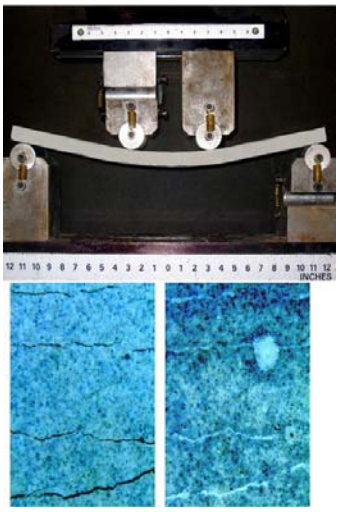
Reports from AC/GPA Subgroups

DISCOVERY SUBGROUP

The Committee concluded that there has been significant achievement for the Discovery outcome goal.

Introduction



The Discovery Subgroup of the Advisory Committee for GPRA Performance Assessment was asked to assess activities at the NSF in the area of Discovery. Specifically, it is a goal of the Foundation to "*Foster research that will advance the frontiers of knowledge, emphasizing areas of greatest opportunity and potential benefit and establishing the nation as a global leader in fundamental and transformational science and engineering"* (NSF Strategic Plan FY 2006-2011).

Process Followed and Criteria Used

A total of 260 highlights, out of 929 highlights submitted by NSF staff, were randomly selected and reviewed by subgroup members. Subgroup members were each assigned 35-40 highlights to review, and were asked to select a few that stood out and demonstrate or exemplify NSF accomplishments under Discovery. In addition, the Chair (D. Apelian) reviewed the 669 highlights that were not selected and concluded that the selected highlights were a representative sample. The Chair also reviewed the highlights cited by Dr. Arden Bement, NSF Director, in his presentation to Congress on the FY2009 Budget (see: http://www.nsf.gov/news/speeches/bement/08/alb080204_budget.jsp).

The Subgroup was asked to review and evaluate the accomplishments against one or more of the following criteria:

Research Grants (grants that deal primarily with traditional investigator-initiated research projects):

- *Strengthen fundamental research across the full spectrum of science and engineering through support for NSF's fundamental or core disciplinary programs.*

- *Foster discoveries that have the potential to transform disciplines or fields of science, engineering, or education research.*

- *Promote innovation and partnerships with industries to stimulate the development of new technologies and processes to further U.S. economic competitiveness and benefit the Nation.*

- *Promote international collaboration among U.S. investigators and partners in other countries and regions.*

Science and Engineering Centers:

- *Enable academic institutions and their partners to integrate discovery, learning, and innovation on scales that are large enough to transform important science and engineering fields and interdisciplinary areas and stimulate increased innovation.*

Over and beyond the AC/GPA criteria, the Subgroup members felt that, for next year, it would be important to also consider two additional NSF investment priorities that are included in the 2006-2011 Strategic Plan, specifically:

Subgroup Members

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- *Investigate the human and social dimensions of new knowledge and technology.* NSF will integrate research on ethics, safety considerations, and virtual communities from the outset in new research and in the applications of emerging technologies.

- *Foster research that improves our ability to live sustainably on Earth.* To strengthen our understanding of the links between human behavior and natural processes, research may range from investigations of deep oceans to urban centers and from basic energy science to climate science.

Results of Analysis

On the basis of the highlights analyzed, the Subgroup concludes that NSF has demonstrated significant achievement in meeting its goals in the area of Discovery. The 260 program highlights that we reviewed clearly demonstrate that NSF fosters research that advances the frontiers of knowledge and helps in establishing our nation as a global leader in fundamental and transformational science and engineering. The Subgroup selected the following highlights as examples of significant achievements in the area of Discovery:

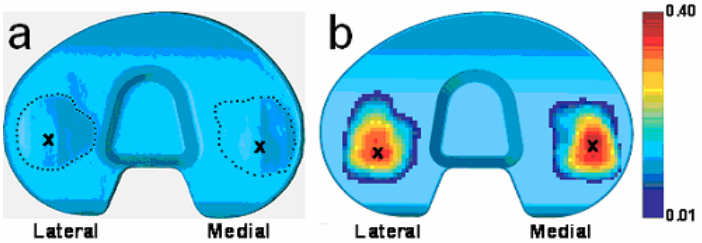
- ***Strengthen fundamental research across the full spectrum of science and engineering through support for NSF's fundamental or core disciplinary programs.***

