boxes (GCB) for capillary counterdiffusion protocols will be used to achieve these goals. A microgravity environment is essential to form a stable supersaturation gradient to obtain the large, high quality crystals required for NMC. Then NMC will be performed with collaborators at Oak Ridge National Laboratory (ORNL). The principal outcome will be to identify the role of hydrogen atoms in enzymatic activity, discern superoxide from peroxide, and water from hydroxide ion by their protonation state and decipher a structure-based mechanism for human MnSOD more precisely than from previous X-ray crystallographic models determined from Earth-grown crystals. These contributions will also provide criteria needed for the protein engineering of desirable properties into enzymatic metal centers for proton coupled electron transfer.

17-EPSCoR-ISS-0003, *In Orbit Structural Health Monitoring of Space Vehicles*

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A significant step in addressing the safety of space vehicles is development and testing of the flight information recorder, or “black box”. It is envisioned, that a structural health monitoring system (SHM) would be an integral part of the “black box” and would record information on structural integrity during all stages of spaceflight. In this project, the team proposes to investigate the effects of the space environment on piezoelectric sensors – active elements of SHM, to explore structural vibrations in microgravity and to demonstrate the feasibility of SHM during long term space missions. To achieve this goal, 1U and 3U payloads (depending on space available) are proposed that will fit into a Nanoracks system outside of the ISS. Mission duration is expected to be less than 1 year (1 year maximum) with minimum of crew time. The power requirement is estimated to approach a few watts. The data collected in the proposed experiment would also benefit the FAA Center for Commercial Space Transportation. The principal investigator is a mechanical engineering professor that has previously participated in a NASA EPSCoR project and launched several suborbital payloads through the NASA Flight Opportunity Program

17-EPSCoR-ISS-0006, *3D printed titanium dioxide foams under extreme environment exposure at low-Earth orbit*

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The proposed project will combine research in materials science and physics of liquid foams with 3-D printing to further advance robotic printing of titanium dioxide (TiO_2) foams and understand their degradation behavior upon exposure to the space environment Low Earth Orbit (LEO). These printed foams exhibit great potential for space applications ranging from efficient solar cells to batteries and radiation shielding.

The proposed experimental work will be accomplished by using the MISSE–FF platform at the ISS to expose the Earth-printed foam samples at LEO conditions. Potential degradation mechanisms will be investigated, upon return to Earth, using a suite of characterization methods. These degradation data for the 3-D printed specimens will give significant early insight into the applicability of our TiO_2 foam materials for the identified potential space applications before going forward and exploring their printing characteristics under microgravity conditions. During this project, further collaborations with NASA (both locally and Nationwide), and UTV will be fostered. Also, a graduate research student will be trained for years 1 and 3 of this project.

At the end of the proposed work it is expected that an advanced understanding about TiO_2 foam degradation mechanisms at LEO will be attained. We expect to attain insights about potential erosion mechanisms of the organic components of the foams due to high atomic oxygen flux. Also, the role of carbon-based materials such as graphene and CNT’s will be investigated in terms of strengthening the printed structures.

17-EPSCoR-ISS-0008, *Enhanced Science on the ISS: Influence of Gravity on Electrokinetic and Electrochemical Assembly in Colloids*

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The proposed work complements ongoing work conducted by the research team on the International Space Station (ISS). In January 2016, the research team conducted a study on the ISS utilizing the Light Microscopy Module (LMM) in order to study nanoparticle haloing under microgravity. This experiment (ACE-H2) was part of a series of colloidal experiments organized by the NASA Glenn Research Center Advanced Colloids Experiments (ACE) whose mission is to gain fundamental understanding of colloidal interactions where gravity would otherwise compromise such investigations. Through our current NASA EPSCoR support (NNX14AN28A), we are to run two ISS experiments (ACE-H2 in January 2016 and ACE-E4 in May 2019). We are tentatively scheduled a six-week timeframe to execute ACE-E4. The work proposed herein will enable additional science beyond the scope of the RA to be conducted during the same six-week period. This study, termed ACE-E4ES (short for ACE-E4 Enhanced Science), will take advantage of updates to the LMM platform since ACE-H2, specifically microscopic confocal imaging and temperature capabilities. This work will enable a greater understanding of nanoparticle haloing which can be used to investigate colloidal stability and controlled self-assembly. Ultimately, the ability to design colloidal particles with a variety of well-controlled three-dimensional bonding symmetries opens a wide spectrum of new structures including photonic crystals.

