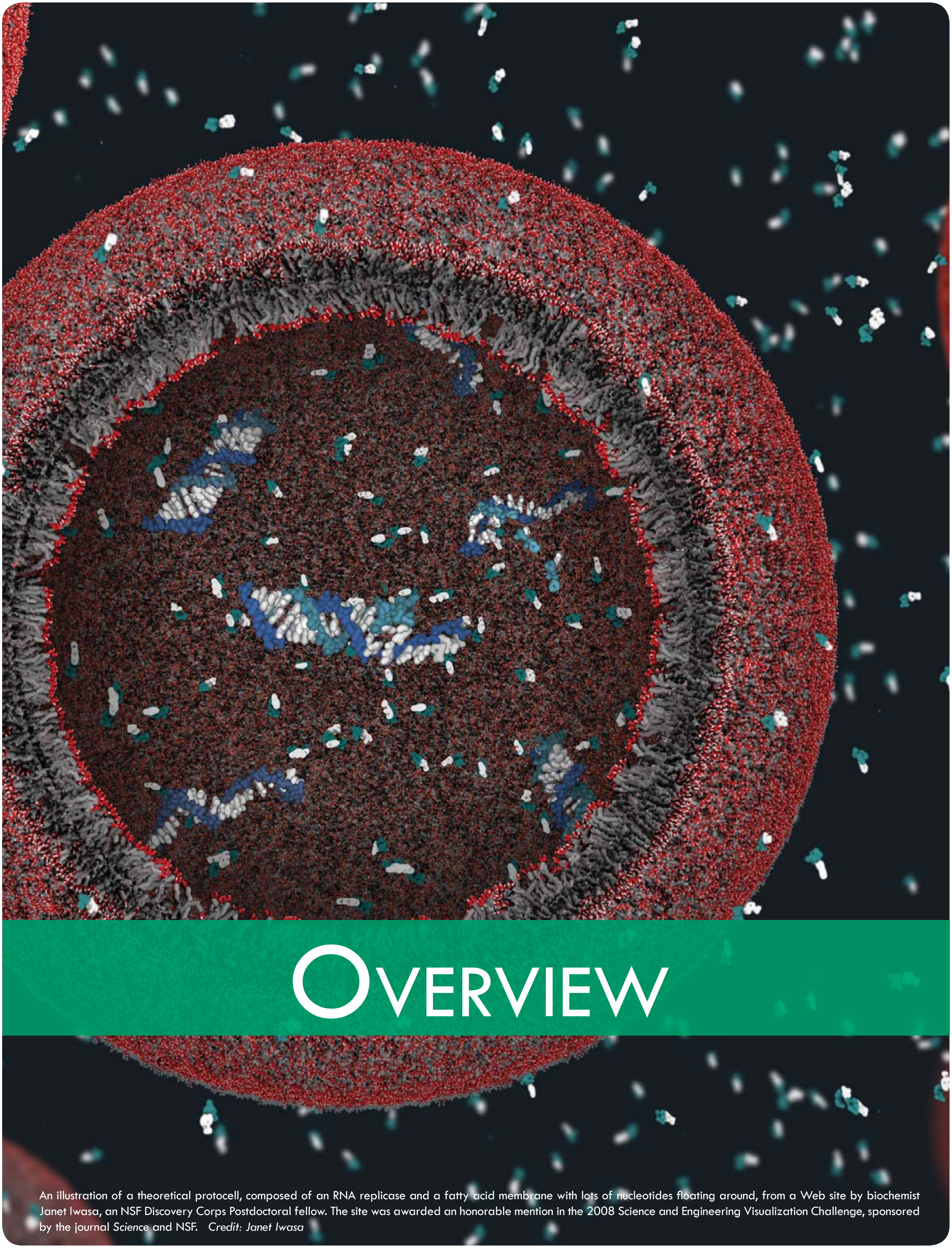
Overview



An illustration of a theoretical protocell, composed of an RNA replicase and a fatty acid membrane with lots of nucleotides floating around, from a Web site by biochemist Janet Iwasa, an NSF Discovery Corps Postdoctoral fellow. The site was awarded an honorable mention in the 2008 Science and Engineering Visualization Challenge, sponsored by the journal *Science* and NSF. *Credit: Janet Iwasa*

NSF is a primary supporter of forefront instrumentation, facilities and infrastructure for the academic research and education communities across all areas of science and engineering.

