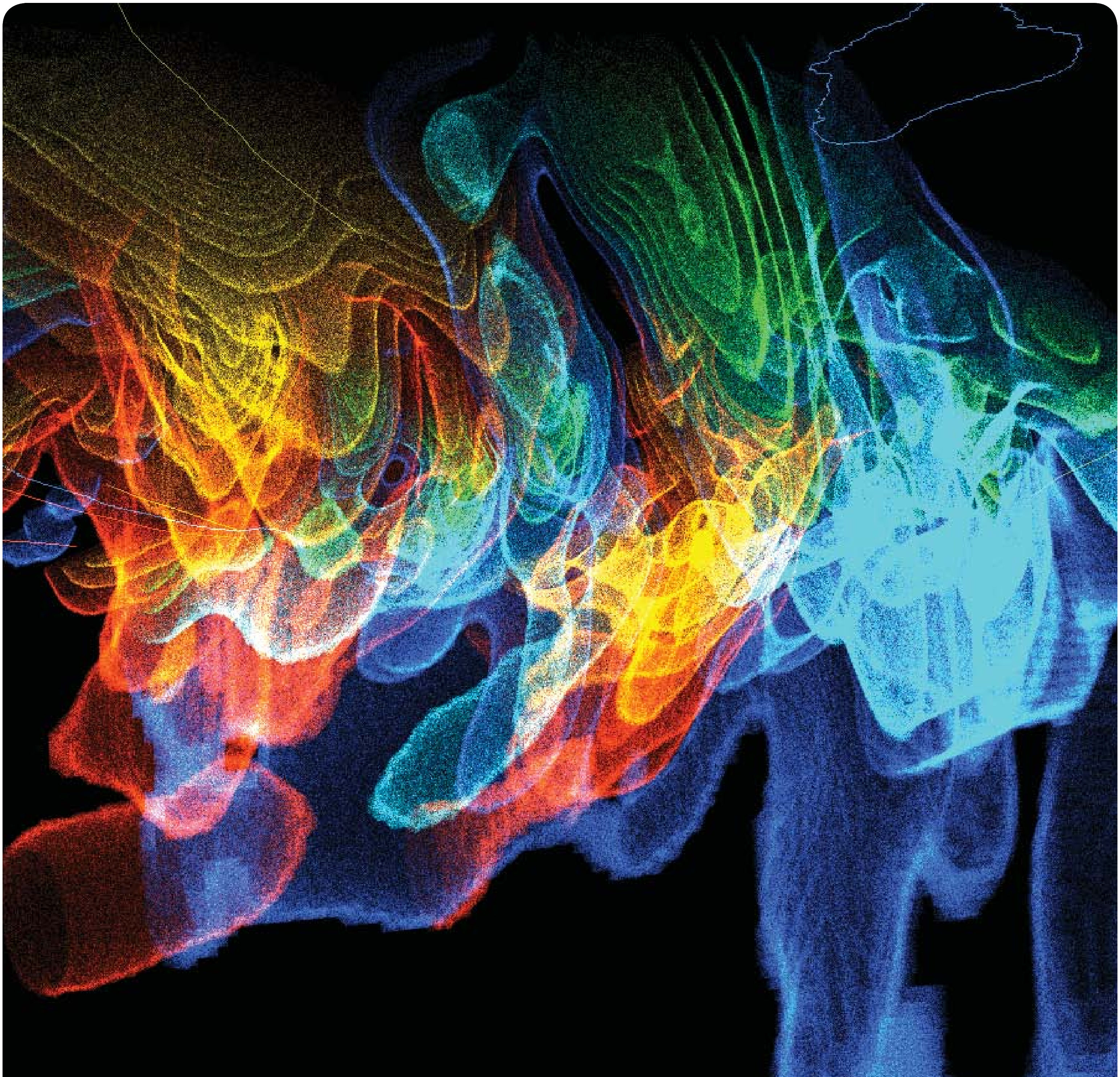


Selected Investments

TeraShake is the largest and most detailed simulation of ground motion during a major earthquake along the San Andreas Fault in southern California. Researchers used the 10 teraflops DataStar supercomputer and large-scale data resources of the San Diego Supercomputer Center (SDSC) at the University of California, San Diego to produce the simulation. The center is a partner site in the TeraGrid. TeraShake is a vivid example of cyberinfrastructure's ability to advance science and engineering. *Credit: Marcus Thiebaux, Information Sciences Institute, USC*

Selected NSF Investments in Research Infrastructure

NSF's investments in equipment, facilities, shared cyberinfrastructure and centers ensure that the U.S. maintains a world-class science and engineering research infrastructure that is second to none. The scale of what we support ranges from small and mid-size instruments in the laboratories of U.S. academic institutions to unique national centers and multiuser facilities to global computer-sensor-communication networks and international partnerships that build and operate state-of-the-art equipment, facilities and experimental tools. The following are examples of NSF investments in research infrastructure (including leading-edge facilities in planning or under construction) and the research they enable, organized by broad theme areas. These examples are representative of the investments made by NSF in research infrastructure, but they are not intended to serve as a complete list of everything we support. Many of the agency's smaller awards are omitted. Also, NSF is making new awards on a continuous basis. A more comprehensive (but still not complete) list of NSF research infrastructure investments is found in Appendix I.

Earth's environments are diverse, ranging from polar ice caps to hot, dry deserts, from dark ocean depths to high mountaintops. NSF invests in research infrastructure to support scientists and educators as they seek to advance our understanding of the planet's physical, chemical, biological and geological processes; the complex interactions among atmosphere, land surface and oceans; and the impacts of human activities on the environment. Researchers need national and global observation facilities and platforms, cutting-edge instrumentation, and advanced computational and networking capabilities to collect, store, transmit and analyze vast data about complex, interdependent geophysical processes and produce new knowledge. These investments, as well as support for related environmental research and education, primarily are made by NSF's Directorate for Geosciences (GEO) and the Division of Environmental Biology (DEB) in the Directorate for Biological Sciences (BIO). NSF's facilities in the Arctic and Antarctic, supported by the Office of Polar Programs (OPP), enable researchers to make unique observations from some of the Earth's most unusual natural laboratories.

Earth, from the Depths of the Oceans to the Sky Above

This illustration shows how the Scientific Ocean Drilling Vessel (SODV) will look once refurbishing is complete. After 20 years of service, the pioneering scientific drillship JOIDES Resolution underwent a refit that is expected to extend the vessel's operational lifetime by at least 15 years. *Credit: Charles Floyd, Integrated Ocean Drilling Program*

Academic Research Fleet

The Academic Research Fleet consists of 23 vessels in the University-National Oceanographic Laboratory System (UNOLS). These vessels are varied in size, endurance and capabilities, and they make it possible for scientists supported by NSF and other federal agencies to conduct marine research in coastal and open waters. Funding for the Academic Research Fleet includes investments in ship operations; shipboard scientific support equipment; oceanographic instrumentation and technical services; and submersible support. NSF owns seven of the fleet's ships (listed below) and has another vessel proposed for construction. The NSF-owned research ships are:

- ***R/V Marcus Langseth***, a 235-foot research vessel operated by Lamont-Doherty Earth Observatory of Columbia University. The ship was built in 1991 as a seismic vessel and, in 2004, it was acquired and outfitted as a research ship. A large ship with a global area of operation, the *Langseth* is equipped with extensive seismic recording equipment and sound source arrays, affording the academic community unique geophysical research capabilities. It can accommodate 35 researchers and a crew of 20.

- ***R/V Wecoma***, a 185-foot research vessel operated by Oregon State University's College of Oceanic and Atmospheric Sciences. The intermediate-size ship was built in 1975 and underwent a mid-life refit and general upgrade in 1993-1994. It features specialized oceanographic research equipment including wet and dry labs and a CTD system (an instrument package with cylindrical sampling bottles and instruments for measuring the conductivity, temperature and depth of water). The *Wecoma* can accommodate 18 researchers and a crew of 13.

- ***R/V Endeavor***, a 185-foot ship operated by the University of Rhode Island's Graduate School of Oceanography. The vessel was built in 1975 and underwent a mid-life refit in 1993. The intermediate-size ship features a main lab, wet lab, special purpose lab, deck lab and portable isotope lab. The *Endeavor* can accommodate 18 scientists including a marine technician and a 12-member crew.

- ***R/V Oceanus***, a 177-foot ship operated by the Woods Hole Oceanographic Institution. The vessel was built in 1975 and in 1994, it underwent a mid-life refit. The intermediate-size ship features a main lab, wet lab and a lab on the upper (01) deck. It is also outfitted with three winches and a crane, and is often used for deploying oceanographic buoys and moorings, and for hydrographic surveys. The *Oceanus* can accommodate 19 researchers and a crew of 12.

- ***R/V Point Sur***, a 135-foot ship operated by Moss Landing Marine Laboratories for the San Jose State University Foundation. The laboratories are run by a consortium of California State Universities. The *Point Sur* was built in 1980. Much of the ship's marine research is conducted within the region of central California, and especially in Monterey Bay at the head of the deep undersea Monterey canyon. The ship can accommodate 13 researchers and technicians and a crew of 8. For day cruises, it has a capacity of 40 researchers.

- ***R/V Cape Hatteras***, a 135-foot ship operated by the Duke University/University of North Carolina Oceanographic Consortium. The ship was built in 1981. It's used for regional operations, primarily off the coast of North America from Nova Scotia to the Caribbean. Its scientific equipment includes CTD and other instruments for seawater sampling and analysis, corers and related seafloor sampling equipment, echo sounding and seismic equipment, and other instruments and sensors. The *Cape Hatteras* can accommodate 14 scientists including a marine technician and a crew of 10.

- ***R/V Clifford A. Barnes***, a 66-foot ship operated by the University of Washington's School of Oceanography. The ship is used primarily in the inland waters of the Puget Sound region and lower British Columbia. This small vessel can accommodate six scientists and a two-person crew.

The proposed Alaska Region Research Vessel (ARRV) is designed to operate up to 300 days per year in the harsh, icy waters around Alaska. The ship would provide a much needed platform for addressing critical regional and global ecosystem issues including ocean circulation and climate change. *Credit: The Glosten Associates, Inc.*

Alaska Region Research Vessel (ARRV)–Proposed

The Alaska Region Research Vessel will be the newest addition to NSF's complement of research ships. This technologically advanced, highly capable, 242-foot ship is designed to operate in both seasonal ice and the harsh open waters surrounding Alaska. It will provide a crucial support platform to enhance scientific understanding of the polar regions and their impact on global climate change. The project is approaching the final design review and ship construction is expected to get underway in early 2010. If all goes as planned, scientific operations could begin in late 2013 following extensive sea trials and equipment testing. The ARRV will be able to accommodate 24 researchers on missions lasting up to 45 days. The ship will be able to spend up to 300 days per year at sea. The ARRV was proposed as a new start in FY 2007; continuation of design and future construction depends upon successful project design reviews, continued prioritization by NSF, NSB approval and the availability of federal funds.

Vessels for Research at the Earth's Poles

Ships provided by the USAP and the RSL program offer research and logistical support for the activities of scientists, engineers and educators conducting research in the Antarctic and Arctic regions. The vessels include:

- ***R/V Nathaniel B. Palmer (NBP)***, an icebreaking research ship that began science operations in late 1992 when it sailed from Punta Arenas, Chile, in support of the Russian-U.S. Ice Camp Weddell. The 94-meter vessel provides a first-rate platform for global change studies, including biological, oceanographic, geological and geophysical components. It can operate safely year-round in Antarctic waters that often are stormy or covered with sea ice. It accommodates 37 scientists, has a crew of 22, and is capable of 75-day missions. The *Palmer* is owned and operated by Louisiana-based Edison Chouest Offshore (ECO), and is chartered by the USAP.

- ***R/V Laurence M. Gould (LMG),*** an ice-strengthened research ship that began its service in Antarctica in January 1998. A multi-disciplinary research platform, the *Gould* is designed for year-round polar operations and can accommodate 26 research scientists for missions up to 75 days long. Its primary mission is to support research in the Antarctic Peninsula region and to resupply and transport researchers and staff between Palmer Station and South American ports. Owned and operated by ECO, the *Gould* is chartered by the USAP.

- **U.S. Coast Guard Cutter (USCGC) *Healy,*** an icebreaker designed to support scientific research. It has been used in a number of research cruises, mostly in the Arctic Ocean region. The ship is able to accommodate 35-50 scientists and is equipped with more than 5,000 square feet of science lab and support space. The *Healy*'s first science cruise was in 2001, as part of the Arctic Mid-ocean Ridge Expedition (AMORE).

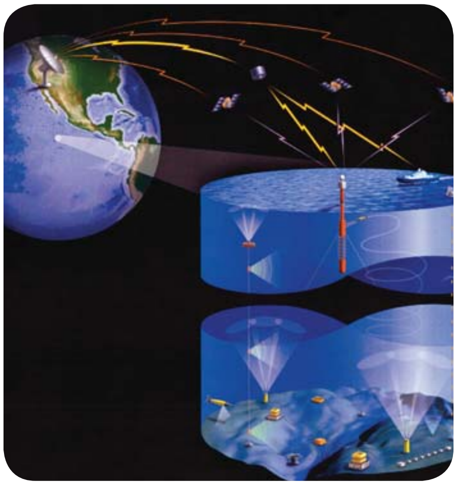
Integrated Ocean Drilling Program (IODP)

About 70 percent of the Earth is seafloor. The Integrated Ocean Drilling Program is an international marine research program that explores Earth's history and structure, as recorded in seafloor sediments and rocks. The program also monitors sub-seafloor environments. The IODP is led by NSF and Japan's Ministry of Education, Culture, Sports, Science and Technology (MEXT). Japan and the U.S. are providing drillships to the program. Japan's vessel, the *Chikyu* (Earth), was launched in January 2002, underwent outfitting and testing in 2003-2006 and began IODP operations in 2007. The U.S.-provided SODV is undergoing an extensive refitting and is scheduled to begin IODP operations in early 2009. The European Consortium for Ocean Research Drilling is a contributing member of the IODP, and two other partners—the People's Republic of China Ministry of Science and Technology and the Interim Asian Consortium, represented by the Korea Institute of Geoscience and Mineral Resources—are associate members.

Scientific Ocean Drilling Vessel (SODV)

A highly trained crew and specialized engineering equipment aboard the *JOIDES Resolution* make it possible to target and core the seafloor. *Credit: Integrated Ocean Drilling Program*

The Scientific Ocean Drilling Vessel project is refurbishing the *JOIDES Resolution*, the pioneering scientific ocean drilling vessel. The next-generation research ship will support the recovery of sediment and crustal rock from the seafloor; the placing of observatories in drill holes to study the deep biosphere; the study of fluid flow in sediments and the crust; and long-term efforts of the IODP to investigate solid Earth cycles, geodynamics, and the processes contributing to and affecting environmental change. During its 20 years of service, *JOIDES Resolution* expeditions produced significant contributions and discoveries, including the first recovery of igneous rocks (known as gabbros) from intact ocean crust, the discovery of the deepest-living microbes on earth, and the discovery of "frozen" natural gas at unexpectedly shallow depths below the seafloor. Core samples brought up during research expeditions have helped scientists validate the theory of plate tectonics, provided extensive information about earth's past climate, and recovered evidence of the catastrophic asteroid impact that is believed to have wiped out the dinosaurs 65 million years ago. The new vessel, which promises to improve the quality and rate of core samples brought up from the deep, will include a large increase in laboratory space, allowing for greater instrumentation to analyze core samples while at sea. The refit also will result in enhanced ship stability. Work began in September 2006 and is expected to conclude in early 2009, with sea trials scheduled for early 2009.



An artist's illustration of the proposed Ocean Observatories Initiative (OOI). The OOI will provide an integrated array of communications devices and sensors placed on or below the sea floor and throughout the water column. Instruments will transfer data to buoys on the sea surface that will transmit the information to the mainland by satellite. *Credit: John Orcutt, Scripps Institute of Oceanography*

Ocean Observatories Initiative (OOI)–Proposed

The Ocean Observatories Initiative has the potential to revolutionize ocean science by providing the means to collect unique, sustained, time-series data sets that will enable researchers to study complex, interlinked physical, chemical, biological, and geological processes operating throughout the global ocean. The OOI would help researchers make significant progress in understanding such critical processes as climate variability, ocean food webs, coastal ocean dynamics and ecosystems, and global and plate-scale geodynamics. Scientific discoveries arising from the OOI would also provide exciting opportunities for ocean education and outreach through the capabilities for real-time data transmission and, particularly, real-time display of visual images from the seafloor. If constructed, the OOI would provide a globally distributed and integrated observatory network of platforms and sensors to obtain measurements within the ocean and below the seafloor, at temporal and spatial scales beyond the capability of tools and methods currently used to study ocean processes. As planned, the integrated observatory system would have three elements: a global component consisting of deep-sea buoys with capabilities appropriate to the experiments; a regional electro-optical cabled network consisting of interconnected sites on the seafloor spanning several geological and oceanographic features and processes; and new fixed and relocatable coastal observatories. OOI infrastructure would be deployed in the deep ocean at locations west of Canada and southern Chile, and south of Greenland, in the region of the Juan de Fuca plate in the Pacific Northwest and near the adjacent shore, and in the northeastern U.S. coastal region. Researchers would be able to access and control these marine assets in real or near real-time through an interactive cyberinfrastructure. OOI was proposed as a new start in FY 2007; continuation of design and future construction depends upon successful project design reviews, continued prioritization by NSF, NSB approval and the availability of federal funds. The reviews will include the identification of optimal sites for the extensive sensor network.

Antarctic Research Facility

The Antarctic Marine Geology Research Facility at Florida State University is a national repository for geological materials collected in and around Antarctica. It houses and curates over 20,000 meters of deep-sea core sediment, 6,000 meters of rotary drilled continental and shallow-water cores and over 5,000 kilograms of dredge, trawl and grab samples—the largest such Antarctic and Southern Ocean collection in the world. These materials have been acquired from over 90 USAP research cruises and field expeditions.

3-D Seismic Data Depicts Layers of Ocean Crust, Helps to Reveal the Inner Workings of a Tsunami Factory

Debris from the Indian Ocean tsunami of Dec. 26, 2004. The wave came from the distance and left nearly nothing standing in Banda Aceh, Sumatra. *Credit: © Jose C. Borrero, University of Southern California Tsunami Research Group http://www.usc.edu/dept/tsunamis/2005/index.php*

Research by a team of U.S. and Japanese scientists may help explain why earthquakes below some parts of the seafloor trigger large tsunamis, while earthquakes elsewhere do not. NSF-supported geoscientists from the University of Hawaii and University of Texas and their colleagues collected three-dimensional seismic data that reveals the structure of Earth's crust below a region of the Pacific seafloor known as the Nankai Trough. That area of the seafloor near the southwest coast of Japan is particularly good at generating devastating tsunamis. The researchers were able to reconstruct how layers of rock and sediment have cracked and shifted over time. They found two things that contribute to big tsunamis. First, they confirmed the existence of a major fault that runs from about 10 kilometers (6 miles) deep right up to the seafloor in a region known to unleash earthquakes. When an earthquake happens, the fault moves the seafloor up or down, carrying a column of water with it and setting up a series of tsunami waves that spread outward. Second, and most surprising, the team discovered that the recent fault activity has shifted landward, and the fault is shallower and steeper than it was in the past. This geometry increases the potential for tsunamis.

HIAPER—the High-Performance Instrumented Airborne Platform for Environmental Research—is the nation's most advanced aircraft for environmental research. *Credit: NCAR*

High-performance Instrumented Airborne Platform for Environmental Research (HIAPER)

A medium-altitude, long-duration jet has been a requirement of the science community since the 1980s. NSF funded development of the High-performance Instrumented Airborne Platform for Environmental Research to meet those needs, and HIAPER has become the premier plane for scientific discovery. The modified Gulfstream V jet is capable of reaching an altitude of 51,000 feet and can cruise for 7,000 miles. It is equipped with advanced instrumentation for environmental research. NSF and the University Corporation for Atmospheric Research entered into a cooperative agreement to develop the aircraft, and its operations are managed by NCAR. HIAPER began operational science missions in

2006. Its first major scientific project was the Terrain-Induced Rotor Experiment (T-Rex), a project to learn more about rotors, the dangerous whirlwinds that develop on the lee side of high, steep mountains like California's Sierra Nevada range. (See the sidebar on page 24 for more on HIAPER.)

