RESEARCH PROGRAM

Science and Engineering Abstracts
for Grants Awarded in December 2019

Montana State University
Bozeman, MT
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The subsurface hosts arguably the most diverse and underexplored microbiome on Earth. However, logistical constraints and costs associated with obtaining relevant subsurface samples have limited our understanding of the processes that supply nutrients to these isolated microbial communities over extended time periods. Seismic activity, such as an earthquake, can shear rock and expose fresh mineral surfaces capable of reacting with water and generating nutrients. Such activity is acutely expressed in Yellowstone National Park (YNP), the site of one of Earth's largest active volcanos. Recently drilled boreholes equipped with seismometers in YNP combined with the development of seismically triggered, autonomous sampling technology now allows for the isolation, capture, and preservation of fluids and the microorganisms they contain, following seismic events. The primary goal of this project is to determine the timing, magnitude, and complexity of microbial responses at the level of cell abundance, biodiversity, and activity as they relate to earthquake magnitude, focal mechanism, and distance. Over the course of this project, our team will deploy the Kinetically Activated Subsurface Microbial Sampler in YNP boreholes with varying source waters and seismic activity. We will characterize nutrient release (gases and solutes) and the microbial response at the level of taxonomic and functional biodiversity in temporally resolved samples using (meta)genomic, (meta)transcriptomic, and cultivation-based methods. Parallel monitoring will be conducted with existing borehole seismometers. This information will be integrated within our emerging understanding of the subsurface geology and hydrology in YNP to better define the basis for observed differences in the geochemical and microbial response to different seismic events.

University of Arizona
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In the last decade, Ultrafast Electron Microscopy (UEM) has imaged atomic motion in real time and space, and table-top tools have opened up a vast range of science. Current UEM research focuses on improving both spatial and temporal resolution to resolve the electron dynamics of matter on sub-femtosecond timescales. Yet the imaging of electron dynamics remains beyond reach. The first project goal is to enhance the temporal resolution for electron microscopy to the extreme limits of an attosecond timescale, which is a thousand-times faster than cutting-edge UEM—an advance the PI calls "Attomicroscopy." The PI will attempt to achieve this extreme imaging speed by generating single isolated attosecond electron pulses. Specifically, this optical gating approach will use a laser pulse to control, tame, and confine the burst of free electrons inside the microscope on an attosecond timescale. Attomicroscopy will open a new era to both directly image and record electron motion in action, for the first time. As a second goal, the proof-of-principle for the unique Attomicroscopy camera is to directly record movies in real time and space for the surface-plasmon electron motion of a silver nanostructure. The images and movies will reveal the electronic motion in the context of nanostructure morphology, and potentially pave the way to laser-driven, million-times faster electronics that shape the future of information technology.

University of California, Santa Barbara
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Chromatin packaging, on multiple scales, is now understood to be driven in part by liquid-liquid phase transitions, typically involving droplets of biomolecules that surround and sequester genomic segments. Further, the phase separations are themselves regulated by genetic outputs. Phase transitions differ strongly from classic biomolecular interactions, exhibiting discontinuous responses to solution changes and unique dynamics (e.g. nucleation). How these phenomena affect regulation is an open question. These investigators will illuminate this issue using a synthetic chromatin system consisting of self-assembled DNA particles that phase separate to form droplets. The DNA liquid will be interfaced with a gene such that liquid formation modulates transcription, while the transcribed RNA modulates liquid stability. The resulting feedback network will permit chromatin-like phase-based autoregulation in a well-controlled model system. The researchers will exploit this genetically-controlled phase behavior to create oscillating or self-patterning systems. Experiments will use multi-modal methods to track the dynamics of several molecular parameters across many system designs. Results will be analyzed using biophysical models that predict behavior based on known molecular mechanisms, and unbiased machine-learning models that exploit the broad data set, allowing for the discovery of unexpected mechanisms. The result will be the development of validated concepts describing the interplay of genetics and phase transitions that can be applied to other systems. This project could transform our understanding of chromatin structure-forming processes; to establish the unique abilities of phase-transition dynamics within a systems biology framework; and to define a novel direction in synthetic biology and biomaterials.

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The ascent of quantum materials and nanotechnology should eventually advance transistors, detectors, and lasers to become quantum-ready so that they can operate on exquisite multi electron–light quantum states. As the next leap for quantum sciences, this team of researchers will introduce atomically thin gallium nitride (GaN) as quantum-ready semiconductors for a scalable quantum optoelectronics technology that functions at room temperature and operates on entanglement. They predicted that Coulombic many-body interactions of atomically thin nitrides are so strong that they bind electrons and holes (electronic vacancies) to quantized excitons that are stable even at room temperature, unlike any other commercial inorganic semiconductor. Such strong interactions can also cluster electrons to other complexes, such as exciton molecules (biexcitons) and dropletons, as abundant resources for storing and processing entanglement. This project forms a closed loop between the most precise quantum-theory-synthesis-experiment efforts, through which the team will introduce room-temperature quantum optoelectronics, including quantum-light sources, stable electron–hole clusters, and detectors, wherein entanglement can be excited, processed, and detected at will. The investigators will use the most accurate quantum theory to predict material properties and to determine quantum dynamics relevant for entanglement-processing applications. Based on these insights, they will develop atomically thin nitrides into a unique platform for quantum technologies by growing them with molecular beam epitaxy, characterizing them with electron microscopy, and demonstrating quantum optoelectronic protocols with ultrafast optical and quantum spectroscopy, all highest-precision quantum techniques. The project could revolutionize quantum technologies by amplifying and extending quantum-coherent effects on a quantum-ready semiconductor platform and at room temperature.