NSF major research infrastructure investments provide state-of-the-art equipment and multi-user research facilities, such as distributed instrumentation networks, arrays, accelerators, telescopes, research vessels, aircraft, and earthquake simulators for research and education. In addition, investments in Internet-based and distributed user facilities are increasing as a result of rapid advances in computer, information and communication technologies.

NSF also supports shared cyberinfrastructure projects, integrative research and education centers programs, and programs to fund the acquisition and/or development of mid-scale scientific and engineering equipment for research and research training, all of which strengthen the U.S. research and educational enterprise.

Major Research Infrastructure

Construction of most large-scale facilities is supported through our Major Research Equipment and Facilities Construction (MREFC) appropriation. Established in 1995 as the Major Research Equipment account (and renamed MREFC in fiscal year (FY) 2002), the account provides an NSF-wide mechanism for funding large facility construction projects, costing tens of millions to hundreds of millions of dollars over a multi-year period.

In order for a project to be considered for MREFC funding, it must represent an exceptional opportunity for research and education, and provide the potential for transforming scientific understanding, technology or infrastructure. Over the years, awards have funded the construction of such diverse projects as accelerators, telescopes, vessels, aircraft, and geographically distributed but networked earthquake engineering simulation equipment.

Once a project is identified—but before it is selected—for construction, there are extensive discussions to establish priorities and multi-stage planning, design, cost and schedule reviews (see the *Large Facilities Manual,* available at http://www.nsf.gov/pubs/2007/nsf0738/nsf0738.pdf, for more information). The process includes multiple opportunities for input from the research community whose members alert NSF to the most promising areas of inquiry and the tools or facilities needed to explore them. NSF program officials and senior management, including the National Science Board (NSB), play key roles in the MREFC process, as described in the manual.

After a project is selected for construction and funds have been appropriated, NSF makes an award for the development of the new MREFC facility. With one exception, NSF does not construct or operate the facilities it funds, but the agency does provide technical and program oversight and closely monitors financial and administrative performance throughout the life cycle of each facility. The exception is for U.S. government facilities in Antarctica. For the full interagency Antarctic Program, NSF was assigned via presidential mandate (Presidential Memorandum 6646, 1982) to acquire construction, operating, logistics and maintenance services.

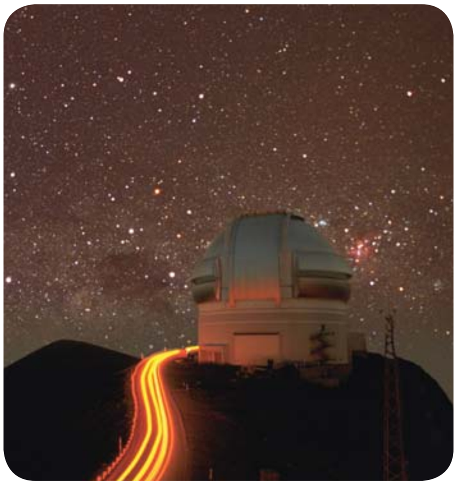
In FY 2008, the following MREFC projects (which are described in detail in the *Selected Investments* section of this document) were ongoing:

- Advanced Laser Interferometer Gravitational Wave Observatory (AdvLIGO)
- Alaska Region Research Vessel (ARRV) - *Proposed*
- Atacama Large Millimeter Array (ALMA)
- EarthScope
- IceCube Neutrino Observatory
- National Ecological Observatory Network (NEON) - *Proposed*
- Ocean Observatory Initiative (OOI) - *Proposed*
- Scientific Ocean Drilling Vessel (SODV)
- South Pole Station Modernization (SPSM) Project

One new project—the Advanced Technology Solar Telescope (ATST)—was proposed for MREFC funding in FY 2009. For more information on MREFC projects, see the *NSF 2008 Facility Plan* (available at http://www.nsf.gov/pubs/2008/nsf0824/nsf0824.pdf).