National Center for Atmospheric Research (NCAR)

The National Center for Atmospheric Research, a Federally Funded Research and Development Center (FFRDC), is a focal point for research in the field of atmospheric science. Its research programs include: studies of large-scale atmospheric and ocean dynamics that contribute to an understanding of the past and present climate processes and global climate change; global and regional atmospheric chemistry; the variable nature of the Sun and the physics of the corona and interactions with the Earth's magnetic field; the physics of clouds, thunderstorms, precipitation formation and their interactions and effects on larger-scale weather; and the examination of human impact on and response to global environmental change. Facilities available to university and other scientists include world-class supercomputing services, research aircraft, airborne and portable ground-based radar systems, and atmospheric sounding and other surface sensing systems. The supercomputing resources enable the development and production of large models and afford capabilities for archiving, manipulating and visualizing large data sets. The center emphasizes education and outreach activities as an integral part of its mission. Some 40 scientists from NCAR participated in the United Nation's Intergovernmental Panel on Climate Change (IPCC), which was named recipient of the 2007 Nobel Peace Prize, along with former U.S. Vice President Al Gore. NCAR is managed under a cooperative agreement between NSF and the University Corporation for Atmospheric Research (UCAR), a nonprofit consortium of 68 North American universities with graduate programs in the atmospheric sciences.

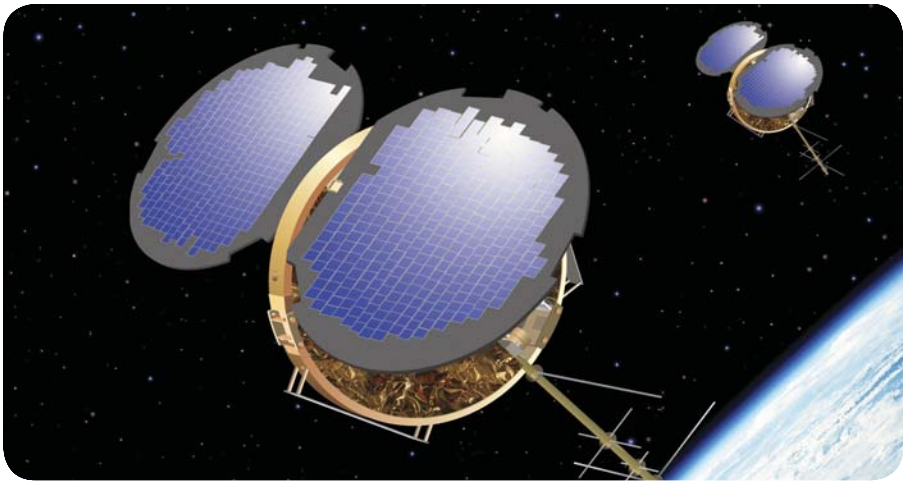
Advanced Modular Incoherent Scatter Radar (AMISR)

The Advanced Modular Incoherent Scatter Radar is a solid-state, phased array incoherent scatter radar for measuring basic properties of the upper atmosphere and ionosphere with unprecedented versatility and power. The AMISR's advanced capabilities include rapid steering provided by the phased array antenna, giving it significant advantages over existing incoherent scatter radars. The phased-array design allows pulse-to-pulse beam steering, thus enabling 3-D "imaging" of ionospheric properties, such as electron density, electron and ion temperatures, and ion drift velocities. The modular design facilitates reconfiguration of the radar antenna, as well as relocation in response to changing scientific priorities. Designed and built with NSF support, AMISR is operated by SRI International under a cooperative agreement that runs through September 2011. The AMISR systems are deployed at Poker Flat, Alaska, and Resolute Bay, Canada.

Other Radar, Sensing Facilities

NSF supports additional facilities for studying the Earth's upper and lower atmospheres. Upper atmosphere facilities include the Millstone Hill Incoherent Scatter Radar Facility, Sondrestrom Radar Facility, incoherent scatter radar facilities at Arecibo Observatory and Jicamarca Radio Observatory, and the Super Dual Auroral Radar Network (SuperDARN). Ground-based and airborne facilities and instrumentation for studying the Earth's lower atmosphere include the Atmosphere Surface Turbulent Exchange Research (ASTER) facility, Cross-chain Loran Atmospheric Sounding System (CLASS), Integrated Sounding System (ISS), Portable Automated Mesonet (PAM III and Flux PAM), S-POL Radar, CHILL Radar, P3Dora Radar (ELDORA), and Dropsondes.

The Sondrestrom Upper Atmospheric Research Facility in Greenland is used to study the Earth's upper atmosphere. Pictured is the Aurora Borealis, or Northern Lights, over the facility. *Credit: Craig J. Heinselman*



An artist's illustration of COSMIC, the Constellation Observing System for Meteorology, Ionosphere and Climate. The system of micro-satellites in low-Earth orbit is expected to greatly improve data for space weather and climate monitoring, and global weather forecasts. *Credit: Courtesy Orbital Sciences Corporation*

Constellation Observing System for Meteorology Ionosphere and Climate (COSMIC)

The Constellation Observing System for Meteorology Ionosphere and Climate, an international collaboration between Taiwan and the U.S., is a constellation of 6 satellites built and launched by Taiwan into low Earth orbits. The satellites' GPS receivers detect delays in the propagation of GPS signals when the signals pass through the atmosphere. Temperature, humidity, and, in the ionosphere, electron density, can be obtained from these radio occultations. COSMIC provides 2,500 atmospheric soundings per day, distributed nearly uniformly over the globe. These data are being used for weather prediction and climate monitoring. NSF is the lead agency for U.S. COSMIC activities. The U.S. partners include the National Aeronautics and Space Administration (NASA), the National Oceanic and Atmospheric Administration (NOAA), the U.S. Air Force Space Test Program, the Office of Naval Research, and the Department of Defense Space and Missile Systems Center's Rocket Systems Launch Program of the U.S. Air Force, which provided logistical support.

Center for Multi-Scale Modeling of Atmospheric Processes (CMMAP)

The Center for Multi-Scale Modeling of Atmospheric Processes, an NSF STC, focuses on improving the representation of cloud processes in climate models. The need for accurately describing cloud processes has been one of the most challenging limitations on the reliability of climate-change simulations. The center, based at Colorado State University, is using extremely powerful computers and new mathematical methods to address the problem. CMMAP researchers hope to harness enough computing power and resources to gain the ability to simulate individual clouds and atmospheric circulation, and tackle long-standing phenomena that are known but not well understood, such as the Madden-Julian Oscillation and the boundary layer of thunderstorms.

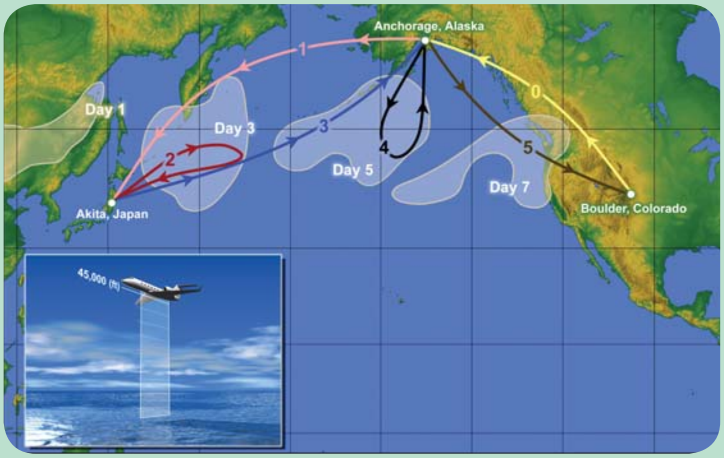
Center for Integrated Space Weather Modeling (CISM)

The mission of the Center for Integrated Space Weather Modeling, another STC, is to develop a better understanding of the dynamic Earth-Sun system and how it affects life and society. Researchers at CISM are working to develop next-generation models that should improve the quality of space weather forecasting in the near future. The work is vital since satellites, electrical grids and other systems on Earth are all vulnerable to radiation damage caused by solar flares or coronal mass ejections.

Atmospheric Research Observatory

The Atmospheric Research Observatory at the South Pole, part of the USAP, was developed to track changes in the Earth's atmosphere.

Tracking the Impact of Asian Dust and Pollution on Clouds and Weather

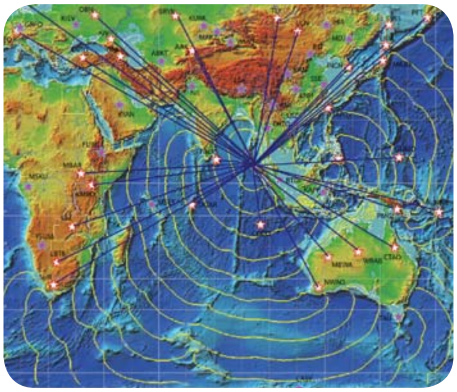


An illustration of a hypothetical plume and series of HIAPER flight patterns considered for the 2007 Pacific Dust Experiment (PACDEX). Researchers conducted a number of flights as part of the field project to examine the massive plumes of airborne dust and pollutants that originate in Asia and travel to North America. *Credit: Illustration by Steve Deyo; University Corporation for Atmospheric Research*

Scientists using HIAPER, one of the nation's newest and most capable research aircraft, launched a far-reaching field project known as PACDEX (for Pacific Dust Experiment) to study plumes of airborne dust and pollutants that originate in Asia and journey to North America. The plumes, among the largest such events on Earth, are so great in scope that scientists believe they might affect clouds and weather across thousands of miles while interacting with the Sun's radiation and playing a role in global climate. For more information, see the NSF news release at http://www.nsf.gov/news/news_summ.jsp?cntn_id=108742.

Incorporated Research Institutions for Seismology (IRIS)

The Incorporated Research Institutions for Seismology program enables the rapid collection and distribution of seismological data for studies of earthquakes and earth structure. The distributed national facility, in operation since 1984, provides for the development, deployment, and operational support of modern digital seismic instrumentation for earthquake and other earth sciences research, and for nuclear test ban monitoring. The Earth's interior is a major scientific frontier, and IRIS data have played a vital role in scientists' work to develop a better understanding of the physical processes underlying our restless planet. For example, researchers mining the data archive from IRIS' Global Seismographic Network (GSN)—a network of 138 permanent seismic stations spread out around the world, most providing real-time access to data—discovered glacial earthquakes, a previously unknown class of low frequency "earthquakes" produced by sudden glacial sliding. Further research could determine if the strong seasonality and increasing frequency of these glacial earthquakes are indicative of a glacial response to climate change. In addition to the GSN, IRIS has three other major elements: the Program for the Array Seismic Studies of the Continental Lithosphere (PASSCAL), which manages a pool of portable seismometers that are made available to the seismology research community for scheduled regional and local scale studies; the IRIS Data Management System (DMS), which provides the national and international seismic research community with timely access to some 70 terabytes of data from the GSN and PASSCAL, as well as data contributed by U.S. and international sources; and an education and outreach program that enables audiences who aren't seismologists to access and use seismological data and research for educational purposes, including teacher workshops, student internships, museum exhibits, educational materials, and programs for under-resourced schools.



The IRIS Global Seismographic Network (GSN) stations used by the Pacific Tsunami Warning Center during the Indian Ocean tsunami. The December 2004 catastrophe raised awareness of the importance of global earthquake monitoring. *Credit: The IRIS Consortium*

A researcher checks out a Global Positioning System (GPS) station in the Aleutian Islands. EarthScope's Plate Boundary Observatory (PBO) uses an array of permanent, continuously recording GPS stations and strainometers installed across the North American continent to monitor Earth motion. *Credit: EarthScope*

EarthScope

The EarthScope facility is a distributed, continental-scale, multipurpose geophysical-instrument array, with the capability to provide a coherent 3-D image of the lithosphere and deeper earth. It functions as a unique downward-looking "telescope" and gives geologists unparalleled means to investigate the structure and dynamics of the North American continent. EarthScope data are used by researchers studying earthquakes and seismic hazards, magmatic systems and volcanic hazards, lithospheric dynamics, regional tectonics, and fluids in the crust. The EarthScope facility is composed of three major elements: the Plate Boundary Observatory (PBO), a dense array of permanent global positioning system (GPS) stations and strainometers in the Western U.S. for recording deformation in and around earthquake-prone regions; the San Andreas Fault Observatory at Depth (SAFOD), a heavily instrumented drill hole that crosses the fault and will provide records of conditions within the seismogenic zone; and the USArray, a combination of portable and permanent seismograph stations that will provide a comprehensive network of sensors to explore seismic activity. The data and related products from EarthScope have already resulted in interesting findings. In one instance, researchers using EarthScope GPS and seismic data reported surprising insights into slow earthquakes (also known as ETS) along the Cascadia subduction zone. EarthScope data are freely and openly available via the Internet, and are also being used in earthquake response planning, for presentations to researchers and the public, and in university and other educational settings.

Critical Zone Observatories (CZO)

Critical Zone Observatories operate at the watershed scale to significantly advance understanding of the integration and coupling of Earth surface processes as mediated by the presence and flux of fresh water. Since 2006, a number of sites have been established, including a long-term hydrologic observatory above the seismogenic zone offshore from Japan's Kii Peninsula; a snowline CZO in the Kings River Experimental Watershed (KREW) in the Sierra National Forest; an observatory in the Boulder Creek watershed in the Front Range of the Rocky Mountains in Colorado; and an observatory in central Pennsylvania named the Susquehanna/Shale Hills Observatory. The Critical Zone Exploration Network (CZEN) links the field sites.

Consortium for Materials Properties Research in Earth Science (COMPRES)

The goal of the Consortium for Materials Properties Research in Earth Science is to enable Earth science researchers to conduct the next generation of high-pressure science on world-class equipment and facilities. The consortium is charged with the oversight and guidance of important high-pressure laboratories at several national facilities, such as synchrotrons and neutron sources. COMPRES facilitates the operation of beam lines and the development of new technologies for high-pressure research.

Students measure evaporation rates in Patagonia, Ariz. Data collection is a vital part of the work of the Center for Sustainability of Semi-Arid Hydrology and Riparian Areas (SAHRA), an NSF Science and Technology Center. *Credit: Jonathan Petti, SAHRA, University of Arizona, Tucson*

Center for Sustainability of Semi-Arid Hydrology and Riparian Areas (SAHRA)

The Center for Sustainability of Semi-Arid Hydrology and Riparian Areas, one of NSF's STCs, has as its mission to furnish new knowledge to help elected officials, water managers and policy experts at the local, state and national levels by supporting their ability to improve the sustainability of water resources in the U.S. and around the world. The Center's primary geographical focus is on two river basins: the Rio Grande/Rio Bravo river basin and the Upper San Pedro river basin in Arizona. Center researchers from multiple disciplines are working to understand the impacts of human population centers, agricultural activities and biodiversity in these semi-arid or arid regions, and are tackling emerging issues such as water markets and water banking. The center's partners include Arizona State University, New Mexico Tech, Scripps Institution of Oceanography, United States Geological Survey, the University of New Mexico in Albuquerque, Penn State University, Los Alamos National Laboratory, U.S. Department of Agriculture's (USDA) Agricultural Research Services, Desert Research Institute, University of California, Irvine, University of California, Merced, University of California, Riverside, Northern Arizona University, U.S. Army Corps of Engineers, University of California, Los Angeles, and Sandia National Laboratories. In 2007, SAHRA was one of two institutions to receive an award made annually by the United Nations Education, Science and Culture Organization (UNESCO). UNESCO cited SAHRA for its research into water usage and water management in arid regions.

Center for Coastal Margin Observation and Prediction (CMOP)

The Center for Coastal Margin Observation and Prediction has as its mission the integration of innovative interdisciplinary research, technology and education to answer complex questions about the interactions between the ocean, Earth's climate and human activities. The center, an STC, is led by Oregon Health and Science University, Oregon State University, and the University of Washington. CMOP researchers are focusing their studies on the Oregon-Washington coastal margin, the region where the Columbia River meets the Pacific Ocean.

National Center for Earth-Surface Dynamics (NCED)

The National Center for Earth-Surface Dynamics, another STC, seeks to develop an integrated and predictive understanding of the processes shaping the surface of the Earth in order to transform management of ecosystems, resources, and land use. The center's multidisciplinary approach involves everything from hydrology and ecology to the social sciences. Center researchers and others could develop new insights into the history of the Mississippi Delta region from data collected by major oil companies and now being made available to the NCED. The data–detailed information about the region's subsurface obtained by bouncing sound off the layers under the delta–had been kept largely in-house by the oil companies.

U.S. National Ice Core Laboratory

Ice cores are powerful tools in paleoclimate research. They can contain uninterrupted, detailed records of climate history going back hundreds of thousands of years. NSF continues to co-fund, with the U.S. Geological Survey (USGS), the U.S. National Ice Core Laboratory, a repository for storage, curation and study of ice cores recovered from the polar regions. The lab allows scientists to conduct examinations and measurements on ice cores, and it preserves the integrity of the ice cores in a long-term repository for current and future investigations. Marine core repositories are coordinated by the IODP.

An assistant curator at the U.S. National Ice Core Lab in Littleton, Colo., holds up a piece of ice taken from above Antarctica's Lake Vostok. The cores are recovered and studied in a variety of scientific investigations. *Credit: Melanie Conner, National Science Foundation*

Byrd U.S. Polar Rock Repository

Existing Antarctic rock samples can be valuable resources for researchers. The U.S. Polar Rock Repository at Ohio State University's Byrd Polar Research Center houses and makes available for research rock samples from Antarctica, the Arctic, southern South America and South Africa. The polar rock collection and database include field notes, photos, maps, cores, powder and mineral residues, and thin sections, as well as microfossil mounts, microslides and residues.

Paleobotany Collection

The Paleobotany Collection of Kansas University houses more than 7,000 specimens of Antarctic fossil plants from throughout the Transantarctic Mountains of Antarctica.

U.S. Antarctic Program Data Coordination Center

The U.S. Antarctic Program Data Coordination Center, at Lamont-Doherty Earth Observatory of Columbia University, coordinates the management of data collected by U.S.-funded scientists in Antarctica and the Southern Ocean. The goal is to help scientists find Antarctic scientific data of interest and help them submit data for long-term preservation.

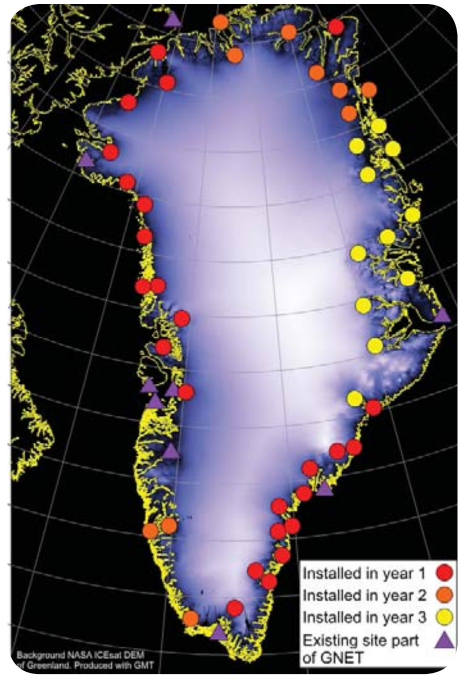
U.S. Antarctic Resource Center (USARC)

The U.S. Antarctic Resource Center is a joint venture between NSF and USGS. The center maintains the nation's most comprehensive collection of Antarctic maps, charts, satellite images and photographs produced by the U.S. and other member nations of the Scientific Committee on Antarctic Research (SCAR).

Center for Remote Sensing of Ice Sheets (CReSIS)

The Center for Remote Sensing of Ice Sheets (CReSIS), an NSF STC established in 2005, engages in technology development, and creates series datasets of the accumulation rate, surface elevation, ice thickness and velocity, and melt rate for the Greenland ice sheet.