It has been the conventional scientific wisdom for almost a century that magnetism in a given material opposes conventional superconductivity, such as that found in pure metals. Nobel laureates J. Bardeen, L.N. Cooper, and J.R. Schriefer showed that when superconductivity occurs the electrons in the metal form pairs. However, in

unconventional superconductors, such as high temperature ones, where materials are on the verge of being magnetic, the electrons causing superconductivity take a different collective form than those in conventional superconductors, but the superconducting mechanism is not yet understood. A project titled **Magnetism Meets Superconductivity** *(Highlight 15821; Award Number 0710492)* is a collaborative effort between Zachary Fisk's group at University of California, Irvine and investigators at Los Alamos National Laboratory and Dresden University in Germany, and explores the boundary between superconductivity and magnetism. In crystals of one of these unconventional superconducting materials, consisting of a combination of cerium, cobalt, and indium, both superconductivity and magnetism have been discovered to coexist. This research is an example of fundamental and transformative research that could lead to a completely new understanding of the mechanisms causing superconductivity in high-temperature superconducting materials. $CeCoIn_5$, discovered in this NSF-funded research, has proven to be an ideal material for studying physics at the magnetic/superconducting boundary. These revolutionary findings are a direct result of support for Dr. Fisk that began with NSF-DMR 7504019, when he was a beginning investigator. Long-term NSF support of his research on fundamental condensed-matter physics has led to exciting, important results and to the field of highly correlated electron systems. This result could benefit many electrical applications areas such as power transmission and electronics.

Two other projects that "strengthen fundamental research across the full spectrum of science and engineering" are CAREER (Faculty Early Career Development Program) Awards. Program officers who highlighted these projects indicated that the projects were not only transformative in nature, but also promoted broadening participation, and had societal benefits as well. The first of these projects is titled: **The High Fidelity of Human Image Representation** *(Highlight 16657, Award Number 0546262)*. Dr. Aude Oliva and her team in the Department of Brain and Cognitive Sciences at MIT are currently exploring a novel avenue to explain the feat of human visual understanding, testing human capacity at remembering visual details for a given image. Her work has demonstrated that human visual memory can encode a massive amount of visual details that is an order of magnitude higher than previously believed. These results challenge assumptions about efficient image representations, which is highly relevant to cognitive psychology, neuroscience, and computer vision. This study potentially could lead to much higher-performance artificial vision systems as well as better understanding of human visual processes, which have potential applications to consumer technologies and homeland security and defense. The project affords significant opportunity to examine the ethical and safety dimensions of new technologies that may emerge.

The second CAREER Award selected for this criterion is titled: **Virtual Prototyping of Artificial Knees** *(Highlight 16684, Award Number 0239042)*. Dr. Benjamin Fregly, University of Florida, and his team are addressing a growing need for the aging American population. By one estimate, 40 million Americans will be affected by osteoarthritis in the year 2020. It is felt that this project could lead to an entirely new



approach for designing knee replacements, and testing innovative designs using computer software rather than physical simulator machines. This work is unique because of its ability to predict long-term wear characteristics of knee replacement designs in a matter of minutes or hours using computer simulations. In terms of Broader Impacts, high school students from underrepresented groups have been involved in the knee research, through the University of Florida Summer Science Training Program. In addition, an orthopedic implant company has already enlisted the research team to participate in design of the next generation of knee replacements. Significant ethical and safety issues implicit in this study are ripe for further examination.