Construction and acquisition of additional large facility or infrastructure projects, though generally of a smaller scale than those funded through the MREFC account, are supported through NSF's Research and Related Activities (R&RA) appropriation, and also can be supported through the Education and Human Resources (EHR) appropriation. Additionally, operations and maintenance of multi-user facilities, including those developed through the MREFC account, are supported through the R&RA account. These unique facilities provide scientists, engineers and educators with access to world-class tools that are essential to the progress of research. Major NSF-supported multi-user research facilities currently providing unprecedented access to advanced tools and capabilities include:

- Academic Research Fleet
- Cornell Electron Storage Ring (CESR)
- EarthScope
- Gemini Observatory
- Incorporated Research Institutes for Seismology (IRIS)
- Integrated Ocean Drilling Program (IODP)
- Large Hadron Collider (LHC)
- Laser Interferometer Gravitational-Wave Observatory (LIGO)
- National High Magnetic Field Laboratory (NHMFL)
- National Nanotechnology Infrastructure Network (NNIN)
- National Superconducting Cyclotron Laboratory (NSCL)
- George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES)
- Other physics and materials research facilities
- Polar Facilities and Logistics
- National Astronomy and Ionosphere Center (NAIC)
- National Center for Atmospheric Research (NCAR)
- National Optical Astronomy Observatory (NOAO) and National Solar Observatory (NSO)
- National Radio Astronomy Observatory (NRAO)

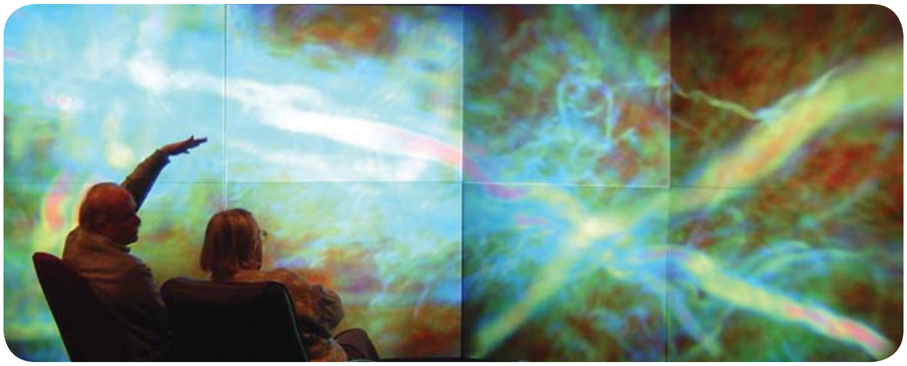


This composite image shows the sky over Gemini North. The 8-meter optical/infrared telescope is located on Hawaii's Mauna Kea, a long dormant volcano. *Credit: Gemini Observatory*

These facilities and others are described in the *Selected Investments* section of this document.

Twenty-first Century Cyberinfrastructure

NSF's portfolio of cyberinfrastructure activities, funded through the R&RA account, is designed to deliver high-performance computing, systems for mass storage, productivity-enhancing software suites and scientific programming tools, scalable interactive visualization tools, large-scale data repositories, networking, and related information technology capabilities to the research and education community, providing unprecedented power and connectivity to tackle challenges and problems that were beyond reach just a few years ago. The goal is a transformational cyberinfrastructure that enhances the usability and accessibility of computational, observational and experimental infrastructure, that powers virtual environments allowing researchers and educators located around the world to collaborate on projects as if they are in the same location, and that enables advances through modeling and simulation at unprecedented scales and complexities across a broad range of scientific and engineering disciplines.



