W. M. KECK FOUNDATION

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Science & Engineering

Tufts University
Medford, MA
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$1,200,000

Understanding and replicating living optical networks inspired by orchid leaves

Selected plants exhibit a unique leaf morphology consisting of an optical network that enables their survival in low-light environments, efficiently collecting the little light available. The structure and the proposed functional role of this network challenges traditional descriptions of light harvesting and photoconversion in plants, offering a new perspective on flexible, curvilinear solar cells that could redefine photovoltaics. This project aims to establish the scientific foundation of this, so far undescribed, novel light management mechanism in plants through three tasks: (1) understanding the formation, hierarchy, and function of optical networks in a selection of plants that grow in low-light conditions, with a particular focus on jewel orchids; (2) developing an optical model to identify key parameters governing light propagation on the leaf plane and growing and studying selected plants under varying light conditions to quantify their light-driven adaptations; and, (3) replicating and studying the leaf's living optical network with biopolymer-based materials. Expected outcomes include (i) a new understanding of light-plant interaction that challenges established understanding in plant science; (ii) acquiring fundamental knowledge on dynamic light-harvesting systems; and, (iii) the development of plant-inspired replicas to generate a new class of soft, flexible, curvilinear, photovoltaic systems with improved photoconversion efficiency.

University of California Riverside
Riverside, CA
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$1,200,000

Deciphering social communication in stress-tolerant honeybees

Decoding how environmental threats are perceived by individuals, processed, and eventually passed on to other members of a society to trigger a coordinated response is a fundamental but still unsolved challenge in sociobiology. A team from UC Riverside will study European honeybees (*Apis mellifera*), which are superorganisms that live in highly complex societies of up to 80,000 individuals while successfully managing an array of environmental stressors. The team will compare the communication of stressors from neurons to individuals, then groups, and ultimately entire societies. To do this, they will compare honeybees from stress-susceptible, domesticated colonies with honeybees from stress-tolerant genotypes. For the latter, they will use a population of locally occurring survivor honeybees. Compared to domesticated honeybees, survivor bees are genetically far more diverse and have been under continuous natural selection to manage environmental stressors including extreme urbanization, harsh climatic conditions, and intense agriculture. Through a series of neurobiological and behavioral lab- and field experiments, they aim to confirm that survivor bees possess highly sensitized neural responses to key effector molecules. The prediction is that survivor bees pass on signals of potential threats to the colony more efficiently and ultimately trigger more effective societal responses compared to stress-susceptible genotypes. The team will also test whether colonies can transmit information about potential environmental threats for multiple generations of worker bees, which would indicate transgenerational stress priming and can be seen as a basic form of culture. Successful completion of this project will not only expand our understanding of superorganisms, but also benefit efforts to safeguard honeybees, their pollination services, and global food production.

University of California Santa Barbara
Santa Barbara, CA
Adrian Stier, Craig Osenberg, Rachael Bay
$1,300,000

Deciphering coral regenerative biology to facilitate coral reef resilience

As coral reefs disappear, so does the extraordinary biodiversity of life they support. Warming seas disrupt the mutualism between corals and their algal symbionts, leading to bleaching and possible death. Increasingly, coral recovery depends on regeneration and regrowth of remnants that persist after disturbances. Studying the fundamental science of coral regeneration is therefore critical to understanding reef resilience in the face of ocean warming. The overarching goal of this work is to reveal how stony corals detect and respond to tissue damage, and to decipher mechanisms governing successful regeneration. Research suggests single coral polyps have extraordinary regenerative capacity, but injuries comprising many polyps exhibit diminished repair capacity. This presents a paradox: how does an organism comprised of individuals with a blueprint for near limitless regenerative ability exhibit an apparent reduction in regenerative capacity when part of a colony? How does the ability to repair or cast aside damaged tissue affect colony persistence in the face of global climate change? Answering these fundamental questions has the potential to inform our understanding of regeneration in all animals and will galvanize restoration of an ecosystem in peril. This research spans from genomics to ecology and has three aims: 1) Understand functional trade-offs among wound healing, reproduction, and growth, 2) unravel the molecular signals that indicate damage and initiate regeneration in the colony, and 3) evaluate how temperature constrains regeneration.