Polar Earth Observatory Network (POLENET)



As part of the International Polar Year 2007-2009, POLENET researchers are deploying a seismic and GPS network around Greenland. This map shows the planned and completed installations. POLENET also is deploying, monitoring and updating instruments in Antarctica. Greenland and Antarctica offer natural laboratories for studying the solid earth processes that influence ice sheet dynamics. *Credit: Dr. Terry Wilson and Dr. Mike Willis, The Ohio State University*

NSF-supported researchers are part of the international Polar Earth Observatory Network project, a consortium involving people from 28 nations who are engaging in field work to improve the collection of geophysical data across the Earth's poles. The project is a core activity of IPY. In the south, researchers are constructing a network of GPS and seismic stations in West Antarctica to understand how the mass of the West Antarctic ice sheet (WAIS) changes with time. The information will be used to predict sea level rise accompanying global warming and interpret climate change records. And in the Arctic, another NSF-funded research team is constructing a network (GNET) of 38 continuous Global Positioning System (GPS) stations in Greenland to collect better data on ice sheets.

Summit Camp

NSF supports Summit Camp, a scientific research station in Greenland. The camp, located at the peak of the Greenland ice sheet—the largest ice sheet in the Northern Hemisphere—enables year-round operations to study air-snow interactions, which are crucial for interpreting data from ice cores drilled in the area and elsewhere. The site has proven to be a nearly ideal location for studies of climate change and snow chemistry.

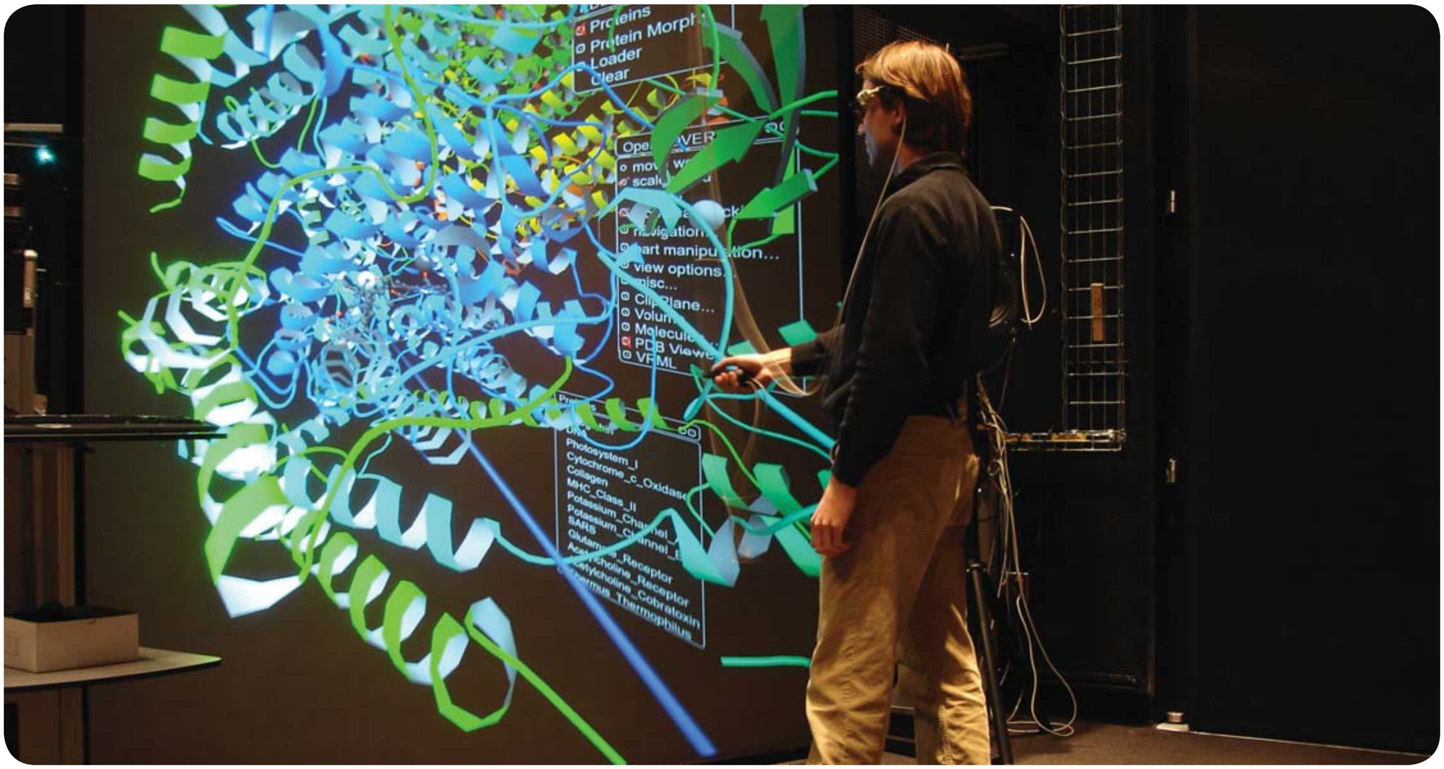
A Sudden Rise in the Yellowstone Caldera

The last time the Yellowstone super-volcano underwent a major, giant eruption was about 640,000 years ago when the caldera was formed. Scientists from the University of Utah and USGS have observed an accelerated rate of uplift of the Yellowstone Caldera during the time span from 2004-2006. The research team took advantage of EarthScope's Plate Boundary Observatory to isolate vertical and horizontal ground motion in the Yellowstone area from GPS measurements. They then coupled this data with InSAR measurements to develop a model of magma (and magmatic fluid) migration to explain the observed deformation. While the scientists do not feel that this increased uplift is indicative of an impending eruption, the data provide insight into the life cycle of a super-volcano. Since its original eruption, the Yellowstone supervolcano has experienced several recent periods of uplift and subsidence, indicating that the area is still active. The researchers reported their findings in the Nov. 9, 2007 issue of the journal *Science.*

A view of the Yellowstone River flowing through Hayden Valley, with the Yellowstone caldera rim in the distance. *Credit: Gwendolyn Morgan*

The convergence of powerful new technologies and fresh insight is contributing to a robust and expansive research infrastructure for biologists and others seeking a better understanding of living things. New tools that make use of approaches from other disciplines, such as computational thinking, together with the launch of new kinds of observatories for collecting and integrating data and the efforts of multidisciplinary teams are also adding to an explosion of new knowledge about living systems. Most of these investments are provided and/or managed by NSF's Directorate for Biological Sciences.

ALIVE: UNLOCKING THE SECRETS OF LIVING THINGS



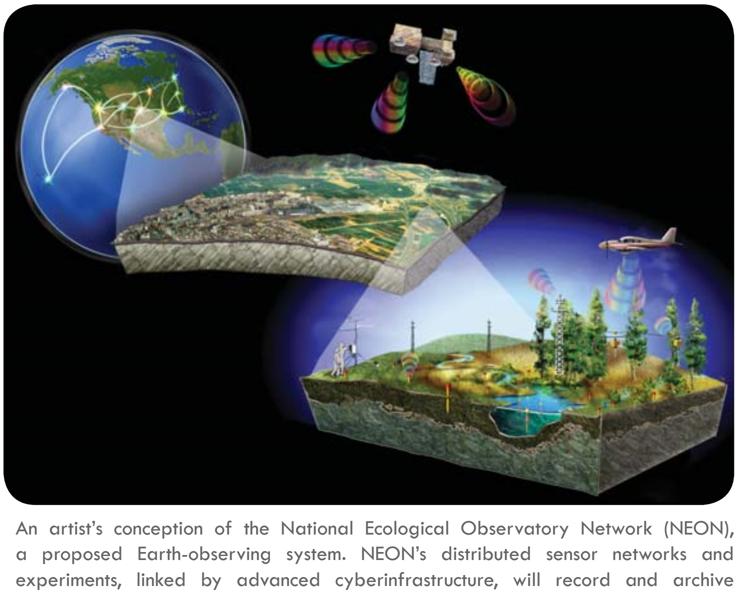
A visualization of a protein from the Protein Data Bank (PDB), shown on a C-Wall (a configurable wall for projecting images) at the California Institute for Telecommunications and Information Technology (Calit2) at the University of California, San Diego. The work on the interactive visualization of proteins from the PDB was performed by Jürgen P. Schulze, project scientist, in collaboration with Jeff Milton, Philip Weber and Philip Bourne. *Credit: Jurgen Schulze, Calit2, UC-San Diego*

Protein Data Bank (PDB)

The assets of the Protein Data Bank just keep growing. In 2004, when NSF announced a new management era designed to ensure open access to the worldwide collection of deposits of molecular structure data, the PDB held the three-dimensional structures of nearly 24,000 proteins and other macromolecules in its collection. In April 2008, the PDB added the 50,000th molecule structure. The holdings profile DNAs, RNAs, viruses, and various proteins, such as enzymes central to photosynthesis, growth, development and brain function. NSF has supported the Protein Data Bank continuously since 1975. A multi-agency support partnership was first formed in 1989. For the past five years, that partnership has included NSF, the National Institute of General Medical Sciences (NIGMS), the Department of Energy (DOE) and the National Library of Medicine (NLM). The partnership later was expanded to include the National Cancer Institute (NCI), the National Institute of Diabetes and Digestive and Kidney Diseases (NIDDK), and the National Institute of Neurological Disorders and Stroke (NINDS).

iPlant Collaborative

A team led by the University of Arizona was selected to create a cyberinfrastructure collaborative to address grand challenges in the plant sciences that are concerned with the environment, agriculture, energy and the very organisms that sustain our existence on earth. The iPlant Collaborative will bring together researchers in every area of plant science—from molecular and cellular biologists to those working at the ecosystem and global levels—as well as computer and information scientists, engineers, mathematicians and social scientists, and the activity will enable specialists from different fields to work together more effectively than ever before. The iPlant center will be located at the University of Arizona's BIO5 Institute. Other institutions working with the University of Arizona include Cold Spring Harbor Laboratory, Arizona State University, the University of North Carolina at Wilmington, and Purdue University. The iPlant Collaborative is a $50 million, five-year project that is potentially renewable for a second five-year period and a total of $100 million. The award is greater than three times the size of any other NSF award received in Arizona to date. The iPlant Collaborative is expected to transform the study of plant science, with cyberinfrastructure and computational science and thinking playing key roles. The iPlant cyberinfrastructure could serve as a model for solving problems in fields outside of plant biology as well. One iPlant feature to be developed is the ability to map the full expanse of plant biology research in much the same way as Google Earth, Microsoft Virtual Earth and Mapquest utilize mapping technology. Like users of those applications, users of iPlant may one day be able to "zoom" in and out among various levels of plant biology, from the molecular to the organismic to the ecosystem level. For example, a researcher might "zoom in" to analyze the carbon fixed, oxygen produced, and water utilized by individual leaves, then "zoom out" to analyze how all of these might effect large-scale changes in ecosystems and how that could, in turn, affect air quality and climate.



An artist's conception of the National Ecological Observatory Network (NEON), a proposed Earth-observing system. NEON's distributed sensor networks and experiments, linked by advanced cyberinfrastructure, will record and archive ecological data. *Credit: Nicolle Rager Fuller, National Science Foundation*

National Ecological Observatory Network (NEON) – Proposed

The National Ecological Observatory Network, a regional-to-continental network of sensors and shared technology in the final planning stages, will provide the infrastructure needed to address the most complex environmental challenges facing the U.S. Through remote sensing, *in situ* observation, experimentation, synthesis and modeling, NEON will offer multidisciplinary teams of researchers the unique tools, technologies and data needed to advance our understanding of ecological theory and the interconnectedness of life. Investigators expect to conduct real-time studies at unprecedented scales and produce significant advances in our understanding of the consequences of the interplay among air, water, land and biota. If constructed, NEON will be a "shared use" research platform consisting of geographically distributed field and laboratory research infrastructure that is connected via cyberinfrastructure to an integrated research instrument. NEON infrastructure will include instrumented towers and sensor arrays, remote sensing capabilities, cutting-edge laboratory instrumentation, natural history archives and facilities for data analysis, modeling, visualization and forecasting–all networked onto a cyberinfrastructure backbone. Infrastructure would be deployed across the continental U.S., Alaska, Hawaii and Puerto Rico using a statistically determined design. NEON was proposed as a new start in FY 2007; continuation of design and future construction depends upon successful project design reviews, continued prioritization by NSF, NSB approval and the availability of federal funds.

National Center for Ecological Analysis and Synthesis (NCEAS)

Researchers at the NSF-funded National Center for Ecological Analysis and Synthesis at the University of California, Santa Barbara are helping people see the "big picture" when it comes to Earth's systems. The center is focused on the development and testing of important ecological ideas and theories using existing data. Other major focuses are cutting-edge analysis of ecological information; research on data access and use; promoting the use of sound science in policy and management decisions; investigating sociological issues that pertain to the science of ecology; projects involving the state of California; and education and outreach. (See sidebar, below.)

Study Presents the "Big Picture" of Human Impacts on the Oceans

Coral reefs are just one of many ocean habitats that have been impacted by human activity. *Credit: Joe Pawlik, University of North Carolina at Wilmington*

Researchers conducting the first global-scale study of human influence on marine ecosystems found more than 40 percent of the world's oceans are heavily impacted and that few, if any, areas remain untouched by human activities. By overlaying maps of 17 different activities, such as fishing, the researchers produced a composite map of the toll that humans have exacted. Past studies focused largely on single activities or single ecosystems in isolation, and rarely at the global scale. In this study, the scientists were able to look at the total influence of human activities across marine ecosystems. The study found that the most heavily affected waters in the world include large areas of the North Sea, the South and East China Seas, the Caribbean Sea, the east coast of North America, the Mediterranean Sea, the Red Sea, the Persian Gulf, the Bering Sea and several regions in the western Pacific. The least affected areas are largely near the poles. The work, published in the journal *Science* in February 2008, was conducted at NSF's NCEAS at the University of California, Santa Barbara. For more information, see the NSF news release at http://www.nsf.gov/news/news_summ.jsp?cntn_id=111113.

National Evolutionary Synthesis Center (NESCent)

The National Evolutionary Synthesis Center enables collaborative biological research efforts by three universities in North Carolina's Research Triangle: Duke University, North Carolina State University and the University of North Carolina at Chapel Hill. The center, located in Durham, has as its central goal fostering greater conceptual synthesis in biological evolution by bringing together researchers and educators, existing data and information technology resources. To achieve this goal, the center will develop new tools and cross-disciplinary standards for management of biological information and meta-information, support data analysis capabilities with broad utility, and host and curate databases. The center will support postdoctoral fellows, sabbatical faculty and computer scientists on site. Researchers will have primary projects of their own design, but as a whole, the group will have a great deal of independence to take advantage of new opportunities for synthesis and collaboration as they arise. In addition, NESCent will coordinate and sponsor a number of working groups tasked with making progress on significant issues in evolutionary biology where opportunities for synthesis have been identified. The center will also support education and outreach activities to enhance public understanding of the science of biological evolution and foster interactions between evolutionary biologists and members of the broader community.

National Institute for Mathematical and Biological Synthesis (NIMBioS)

The National Institute for Mathematical and Biological Synthesis is a new NSF-funded center established to foster research and education at the interface of the mathematical and biological sciences. The center will bring together researchers in small working groups to tackle problems and produce insights into such issues as the control of invasive species, how to limit impacts of infectious diseases, and new methods for drug design. NIMBioS will be located at the University of Tennessee-Knoxville, and one of its unique aspects will be a partnership with the Great Smoky Mountains National Park that will enable researchers to use the park as a testing ground for emerging ideas.

Center for Behavioral Neuroscience (CBN)

At the Center for Behavioral Neuroscience at Georgia State University—one of NSF's STCs—researchers are studying animals such as voles to shed light on the roles of nature and nurture in animal behavior. Scientists in the vole study have found that genes for vasopressin and oxytocin play important roles in the formation of social attachments between animals. The findings could someday help with better treatments of human conditions such as autism and depression. In addition to the group studying affiliation issues, there are other collaboratories—research environments for 15-20

The Center for Behavioral Neuroscience (CBN), an NSF Science and Technology Center, has developed a comprehensive education program to train the next generation of neuroscientists and increase science literacy. *Credit: Atlanta Center for Behavioral Neuroscience*

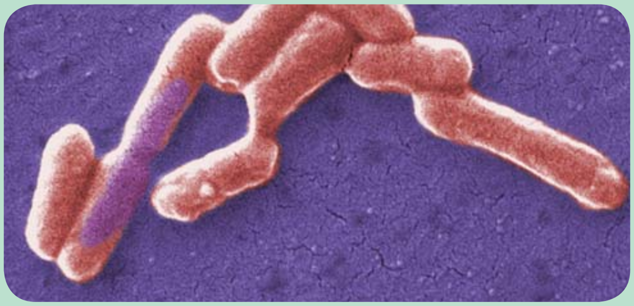
researchers focusing on similar issues—at the center including a group investigating how systems in the brain are involved in conditioned emotional responses that lead to fear and anxiety. One potential outcome of the work could be applicable to helping people overcome post-traumatic stress disorder (PSD), phobias and anxiety disorders. Besides Georgia State, Clark Atlanta University and Emory University, Georgia Institute of Technology, Morehouse College, Morehouse School of Medicine and Spelman College are partners in the CBN.

Center for Environmental Implications of Nanotechnology (CEIN)

NSF and the U.S. Environmental Protection Agency (EPA) have partnered to establish two Centers for the Environmental Implications of Nanotechnology. Announced in September 2008, the centers—one at Duke University and the other at the University of California, Los Angeles—will study how nanomaterials interact with the environment and with living systems, and will translate this knowledge into risk assessment and mitigation strategies useful in the development of nanotechnology. The centers will work as a network, connected to other research organizations, industry and government agencies and will emphasize interdisciplinary research and education. The University of California, Los Angeles CEIN will explore the impact of nanomaterials on the environment and on interactions with biological systems at all scales, from cellular to ecosystem. Duke University CEIN researchers plan to define the relationship between a vast array of nanomaterials—from natural to man-made to incidental, byproduct nanoparticles—and their potential environmental exposure, biological effects and ecological consequences.

A Speedier—And Cheaper—Method for Identifying Strains of *E.Coli*

Researchers at the University of Wisconsin-Oshkosh developed a new method of identifying strains of bacteria in environmental samples, such as water from recreational lakes. *E. coli* is found in water that has been contaminated by fecal material. Many different strains exist naturally in the wild, but a few strains cause serious illnesses in people. The researchers, supported by an MRI grant, developed a special type of mass spectrometer that distinguishes between bacterial strains based on analysis of proteins in the cells. This approach is faster and less costly than DNA fingerprinting, the traditional means of strain identification. Faster identification of the bacterial strains will allow a quicker response to possible health threats. For more information, see the NSF award abstract at http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0321545.



A colorized, scanning electron micrograph (SEM) depicting a number of Gram-negative *Escherichia coli* bacteria under high magnification. Although most strains of *E.Coli* are harmless, this strain (*E. coli* O157:H7) produces a powerful toxin that can cause severe illness. *Credit: Janice Haney Carr, Centers for Disease Control and Prevention*

Long-Term Ecological Research (LTER)

Beginning with an initial set of six sites in 1980, Long-Term Ecological Research project sites are a vital part of the agency-supported research infrastructure. NSF established the LTER program to conduct research on long-term ecological phenomena. Currently, there are 26 sites, located primarily in the U.S., but there are locations in the Arctic, Antarctic and tropics. The sites represent Earth's major ecosystems, including deserts, grasslands, forests, tundra, urban areas, agricultural systems, freshwater lakes, coastal estuaries and salt marshes, coral reefs and coastal ocean zones, and a broad array of research emphases. Research conducted at the LTER sites is contributing to our understanding of climate change, biodiversity, human's impact on the environment and other major ecological challenges. Some studies produce results in a relatively short timeframe. For example, the Sevilleta LTER in New Mexico helped solve a medical mystery in the Four Corners area, when people suddenly started dying of a mysterious respiratory disease. Blood tests of the victims revealed that people had become infected with a previously undetected kind of hantavirus. Hantaviruses were known to spread from rodents to humans in Asia and Europe, but hadn't been seen in the U.S. prior to the 2003 outbreak. The Sevilleta LTER researchers answered key questions about the sudden appearance of the virus and how it spread. They found that El Niño, a periodic pattern of change in the circulation of oceans and atmosphere, had substantially boosted plant productivity after several years of drought, and that more plants led to more rodents which in turn increased the probability of people's exposure to infected rodents. Other LTER research requires many years of sustained observations to produce important results. Examples of LTER sites are presented below; all of the LTERs are listed in Appendix I.