At the Laboratory for Computational Science and Engineering at the University of Minnesota's Digital Technology Center, scientists view a movie of a simulation of fluid dynamics conducted at the Pittsburgh Supercomputing Center, one of the TeraGrid's partner sites. High-bandwidth connections between supercomputers and visualization facilities help researchers explore computationally complex phenomena. *Credit: Paul Woodward, Laboratory for Computational Science and Engineering, University of Minnesota*

Building on the successful deployment of NSF's TeraGrid infrastructure, the agency has begun acquisition and deployment of the next generation of high-performance computing systems to enable sustained petascale performance—computing at sustained rates on the order of 10^{15} floating point operations per second (petaflops) or working with petabytes of data for science and engineering research and education. The efforts are guided by NSF's Cyberinfrastructure Council (see *Cyberinfrastructure Vision for 21st Century Discovery,* at http://www.nsf.gov/pubs/2007/nsf0728/nsf0728.pdf) as well as the previous administration's American Competitiveness Initiative (ACI) and the America COMPETES Act (P.L. 110-69). Responding to outstanding designs that will provide world-class computing system capabilities for the research and education community, NSF's High Performance Computing System Acquisition solicitation—*Towards a Petascale Computing Environment for Science and Engineering*—led to funded awards to a University of Tennessee-Knoxville/Oak Ridge National Laboratory partnership, a Texas Advanced Computing Center at the University of Texas at Austin/Arizona State University/Cornell University partnership, and a University of Illinois at Urbana-Champaign/Great Lakes Consortium for Computing partnership.

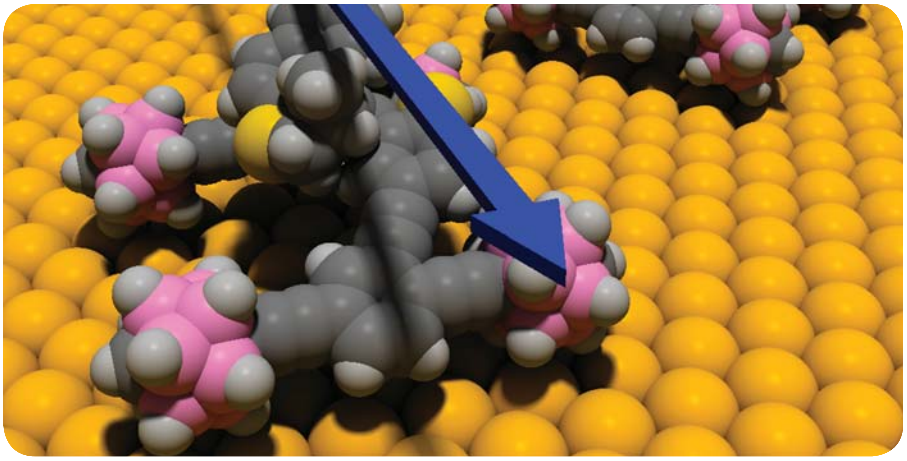
At the Centers: Interdisciplinary Research

The defining characteristic of NSF's centers programs is interdisciplinary research— addressing today's abundance of important science and engineering challenges that occur at the intersections between two or more disciplines. NSF-supported centers are designed to afford unparalleled opportunities for diverse scientists, engineers and students to conduct investigations of important research questions, while facilitating the involvement of multiple universities, other academic institutions, industry and others. The centers emphasize risk-taking and transformative ideas, and embody a commitment to forge new pathways for integrating science and engineering research with education and public outreach.

Some of the center programs are cooperatively managed by NSF's Office of Integrative Activities (OIA) together with our other research directorates and offices. The Science and Technology program is one example of such collaboration. The STC research portfolio reflects the broad spectrum of science and engineering disciplines supported by NSF. In addition to the integration of cutting-edge research and excellence in education, STCs seek to advance discovery and innovation in science and engineering through targeted knowledge transfer and the development of a diverse workforce—broadly advancing the goals and objectives of the ACI and the America COMPETES Act. The centers tackle such issues as cyber-security, advanced nano/microfabrication capabilities, new materials and technologies for monitoring water resources and water quality, medical devices, modeling and simulation of complex earth environments for improving their sustainability, and weather/climate prediction. NSF now supports 17 STCs (listed in Appendix I), and is soliciting proposals for 5-7 new centers that we expect to launch in 2010.