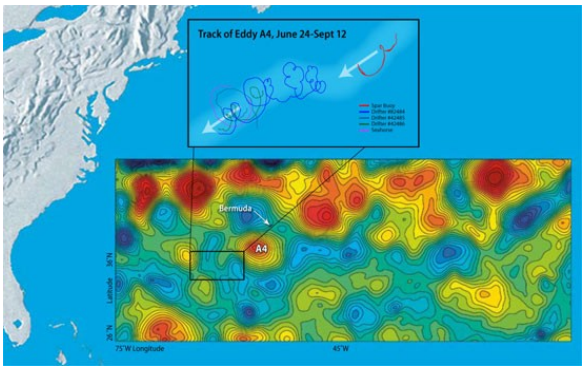
Cross-fertilization of ideas between disciplines can be transformative. Using control theory techniques originally developed for engineering applications, engineers are helping to transform medical treatment of cancer. The project **Control in Genetic Regulatory Networks: An Engineering Approach to Increase the Success Rate in Cancer Therapy** *(Highlight 15041, Award 0355227)* uses control theory from engineering to formulate the process of moving a cell from a diseased state to a disease-free state. The genetic regulatory networks were constructed from experimental data provided by collaborating biologists. The objective was to reduce the activity of certain genes at the tissue level by partitioning the probable outcomes of treatment strategies into good and bad regimes. The theoretically developed control algorithms performed significantly better in simulation studies than alternative approaches currently used. The project strengthens fundamental research in genomics using engineering analysis techniques of signal processing and control, and fosters discoveries whereby an engineering approach may transform medicine. In addition, this work promoted sufficient innovation to win a major follow-up grant from the W. M. Keck Foundation for validation experiments. Finally, it addresses the Strategic Plan goal of investigating the human and social dimensions of new knowledge and technology by transforming medical treatments in cancer.

- ***Foster discoveries that have the potential to transform disciplines or fields of science, engineering, or education research.***

Given the increasing frequency of tornadoes experienced today, new technologies to predict when and where tornadoes and other weather disturbances (floods, severe thunderstorms) will occur are of obvious importance. The NSF Engineering Research Center for Collaborative Adaptive Sensing of the Atmosphere (CASA), located at the University of Massachusetts at Amherst, has developed a method of weather sensing that utilizes dense, low-cost radar networks that can sense the lower atmosphere, an important area that is under-sampled by today's technologies *(***New Radar Network Evaluated in National Weather Service Experimental Warning Program**, *Highlight 15599, Award 0313747)*. The finely grained observations of the lower atmosphere obtained by the CASA researchers allowed forecasters to see small meteorological structures that are close to the

ground, such as mini-wind clusters that are embedded in larger storms. During the 2007 tornado season, CASA transmitted real-time data from its first prototype network in Oklahoma to National Weather Service forecasters for evaluation in the Experimental Warning Program. The Center's data will continue to be evaluated in the Experimental Warning Program during the 2008 tornado season. This research is multidisciplinary, requires a complex-systems approach, and involves collaboration between various universities and government agencies at many levels. The research is transformative because it will introduce a new dimension to weather forecasting and sensing, yielding capabilities that do not exist today. This highlight also represents broadening participation in that the faculty and students involved include many women and members of underrepresented minorities.

Interactions Between the Wind and Oceanic Eddies Stimulate Higher Biological Productivity In Subtropical Ocean Surface Waters *(Highlight 16578, Awards 0241310, 0241340, 0241023)* is a project led by Dr. Dennis McGillicuddy, Woods Hole Oceanographic Institution, with a team of collaborative investigators from eight different institutions. Oceanographers from these institutions have sampled two different types of eddies over a period of months using a sophisticated approach employing high-tech instrumentation to measure horizontal and vertical dispersion of several water properties. This research contributes to the fundamental knowledge about what factors control biogeochemical cycles and the conversion of carbon dioxide into biomass in the oceans. Their work has demonstrated that episodic eddy-driven upwelling may supply a significant fraction of the nutrients required to sustain primary productivity in the subtropical ocean. The results from this study are changing the view of how biological production and export of carbon to the deep ocean is taking place in the mid-ocean.



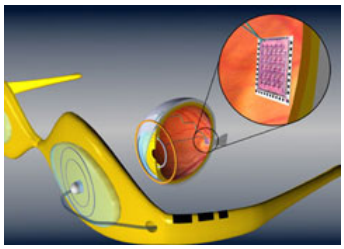
Fundamental research at the atomic level is still alive and well, and established wisdom continues to be challenged. A striking example of this is the preparation of "ultra-heavy" isotopes, magnesium-40 (normally Mg-24), aluminum-42, and aluminum-43 (normally Al-27). These extraordinarily heavy isotopes, created at the National Superconducting Cyclotron Laboratory at Michigan State University *(***Newly Created Forms of Magnesium and Oxygen***, Highlight 16189, Award 0606007)*, defy established theory, which predicts that they should not be stable. The results emerged from careful detection with enhanced techniques that allowed observation of one in one billion particles, an experiment that could not have been carried out without a user facility of this unique type.