Arctic LTER

The Arctic LTER site at Toolik Lake Field Station is located in the foothills region of the North Slope of Alaska and includes the entire Toolik Lake watershed and the adjacent watershed of the upper Kuparuk River, down to the confluence of these two watersheds. The area features continuous permafrost—no trees, complete snow cover for seven to nine months, winter ice cover on lakes, streams and ocean, and

The NSF-supported research station at Toolik Lake in Alaska, part of the Arctic Long-Term Ecological Research (LTER) site. Researchers study the ecology of the surrounding tundra, streams, and lakes to gain a better understanding of the controls of ecosystem structure and function. *Credit: © 2002 James H. Barker and Institute of Arctic Biology*

cessation of river flow during the winter. The LTER site enables research aimed at understanding how tundra, streams and lakes function in the Arctic. Researchers are studying the movement of nutrients from land to stream to lake, changes due to human influences, and controls of ecological processes by nutrients and by predation. The Toolik Lake Field Station is operated by the Institute of Arctic Biology at the University of Alaska Fairbanks.

Baltimore Ecosystem Study (BES)

Initiated as an LTER site in 1997, the Baltimore Ecosystem Study is led by Institute of Ecosystem Studies. It is one of two LTERs that focuses on a metropolitan region as an ecosystem (the other is the Central Arizona-Phoenix LTER). Researchers at the University of Maryland, Baltimore County, Johns Hopkins University, and the USGS are key members of the BES LTER team. BES received a Phase II award in 2005 to continue work on research topics that include patch dynamics of built, social, biological and hydrological components of the metropolitan area; feedbacks between social, economic and ecological components of an urban ecosystem; and the effects of infrastructure and development on fluxes of nutrients, energy, and water in upland, stream, and coastal regions of metropolitan Baltimore. The ecological knowledge resulting from research helps support educational and community-based activities. Interactions between the project and the Baltimore community are important components of the LTER's work.

Bonanza Creek LTER

The Bonanza Creek LTER site is located in the boreal forest of Alaska's interior, with facilities centered in the city of Fairbanks, Alaska. The LTER includes two research areas—the Bonanza Creek Experimental Forest and the Caribou-Poker Creeks Research Watershed. Researchers at the LTER site are focusing on improving our understanding of the long-term consequences of changing climate and disturbance regimes in the Alaskan boreal forest. The overall objective is to document the major factors controlling forest dynamics, biogeochemistry and disturbance and their interactions in the face of a changing climate.

McMurdo Dry Valleys LTER

The McMurdo Dry Valleys LTER site is located on the western coast of McMurdo Sound. The dry valleys form the largest, relatively ice-free area on the Antarctic continent. The perennially ice-covered lakes, ephemeral streams and extensive areas of exposed soil within the McMurdo Dry Valleys LTER

Beacon Valley field camp, located in the Dry Valleys of the Transantarctic Mountains. The McMurdo Dry Valleys are one of the NSF Long-Term Ecological Research (LTER) sites. The research group pictured above was studying the landscape features and soils of Antarctica's Dry Valley region to provide a more complete understanding of past global climatic and environmental conditions. *Credit: Josh Landis, National Science Foundation*

are subject to low temperatures, limited precipitation and salt accumulation. Thus, the dry valleys represent a region where life approaches its environmental limits, and is an "end-member" in the spectrum of environments included in the LTER Network. Ohio State University is the lead institution for the McMurdo Dry Valleys LTER.

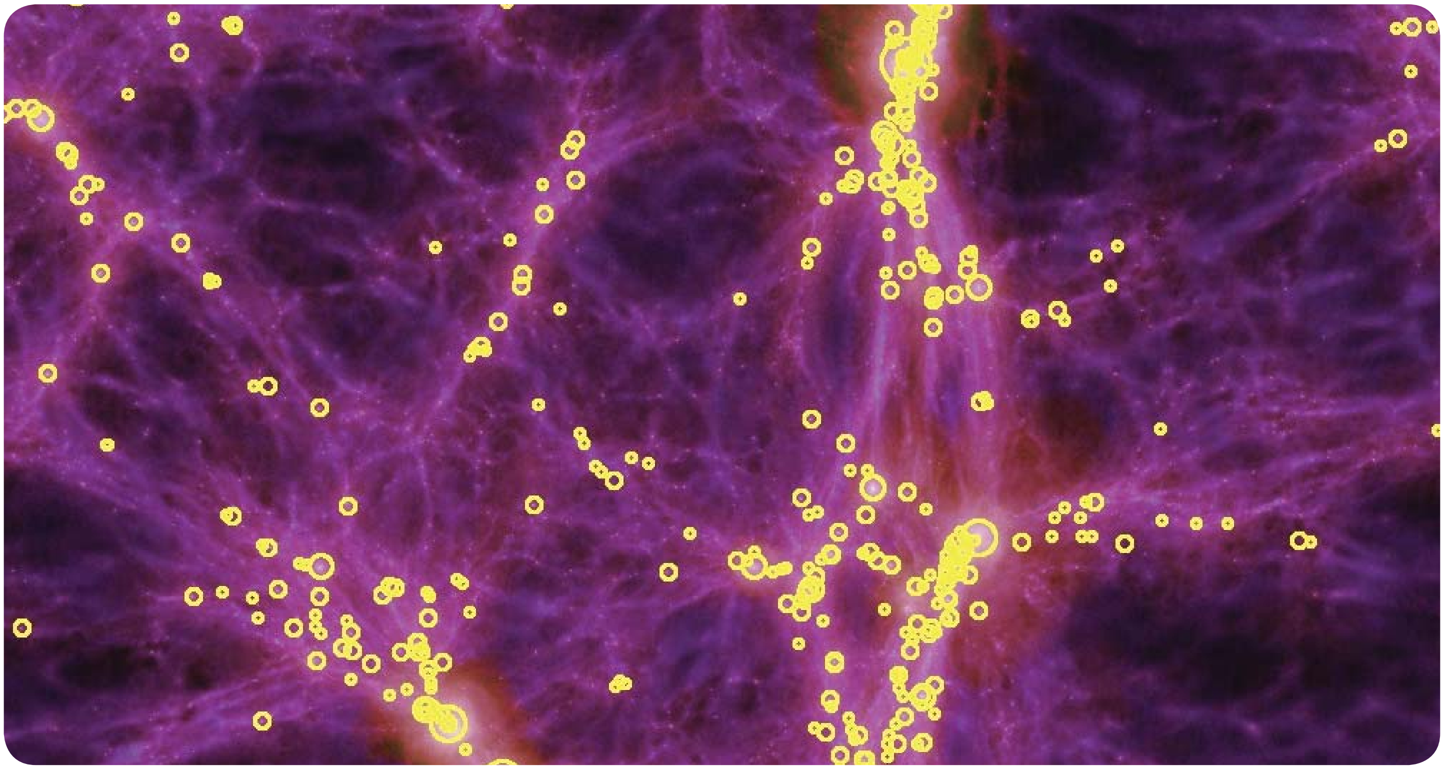
Diverse Native Prairie Plant Species as Better Biomass Fuel Source

Plant-based (biomass) sources of fuel have emerged in recent years as promising alternatives to fossil fuel. Ethanol, made from corn, is in the marketplace, but production of ethanol has raised questions about its efficiency, as well as the impact of diverting cropland from growing food to growing biofuel. Biodiesel from soybeans faces similar concerns. Is there a better alternative? Recent research has identified diverse mixtures of native prairie grasses and other flowering plants as a leading option. Researchers conducting a study over a 10-year period at Minnesota's Cedar Creek Natural History Area found that the biomass mixture produced more usable energy per acre than corn- and soybean-based sources, and that prairie plant biomass would be "carbon negative," meaning that producing and using the prairie grass mixture would reduce the amount of carbon dioxide, a greenhouse gas, in the environment. The Cedar Creek area is one of the 26 LTER sites supported by NSF. The research results were reported in the Dec. 8, 2006, issue of the journal *Science*. For more information, see the NSF news release at http://www.nsf.gov/news/news_summ.jsp?cntn_id=108206.

At Minnesota's Cedar Creek Natural History Area, one of NSF's Long-Term Ecological Research (LTER) sites, researchers identified mixed prairie grasses as a leading source for producing environmentally friendly, bio-based fuel. *Credit: Cedar Creek LTER Site*

It's nearly impossible to imagine a field of science and engineering that has not been impacted by advances in computing, communications and information technology. In fact, it's hard to imagine any area of society that hasn't been affected. According to a 2007 report by the President's Council of Advisors in Science and Technology, "since 1995, networking and information technology industries have accounted for 25 percent of the nation's economic growth…." In science and engineering, advances in computing and related information technology are providing researchers with the ability to explore questions that were previously out-of-reach. NSF is working to ensure the U.S. has a world-class cyberinfrastructure that enables researchers to advance the frontiers of what is known. Besides being the principal source of government-funding for university-based computer science research, the foundation also funds the acquisition, development and operation of high performance computers, storage systems, programming, scalable interactive visualization tools, virtual environments, networking and more. NSF's Office of Cyberinfrastructure (OCI) and Directorate for Computer and Information Science and Engineering are primarily responsible for investing in shared cyberinfrastructure to continue the successful efforts, begun more than 20 years ago, to give the academic research community open access to supercomputing capabilities.

The Continuing Computing and Storage Revolution



A snapshot from a simulation showing the evolution of structure in a large volume of the universe. The simulation relied on the resources of the TeraGrid, using the Pittsburgh Supercomputing Center's 2,000 Cray XT3 processors—the whole system—over four weeks of run time. This is the first simulation to incorporate black hole physics, according to theoretical cosmologist Tiziana Di Matteo of Carnegie Mellon University. The model has yielded new insight into the role played by black holes in galaxy formation. *Credit: Tiziana Di Matteo, McWilliams Center for Cosmology, Carnegie Mellon University*

TeraGrid

NSF's TeraGrid (actually the Extensible Terascale Facility) is the world's leading high-end computing environment for open research. It integrates high-performance computers, data resources and tools, and high-end experimental facilities around the world. The advanced cyberinfrastructure, which entered full production mode in 2004, combines the resources of 11 partner sites—Indiana University, the Louisiana Optical Network Initiative, the National Center for Atmospheric Research, the National Center for Supercomputing Applications at the University of Illinois at Urbana-Champaign, the National Institute for Computational Sciences (NICS), the Oak Ridge National Laboratory, the Pittsburgh Supercomputing

Ultra-high resolution display systems such as the one pictured to the left—the Highly Interactive Parallelized Display Space, or HiPerSpace, wall at the California Institute for Telecommunications and Information Technology (Calit2) at the University of California, San Diego—provide scientists using the TeraGrid with a better way to view real-time, rendered graphics of large data sets and collaborate in their research. *Credit: Falko Kuester, California Institute for Telecommunications and Information Technology (Calit2), University of California, San Diego (UCSD)*

Center (PSC), Purdue University, the San Diego Supercomputer Center (SDSC), the Texas Advanced Computing Center and the University of Chicago/Argonne National Laboratory—to create an integrated, persistent, computational resource. The TeraGrid supports more than 1,000 projects and more than 4,000 researchers across the U.S. Currently, TeraGrid integrated resources include more than 750 teraflops of computing capability and more than 30 petabytes (quadrillions of bytes) of online and archival data storage, with rapid access and retrieval over high-performance networks. The TeraGrid also provides researchers with access to more than 100 discipline-specific databases.

Ranger Supercomputer

Ranger, the new high performance computing system at the Texas Advanced Computing Center at the University of Texas at Austin, was ranked as the fourth fastest supercomputer, according to the June 2008 list of the top 500 supercomputers worldwide. The list is compiled twice a year, and the three machines ranked as faster than Ranger are owned by the DOE and reserved primarily for nuclear weapons research and related tasks. Ranger is the most powerful supercomputer available to the open science research community–it's used for computational research in all scientific disciplines–and the system has more memory than any other supercomputer on the Top 500 list. As part of NSF's four-year initiative to fund the

Ranger, the new high performance computing system at the Texas Advanced Computer Center at the University of Texas at Austin, has been ranked as one of the world's fastest supercomputers. *Credit: TACC, The University of Texas at Austin*

deployment and operation of leading-edge systems to greatly increase the availability of computing resources to U.S. researchers, the new system provides the first petascale computing platform based within the U.S. university research community, with peak performance of one-half petaflop per second. Ranger is specifically designed to provide unprecedented power to meet very large science and engineering computational requirements, and is currently supporting some 150 research projects, ranging from earthquake simulation and advanced biology to nanoelectronics and particle physics. Ranger significantly boosts the computational capacity of the TeraGrid. In its final configuration, Ranger will have a peak performance of some 504 teraflops. The system architecture includes an unusually large total system memory. With 125 terabytes of memory and 1.7 petabytes of raw disk storage, Ranger makes possible very data-intensive and memory-intensive calculations. Ranger began normal operations this year, following its dedication in February 2008.

National Institute for Computational Sciences (NICS) Kraken

The newest NSF high performance supercomputer for transformational research projects is National Institute for Computational Sciences Kraken**,** led by the University of Tennessee at Knoxville, in collaboration with the Oak Ridge National Laboratory. If petascale computing is the gold standard for the next generation of academic cyberinfrastructure, this mid-range high performance system will move U.S. researchers toward that goal, providing peak performance of just under one petaflop. The new near-petascale system's computing capability significantly expands the capacity of the TeraGrid and enables investigators to pursue breakthrough science and engineering research in a wide range of computationally demanding areas including: life sciences, earth, atmospheric and ocean sciences, chemistry and biochemistry, materials research and nanoscale engineering, computational fluid dynamics, high-energy physics, astronomy and astrophysics, space physics, economics, neuroscience and social science.

Blue Waters

Blue Waters is being built to be the world's most powerful "petascale" system for academic science and engineering research, capable of making arithmetic calculations at a sustained rate in excess of 1,000-trillion operations per second. It will have more than 200,000 processor cores coupled to more than a petabyte of memory and more than 10 petabytes of disk storage. This leadership class computing system will provide unprecedented computing resources to enable the next generation of science and engineering applications, those that use multiple models at multiple scales to describe complex processes. The system will help investigators advance studies of some of the world's most challenging science and engineering research problems, such as the formation and evolution of galaxies in the early universe; the interaction of the Sun's coronal mass ejections with the Earth's magnetosphere and ionosphere; the chains of reactions that occur with living cells, organs and organisms; and the design of novel materials. The Blue Waters system will be located at the University of Illinois at Urbana-Champaign and will be operated by the National Center for Supercomputing Applications and its partners in the Great Lakes Consortium for Petascale Computing. NCSA finalized a contract with IBM to build the system in August 2008. Blue Waters is expected to come online in 2011.

High Performance Wireless Research and Education Network (HPWREN)

With NSF support, researchers at the University of California, San Diego developed the High Performance Wireless Research and Education Network (HPWREN). The research project includes creating, demonstrating and evaluating a non-commercial, prototype, high-performance, wide-area, wireless network in San Diego, Riverside and Imperial counties in California. The versatile network research project functions as a collaborative cyberinfrastructure on research, education and first responder activities. The network includes backbone nodes at the University of California, San Diego, and San Diego State University campuses, and a number of "hard to reach" areas in remote environments. HPWREN has proven its value to scientists, educators and many others, including firefighters. The network has provided next-generation communications services to firefighters battling California wildfires in recent years, while the network's cameras and sensors provide real-time images and current data, enabling better decision making about the use of resources to fight the

With relays like this one on Palomar Mountain, the High-Performance Wireless Research and Education Network (HPWREN) brought connectivity to firefighters at the scene of the 2003 Coyote wildfire, allowing them to receive weather notices and submit incident summaries in real-time. Before it was brought under control, the fire burned more than 17,000 acres in southern California. *Credit: High Performance Wireless Research and Education Network (HPWREN)* wildfires. The high performance network has also aided astronomers, giving researchers at the California Institute of Technology's Palomar Observatory the speed they needed to pinpoint the location of short-lived gamma ray bursts and observe them as they exploded. More recently, data collected from observations of a supernova explosion by the robotic telescope at the Palomar Observatory were transmitted from the remote mountain site in southern California to astronomers via HPWREN.

Global Ring Network for Advanced Applications Development (GLORIAD)

The Global Ring Network for Advanced Applications Development is a high-speed (10-gigabit-per-second) optical network around the entire Northern Hemisphere, supported by a consortium of government agencies and science organizations to enable increased science and education support among the U.S., Russia, China, Korea, Canada and Netherlands, as well as broader Europe and Eastern and Central Asia. GLORIAD supports increased science and education cooperation and ensures a rational, coherent strategy and architecture for the future of science and education networking. In addition to the jointly managed, hybrid circuit-switched and routed production environment, the project provides services to support increased science and education cooperation for both general and highly advanced (in terms of network needs) user communities.

Grid Physics Network (GriPhyN)

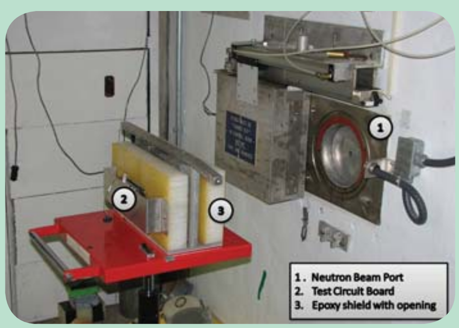
The Grid Physics Network is a collaboration of experimental physicists and information technology researchers to implement the first petabyte-scale computational environments for data intensive science in the 21st century. The project is developing grid technologies for scientific and engineering projects that need to collect and analyze distributed petabyte-scale datasets. Examples of areas of science which will produce very large collections of measured data include the Sloan Digital Sky Survey, LIGO and experiments of the LHC.

Data Intensive Science University Network (DISUN)

The Data Intensive Science University Network is a distributed cyberinfrastructure for applications requiring data-intensive, distributed computing technology. The grid-based facility comprises computing, networking, middleware and personnel resources from four universities—California Institute of Technology, the University of California, San Diego, the University of Florida and the University of Wisconsin-Madison.

One of a Kind Test Facility to Reduce Chip Errors

Some computer chips, such as field programmable gate array (FPGA) components, are subject to radiation-induced errors, called soft errors. An FPGA is an integrated circuit that can be programmed in the field after manufacture. Cosmic rays and other radiation can cause unwanted state changes in the integrated circuits. For an FPGA at 3,600 meters above sea level–approximately the altitude of a commercial airplane–soft errors can occur as frequently as four errors per every 28 days. The number of soft errors is expected to increase as chip feature sizes become smaller, voltages lower, clock speeds increase and systems incorporate greater numbers of chips. An NSF-supported interdisciplinary research team at Penn State University has established an accelerated test facility, the only one of its kind in an academic environment, to conduct research aimed at understanding the phenomenon of radiation-induced errors. Facility collaborators have access to the university's Breazeale TRIGA nuclear research reactor to gather actual data on radiation effects on computer chips. The researchers' results were the first to show correlation between soft errors and power optimizations, aging, process and environmental variations. Experiments have confirmed that there is a strong correlation between higher failure rates and lower voltages. Aging has been shown to not affect soft error rates, while higher temperatures reduce soft errors. The researchers are developing models for soft error analysis and design methods that mitigate the effects of these errors.



At Penn State University's accelerated soft error testing facility, a digital circuit board is aligned for exposure from the neutron beam port, enabling researchers to study the impact of radiation on microprocessor reliability. *Credit: © Vijaykrishnan Narayanan*

Collaborative Center for Internet Epidemiology and Defenses (CCIED)

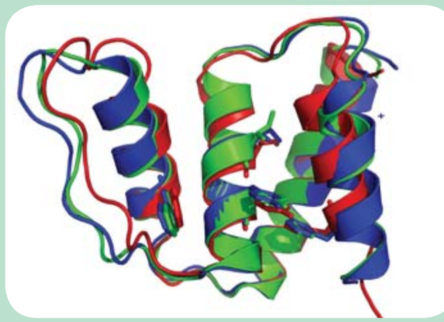
The Collaborative Center for Internet Epidemiology and Defenses is an NSF-supported joint effort between researchers at the University of California, San Diego, and the International Computer Science Institute's Center for Internet Research to address critical challenges posed by large-scale Internet-based pathogens, such as worms and viruses. CCIED efforts focus on analyzing the behavior and limitations of Internet pathogens, developing early-warning and forensic capabilities, and developing technologies that can automatically defend against new outbreaks in real-time. One of the important tools used is the University of California, San Diego's network telescope that looks at the literal dark side of the Internet—Internet traffic destined for an unoccupied section of the Internet, with legal addresses but no active computers.