NSF also supports, directly through the research directorates and offices, the following center programs:

- Centers for Analysis and Synthesis (CEAS)
- Centers for Chemical Innovation (CCI)
- Engineering Research Centers (ERC)
- MRSECs
- Nanoscale Science and Engineering Centers (NSEC)
- Science of Learning Centers (SLC)



An animation showing two nanometer-scale cars on a gold surface. Developed by a research team at Penn State University's Materials Research Science and Engineering Center (MRSEC), each vehicle is slightly wider than a strand of DNA. Nanocars could one day deliver molecular cargo for nanoscale construction. *Credit: Yasuhiro Shirai, Rice University*

NSF supports centers for specific durations of time, usually five years. Following satisfactory performance, they often have the option of a one-time renewal for an additional fixed period of time. Ultimately, many centers "graduate" from NSF support and are then sustained by funding from existing or new partnerships. Some centers may evolve into entirely different entities focusing on another emerging issue in science and engineering, and still other centers may be phased out.

NSF updated our principles for managing centers programs in 2005. Among the key elements of the updated principles is that the value of supporting the targeted research using the center mode of funding versus the individual investigator mode will be evaluated as one of the merit review criteria. Another is that NSF's support for centers will be of limited duration, with a built-in phase-out period.

A Unique Role in the Polar Regions

The United States Antarctic Program (USAP) supports U.S. scientific research in Antarctica and the Southern Ocean. NSF manages the USAP under Presidential Memorandum 6646 (1982) that directs an "active and influential presence in Antarctica designed to support the range of U.S. Antarctic interests." The memo states that the U.S. presence "shall include the conduct of scientific activities in major disciplines." The world's southernmost continent offers unique opportunities to advance understanding in wide-ranging scientific fields, including astronomy and astrophysics, oceanography, geology, glaciology, biology and climate studies. NSF provides the facilities, research infrastructure and logistics to support researchers who are advancing knowledge in these and other vital areas of science and engineering. The USAP operates three year-round scientific stations in Antarctica: Amundsen-Scott South Pole Station, McMurdo Station and Palmer Station.

Amundsen-Scott South Pole Station

In January 2008, NSF dedicated the Amundsen-Scott South Pole Station at the South Pole. The third station since 1956, it is the result of the South Pole Station Modernization, a MREFC project. The new elevated structure is a state-of-the-art research station that is larger and more sophisticated than any previous structure built at the bottom of the world. The station's size and capabilities respond to an ever growing requirement for logistical support to carry out the range and quantity of research taking place at the South Pole, from

In January 2008, honored guests joined with NSF to dedicate the Amundsen-Scott South Pole Station. The new, elevated station is larger and much more sophisticated than any previous structure built at the Pole—a reflection of the logistical support needed for the ever-increasing range and diversity of the research taking place there. *Credit: Peter Rejcek, National Science Foundation* investigations into the origin of the universe to work aimed at determining the status of global climate change. Features of the new station include a "quiet sector" to support monitoring of the Earth's seismicity, a "clean air sector" for research in atmospheric chemistry, and a "dark sector" to support astronomy and astrophysics. The new station replaced an aging structure built three decades ago. Approximately 50-60 science and support personnel winter over at the South Pole Station to carry out and support ongoing research projects, while the population during the three-month austral summer swells to about 150 people.

McMurdo Station
Located on the Ross Sea, Antarctica's largest station serves as a "gateway" to Antarctica for U.S. scientific field teams, as well as the hub for most of the U.S. scientific activity. During the austral summer, the population of scientists and support personnel at McMurdo often exceeds 1,000 people.