A project, **Beware What's Unaware: Deep Impact of Subtle Distractions**, undertaken by Takeo Watanabe, a cognitive neuroscientist at Boston University *(Highlight 15885, Award 0549036)*, fosters discovery into the mechanisms of attention disorders by demonstrating how different regions of the brain interact. He found that participants had

more difficulty suppressing subliminal, low-coherence stimuli (randomly moving dots on a computer screen) when trying to focus on a particular task. This was demonstrated by imaging a particular area of the brain, Middle Temporal, (MT), which perceives motion. The project also simultaneously imaged another area of the brain, the dorsolateral prefrontal cortex (DLPFC), which is responsible for inhibiting responses in the MT. They found that the DLPFC area did not activate when presented with low-coherence stimuli, thereby causing activity in the MT area. They also showed more activity in the MT area with low-coherence stimuli than with high-coherence (coordinated) stimuli. This project has implications for understanding attention disorders in humans (as this research shows that subtler distractions are harder for the brain to screen out) as well as understanding how different regions of the brain interact. It may result in more efficient workplace design. This meets the evaluation criteria of strengthening fundamental research (in understanding better how different regions of the brain interact) and fostering discoveries that could transform cognitive research on attention disorders. Finally, it addresses the Strategic Plan goal of investigating the human and social dimensions of new knowledge and technology.

- ***Promote innovation and partnerships with industries to stimulate the development of new technologies and processes to further U.S. economic competitiveness and benefit the Nation.***

More than 25 million people around the globe, including six million in the United States, are visually affected by genetic retinal diseases. Researchers are working to help patients blinded by Retinitis Pigmentosa; the work involves development of a second generation prosthetic implant (ARGUS II) that will enhance the vision of individuals who have lost sight *(***USC Research May Help Patients Blinded by Retinitis Pigmentosa***, Highlight 15664; Award 0310723).* The new implant was developed by Dr. Mark Humayun's research team at the University of Southern California and Second Sight Medical Products Inc. The ARGUS II consists of a tiny camera and transmitter mounted on eyeglasses, an implanted receiver, and an electrode-studded array that is secured to the retina with a microstack the width of a human hair. A wireless microprocessor and battery pack powers the entire device. Six patients were implanted with earlier prototypes in 2002, and can now perceive light, distinguish between objects, and detect motion. The new implant contains nearly four times as many electrodes as the original (60 vs. 16), each of which is independently controllable, allowing patients to process higher-resolution images. Researchers hope the ARGUS II will be available in a few years and are currently enrolling subjects in clinical trials. This work is transformational in that it represents breakthroughs in microelectronics, image processing, and bio-engineering, which are likely to lead to radically new prosthetic technologies in other areas beside the retina. By 2020, some 50 million patients who have lost their sight due to genetic eye diseases that affect the retina are projected possibly to be able to regain some of their sight using a new retinal implant. The research also satisfies the NSF Strategic Plan's emphasis on broadening participation in that a number of key members of the research team are women. Finally, it demonstrates one of the investment priorities of the Strategic Plan



goal of investigating human and social dimensions of new knowledge and technology by developing products to give some level of sight to patients suffering from Retinitis Pigmentosa.

Bendable Concrete for Safe, Durable, and Sustainable Infrastructure *(Highlight 15376, Awards 0223971, 0329416, 0700219)* is a project by investigators at the University of Michigan who have designed a new type of concrete that maintains all the advantages of current concrete but adds ductility, allowing it to bend under stress without fracture. The new type of concrete has 300-500 times the tensile ductility of normal concrete; it can be bent without fracturing when overloaded. The material also exhibits self-healing properties, which further enhances its durability. The work may establish the United States as the global leader in "designer" cement-based composites. It also embodies collaboration among several sectors: government, industry, and academic partners. It has potential consequences in the design of sustainable structures resistant to earthquakes and weather events. This research also exemplifies the NSF Strategic Plan goal of integrating research on ethics, and safety considerations.