University of Central Florida
Orlando, FL
Enrique del Barco, Ran Cheng, Andrew Kent, Simranjeet Singh
$1,300,000

Magnetic topological insulators for lossless spintronics

The physical foundation underpinning all spintronic effects is the intricate interplay between electron transport and magnetic dynamics, which has a wide variety of manifestations. However, two universal problems prevail in almost all experimentally realized systems: 1) Joule heating due to Ohmic conduction and 2) inhibited transfer of angular momenta across interfaces. This multidisciplinary team from the University of Central Florida, the University of California, Riverside, New York University, and Carnegie Mellon University, strives to solve these two fundamental issues by exploiting the unique physics of a recently discovered material family known as intrinsic magnetic topological insulators, in which electronic structures are highly intertwined with the layer-resolved magnetism due to the spin-orbit coupling. While the material is insulating and does not admit Ohmic currents, it allows for adiabatic currents when the magnetic moments are set into motion, thanks to the topological structure crosslinking the crystal momentum and the magnetic orientations (an effect overlooked by existing studies). The researchers plan to harness the lossless adiabatic currents to drive the dynamics of magnetic moments, in which the magnetic order can be effectively operated by a pure voltage devoid of Joule heating. Moreover, because the material can generate and deliver spins independently without needing another material, it realizes a self-driven device, eliminating the interfacial spin-transfer processes and their ensuing problems prevailing in engineered heterostructures. With encouraging preliminary theoretical findings, they will integrate theory with experiments to uncover a new paradigm of spintronics featuring lossless and monostructural manipulation of magnetism.

University of Colorado – Boulder
Boulder, CO
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$1,000,000

Testing the role of extreme climate in early animal evolution

During the Cryogenian Period (720 – 635 million years ago) the Earth underwent two global glaciations when sea ice extended from the poles to the equator for millions of years. Surprisingly, the fossil record reveals that, after over a billion years of relative evolutionary quiescence, the first marine animals evolved and diversified during this period of dynamic climate. The team from the University of Colorado hypothesizes that these glaciations directly enabled the origin of animals as an adaptation to overcome the physics of the high viscosity of cold pre- or syn-glacial seawater. If true, this idea would transform our understanding of the relationship between climate and evolution: the Snowball glaciations were drivers of, not barriers to, evolution. A key challenge in evaluating this hypothesis is a lack of effective tools to measure primary environmental temperatures from rocks this old. A broad suite of geochemical proxies for temperature that are effective in younger rocks cannot accurately reconstruct temperatures from this period: using them on subglacial Cryogenian rocks produces estimates of ≥20°C, more like the modern warm Bahamas than icy Antarctica. The PI has been developing a novel tool that will unlock temperature information stored in Cryogenian-aged rocks for the first time. The researchers will use this novel proxy to generate predictions of body size evolution spanning the Cryogenian Period using a mechanistic model, which they will compare with a new compilation of fossil body size to assess the role of extreme climate as a causal factor of the evolution of animals.

Woods Hole Oceanographic Institution
Woods Hole, MA
Catherine Walker, Weifeng Zhang
$1,600,000

A prototype self-deploying autonomous mooring system for studies of Antarctic ice shelf melt

The Antarctic ice sheet is one of the greatest threats to humanity's ability to successfully adapt to a redrawing of the world's coastlines in the coming century, because it is the largest source of uncertainty in global sea level rise projections over the next century and beyond. The giant ice shelves that surround Antarctica hold back glaciers draining into the ocean. As the largest sources of ice mass loss, they are "ground zero" for sea level rise. A better understanding of how they lose mass over time is crucial to reducing uncertainties in sea level rise projections and predicting changes to global thermohaline circulation. The overarching objective of this project is to quantify basal melt of Antarctic ice shelves. No existing technology permits the long-term observations required to address how ice-ocean feedbacks evolve over time or how rapidly ice shelf basal melt will increase in coming decades. Ocean observing is difficult even in the most benign conditions. To advance observing capabilities in these hostile environments, while at the same time revolutionizing our understanding of critical ice-ocean interactions, this team from the Woods Hole Oceanographic Institution will develop a prototype Self-deploying Autonomous Mooring System (SAMS). SAMS will be deployed at the ice shelf front, travel into the ice shelf cavity, and station in the cavity for periods up to years, transmitting data to shore in near real-time. SAMS will enable systematic quantification of Antarctic ice shelf basal melt, and improve prediction of future ice loss and sea level rise. Development and deployment of SAMS represent significant advancements in different aspects of marine technology. Combining them will transform approaches to sustained measurements in this rarely observed icy ocean realm.