Palmer Station
Located on Anvers Island in the Antarctic Peninsula region, Palmer Station is the only U.S. Antarctic station north of the Antarctic Circle. More than 40 people can occupy Palmer in the summer; wintering population is about 10, although Palmer does not have the long period of winter isolation that McMurdo and South Pole have.

In addition to these permanent sites, the USAP provides other facilities including ships, aircraft and research platforms that are described in the *Selected Investments* section and Appendix I of this document.

Like its counterpart at the bottom of the world, the Arctic region provides unique opportunities for transformative research and discovery. As chair of the Interagency Arctic Research Policy Committee (IARPC), NSF acts as the lead agency for implementing Arctic research policies. NSF's Arctic Research Support and Logistics (RSL) program assists the field component of research projects that focus on gaining a better understanding of the Arctic's physical, biological, chemical, social and cultural processes, as well as work exploring the interactions of ocean, land, atmosphere, biological and human systems in the Arctic. The program funds base support of the Arctic Research Consortium of the U.S., Toolik Field Station, procurement and maintenance of instrumentation on the U.S. Coast Guard Cutter *Healy*, and the development of a digital elevation model of the Kuparuk Watershed in northern Alaska. Additional information about Arctic-related research infrastructure is presented in the *Selected Investments* section and in Appendix I.

An intense international scientific campaign to explore new frontiers in polar science is currently underway in both the Arctic and Antarctic. The International Polar Year (IPY) 2007-2009 began in March 2007 and extends through March 2009, and its activities are already improving our understanding of the critical role of the polar regions in global processes and educating students, teachers and the public about the importance of these regions. NSF was designated by the President's Office of Science and Technology Policy (OSTP) as the lead federal agency in organizing U.S. IPY activities. (A list of U.S. agencies and organizations participating in IPY is available at http://www.us-ipy.gov.) IPY supports projects that are multi- and interdisciplinary in scope, expand international cooperation, attract and train the next generation of scientists and engineers, and engage the public in polar discovery. Among IPY's legacies will be a significant expansion of infrastructure and data for studying these unique regions of the globe.

Mid-Range Instrumentation

Scientific advances in many fields are critically dependent on access to sophisticated instruments at the nation's universities and colleges, and at other entities that conduct research and education. NSF's Major Research Instrumentation (MRI) program is one of the agency's approaches for funding the acquisition and development of key instrumentation for research and training in U.S. institutions of higher education, research museums and independent, nonprofit research organizations. The primary focus of the agency-wide program is to improve the quality and expand the scope of research and research training in science and engineering, and foster the integration of research and education, by providing advanced instrumentation for research-intensive learning environments. Expanding the capabilities of the research community to develop new instruments is another key focus of the MRI program. A third focus is building up the science and engineering infrastructure for research and research training at smaller and minority-serving institutions. Academic researchers and others benefit from new generations of sophisticated research instrumentation. The right design, development and manufacturing processes can yield new instruments that are more widely used, open up new areas of research and training, and have potential as commercial products.

MRI awards are for mid-range instrumentation. Responding to recommendations made by the National Academy of Sciences Committee on Advanced Research Instrumentation in a 2005 study and codified in Sec. 7036 of the ACI, NSF recently increased the upper limit for an MRI proposal from \$2 million to \$4 million. Proposals requesting more than \$2 million must be for the acquisition of a single instrument. Requests for \$2 million or less can support instrument development or the acquisition of a single instrument, a large system of instruments, or multiple instruments that share a common or specific research focus. The minimum that institutions may request is generally \$100,000. But organizations that do not award doctoral degrees, as well as the disciplines of mathematical science and social, behavioral and economic sciences at any eligible organization, may submit proposals requesting less than \$100,000.

In FY 2007 (the latest year for which complete information is available), NSF received 774 proposals for MRI grants and funded 221 of them. Of the 221 proposals funded, non-Ph.D. granting institutions received 87 awards totaling \$21.1 million. Minority-serving institutions received 36 awards totaling \$11.66 million. The FY 2007 awards are listed in Appendix I.