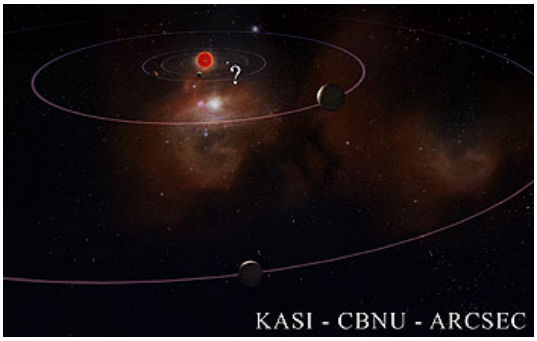
- ***Promote international collaboration among U.S. investigators and partners in other countries and regions.***

Research and Education Experiences for Students to Examine Earthquake Hazard Mitigation Utilizing the Network for Earthquake Engineering Simulation (NEES) is an excellent example of international collaboration *(Highlight 16728, Award 0526590).* Professor Richard Christenson and graduate and undergraduate students traveled to Thailand and Japan to conduct research in innovative ways to reduce structural damage arising from natural hazards, such as earthquakes. The visits and collaborative research in the two countries are enabling partnership building between United States, Thai, and Japanese institutions, and scientists who are engaged in the study of ways to create better designed buildings that can withstand strong forces during earthquakes and tsunamis, thus enhancing public safety.

The societal urgency of understanding impacts of global warming on sea level rise requires establishment of innovative observations and partnerships. In the project, **Sea Level Rise from Polar Ice Sheets: Societal Relevance and Broader Impacts** *(Highlight 14730, Awards 0122520, 0407827, 0424589)*, the Center for Remote Sensing of Ice Sheets (CReSIS) serves to join forces between U.S. universities (U. Kansas, Ohio State, Penn State, U. Maine, Elizabeth City State University, and Haskell Indian Nations University) and international collaborators from Denmark, Norway, Australia, the United Kingdom, and Iceland, and the Topeka K-12 school district. This team is transforming science and engineering fields by using satellite-based sensing of the earth with UAV (Unmanned Aerial Vehicle) and traditional airborne-based radar, along with seismic and other measurements with data products, modeling, and analysis to improve on current estimates of sea level rise resulting from global warming. The Nobel-Prize-winning IPCC (Intergovernmental Panel on Climate Change) 2007 estimates, which may under-predict the rate of future sea level rise, are based on traditional modeling of the ice sheets, which ignore rapid changes that may occur due to recently observed mechanisms of bed lubrication and ice shelf stability effects. CReSIS is integrating discovery and learning

via classroom activities developed for K-12 education, which are free and available to all via their website (https://www.cresis.ku.edu/), along with the Summer School for Teachers and PolarTrec, which increase classroom knowledge of climate change. This project has genuine partnerships with minority-serving institutions, which play integral roles in the discoveries and reporting of results. Finally, this work investigates human and social dimensions of new knowledge and technology by integrating discovery (better modeling of sea level rise due to the integration of various observations and data sets) and learning using K-12 classroom activities.

Going from the subatomic to the cosmological, astronomers collaborating from 11 universities have observed a new solar system analogous to ours but smaller in size that contains planets similar to Jupiter and Saturn (**Newly Found Solar System has Jupiter/Saturn Pair Similar to Ours, just scaled down**, *Highlight 16275, Awards 0206189, 0452758, 0708890*). The system was detected by "gravitational microlensing," in which light from another star is magnified by the passing of another body—in this case, the star detected—in front of it. Observations from the 11 different ground-based telescopes provided the sensitivity to observe the planets. The small size of the solar system compared to other exosystems suggests that solar systems like ours may not be rare. The work is an excellent example of an international collaboration, including participation of amateur astronomers.



Research stimulated by the devastation caused by tsunamis has revealed possible origins for their profound impact. Japanese and U.S. scientists (**"Ultrasound" of Earth's Crust Reveals Inner Workings of a Tsunami Factory**, *Highlight 16358, Award 0451790*) examining the seafloor near the southwest coast of Japan, where tsunamis are particularly prevalent, have found a major fault line that can trigger serious earthquakes, which are known to occur in that region. Core drilling also reveals that the fault line appears to have shifted landward over time, and has become shallower and steeper, conditions that are ideal for tsunamis. These multidisciplinary results, carried out through an international partnership, contribute to developing ways for living sustainably on Earth.