17-EPSCoR-ISS-0009, Arkansas CubeSat Agile Propulsion Technology Demonstrator Mission (ARKSAT-2)

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ARKSAT-2 is a 2U CubeSat propulsion technology demonstrator and a developmental subset of an innovative free-space spectrometer system using paired CubeSats in formation flight. The paired system is called the Diurnal Atmospheric Surveyor CubeSats (DAS-Cubes), where a light emitting DAS-E (Emitter; "das-ee") is followed by a chasing DAS-C (Chaser; "dask"). The DAS-Cubes concept will enable exploring new space science missions such as compositions and dynamics of extraterrestrial atmospheres, asteroid dusts, comet trails, plumes and ejecta. An agile, low-cost, non-toxic, biocompatible, and non-pressurized micro-propulsion system (CubeSat Agile Propulsion System, CSAPS) for DAS-C is currently being developed at the University of Arkansas-Fayetteville (UAF). The in-space demonstration and validation of this propulsion system forms the primary objective of ARKSAT-2. The secondary objective of the ARKSAT-2 will be on raising the TRL from 5 to 7 for the Solid State Inflation Balloon (SSIB) deorbit technology subsystem currently funded as part of STMD's Small Spacecraft Technology Program. The SSIB is a low cost, simple, and scalable deorbit technology designed for the entire range of small spacecraft (from 1U CubeSats to 180kg Microsats).

17-EPSCoR-ISS-0010, *Evaluation of graphene-silicon photonic integrated circuits for high-speed, light weight and radiation hard optical communication in space*

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Free space optical (FSO) communication holds significant promise for use in space due to its large bandwidth, high data rate, easy deployability, low power, and low mass. An optical carrier in the visible band could be used to establish ground-to-satellite or satellite-to-satellite links. Silicon offers high yield, high density, and low optical loss, and compatibility with CMOS electronic systems. The speed of the photonic circuits would be further enhanced by single atomic layer of graphene, which could increase optical absorption and improve electrical conductivity (compared to monolithic silicon structures). Silicon photonic integrated circuits have already been implemented for 100 Gbps of telecommunication bandwidth, and the addition of graphene may allow Terahertz bandwidths.

Through an established collaboration with Bell Labs Nokia, we hope to further develop graphene-based integrated silicon nanophotonic circuits for use in space applications. Solid state photonic/electronic devices perform stably in vacuum. Nevertheless, the performance of such devices in microgravity and with the extreme radiation exposure of space has not yet been evaluated.

Therefore, we propose a project to evaluate the potential use of advanced integrated graphene-silicon photonic circuits as part of a space-based FSO system. The miniaturized on-chip photonic circuits can be assembled into a 1U CubeSat for radiation test on Materials on the International Space Station Experiment (MISSE). This will allow us to establish how much radiation shielding they require and how the nanoscale design of the circuits can be adjusted to better function in a high-radiation environment.

This project relates directly to multiple areas laid out in the NASA Technology Roadmap: in particular, TA 5.1 ("Optical Communications and Navigation") and TA 12 ("Materials, Structures, Mechanical Systems and Manufacturing"). Additionally, this project complements ongoing projects at NASA such as the Optical Payload for Lasercomm Science (OPALS) and the Laser Communications Relay Demonstration (LCRD).

17-EPSCoR-ISS-0011*, Assessment of Radiation Shielding Properties of Novel and Baseline Materials External to ISS*

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In 2014, NASA EPSCoR funded the "Radiation Smart Structures with H-rich Nanostructural Multifunctional Materials" project (contract # NNX14AN41A) to develop new multifunctional materials to shield space crews from the ionizing radiation environment encountered during space flight. This project also includes a major component to test the radiation shielding properties of these novel materials using ground-based particle accelerators and computer model-based simulations. A number of promising new materials have been developed as a result of this work, in particular a hydrogen-rich carbon fiber composite suitable for use in the fabrication of high-pressure storage tanks for oxygen, water and other consumables needed during space flight and in the pressure vessel of the space craft or planetary habitat.

In response to the NASA EPSCoR ISS Flight Opportunity CAN of 12/5/2016, we propose an experiment to test and measure the radiation shielding and other properties of our multifunctional materials in the actual space environment external to the International Space Station (ISS). The proposed experiment would consist of mounting samples of the multifunctional materials, as well as samples of a number of baseline materials such as aluminum, polyethylene and copper, on the existing Materials for ISS Experiment (MISSE) [1,2] platform. Another possibility would be to use a NanoRacks external platform [3]. Passive radiation detectors in the form of CR-39 plastic nuclear track detector (PNTD) and thermoluminscence detector (TLD) will be placed behind the material samples at varying depths in order to measure the Linear Energy Transfer (LET) spectrum, absorbed dose, and the biologically weighted dose equivalent as a function of depth behind the materials. These types of detectors require no electrical power and have been successfully used by the proposers on several previous experiments to measure ionizing radiation outside spacecraft [4-8].