Examples abound of the benefits from MRI investments:

- A team of researchers using a supercomputing cluster at Northwestern University's Theoretical Astrophysics Group that was partly acquired through an MRI grant ran a range of sophisticated simulations tracking the important parts of the planet formation process from different types of starting conditions. In August 2008, they announced the surprising finding that the formation of planetary systems like our solar system is unusual.

- With support from an MRI award, Hampton University, one of the country's Historically Black Colleges and Universities (HBCU), is acquiring a high performance computing cluster that will provide substantial capability to faculty and students to expand their ability to investigate computationally complex challenges including carrying out computations that will solve equations that simulate and model phenomena in nature, and visualize computational data.

- An NSF MRI award enabled Central Michigan University to acquire a three-dimensional laser scanner that is being used to help build a database about the human body. The scanner is one of just a handful available at U.S. universities. So far, Central Michigan University researchers have collected more than 400 scans of people ranging in age from 8 to 87.

The first commercial prototype of a super-resolution optical microscope based on structured illumination. The instrument was installed in March 2008 at the Center for Biophotonics Science and Technology at the University of California, Davis (see page 12). *Credit: Thomas Huser, Center for Biophotonics Science and Technology, University of California, Davis*

- With support from another MRI grant, the first commercial version of the world's highest resolution wide-field light microscope is now in operation at the NSF-funded Center for Biophotonics Science and Technology's headquarters on the Sacramento campus of the University of California, Davis. The new system uses an imaging technology called Structure Illumination that was invented by University of California, San Francisco scientists to overcome the long-standing barrier that the diffraction limit of light presents to significant increases in the resolution of light microscopes. The system installed at the Center for Biophotonics Science and Technology has already demonstrated a two-fold improvement in resolution compared to the best conventional light microscopes and further improvements are expected. The higher resolution light microscopes will help scientists to visualize living cells and how they interact in real-time.

NSF also has programs supporting the acquisition and development of instrumentation and facilities for specific discipline areas. Examples include: Atmospheric Sciences Mid-Size Infrastructure Opportunity, Advanced Technologies and Instrumentation, Chemistry Research Instrumentation and Facilities, Directorate for Computer and Information Science and Engineering (CISE) Computing Research Infrastructure, Cyberinfrastructure for Environmental Observatories: Prototype Systems to Address Cross-Cutting Needs, Earth Sciences: Instrumentation and Facilities, Improvements in Facilities, Communications and Equipment at Biological Field Stations and Marine Laboratories, Instrument Development for Biological Research, Instrumentation for Materials Research, Next Generation Cyberinfrastructure Tools, Oceanographic Technology and Interdisciplinary Coordination, Program for Research and Education with Small Telescopes, and Scientific Computing Research Environment for the Mathematical Sciences.

Other Facilities, Equipment and Infrastructure Funding

By stimulating partnerships for innovators, two small business research programs—the Small Business Innovation Research (SBIR) program and the Small Business Technology Transfer (STTR) program—bring about infrastructure advances and also catalyze the transformation of discoveries into societal benefits. Another program to advance development of the nation's research infrastructure is the Experimental Program to Stimulate Competitive Research (EPSCoR)'s Research Infrastructure Improvement (RII) initiative. EPSCoR helps promote scientific progress nationwide by directing support to jurisdictions that have historically received lesser amounts of NSF research and development (R&D) funding. Twenty-five states, the Commonwealth of Puerto Rico and the U. S. Virgin Islands currently participate in EPSCoR. In addition to the basic RII awards to a single EPSCoR jurisdiction, RII-Track 2 awards provide funds to consortia of EPSCoR jurisdictions to support innovation-enabling cyberinfrastructure of regional, thematic or technological importance.

Researchers in the Arkansas Nanoscience Program use scanning probe microscopy to observe the nanostructure of a chloroplast. The Arkansas program is supported by NSF's Experimental Program to Stimulate Competitive Research (EPSCoR). *Credit: Nanoscience Program, University of Arkansas*

In addition to these programs, NSF research directorates and offices have the discretion to fund facilities, equipment, centers, and other research infrastructure on a case-by-case basis from R&RA program funds. They may also include funds to cover acquisition of instrumentation as part of a research grant to an individual investigator or group of investigators.