Cooperative Association for Internet Data Analysis (CAIDA)

The Cooperative Association for Internet Data Analysis was established to foster engineering and technical collaborations among Internet providers, vendors and user groups. It was launched in 1997 with an NSF seed grant to the University of California, San Diego, and today, its primary support comes from NSF and the Defense Advanced Research Projects Agency (DARPA). Based at the San Diego Supercomputer Center, CAIDA's members represent the commercial, government and research sectors. Its primary focus is on the development of measurement, analysis and visualization tools of benefit to the community and pursuit of initiatives to improve the robustness and scalability of the Internet.

Speeding Simulations for Drug Design

Proteins are one of the building blocks of the body. Determining the 3-D shapes of proteins—crucial to understanding the ways proteins function—has been a slow and exacting process. To enable researchers to accelerate their predictions of 3-D protein structures, which can play a crucial role in endeavors such as rational drug design, SDSC and NCSA researchers worked to optimize the Rosetta code used for such predictions. Using 1.3 million processor hours on TeraGrid Condor resources at NCSA and 730,000 processor-hours on the SDSC's BlueGene, 22 targets were determined and used to generate the high-resolution structures. SDSC also worked with the researchers for extreme-scaling modifications that allowed the Rosetta code to run its largest-ever computation on 40,960 processors of the 114 peak teraflop IBM Blue Gene Watson system. In an important step toward petascale computing, the computation allowed a complete, from scratch, prediction of a protein structure to be completed in less than three hours, something that requires several days on a 1,000-processor machine.



Discovering the 3-D structure of proteins opens the door to understanding their life-giving functions. Computational scientists from the San Diego Supercomputer Center at the University of California, San Diego collaborated with researchers in Howard Hughes Medical Institute investigator David Baker's group at the University of Washington to compute the high-resolution protein structure shown here. *Credit: Courtesy of R.C. Walker, SDSC/ UCSD; S. Raman, U. Washington Source: San Diego Supercomputer Center, UC San Diego*

Wireless Open-Access Research Platform for Networks (WARPnet)

Rice University is developing an experimental platform to advance high-speed wireless technology. The Wireless Open-Access Research Platform for Networks will help researchers develop and test next-generation wireless technology. It is expected to lead to collaborations among researchers and industry to design smarter, more robust and more efficient hardware and software for tomorrow's wireless applications. The work is supported by an MRI grant.

Cluster Exploratory (CluE)

A new Cluster Exploratory initiative will provide NSF-funded researchers with access to software and services running on a Google-IBM data cluster to explore innovative research ideas in data-intensive computing. The two companies created a large-scale computer cluster of approximately

1,600 processors to give the academic community access to the otherwise prohibitively expensive resources (also called data centers and server farms). NSF joined the project and will allocate cluster computing resources for a broad range of proposals to explore the potential of the massively scaled, highly distributed computing resources to contribute to science and engineering research and produce applications which promise to benefit society as a whole.

Team for Research in Ubiquitous Secure Technology (TRUST)

The Team for Research in Ubiquitous Secure Technology, another of NSF's STCs, addresses the need for the integration of secure, robust computing and communications capabilities across crucial infrastructures. Computer technologies are now part of the critical infrastructure for everything from telecommunications and finance to energy distribution and transportation. The need for security and reliability is of paramount importance in these modern, interconnected times. The center, located at the University of California, Berkeley, brings together computing experts, social scientists and the legal and policy communities to explore approaches to strengthening the security and trustworthiness of the nation's computing and critical infrastructures. Besides the University of California, Berkeley, TRUST's partners include Carnegie Mellon University, Cornell University, Stanford University, Vanderbilt University, Mills College, San Jose State University and Smith College.

Center for Embedded Networked Sensing (CENS)

The Center for Embedded Networked Sensing is an NSF STC at the University of California, Los Angeles that makes it possible for researchers to use embedded networked sensing systems to derive knowledge about the world around us. The large-scale, distributed systems are composed of smart sensors and actuators embedded in the physical world. Besides embedding sensor systems to learn about the natural systems, center researchers are also learning how to design better embedded systems. (See sidebar, below.)

Digital River Captures Data Flow

Scientists and engineers from the Center for Embedded Networked Sensing at the University of California, Los Angeles have tested a sensor deployment campaign at the confluence of California's Merced and San Joaquin Rivers. Their objective was to create a system for rapidly characterizing a complex river not only in terms of its bathymetry (underwater depth) and floodplain, but also its flow and water quality parameters. Using a robotic sensing device, researchers scanned flow and water quality conditions across transects taken upstream, downstream and within the confluence zone. Over a five-day period, they collected substantial data that resulted in a 3-D map of the confluence zone, which will be used with the transect data to create a multidimensional river model that scientists can use to analyze and forecast river conditions. CENS is one of NSF's STCs. For more information, see the NSF award abstract at http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0120778.

A robotic sensor node deployed over the Merced River in Washington State allows researchers to directly visualize the distribution and flow of contaminants. The sensor node is part of the University of California, Los Angeles' Network Infomechanical Systems (NIMS) project of the Center for Embedded Networked Sensing (CENS). *Credit: Network Infomechanical Systems (NIMS)/Center for Embedded Networked Sensing (CENS) (http://www.cens.ucla.edu/*

Arctic Observing Network (AON)

The Arctic Observing Network is an internationally supported network for providing critical observations of the Arctic environment and uses cyberinfrastructure tools to form a true network from the existing sites. AON responds to the need to understand the causes and consequences of Arctic change, and is part of the legacy of the IPY.

Exchange for Local Observations and Knowledge of the Arctic (ELOKA) Project

The Exchange for Local Observations and Knowledge of the Arctic project is another IPY-related activity supported by NSF. The data management and networking project facilitates the collection, preservation, exchange and use of observations and knowledge of the Arctic by local Arctic residents and indigenous peoples. NSF is also funding the National Snow and Ice Data Center's (NSIDC) participation in IPYDIS (International Polar Year Data and Information Service), a global partnership of data centers, archives and networks working to ensure proper stewardship of IPY and related data.

NSF investments in research infrastructure span the continuum from basic research and discovery to the development of new technologies, systems and other engineering solutions that make people's lives better, safer and more productive. Investments in fundamental research leading to emerging technologies such as sensors and sensor systems, photonics, metabolic engineering, bioengineering and manufacturing build and strengthen the nation's capacity to lead the world in innovation. Funding for research centers and networks, advanced instrumentation and facilities are enabling scientists and engineers to better understand the natural world and improve the ability of the built environment to adapt. NSF's Directorate for Engineering (ENG) is primarily responsible for providing and/or managing these investments.

Innovation Inspired by Human Need

The Tsunami Wave Basin at Oregon State University is the world's largest facility for investigating the effects of large waves. By studying the impact of tsunamis on model buildings (the boxes, above) and other structures, engineers and scientists can develop better designs and materials to mitigate damage to people and property. The Tsunami Wave Basin is part of the George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES). *Credit: College of Engineering, Oregon State University*

George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES)

Almost from the agency's start, NSF has been a key player in supporting research to understand earthquakes and prevent or mitigate the damage they cause. The George E. Brown, Jr. Network for Earthquake Engineering Simulation is a centerpiece of ongoing efforts. Constructed during FYs 2000-2004 and opened for operations on Oct. 1, 2004, NEES comprises a network of 15 earthquake engineering experimental equipment sites available for experimentation on-site, in the field and through remote operations. The sites, which include shake tables, geotechnical centrifuges, a tsunami wave basin, unique large-scale testing laboratory facilities, and mobile and permanently installed field equipment, help researchers understand how earthquake and tsunami forces affect ground motion and soil liquefaction, the built environment—buildings, bridges, utility systems—and nearshore and coastal environments. The NEES networking cyberinfrastructure connects, via Internet2, the equipment sites as well as provides telepresence, a curated central data repository, simulation tools and collaborative tools for facilitating on-line planning, execution and post-processing of experiments. The 15 NEES sites are:

- Cornell University - Large Scale Structural Lab
- Lehigh University - Large Scale Structural Lab
- Oregon State University - Tsunami Wave Basin
- Rensselaer Polytechnic Institute - Geotechnical Centrifuge Lab
- University at Buffalo - Shake Table and Large Scale Structural Lab
- University of California, Berkeley - Large Scale Structural Lab
- University of California, Davis - Geotechnical Centrifuge Lab
- University of California, Los Angeles – Mobile Field Testing Equipment
- University of California, San Diego - Shake Table Lab
- University of California, Santa Barbara – Instrumented Field Sites
- University of Colorado at Boulder - Large Scale Structural Lab
- University of Illinois at Urbana-Champaign - Large Scale Structural Lab
- University of Minnesota - Large Scale Structural Lab
- University of Nevada, Reno - Shake Table Lab
- University of Texas at Austin – Mobile Field Testing Equipment

Researchers at NEES sites are addressing critical challenges. The following examples are illustrative:

- In 2006, several months after Hurricane Katrina devastated New Orleans, a team of researchers used the centrifuge at Rensselaer Polytechnic Institute to model a section of the city's levees and subject it to forces similar to those that lead to the Katrina-related failure of the 17th Street Canal levee. The effort was part of the U.S. Army Corps of Engineers Hurricane Katrina Interagency Performance Evaluation Task Force.

- As part of a national effort to help make buildings safer in earthquakes, a team of engineering researchers concluded three months of earthquake simulation tests on a half-scale, three-story garage-like structure and are now sifting through the data. The goal is to help improve U.S. building codes. The NEES shake table at the University of California, San Diego, subjected the one-million pound, pre-cast concrete building to jolts as powerful as magnitude 8.0. The tested structure has one of the largest footprints of any structure ever tested on a shake table in the U.S.

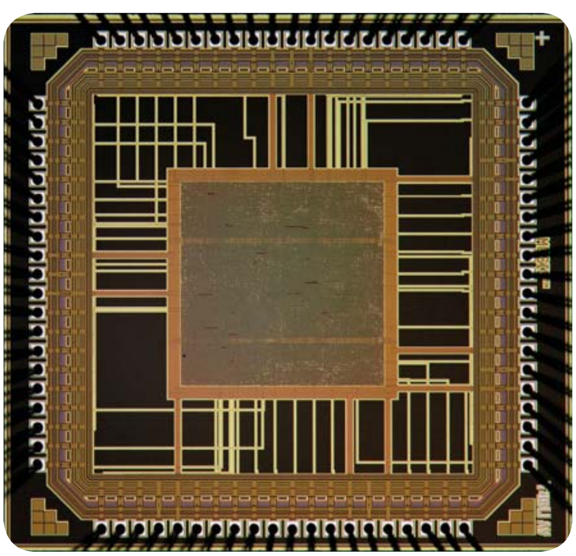
When the Ground Shakes, Is the Bridge Safe?

Researchers using the multiple shake table facility at the University of Nevada, Reno–part of the George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES)–are investigating the performance of large-scale models of four-span bridges and full-scale bridge components. *Credit: Lyle Carden, University of Nevada, Reno*

In a first-of-its-kind type of testing, researchers at the University of Nevada at Reno, one of the NEES sites, are examining the performance of entire four-span bridges along with the performance of individual bridge components to better understand the structures' ability to withstand earthquakes and other hazards. In cooperation with several other universities in the U.S. and abroad, the researchers are building large-scale models of bridges in the University of Nevada laboratory and subjecting them to simulated earthquake ground motions. They plan to study three models that are constructed with different materials and design details, and are built at about one-fourth the size of real bridges. The first bridge model, a conventional reinforced concrete structure about 110 feet long, was tested in February 2007. Two other bridge models that incorporate innovative seismic-resistant features will be tested over the next two years. Researchers from other NEES-supported facilities are contributing to the research. For example, researchers at the University of California, San Diego are using the large high-performance outdoor shake table there to study the seismic performance of full-scale bridge abutments. Engineers at Florida International University are fabricating, testing and modeling innovative piers, which will be incorporated in the bridge model. The project also involves a unique international collaboration with researchers at Japan's Tokyo Institute of Technology who are working with the University of Nevada team on the design of isolators that will be tested in the bridge columns. The project's results are expected to lead to improved design criteria and seismic codes, and they in turn should ensure better bridge performance in future earthquakes.

Engineering Research Centers (ERC)

NSF's Engineering Research Centers program was established in 1984 to develop a new interdisciplinary culture in engineering research and education in partnership with industry. The overarching objective was to strengthen the competitiveness of U.S. industry in the face of challenges from other countries. Now there have been three generations of this successful program that, among other advances, is credited with revolutionizing U.S. engineering education. The centers bring knowledge of industrial practices and needs to universities, and speed the translation of their research into useful products and processes. The partnerships have educated thousands of ERC engineering graduates who have proven to be more effective in speeding innovation in industry. The Gen-3 ERCs,



Researchers at the University of Southern California's Center for Biomimetic MicroElectronic Systems (BMES), an Engineering Research Center (ERC), developed this novel, mixed-signal system on a chip as a platform for implantable prosthetic devices. The goal is to create platforms for an entire range of implantable devices, including chips for use in restoring vision, reanimating paralyzed limbs and overcoming certain cognitive impairments. *Credit: USC BMES ERC* starting with the Class of 2008, have been designed to build on the well-developed understanding laid down by the two previous generations, with several new dimensions designed to speed the innovation process and prepare engineering graduates who are innovative, creative and understand how to function in a global economy where engineering talent is broadly distributed throughout the world. These new dimensions include the engagement of small firms in the research programs to carry out translational research to speed innovation, partnerships with organizations devoted to entrepreneurship and innovation, and partnerships in research with foreign universities. NSF currently supports 15 ERCs:

- Biomimetic Microelectronic Systems - University of Southern California
- Biorenewable Chemicals - Iowa State University (Gen-3)
- Collaborative Adaptive Sensing of the Atmosphere - University of Massachusetts Amherst (see sidebar, next page)
- Compact and Efficient Fluid Power - University of Minnesota
- Extreme Ultraviolet Science and Technology - Colorado State University
- Future Renewable Electric Energy Delivery and Management Systems - North Carolina State University (Gen-3)
- Integrated Access Networks - University of Arizona (Gen-3)
- Mid-Infrared Technology for Health and the Environment - Princeton University
- Quality of Life Technology - Carnegie Mellon University/University of Pittsburgh
- Revolutionizing Metallic Biomaterials - North Carolina Agricultural and Technical State University (Gen-3)
- Smart Lighting - Rensselaer Polytechnic Institute (Gen-3)
- Structured Organic Composites - Rutgers University
- Subsurface Sensing and Imaging Systems - Northeastern University
- Synthetic Biology - University of California, Berkeley
- Wireless Integrated MicroSystems - University of Michigan

The mission of the ERC for Biomimetic Microelectronic Systems (BMES) is to restore neural function through the coordinated efforts of multidisciplinary research groups at the University of Southern California, the California Institute of Technology and the University of California, Santa Cruz. Center researchers are working on an implantable artificial retina that could help people who lose their sight due to genetic retinal diseases. The device was developed by Mark Humayun's research team at the University of Southern California and Second Sight Medical Products Inc. The prosthetic uses a tiny external 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 to send signals through an individual's still healthy neural pathways. The researchers are currently enrolling subjects for clinical trials of the second generation of the prosthetic implant (ARGUS II). Six patients were implanted with earlier prototypes in 2002 and were able to perceive light and detect motion. A clinically approved version of the prosthesis could be available within a few years, offering hope of restored vision for the millions of people who lose their sight due to macular degeneration and other eye diseases.

Research conducted at the Emerging Cardiovascular Technologies Center at Duke University has improved electrodes and biphasic waveforms, important to devices designed to shock the heart out of arrhythmia. The breakthroughs reduced the energy needed to defibrillate, which means less tissue damage and reductions in the size of defibrillators and the time needed to charge them, plus extended battery life. The developments made implantable defibrillators an option for a wider range of patients. Similarly, the improvements made external, portable defibrillators easier to use and cheaper to manufacture. Portable defibrillators are now found on airplanes, in shopping malls and in other public places. The worldwide market for implantable and portable defibrillators is estimated to be in the billions of dollars. The Duke center, which also developed the first 3-D ultrasound system that allowed physicians to examine a beating heart in real-time, was one of the ERCs started by NSF in 1987; the center graduated from agency support in 1996.

New Radar Network Evaluated for Detecting Severe Weather

Researchers at the NSF ERC for Collaborative Adaptive Sensing of the Atmosphere (CASA), located at the University of Massachusetts Amherst, have developed a new method of weather sensing that uses dense, low-cost radar networks to scan the lower atmosphere, an important area that is under-sampled by existing technologies. CASA researchers installed a prototype four-node distributed collaborative adaptive sensing system in the area known as tornado alley in southwestern Oklahoma. During the 2007 tornado season, they transmitted real-time data to National Weather Service (NWS) forecasters for evaluation in the Experimental Warning Program. The testbed radar network's finely grained observations allowed forecasters to see small meteorological structures that were close to the ground, such as mini-wind clusters that are embedded in larger storms. NWS classified one of these observed circulations as an EF1 tornado (having wind gusts of 86-110 miles per hour). The center's data continued to be evaluated in the Experimental Warning Program during the 2008 tornado season. The research could lead to better predictions of when and where tornados and other weather disturbances will occur. For more information, see the NSF highlight at http://www.nsf.gov/eng/highlights/eec/0313747.McLaughlin.pdf.

Damaged houses are all that remain after a powerful tornado tore across central Oklahoma in May 1999, killing 36 people and causing a billion dollars in damage. Researchers are working to develop new and better radar systems in an effort to improve predictions of when and where severe weather will strike. *Credit: © University Corporation for Atmospheric Research, photo by Bob Henson*

Industry/University Cooperative Research Centers (I/UCRC)

NSF's Industry/University Cooperative Research Centers program develops long-term partnerships among industry, academia and government. The centers focus on research in crucial areas of interest to both industry and university researchers such as advanced electronics, advanced manufacturing, advanced materials, biotechnology, civil infrastructure systems, information-communication-computing systems, energy and environment, fabrication and processing technology, health and safety, and system design and simulation. I/UCRCs are catalyzed by a small investment from NSF and are primarily supported by the center's members. NSF supports 47 existing and planned centers (listed in Appendix I) and, in July 2008, the agency released a solicitation for new center proposals. The following are just three examples of the wide-ranging activities and impacts of I/UCRCs:

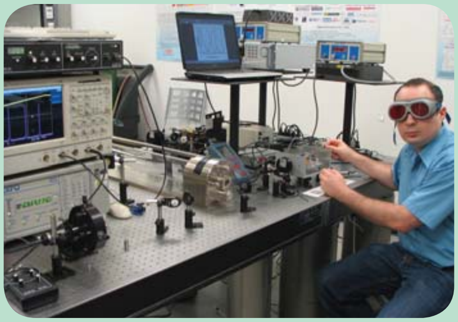
- Since its founding in 1986, the Berkeley Sensor and Actuator Center (BSAC) has been a pioneer in the world of microelectromechanical systems (MEMs). One of the most common uses of the micro-sized machines today is in accelerometers to trigger the release of airbags in automobiles. Other unique devices fabricated by BSAC include microresonators, microphotonic systems, ultrasonic sensors, microhypodermic injection needles, microsignal processing filters, microencapsulation shells, micropumps and micromixers that employ both low-stress membranes and piezoelectric films. Center researchers are also developing wireless networks of "smart dust" sensing nodes that can be interrogated remotely.

- The Center for Repair of Buildings and Bridges with Composites (RB2C), the I/UCRC based at the University of Missouri at Rolla and North Carolina State University, focuses on civil infrastructure systems. Using new fiberglass-polymer materials, contractors in Springfield, Mo., subjected a decaying, 70-year-old bridge to a makeover that was as quick as it was dramatic. The workers used prefabricated plates and cages developed by RB2C researchers and others to finish the bridge reconstruction job in a mere five days. The Missouri researchers joined with their industry partners and colleagues at the University of Wisconsin-Madison to develop the new construction solution. Before the renovation, local officials had imposed weight restrictions on vehicles using the old bridge on Farm Road 148 near Springfield because of the structure's dangerous condition.