The proposed experiment is highly feasible, not only in terms of the proposed budget ($90K), but also in terms of the five (5) feasibility criteria listed in Section 1.5 of the CAN. By using existing facilities (MISSE or NanoRacks), hardware costs are minimal and time to flight is less than 1 year, crew time is already allocated as part of the larger MISSE or NanoRacks programs, the experiment does not require power, and the physical space requirements are already allocated, again as part of the larger MISSE or NanoRacks programs. Previous experience with measuring radiation on the exterior of spacecraft indicates a strong likelihood of success.

17-EPSCoR-ISS-0013, *Satellite Demonstration of a Radiation Tolerant Computer System Deployed from the International Space Station*

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The overall goal of this project is to conduct a satellite mission to demonstrate a novel radiation tolerant computer technology. A 3U small satellite will be deployed from the International Space Station (ISS) using the NanoRacks CubeSat Deployer (NRCSD), which will provide 12 months of operation of the computer technology in Low Earth Orbit (LEO). The successful operation of the computer in a full stand-alone mission will increase its technical readiness level (TRL) to TRL-9. This computer technology has been in development for nearly a decade at Montana State University (MSU), with the majority of funding coming from NASA EPSCoR. The computer technology is currently in-orbit on the ISS as an internal experiment through funding from the 2014 NASA EPSCoR ISS Flight Opportunity program. This internal demonstration has allowed our team to verify the operation of the computer in a controlled environment and reach TRL-7. In this proposal, we seek funding to support a different, more advanced experiment in which the computer technology will be integrated into a satellite, deployed from the ISS, and operated for 12 months in LEO. This next critical demonstration is necessary to take the computer technology to its final level of TRL-9. The proposed satellite has been selected by the NASA CubeSat Launch Initiative (CSLI) program for a flight in summer of 2018. As such, we do not require any launch services support from the EPSCoR program. Our team has also been able to design and prototype the satellite through the NASA Undergraduate Student Instrument Program (USIP). These prior NASA programs have enabled our technology to be ready for flight within 12 months of project funding. The funding request in this proposal is for flight unit qualification, integration, and safety coordination (achieving TRL-8) to demonstrate the computer in LEO using the ISS-based NRCSD (achieving TRL-9).

The computer to be demonstrated achieves radiation tolerance through a novel architecture that can detect, avoid, and repair faults caused by high energy ionizing radiation by exploiting the re-programmability of commercial off-the-shelf (COTS) Field Programmable Gate Arrays (FPGA). This fault mitigation approach has been shown to deliver higher reliability, increased computation and power efficiency, and an order of magnitude cost reduction compared to existing radiation-hardened computer systems. The success of our team's initial EPSCoR project has led to four competitively awarded follow-on projects from NASA that has allowed this computer technology to be matured to the point where a satellite demonstration using the ISS-based NRCSD is feasible within the criteria of the 2017 EPSCoR ISS Flight Opportunity call. Testing of this technology in a stand-alone mission will expose the system to a high-energy radiation environment that cannot be duplicated on earth (>GeV/amu). A satellite demonstration will also provide prolonged exposure to the infrequent high energy radiation strikes (2-3 faults per day) in order to provide a comprehensive evaluation of the reliability of the computer system. A stand-alone mission is also required in order to advance the technology from controlled experiments into a fully operational situation so that TRL-9 can be achieved. The ISS-based NRCSD is an ideal launch opportunity due to the reduced launch environment requirements, the logistical support provided by NanoRacks, and the existing relationship between MSU and NanoRacks created through our ongoing internal EPSCoR experiment. Figure 1 shows the mission concept for the proposed experiment.

17-EPSCoR-ISS-0014, *Utilizing ISS as a Test Bed to Validate the Performance of Nano-Enhanced Polymers Subjected to Atomic Oxygen and/or Hypervelocity Impact*

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The PIs of this proposal investigated the efficiency of using nano materials to improve the performance of polymeric materials in space applications through a number of ground/ lab tests. The research was part of an EPSCoR research grant titled "Hypervelocity Impact – Environmental Resistant Nano Materials in Space Applications". The research attempted to improve the state of the art of hypervelocity impact-resistant materials and structures by designing and manufacturing a new family of composite materials for space applications. It focused on two debris-related threats to spacecraft survivability: hypervelocity impact and environmental degradation of transparent polymeric materials. The two threats were evaluated in the context of using graphene nanoparticles embedded in POSS modified polymers.

The objective of the proposed research is use ISS as a test bed for evaluating the performance of a new class of nanocomposites manufactured at University of Mississippi under a NASA EPSCoR program and perform relevant ground test experiments required, including flammability, off gassing, and toxicity, before deployment to ISS.

The proposed development and testing will determine the post space exposure performance of a specific type of ultra-lightweight nano-composite sheet that can prove to be a significant improvement in the shock absorption/attenuation and dispersion of modern debris shields. These new shields could be retrofitted on ISS and also used on spacecraft destined for planetary missions.