Education and Public Outreach

Educating the next generation of scientists and engineers, training the science, technology, engineering and mathematics (STEM) workforce of the 21st century, and engaging the public are crucial for the health of our nation's future science and engineering enterprise. All activities described above promote the strong integration of research and education and embody the concepts of broader impact and public outreach. Here, we note a few examples of the strong outreach programs that our supported facilities and centers offer:

- The NHMFL provides opportunities and mentorship experiences for teachers and students at all academic levels. The lab's annual regional K-12 outreach efforts engage more than 7,000 students from across Florida and neighboring Georgia in hands-on science activities and tours.
- The Natural History Museum of Los Angeles County acquired a state-of-the-art Scanning Electron Microscope (SEM), with support from NSF's MRI program, for use by the museums research staff and also by its Education Division for activities to enhance public understanding of science and highlight the work of museum scholars. The museum's "Adventures in Nature" summer program for children in grades pre-K through 8 provided youngsters with hands-on experience using the SEM to zoom in on small objects.
- The Center for Behavioral Neuroscience in Atlanta, one of NSF's STCs, has developed a series of outreach programs, including "Brain Camps" for middle school students, seminars and summer research programs for undergraduates, teacher workshops, and an annual exposition held in partnership with the Atlanta zoo, that bring advances in neuroscience and the work of center researchers to all segments of the public.
- The Team for Research in Ubiquitous Secure Technology (TRUST) sponsors a number of education and outreach activities, including the Women's Institute in Summer Enrichment and the Summer Undergraduate Program in Engineering Research, both at the University of California, Berkeley. The women's institute brings together graduate students, post-doctoral fellows, and professors from all disciplines for a week-long, residential program in the summer. Topics, such as cybersecurity, privacy and sensor networks, and health care, are selected to complement TRUST's research areas. The summer undergraduate program provides students from historically underrepresented populations with opportunities to gain research experience by participating in projects with engineering faculty and graduate students as mentors.
- Students and faculty of the Texas A&M University at Kingsville's Center for Research on Environmental Sustainability of Semi-Arid Coastal Areas, one of NSF's Centers of Research Excellence in Science and Technology (CREST), partnered with the Corpus Christi Museum of Science and History on an exhibit to educate the citizens of South Texas about local air quality. The kid-friendly exhibit was designed to teach elementary and middle school students about air pollution and ozone levels. The exhibit included an HDTV screen showing near real-time air quality data captured from an air monitoring station located on the museum's rooftop in downtown Corpus Christi.
- Participants and staff at the Northwestern University NSEC developed DiscoverNano, a Web site to introduce the public to nanoscale objects, nanoscience, and nanotechnology. Besides a basic primer (Nano 101), the site (http://www.discovernano.northwestern.edu/) features a timeline tracing the history of nanotechnology, video interviews with researchers, a Nano Art Gallery, a searchable glossary, and a section for educators that includes a video introduction to the center's nanoscience and nanotechnology module of classroom activities.
- The Arkansas EPSCoR joined with the Winthrop Rockefeller Foundation to support teams competing in the Frontiers Rails BEST Robotics Competition, a program that uses a series of competitions to excite junior and senior high school students about science, engineering, and technology fields. They were able to fund three robotics hubs (each serving up to 30 schools) in the northern and eastern part of the state, with teams competing at local and regional levels.

A World Class Research Infrastructure

In summary, NSF has spent approximately $1.6 billion in FY 2008 for the activities described above, our contribution towards a world-class research infrastructure for the nation.

The next section presents brief descriptions of some of the current NSF-supported equipment, facilities, shared cyberinfrastructure and centers that contribute so much to today's and tomorrow's advances in science and engineering. The profiles are grouped by theme area. A more comprehensive list is found in Appendix I.