- With help from an MRI grant, plus other program support, researchers at the University of Minnesota-Twin Cities have developed a new generation of miniature robot "scouts" that can be thrown or placed in buildings, hazardous areas or hostile territory to collect and provide intelligence. Equipped with multiple sensors, including a camera, the robots drive to a particular location and transmit video to handheld receivers up to 300 feet away. The first robot scouts were developed at the Center for Safety, Security and Rescue Research, an I/UCRC located at the University of South Florida and the University of Minnesota. Researchers at the University of Minnesota, the University of Pennsylvania and the California Institute of Technology are now working to develop software that will allow groups of small robots to coordinate their actions and carry out complex commands from a human operator.

Researchers Develop Mid-infrared Laser "Optical Nose"

Researchers at the University of Alabama at Birmingham, supported by an MRI grant, have developed a powerful system combining three types of lasers that could rapidly detect a wide range of substances in complex mixtures, including trace gases at the parts-per-trillion level. Designed to detect and identify many types of organic molecules, the system combines high power, low noise and coverage of the infrared spectrum that matches a large library of molecular energies. Potential uses for the "optical nose" include detecting the presence of oil, pollutants in the atmosphere, harmful chemical or biological substances, or the early stages of disease. For more information, see the NSF award abstract at http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0521036.



A team of researchers at the University of Alabama at Birmingham, led by physics professor Sergey Mirov, developed a novel laser-based "optical nose" for the rapid identification and quantification of organic trace-gases in multi-compound gas mixtures with full biochemical specificity and high sensitivity. Above, Dmitri Martyshkin uses the optical nose for sensing hydrogen fluoride molecules. *Credit: Courtesy Sergey Mirov, University of Alabama at Birmingham*

Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) Programs

NSF continues to play a major role in encouraging innovation by small companies, and the results contribute to both the nation's research infrastructure and American competitiveness. The primary objective of the Small Business Innovation Research and Small Business Technology Transfer programs is to increase the incentive and opportunity for small firms to undertake cutting-edge, high risk, high quality scientific, engineering or science/engineering education research that would have a high potential economic payoff, if the research is successful. With SBIR support, engineers created a solid-state micro-fan that is the most powerful and energy efficient fan of its size. The device produces three times the flow rate of a typical small mechanical fan and is one-fourth the size. It could provide a low-power, low-maintenance cooling system for laptop computers and

For the first time, a robot, acting independently and without a human operator, aided doctors performing surgery in 2005. The Penelope Surgical Instrument Server (SIS), developed in part with funding from NSF's Small Business Innovation Research (SBIR) program, successfully delivered and retrieved instruments during the procedure to remove a tumor. *Credit: Courtesy of New York-Presbyterian Hospital* other electronic devices. The engineers began work on the device as NSF-supported graduate students at Purdue University, and they continued their work with an SBIR award. The STTR program further expands the public/private partnership to include joint venture opportunities for small businesses and nonprofit research institutions. A significant difference between the SBIR and STTR programs is that the STTR requires researchers at universities and other research institutions to play a significant intellectual role in the conduct of each STTR project. By joining forces with a small company, the university-based researchers can spin-off their commercially promising ideas while they remain primarily employed at the research institution.

Center of Advanced Materials for the Purification of Water With Systems (WaterCAMPWS)

The Center of Advanced Materials for the Purification of Water With Systems, one of NSF's STCs, was established to develop revolutionary new materials and systems for safely and economically purifying water for human use, while simultaneously developing the diverse human resources needed to exploit the research advances and the knowledge base created. The center is led by the University of Illinois at Urbana-Champaign. Its primary objectives are desalination/reuse, decontamination, and disinfection. A team of researchers at WaterCAMPWS has developed a promising new photocatalyst called TiON. There have been several versions of the nitrogen-doped titanium oxide material and the latest has achieved tremendous increases in disinfection rates, plus it works in visible light instead of the ultraviolet range that is necessary for today's technologies for water decontamination. The Metropolitan Water Reclamation District of Greater Chicago is currently testing TiON using real wastewater in a laboratory setting.

NSF's investments in research infrastructure are not limited to equipment and facilities. Developing and maintaining longitudinal surveys, panel studies and large data sets for use by researchers to better understand human actions and decision making are another way NSF provides the tools most needed by social scientists and other researchers. The studies described below, and supported by NSF's Directorate for Social, Behavioral and Economic Sciences (SBE), are examples of what is available to researchers to help them develop a panoramic view of the economic, political and social indicators that define American life and gain a better understanding of how society functions and changes over time. Analyses of the data help policymakers shape important programs and policy recommendations. SBE also coordinates a cross-directorate centers program that helps researchers gain new insights into how people acquire knowledge. As the principal source of federal support for strengthening science and engineering education through education research and development, NSF invests in educational research infrastructure and centers to attract people to science, technology, engineering and mathematics, help prepare future generations of scientists and engineers, and broaden participation of underrepresented groups, geographic regions and types of institutions involved in science and engineering fields. NSF's EHR Directorate is a primary supporter of many of these activities.

The Human Element

The NSF-supported research infrastructure enables researchers and educators to study and develop a deeper understanding of human actions and decision making, the social dimensions of knowledge and technology, and how people learn. *Credit: Photos.com*

The General Social Survey (GSS)

At the core of America's social science research infrastructure, the General Social Survey of the National Data Program for the Social Sciences has chronicled the attitudes, beliefs and opinions of more than 44,000 adults from a cross-section of American households since 1972. Recent GSS enhancements have incorporated Spanish language capability and data collection on social context and social units other than individuals and households. Researchers at the National Opinion Research Center (NORC) at the University of Chicago conduct the GSS, and have documented over 8,500 uses of the GSS among researchers. Considered the "gold standard" of social science research, the GSS has inspired such cross-cultural surveys as the International Social Science Program and the European Social Survey. NSF, in collaboration with the U.S. Department of Homeland Security (DHS), has funded the addition of a new module to the ongoing survey to measure the public's preparedness for disasters and acts of terrorism, and reasons for action/inaction. The new data could assist policymakers in crafting effective public education efforts.

The Panel Study of Income Dynamics (PSID)

The Panel Study of Income Dynamics is the world's longest running, nationally representative panel survey. With nearly 40 years of data on the same families and their descendents, the PSID can justly be considered a cornerstone of the data infrastructure for empirically-based social science research in the U.S. and the world. The study began with 4,800 individuals and their family units in 1968, and has grown to nearly 8,000 families with over 65,000 individuals, some of whom have participated for nearly 40 years. Frank Stafford, a professor of economics at the University of Michigan, directs PSID data collection efforts. The longitudinal study's design and content variables, which focus on economic and demographic data, income, employment, family composition changes and residential location, have remained largely unchanged over time. Consistent and comparable data is what makes the study so valuable to researchers. Newer topics in the PSID include housing and food expenditures, housework time, health, wealth, child development, family dynamics and issues related to aging. The PSID data archive is among the world's most advanced and heavily used.

Science Resources Statistics (SRS)

The NSF Division of Science Resources Statistics (SRS) produces publications, data and analyses about the U.S. science and engineering enterprise. As mandated by the National Science Foundation Act, the division collects and analyzes data to inform the public and to assist policymakers in the development of national science policy. SRS designs, supports and directs about 11 periodic surveys as well as a variety of other data collections and research projects. These activities yield the materials for SRS staff to disseminate quantitative information about domestic and international resources devoted to science, engineering and technology. SRS has primary responsibility for *Science and Engineering Indicators*, the biennial publication of the NSB. Called the "gold standard," *Indicators* provides a comprehensive source of information on the state of science and engineering research and education in the U.S. SRS data have provided insight into the value of investing in research and development (R&D). If R&D spending were treated as investment in the U.S. national income and product accounts, the nation's gross domestic product (GDP) would be nearly 3 percent higher each year between 1959 and 2004, according to a joint analysis in 2007 by the Commerce Department's Bureau of Economic Analysis (BEA) and NSF. BEA and NSF's SRS developed the R&D satellite account as a supplemental set of data that can be factored into economic measurements to determine the impact of R&D spending on U.S. growth and productivity. In 2004 alone, the U.S. GDP would have been $284 billion more with the R&D satellite account.

Science and Engineering Indicators, published every other year by the National Science Board, provides a wealth of information about the state of science and engineering in the U.S. The 2008 edition's cover celebrates International Polar Year 2007-2009 with images from the Arctic and Antarctic regions. *Credit: Ice cave: Zenobia Evans, National Science Foundation (NSF). Images right to left: Josh Landis, NSF; Katrin Iken and Bodil Bluhm, University of Alaska, Fairbanks; The Hidden Ocean, Arctic 2005 Exploration; Ariana Owens, NSF; Patrick Smith; Ken Ryan, NSF; Jerry Marty, NSF).*

Preserving and Making Available Endangered Languages

Of the estimated 6,500 to 7,000 languages that exist in the world, some 3,000 will become extinct in the next century. Globalization, strife and political turmoil are among the factors contributing to language losses. Once a language's native speakers are gone, understanding the history and culture of that population becomes more difficult, if not impossible. We also lose what those languages could have taught us about human cognition. NSF-supported researchers are working against time to document, preserve and make available to others as many of these endangered languages as possible. For example, Andrew Hofling of Southern Illinois University has compiled digital databases for the Yukatekan branch of Mayan languages, and he is currently conducting field research to produce bilingual Mopan-Spanish and Mopan-English dictionaries, of the Mopan Maya language, spoken in the Petén region of Guatemala and southern Belize. Meslissa Axelrod and others from the University of New Mexico are working with a Native American community north of Santa Fe, the Nanbé Tewa, to document its language and populate an Internet-based archive with materials, including conversations, stories and historical narrative; a dictionary with full lexical and grammatical coverage; and a video production showing traditional bread-making, with accompanying fully annotated dialog. Nanbé Tewa is one of the most endangered of currently spoken languages: out of 650 tribal members, there are only 36 fluent speakers and their average age is around 70 years old. NSF also is helping to make endangered language materials more widely accessible. In 2004, the Rosetta Project, a global collaboration to build a publicly accessible digital library of human languages, became a National Science Digital Library collection. With more than 100,000 pages of material documenting over 2,500 human languages, the Rosetta Archive is thought to be the largest resource of its kind on the Internet. The Rosetta Project is sponsored by the nonprofit Long Now Foundation, with support from the Stanford University Libraries and NSF.

An illustration showing "Mopan" as a Mayan glyph. *Credit: Andrew Hofling, Southern Illinois University*

Science of Learning Centers (SLC)

While all of NSF's investments in research infrastructure have an educational component, other investments have education as their main focus. The Science of Learning Centers are an example. They are built around a unifying research focus on the science of learning, and they incorporate diverse, multidisciplinary environments involving appropriate partnerships with academia, industry, international partners, all levels of education and other public and private entities. NSF supports the following SLCs:

First Group of SLC Awards

- Center for Learning in Education, Science and Technology - Boston University
- Pittsburgh Science of Learning Center: Studying Robust Learning - Carnegie Mellon University
- LIFE Center-Learning in Formal and Informal Environments - University of Washington

Second Group

- Visual Language and Visual Learning - Gallaudet University
- Spatial Intelligence and Learning Center - Temple University
- Temporal Dynamics of Learning Center - University of California, San Diego

Centers of Research Excellence in Science and Technology (CREST)

One of NSF's goals, as set forth in the *NSF Strategic Plan FY 2006-2011*, is the cultivation of a world-class, broadly inclusive science and engineering workforce, and expansion of the scientific literacy of all citizens. The Centers of Research Excellence in Science and Technology play a vital role in efforts to broaden participation by all individuals in science and engineering. The program makes resources available to enhance the research capabilities of minority-serving institutions through the establishment of centers that effectively integrate education and research. CREST promotes the development of new knowledge, enhancements of the research productivity of individual faculty, and an expanded presence of students who have been historically underrepresented in STEM disciplines. The list of CREST centers is included in Appendix I.

CREST Center Contributes to TerraFly Project

Florida International University in Miami is the lead institution for the CREST Center of Emerging Technologies for Advanced Information Processing. The Florida International University center produces some 20 percent of the nation's computer science Ph.D.s among Hispanic students. In 2001, Florida International University launched TerraFly, an Internet-based technology it developed that uses spatial data sets including high-resolution imagery collected by the USGS to allow users to virtually "fly-over" most locations in the U.S. using only a Web browser. Florida International University's CREST center contributed major research and development to the TerraFly project.

TerraFly makes high-resolution, aerial imagery layered with street, business and demographic data available to anyone using a Web browser. The Center of Emerging Technologies for Advanced Information Processing, an NSF Center of Research Excellence in Science and Technology (CREST) led by Florida International University, contributed major research and development to the TerraFly project. *Credit: Naphtali Rishe, Florida International University*

North Carolina Agricultural and Technical State University's Center for Advanced Materials and Smart Structures conducts research in the areas of nanoengineered and surface-engineered coatings and materials, nanocomposites and other innovative composites, and electronic and smart materials and structures. Jagannathan Sankar, distinguished professor of mechanical engineering, received Phase I and II CREST awards and is now the principal investigator for the new Gen-3 ERC for Revolutionizing Metallic Biomaterials. The center, to be located at North Carolina Agricultural and Technical State University, will develop interdisciplinary research and education programs to revolutionize medical implants and related health care issues, and provide the foundation for new industries through innovation. It is the first ERC to be headquartered at a historically black college or university.

Historically Black Colleges and Universities Research Infrastructure for Science and Engineering (HBCU-RISE)

The Historically Black Colleges and Universities Research Infrastructure for Science and Engineering program is another part of NSF's efforts to strengthen the science and engineering research and education capabilities of minority-serving institutions. Program support helps to develop the research capability at HBCUs that offer doctoral degrees in science and engineering disciplines. The HBCU-RISE centers are listed in Appendix I.

National Science Digital Library (NSDL)

The National Science Digital Library is the nation's online library for education and research in science, technology, engineering and mathematics. It was established by NSF in 2000, under the auspices of the multiagency Digital Library Initiative. NSDL provides organized access to high quality resources and tools that support innovations in teaching and learning at all levels of science, technology, engineering and mathematics education. More than 200 projects have been funded to create collections and services for teachers and learners at all levels, and to perform targeted research in digital libraries and their application to education. NSDL can be accessed at http://nsdl.org/ .

The Fun Works: A Dynamic Digital Library for STEM Careers

The Fun Works (http://www.thefunworks.org/) is an innovative digital library that engages young people in the exploration of career opportunities in STEM fields. Developed by the Education Development Center, the Fun Works is supported by NSF's National Science, Technology, Engineering and Mathematics Education Digital Library. The Fun Works is designed for–and by–middle school students. The Education Development Center first consulted approximately 300 middle-school students from diverse backgrounds in Boston to learn about student Web site preferences and interest in science-related careers. Then, a middle-school team of four girls and four boys from a Boston community technology center worked with the center to develop the site's contents. The result is a dynamic digital library that uses music, sports and other "real world" contexts to interest young people in science-related careers.

The Fun Works, a Web site for middle-school students, encourages young people to think about becoming the scientists and engineers of tomorrow. Part of NSF's National Science Digital Library initiative, the site uses the students' current interests and passions, including sports and music, to help younger visitors explore future science, technology, engineering and mathematics careers. *Credit: Education Development Center Inc.*

Powerful radio and optical telescopes are providing scientists with a better look at the universe. Astronomers have discovered new "dwarf planets" within our solar system, more than 300 extra-solar planets orbiting stars other than our own, and a black hole at the center of the Milky Way. Meanwhile, a startling discovery by astronomers in 1998—that the rate of the expansion of the universe is accelerating—continues to excite and energize the field. Many of these developments and other cutting-edge results relied on ground-based telescopes and related facilities supported by the Division of Astronomical Sciences (AST) in NSF's Mathematical and Physical Sciences (MPS) Directorate. The facilities listed below have been essential to the nation's progress in astronomical science. Meanwhile, the National Research Council of the National Academy of Sciences and others have proposed new facilities needed to pursue emerging areas of scientific interest and to ensure that the U.S. astronomy program remains a world-leader. Anticipating concern that support of new facilities might limit NSF's ability to maintain the current research infrastructure, senior AST program managers asked an external group of experts to conduct an extensive review of the division's portfolio of facilities, and, in November 2006, this group of experts provided a number of recommendations (the Senior Review) to AST to balance current needs and future opportunities. For more on the AST Senior Review, see http://www.nsf.gov/mps/ast/ast_senior_review.jsp.

(The Answers Are) Out There

An artist's conception of the VertexRSI antenna (left foreground) and the AEM antenna (right foreground) superposed on a photo of the Atacama Large Millimeter Array (ALMA) site. When completed, ALMA will be the world's most sensitive and highest resolution millimeter-wavelength telescope, enabling researchers to explore fundamental questions of astronomy. ALMA also will play a central role in the education and training of U.S. astronomy and engineering students who are expected to account for at least 15 percent of ALMA's approximately 2,000 anticipated yearly users. *Credit: Courtesy of ALMA/ESO/NRAO/NAOJ*

National Optical Astronomy Observatory (NOAO) and National Solar Observatory (NSO)

The National Optical Astronomy Observatory and the National Solar Observatory operate telescopes and supporting instrumentation that enable research on some of the most compelling science questions in astronomy and solar physics. The facilities provide researchers with powerful and sophisticated tools to peer deep into space and back in time to investigate age-old questions and unexplained phenomena including the expansion of the universe, the formation and evolution of galaxies and individual stars, the evolution of planetary systems, and the generation, structure and dynamics of solar surface magnetic fields. The telescopes have been used in work leading to some of the most profound breakthroughs in astronomy and cosmology in recent years. For example, the NOAO 4-meter telescope in Chile was used in the remarkable 1998 discovery of the accelerating rate of the expansion of the universe, which led to the realization that the universe is permeated with a mysterious "dark energy." Understanding the nature of dark energy is one of the major questions in contemporary physics. NOAO operates the following facilities.

- **Kitt Peak National Observatory** (KPNO), located in the Quinlan Mountains near Tucson, Ariz., boasts a large collection of optical telescopes and some of the finest night skies in the world. In addition to the three telescopes that KPNO operates directly—the Mayall 4-meter, the Wisconsin-Indiana-Yale-NOAO (WIYN) 3.5 meter and the small 2.1-meter telescopes—the observatory hosts another 19 optical telescopes and two radio telescopes for various astronomy consortia.

This panorama of Kitt Peak National Observatory (KPNO) near Tucson, Ariz., shows telescopes and instrumentation operated by the National Optical Astronomy Observatory (NOAO) and the National Solar Observatory (NSO), including the triangular McMath-Pierce solar facility in the foreground and the WIYN 3.5-meter telescope on the far left. *Credit: NOAO/AURA/NSF*

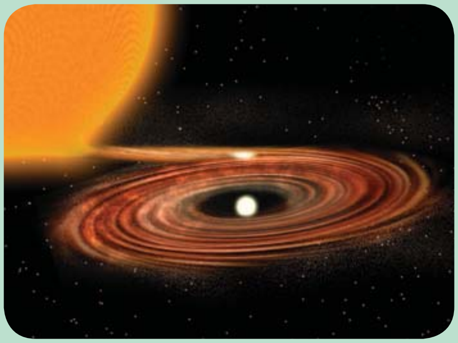
- **Cerro Tololo Interamerican Observatory** (CTIO) near La Serena, Chile, operates the 4-meter Blanco telescope and the 4-meter SOAR telescope, which is funded by NOAO, Brazil, Michigan State University and the University of North Carolina. Three smaller telescopes at CTIO are operated by a university consortium with a portion of telescope time available through NOAO.

- The **Gemini Science Center**, in Tucson, Ariz., coordinates access for U.S. astronomers to the twin optical/infrared 8-meter telescopes that comprise the **Gemini Observatory** (see next page).

NOAO also manages the U.S. astronomy community's involvement in the development of future infrastructure projects such as the Giant Segmented Mirror Telescope and the Large Synoptic Survey Telescope, both of which are high priority recommendations of the 2000 Decadal Survey conducted by the National Research Council's Astronomy and Astrophysics Survey Committee. Furthermore, NOAO administers the Telescope System Instrumentation Program (TSIP), funded by NSF, which supports improving instrumentation at private observatories in exchange for observing time for the general community.

Dusty Disks Revealed

Observations of an interacting binary star by a team of astronomers and educators suggest that the disks of hot gas that accumulate around a wide variety of astronomical objects— from white dwarf stars in energetic binary systems to supermassive black holes at the hearts of active galaxies—are likely to be much larger than previously believed. As part of a program called the Spitzer-NOAO Observing Program for Teachers and Students, Steve B. Howell of NOAO and a team of astronomers and educators used the 2.1-meter telescope and the WIYN 0.9-meter telescope, both located at Kitt Peak National Observatory, and NASA's Spitzer Space Telescope to image an interacting binary star (called WZ Sagittae) located in the constellation Sagitta. Interacting binary stars such as WZ Sagittae contain a white dwarf star (a compact star about the size of the Earth, but with a mass near that of the Sun) and a larger, but less massive and much cooler, companion star. The companion star has material ripped off its surface by the stronger gravity of the white dwarf. The material flows toward the white dwarf, forming an accretion disk surrounding the smaller star. The "standard accretion disk" model is a geometrically thin disk of gaseous material surrounding the white dwarf. Howell's team obtained optical observations that confirmed the standard view of the accretion disk size and temperature. However, mid-infrared observations were completely unexpected. They revealed that a larger, thicker disk of cool dusty material surrounds much of the gaseous accretion disk. This outer dust disk likely contains as much mass as a medium-sized asteroid. The newly discovered outer disk extends about 20 times the radius of the gaseous disk. The implications from such a discovery are far reaching, affecting not only the theoretical models, but also nearly all previous observations of systems containing accretion disks.



An artist's concept of the generally accepted model of an accretion disk in the binary star system WZ Sagittae. New data from Kitt Peak National Observatory and the Spitzer Space Telescope revealed a larger, thicker disk of cool, dusty material surrounding much of the gaseous accretion disk. An illustration of the new model can be viewed at http://www.noao.edu/image_gallery/html/im1044.html. *Credit: P. Marenfeld and NOAO/AURA/NSF*

The NSO operates facilities in Sunspot, N.M., and at KPNO. These facilities offer the world's largest collection of optical and infrared solar telescopes and auxiliary instrumentation for observation of the solar photosphere, chromosphere and corona, as well as a coordinated worldwide network of six telescopes specifically designed to study solar oscillations (Global Oscillations Network Group). Both NOAO and NSO are deeply involved in education and training of the next generation of astronomers and solar physicists. They offer research experiences for undergraduate students and afford use by graduate students to conduct research for their advanced degrees. Modern visitors' centers and Web sites featuring online image galleries and other outreach content contribute to promoting public understanding of and interest in astronomy. Each summer, for example, approximately 30 teachers are immersed in science at the NSO. The NOAO's Hands-On Optics program has engaged 17,000 middle-school students in activities with lenses, mirrors, lasers and mini-kaleidoscopes.

NOAO and NSO are managed and operated by the Association of Universities for Research in Astronomy, Inc. (AURA) under a cooperative agreement that runs through March 2009.

Gemini Observatory

The twin telescopes of the Gemini Observatory are helping astronomers explore important questions about the age and rate of expansion of the universe, its structure, the evolution of galaxies and the formation of stars and planetary systems. Gemini South is located at an almost 9,000-foot elevation on a mountain in the Chilean Andes called Cerro Pachon. The Frederick C. Gillett Gemini North Telescope is located on Hawaii's Mauna Kea, a long dormant volcano that rises almost 14,000 feet into the dry, stable air of the Pacific. Located on two of the best sites on Earth for observing the universe, the telescopes together can access the entire sky. The Gemini Observatory's international headquarters is in Hilo, Hawaii, at the University of Hawaii. Both of the Gemini telescopes have been designed to take advantage of the latest technology and thermal controls to excel in a wide variety of optical and infrared capabilities. Gemini was built and is operated by a partnership of 7 countries—the U.S., United Kingdom, Canada, Chile, Australia, Brazil and Argentina. NOAO represents the U.S. astronomical community in the International Gemini Project. Enhanced operational and visitor support and a new generation of advanced instrumentation including the construction of the Gemini Planet Imager, a camera designed to directly detect planets orbiting nearby stars, are in the planning stages.

Advanced Technology Solar Telescope (ATST)–In Planning

The Advanced Technology Solar Telescope, now in planning, would provide unprecedented observations of solar plasma processes and magnetic fields, and enable a deepening understanding of the Earth's nearest star, the Sun. The facility would be built at the Haleakala High Altitude Observatory on the Hawaiian island of Maui and, if constructed, it would be the first new large U.S. solar telescope in 30 years. The ATST has the potential to become the world's flagship facility for ground-based solar physics observation. The 4-meter, off-axis Gregorian (all reflective) telescope with integrated adaptive

A rendering of the proposed Advanced Technology Solar Telescope (ATST) as it would appear with the existing facilities of the Haleakala High Altitude Observatories in Hawaii. *Credit: Tom Kekona, KC Environmental Inc.*

optics would have a field view of 3 arc minutes, an angular resolution of less than 0.03 acc seconds, and wavelength sensitivity that spans the entire visible and near-infrared regions of the electromagnetic spectrum. Its light grasp would be a factor of ten greater than the largest solar telescope in existence, and adaptive correction would yield an increase in angular resolution of a factor of three to seven over the best adaptively corrected systems currently available. The ATST is an international collaboration, involving 22 institutions from the U.S. and eight other countries. The project is managed by NSO. Continuation of design and future construction depends upon successful project design reviews, continued prioritization by NSF, NSB approval and the availability of federal funds.

National Astronomy and Ionosphere Center (NAIC)

The National Astronomy and Ionosphere Center, in operation since 1962 and the world's largest single-dish radio telescope, is used in radio astronomy, planetary radar and ionospheric physics. Radio astronomers and planetary scientists use the NAIC facility to study such diverse areas as interstellar gas, galactic structure formation and evolution, pulsars, and topics in solar system astronomy such as the physical properties of asteroids, planetary surfaces and moons. The center's principal observing facilities include a 305-meter fixed spherical radio/radar telescope. Made famous to non-astronomers in movies such as "Contact" and "Golden Eye," the dish is located near the town of Arecibo in western Puerto Rico. The facility has been used for ground-breaking research by many prominent scientists over the decades, including Nobel laureates Russell Hulse and Joseph Taylor. They studied the evolution of the orbits of binary neutron star systems, when one of the orbiting stars is a pulsar, to confirm the formulation of gravitational radiation put forth in Einstein's General Theory of Relativity. The facility provides users with a wide range of research instrumentation, including an L-Band Feed Array, essentially a seven-pixel camera that allows astronomers to collect data about seven times faster than before. The NAIC, like other NSF facilities, places strong emphasis on education and outreach. It was one of NSF's first sites for the Research Experiences for Undergraduates (REU) program. NAIC sponsors a major outreach program in Puerto Rico with a modern visitors' center, a learning center and summer programs for K-12 teachers. The facility attracts approximately 120,000 visitors a year, including K-12 school groups from across Puerto Rico. NAIC is operated and managed for NSF by Cornell University under a cooperative agreement that runs through March 31, 2010.

The November 2006 report of the AST Senior Review committee recommended, among other things, that NSF reduce support for NAIC's base operating budget to $8 million over the next three years. Cornell and Arecibo staff are actively pursuing opportunities for partnerships with, and support from, others to maintain the observatory as a viable facility for scientific research, education and public outreach. A final decision about the NAIC's long-term future is expected by the time of NSF's FY 2011 budget.

National Radio Astronomy Observatory (NRAO)

The National Radio Astronomy Observatory designs, builds and operates state-of-the-art telescopes for studying the universe by means of radio waves. Scientists from around the world use these powerful tools to study the Sun, planets and other objects in our own solar system, as well as distant stars, galaxies and other mysterious objects many millions, or billions, of light-years away. NROA facilities include the following:

This map shows the locations of the 10 radio antennas of the Very Long Baseline Array (VLBA). The antennas function together as one instrument with very high resolution and sensitivity. *Credit: NRAO/AUI*

- Major radio telescopes located in Green Bank, W.Va.—the Green Bank Interferometer, Green Bank 140-ft Telescope and the Robert C. Byrd Green Bank Telescope (GBT). The GBT is the world's largest, fully steerable radio telescope. Its surface measures 100 by 110 meters—roughly two acres. The telescope can rotate 360 degrees on a track that is 210 feet in diameter, yet level to within a few thousandths of an inch, and capable of bearing 16 million pounds of moving weight.

- The **Very Large Array (VLA)** features 27 operating antennae in a "Y" pattern spread out through the plains of San Augustin, N.M., and arranged in one of four configurations that are changed every few months. In their closest configuration, the antennas cover about 0.6 miles (1 kilometer), while in the largest configuration, they span up to 22 miles (36 kilometers) across and are able to hone in on the fine details of astronomical objects. At its highest frequency, the VLA has a resolution of .04 arc seconds. Through the Expanded VLA (EVLA) project, NSF is refurbishing and updating the telescope's receivers to allow increased data sensitivity, more efficient transmission of data, and fine-tuned estimates of how emissions vary with frequency. The EVLA project's planned completion date is 2011.

- The **Very Long Baseline Array (VLBA)** consisting of 10 radio antennas at locations ranging from St. Croix in the Virgin Islands to Mauna Kea in Hawaii. Observation data are recorded on digital tape at each antenna site. At the Socorro, N.M., operations center, the data on the tapes are correlated and then delivered to the scientists. The AST Senior Review has recommended a reduction in support for the VLBA beginning in FY 2011.

NRAO is also the North American implementing organization for the international Atacama Large Millimeter Array (ALMA) project (see next page). Associated Universities, Inc. (AUI) operates NROA under a cooperative agreement with NSF.

Interstellar Chemistry Gets More Complex

Astronomers using data from the GBT have found the largest negatively charged molecule yet seen in space. The discovery was the third negatively charged molecule, called an anion, found in less than a year, and it could force a drastic revision of theoretical models of interstellar chemistry, according to astronomers. Two teams of scientists found negatively charged octatetraynyl--a chain of eight carbon atoms and one hydrogen atom--in the envelope of gas around an old, evolved star and in a cold, dark cloud of molecular gas. In both cases, the molecule had an extra electron, giving it a negative charge. Anthony Remijan of NRAO and his colleagues found the octatetraynyl anions in the envelope of an evolved giant star (called IRC +10 216) about 550 light-years from Earth, in the constellation Leo. They found radio waves emitted at specific frequencies characteristic of the charged molecule by searching archival data from the GBT. Another team from the Harvard-Smithsonian Center for Astrophysics found the same characteristic emission when they observed a cold cloud of molecular gas (called TMC-1) in the constellation Taurus. These observations also were done with the GBT. In both cases, earlier laboratory experiments by the Harvard-Smithsonian team showed which radio frequencies actually are emitted by the molecule, and thus told the astronomers what to look for. The discovery could lead to new insights into the formation of amino acids and other compounds in regions of space that spawn stars and planets.

An artist's concept showing how scientists believe negatively charged octatetraynyl formed in space. Astronomers searching archival data from the Robert C. Byrd Green Bank Telescope found the molecule, a chain of eight carbon atoms and one hydrogen atom, in the envelope of gas around an old, evolved star and in a cloud of molecular gas. *Credit: Bill Saxton, NRAO/AUI/NSF*

Atacama Large Millimeter Array (ALMA)

The Atacama Large Millimeter Array is a giant international observatory under construction in the 5,000-meter high Atacama Desert in northern Chile. It will be the world's most sensitive and highest resolution millimeter-wavelength telescope, providing astronomers with an unprecedented ability to explore the universe as seen at wavelengths from 3 millimeters to 0.4 millimeters. The high sensitivity and resolution in this range of the spectrum will allow researchers to test novel theories about the origins of stars and planetary systems, the nature of early galaxies and the evolution of the universe. When completed, ALMA will comprise an array of 50 high precision 12-meter antennas, plus 16 additional antennas in a component array, that work together as one telescope. With its adjustable configurations, ALMA will provide researchers with a "zoom lens" to focus deep in space. ALMA construction is carried out through a partnership between North America, Europe and Japan. The North American side, consisting of the U.S. and Canada, is led by AUI through NRAO.

South Pole Telescope (SPT)

The South Pole Telescope is a 10-meter telescope designed to study phenomena such as the formation and evolution of the early universe and the formation and evolution of solar systems like our own. It was first assembled in Kilgore, Texas, then taken apart and shipped to New Zealand, and then flown from there to the South Pole where it was reassembled. Telescope construction is funded primarily by NSF, with additional support from the Kavli Foundation of Oxnard, Calif., and the Gordon and Betty Moore Foundation of San Francisco. A major milestone for the project, SPT's first light—the scientific term for the time when a telescope becomes operational—occurred in February 2007.

The South Pole Telescope (left) is located in the "Dark Sector" at Amundsen-Scott South Pole Station. The Dark Sector is an area devoid of light and radio interference. *Credit: Calee Allen, National Science Foundation*

Martin A. Pomerantz Observatory (MAPO)

The Martin A. Pomerantz Observatory, one of the facilities provided by the U.S. Antarctic Program, houses equipment that scientists use to store and analyze observations from the astronomical instruments around the South Pole.

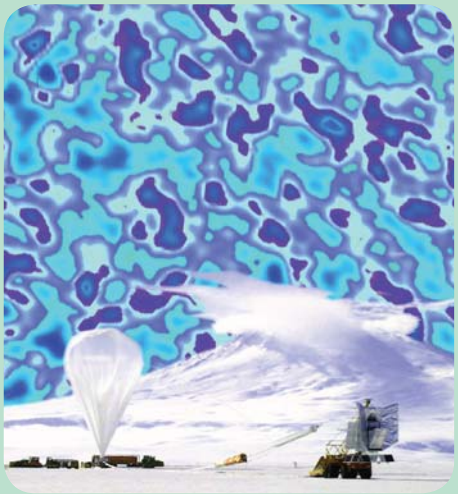
Center for Adaptive Optics (CfAO)

Researchers at the Center for Adaptive Optics, one of NSF's STCs, have developed technologies that enable telescopes to obtain clear, sharp images of space. Telescopes at the W.M. Keck, Gemini and other observatories are now equipped with sophisticated adaptive optics technology so they can overcome the turbulence in the Earth's atmosphere that causes images of stars and planets to appear fuzzy. The Keck Observatory was used by University of California, Los Angeles astronomer Andrea Ghez in her research to estimate the mass of a black hole at the center of the Milky Way galaxy. Adaptive optics have another application that, at first glance, appears very different from astronomy. Researchers at CfAO are studying the capabilities for adaptive optics to correct people's vision and enhance imaging of the retina in the diagnosis and treatment of eye diseases. The center's industrial partners, such as Bausch & Lomb, would facilitate the transfer of research results into marketable products, such as drugs for glaucoma and age-related macular degeneration.

This color composite image of Jupiter and its two "red" spots was obtained in near-infrared light using Gemini North's adaptive optics which correct, in real-time, for most of the distortions caused by turbulence in Earth's atmosphere. In the near-infrared, the red spots appear white. *Credit: Gemini Observatory*

Seeing the Universe in Infancy

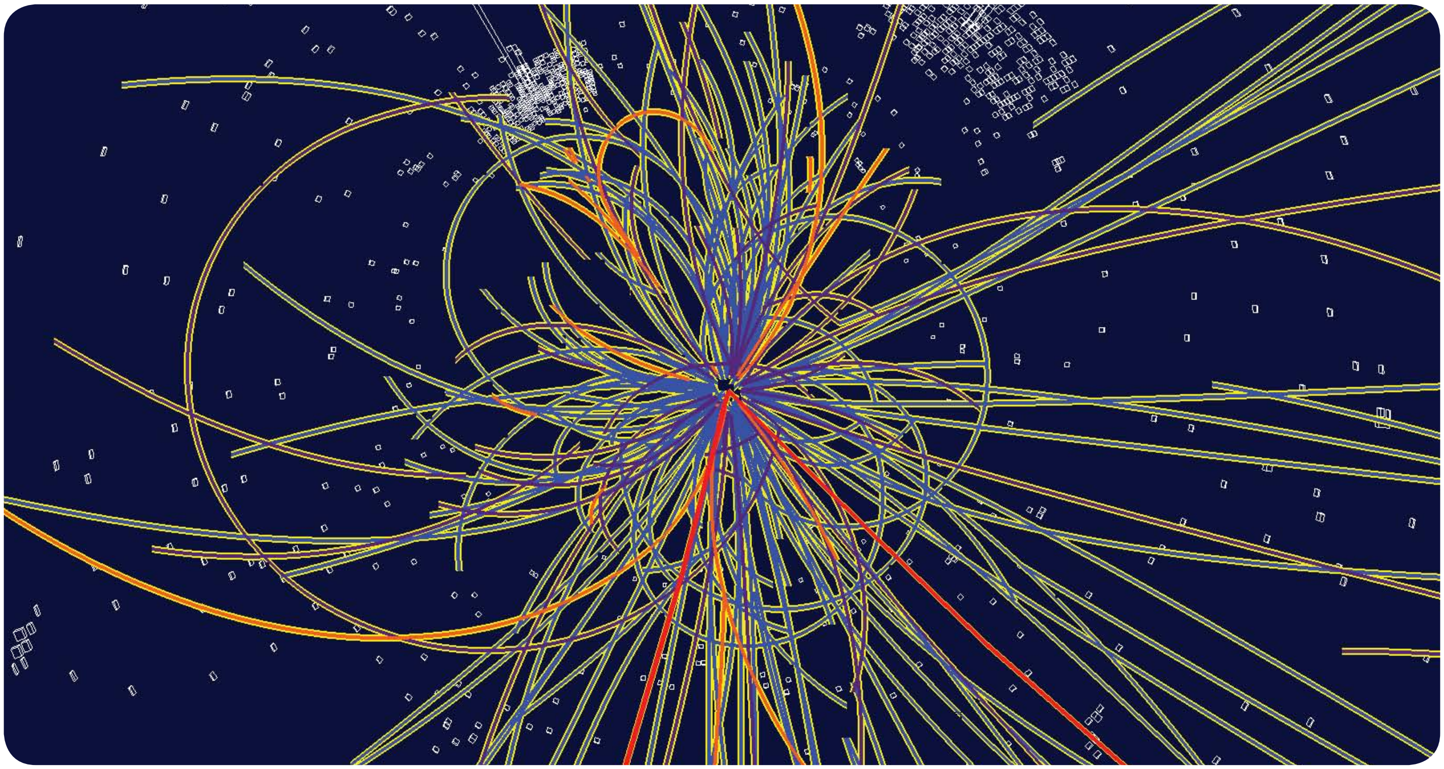
An international team of cosmologists supported in part by NSF produced the first detailed images of the universe in its infancy. The work brought into sharp focus the faint glow of microwave radiation, called the Cosmic Microwave Background (CMB), that filled the embryonic universe soon after the Big Bang. The information was assembled from measurements of the subtle temperature differences in the CMB radiation. The BOOMERANG (Balloon Observations of Millimetric Extragalactic Radiation and Geomagnetics) project captured the data using an extremely sensitive telescope suspended from a balloon that circumnavigated Antarctica in 1998. The atmospheric circulation over the continent allows balloons that are released near McMurdo Station, NSF's logistics hub in Antarctica, to circle the continent and return to be retrieved almost at the point of launch. Andrew Lange of the California Institute of Technology shared the 2006 Balkan Prize for Astronomy and Astrophysics with his BOOMERANG co-investigator, Paolo de Bernardis of Italy, in recognition of their contributions to cosmology. For more information, see the NSF news release at http://www.nsf.gov/news/news_summ.jsp?cntn_id=103063



A composite image showing the sky over Antarctica's Mt. Erebus, overlaid with images of the early universe as seen by the BOOMERANG experiment to indicate the size fluctuations in the Cosmic Microwave Background (CMB) that would appear if a 35-millimeter camera were sensitive to microwave light. The color map of the CMB images has been changed here to aesthetically match the rest of the picture. *Credit: Boomerang Team*

A research infrastructure that offers advanced capabilities and cutting-edge tools is necessary to transform the frontiers of research and deepen our knowledge of the physical world. NSF's Directorate for Mathematical and Physical Sciences supports state-of-the-art facilities and instrumentation that give researchers new powers to observe and analyze phenomena of great scientific interest, and, hopefully, unlock secrets of matter, energy, time and space, opening new windows on the universe.

Universal Laws and Order



Simulation of a detection of the Higgs boson in the Compact Muon Solenoid (CMS) experiment, one of two detectors built by NSF and the Department of Energy for the Large Hadron Collider. Over the next decade, the LHC will, among other things, enable a search for the Higgs particle, the existence and properties of which would provide a deeper understanding of the origin of mass of known elementary particles. *Credit: CERN*

Laser Interferometer Gravitational-Wave Observatory (LIGO)

Aerial view of the Laser Interferometer Gravitational-Wave Observatory (LIGO) site at Livingston, La., looking south along one of its two interferometer arms. LIGO consists of three interferometers at two locations—the other location is Hanford, Wash.—that are approximately 3,000 kilometers apart. *Credit: LIGO Laboratory, California Institute of Technology*

The Laser Interferometer Gravitational-Wave Observatory is the most sensitive gravitational wave detector built to-date. Gravitational waves are ripples in the fabric of space-time, produced by rare cataclysmic events emanating from supernovae, pulsars and neutron star collisions occurring as far away as 50 million light years, and black hole mergers occurring at still greater ranges throughout the universe. Though Albert Einstein predicted the existence of gravitational waves in his 1918 general theory of relativity, their existence has never been directly observed. The observatory consists of three Michelson interferometers located at Hanford, Wash., and Livingston, La.—locations approximately 3,000 kilometers apart. The separation between the two locations ensures that the very small signals induced by gravitational waves in the LIGO apparatus can be distinguished from local sources of random noise that may affect one site, but not both simultaneously.

Advanced Laser Interferometer Gravitational Wave Observatory (AdvLIGO)

The Advanced Laser Interferometer Gravitational Wave Observatory is a planned upgrade that will improve by a factor of 10 the sensitivity of LIGO. Since the volume of space that the instrument can examine varies as the cube of the sensitivity, AdvLIGO would look at a volume of space 1,000 times larger. As a result, a few hours of AdvLIGO observation time would equal one year of LIGO observations—greatly enhancing the chances of directly observing gravitational waves. The upgrade also comes with a change in the bandwidth of high sensitivity and the ability to tune the instrument for specific astrophysical sources. The upgrade is expected to help maintain U.S. leadership in this area of fundamental physics and keep pace with competing instruments abroad, which are also receiving upgrades. AdvLIGO is completing pre-construction planning activities. If the project moves forward, AdvLIGO could be expected to begin full operations in 2015.

A Calculation the Size of Manhattan

The E8 root system consists of 240 vectors in an eight-dimensional space. Those vectors are the vertices (corners) of an eight-dimensional object called the Gosset polytope 421. In the 1960s, Peter McMullen drew by hand a two-dimensional representation of the Gosset polytope 421. The image above was computer generated by John Stembridge, based on McMullen's drawing. *Credit: John Stembridge, University of Michigan*

An international team of researchers studying the properties of nature's most important groups of symmetries has mapped E8, an extraordinarily complex object described by a numerical matrix of more than 400,000 rows and columns. The four-year effort involved eighteen researchers who planned and executed the computation using powerful computers and programming techniques. The magnitude of the calculation is staggering: the answer, if written out in tiny print, would cover an area the size of Manhattan. For comparison, the human genome, which contains all the genetic information of a cell, is less than a gigabyte in size. The result of the E8 calculation, which contains all the information about E8 and its representations, is 60 gigabytes in size. The final phase of calculations was performed on the NSF-funded supercomputer of the SAGE (System for Algebra and Geometry Experimentation) project, directed by William Stein at the University of Washington. The collaborative effort to map E8 is part of a larger project, sponsored by NSF through the American Institute of Mathematics, that is known as the Atlas of Lie Groups and Representations. Its goal is to map out all of the Lie groups—a collection of symmetries that permits smooth transitions from one motion to another, such as cones, spheres and their higher-dimensional counterparts. E8, an object of interest for applications in physics and mathematics, is the largest of the exceptional Lie groups. For more information, see the NSF news release at http://www.nsf.gov/news/news_summ.jsp?cntn_id=108482.

Large Hadron Collider (LHC)

The Large Hadron Collider, an international project at the European Organization for Nuclear Research (CERN) Laboratory in Geneva, Switzerland, will be the world's premier facility for research in elementary particle physics. The high-energy accelerator will send beams of protons around a 27-kilometer (km) long, underground ring to smash them into other protons circulating from the other direction. The collisions will create brief showers of very exotic materials that physicists will examine as they seek out new types of matter. Detectors stationed around the ring will produce some 15 trillion gigabytes of data each year. The LHC will enable a search for the Higgs particle, the existence and properties of which will provide a deeper understanding of the origin of mass of known elementary particles. The facility will also enable a search for particles predicted by a powerful theoretical framework, known as supersymmetry, which could provide clues to how the four known forces evolved from different aspects of the same unified force in the early universe. Physicists expect the LHC experiments to help answer fundamental questions, including what is dark energy, do undiscovered dimensions of space exist and what is dark matter. NSF's contribution to the LHC includes support for the construction, maintenance and operation of two detectors: A Toroidal LHC ApparatuS (ATLAS) and the Compact Muon Solenoid (CMS). DOE is collaborating with NSF on support for the detectors. ATLAS and CMS are designed to characterize the different reaction products produced in the very high-energy proton-proton collisions that will occur in interaction regions where the two counter-circulating beams collide. In June 2008, NSF and DOE announced that the U.S. contribution to the LHC was completed on budget and ahead of schedule. On Sept. 10, 2008, the first beam of protons was sent around the particle accelerator's 27-kilometer underground ring. After further tests of the beams and acceleration systems, the beams will be brought into collision. Data-taking is expected to begin when beam performance stabilizes.

IceCube Neutrino Observatory

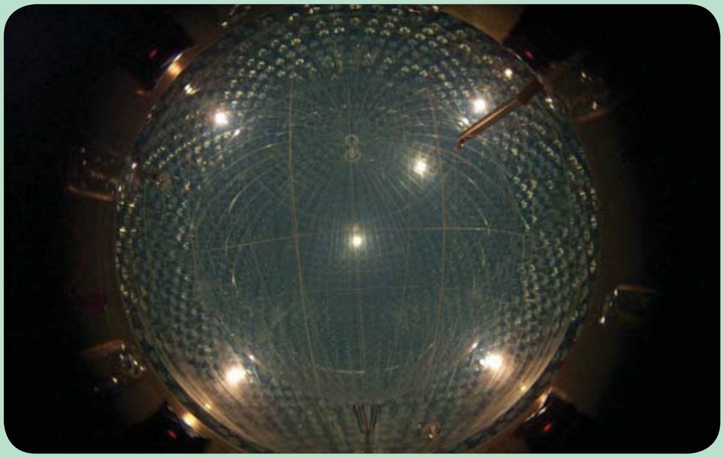
The IceCube Neutrino Observatory, under construction deep in the clear ice at the South Pole, will be the world's first high-energy neutrino observatory. The South Pole is a strikingly inhospitable place to build and operate a telescope. But ice also happens to be an excellent medium for observing neutrinos—nearly massless particles created by exotic deep-space events such as supernovae (the death explosions of large stars)—as they pass through the Earth. One cubic kilometer of ice is being instrumented with photomultiplier (PM) tubes to detect charged reaction products from high-energy neutrino interactions in

A view of the signal cables from strings of Digital Optical Modules (DOMs) extending down into the ice. The IceCube Neutrino Observatory, under construction in the highly transparent ice beneath the surface of the South Pole, will be composed of 70 strings of DOMs and 140 surface cosmic ray air detector modules. *Credit: Kathie L. Olsen, National Science Foundation*

the ice within or near the fiducial volume (the sensitive volume for detection). An array of Digital Optical Modules (DOMs), each containing a PM and associated electronics, will be positioned uniformly from 1.45 to 2.45 kilometers beneath the surface of the South Pole ice cap in highly transparent, bubble-free ice. IceCube will be comprised of 70 strings of DOMs and 140 surface cosmic ray air shower detector molecules upon completion. Astrophysicists from the University of Wisconsin are leading the construction project. IceCube is an international partnership with construction co-funding from Belgium, Germany and Sweden, as well as the U.S.

First Real-time Detection of Low-energy Neutrinos Streaming From the Sun's Core

An international team of researchers has detected elusive, low-energy solar neutrinos—subatomic particles produced in the core of the Sun—and measured in real-time the rate the particles hit the Earth. The researchers also obtained fresh evidence that neutrinos oscillate (transform from one state to another) before arriving on Earth, adding weight to current theories about the nature of neutrinos and the inner workings of the Sun and other stars. The team of more than 100 researchers, including NSF-supported investigators at Princeton University and Virginia Tech, have operated the so-called Borexino experiment in one of the deepest laboratories in the world, the Gran Sasso Laboratory of the Istituto Nazionale di Fisica Nucleare (INFN), the Italian National Institute of Nuclear Physics, near the town of L'Aquila, Italy. The 18-meter (59-foot) diameter Borexino detector lies more than a kilometer (almost a mile) underground at a depth that blocks out cosmic rays and other radiation sources that could create additional background signals. These are the first results from the Borexino experiment. It has been under construction since the late 1990s, with the support of INFN as the lead agency, and NSF in the U.S., and institutions in Germany, France and Russia. As it moves into a precision measurement phase, the Borexino detector will enable further probes that produce new knowledge about the properties of neutrinos and the Sun. For more information, see the NSF news release at http://www.nsf.gov/news/news_summ.jsp?cntn_id=109893.



The fully-assembled Borexino detector is visible from multiple cameras embedded in the structure. In the image above, the view of the interior of the sphere is distorted by the camera lens. *Credit: INFN*

National Superconducting Cyclotron Laboratory (NSCL)

The National Superconducting Cyclotron Laboratory is the leading rare isotope research facility in the U.S. Located on the campus of Michigan State University, the national user facility operates two superconducting cyclotrons–K500 was the world's first cyclotron to use superconducting magnets and K1200 is the highest-energy continuous beam accelerator in the nation. Through the Coupled Cyclotron Facility (CCF), the two cyclotrons make even rarer isotopes. Heavy ions are accelerated by the K500 and then injected into the K1200, enabling the production of rare unstable isotopes at much higher intensities. The research conducted by NCSL scientists is important to understanding stellar processes. Michigan State operates the facility under a cooperative agreement with NSF that was renewed in FY 2007 and runs through FY 2011.

This superconducting magnet was developed by researchers at the National Superconducting Cyclotron Laboratory (NSCL) at Michigan State University to withstand the high radiation environment required for isotope research. *Credit: Chen-yu Gung, MIT Plasma Science and Fusion Cente*

Cornell Electron-positron Storage Ring (CESR)

The Cornell Electron-positron Storage Ring is an electron-positron collider that provides important knowledge of the properties of the b-quark. The facility has a circumference of 768 meters, and is located 12 meters below a parking lot and an athletic field on the Cornell University campus. It is capable of producing collisions between electrons and their anti-particles, positrons, with center-of-mass energies between 9 and 12 GeV. When an electron and positron collide and annihilate, the flash of energy results in the creation of new matter, sometimes exotic and unfamiliar. The products of these collisions are studied with a large and complex detection apparatus, called the CLEO detector.

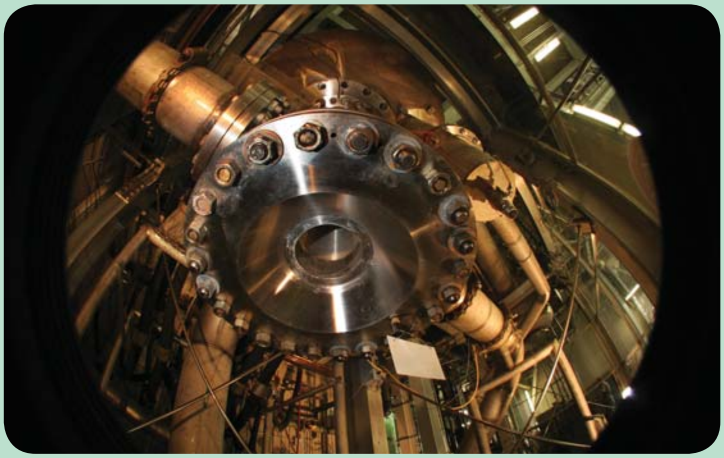
Use of the CESR as a facility for particle physics will conclude with final phase-out over the 2008 and 2009 fiscal years. With the closeout of the particle physics program at the CESR, physicists at Cornell are ramping up their participation in the research program of the Compact Muon Solenoid (CMS) experiment, one of two major detectors at the LHC (see page 64).

National High Magnetic Field Laboratory (NHMFL)

The National High Magnetic Field Laboratory develops and operates state-of-the-art, high-magnetic-field facilities and is among the preeminent facilities in the world for researchers and engineers studying superconductivity and other materials research. In operation since 1994 and the only facility of its kind in the U.S., the NHMFL seeks to provide the highest magnetic fields for scientific research. It holds numerous records—including the current Guinness World Record for highest magnetic field for a continuous field magnet of 45 tesla—which is about one million times the Earth's magnetic field. The record-setting measure provides researchers with a unique scale of magnetic energy to create novel states of matter and probe deeper into electronic and magnetic materials. High magnetic fields are crucial to fundamental research advances in a broad range of disciplines including biology, biochemistry, bioengineering, chemistry, engineering, geochemistry, materials science, medicine and physics. In cooperation with industry, the NHMFL also advances magnet and magnet materials technology. The NHMFL is operated by Florida State University, the University of Florida and Los Alamos National Laboratory.

Getting Warmer: High Magnetic Field Researchers Make Surprising Quantum Physics Discovery

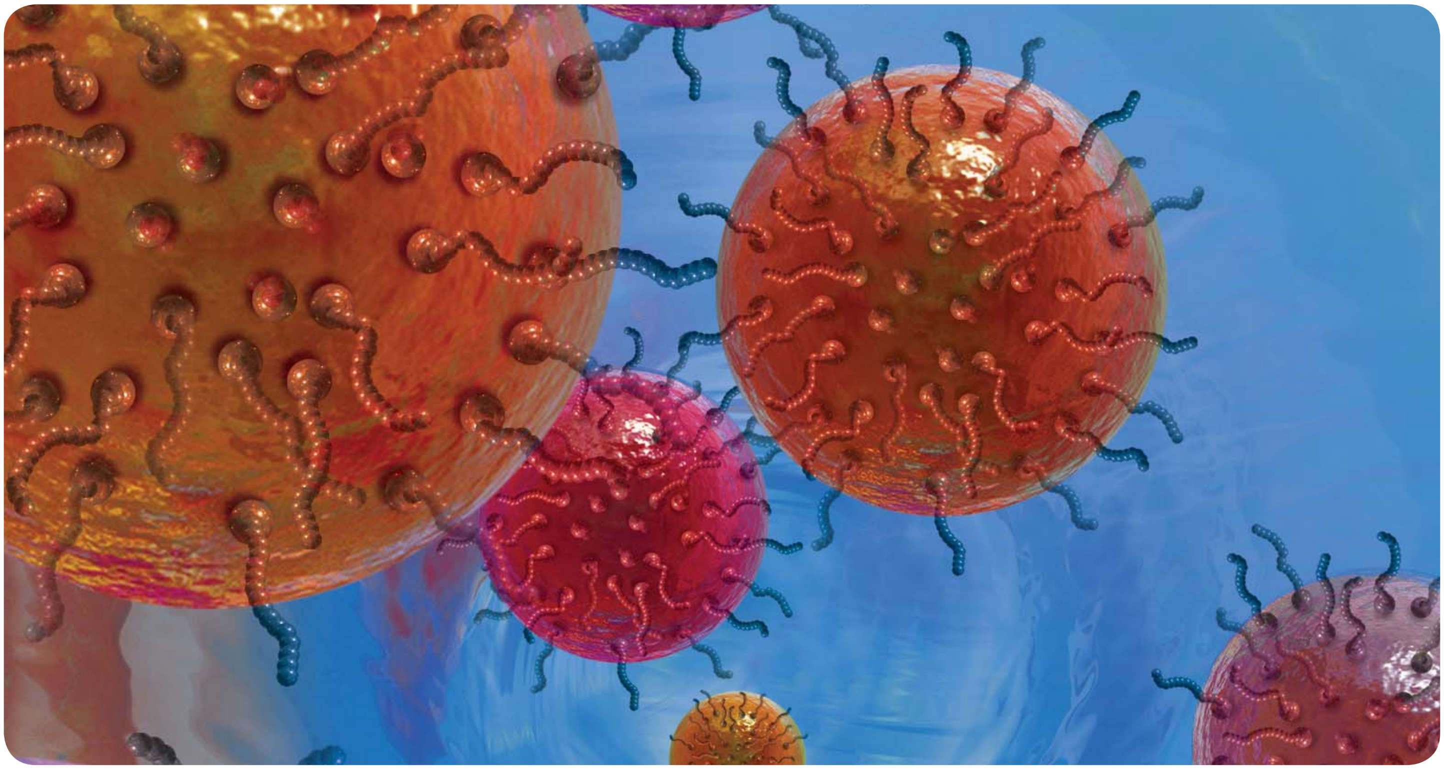
An international team of scientists working with the highest magnetic fields at Florida's NHMFL and in the Netherlands recently observed the quantum Hall effect–a much studied phenomenon of the quantum world–at room temperature. The quantum Hall effect is the basis for the international electrical resistance standard used to characterize even everyday materials that conduct electricity. Before the surprising discovery, the general view was that the quantum Hall effect was observable only at temperatures close to absolute zero (minus 459 degrees Fahrenheit; minus 273 degrees Celsius). The scientists at the NHMFL in the U.S. and at the High Field Magnet Laboratory in the Netherlands put graphene, a recently developed form of carbon made of a single atomic sheet of atoms about as strong as diamond, in very high magnetic fields, and observed the surprising result. The work could lead to a new generation of ultra-small electrical devices. For more information, see the NSF News From the Field story at http://www.nsf.gov/news/news_summ.jsp?cntn_id=110213.



The National High Magnetic Field Laboratory's (NHMFL) 45 tesla hybrid magnet (shown from below) is the strongest magnet of its kind in the world. It holds numerous records including a Guinness World Record. Weighing 35 tons and requiring 400 liters of chilled water per second to keep it cool, the 45 tesla hybrid magnet provides researchers with a unique scale of magnetic energy to create novel states of matter and probe deeper into electronic and magnetic materials. *Credit: Florida State University*

The potential of successfully utilizing our knowledge of various states and properties of matter is only beginning to be realized. NSF's investments in equipment, facilities and centers allow researchers to advance our understanding of materials, and enable scientists to create new, smart materials that are designed for particular uses. Nanotechnology is just one of the promising areas of materials science that is yielding new knowledge. Someday, the ability to manipulate matter at the nanoscale could revolutionize the design and manufacture of most products. The impact of nanotechnology products is projected to exceed $1 trillion worldwide by 2015. NSF-supported research infrastructure is playing a crucial role in preparing the U.S. for leadership in this brave new nanotechnology world. Another area of frontier research is the study of superconducting materials. Supported primarily by NSF's Directorate for Engineering and Directorate for Mathematical and Physical Sciences, research infrastructure in these and related areas enable scientists and engineers to advance our knowledge of the material world.

Big Ideas, Small Packages



The discovery of unexpected magnetic interactions between nanoparticles of rust is leading to a revolutionary, low-cost technology for cleaning arsenic from drinking water. Researchers from the Center for Biological and Environmental Nanotechnology (CBEN) at Rice University described the purification technique in the journal *Science*. CBEN is one of NSF's Nanoscale Science and Engineering Centers, where research at the scale of one nanometer (one billionth of a meter) is leading to breakthroughs in such critical fields as advanced computing, communications, materials development and medicine. *Credit: CBEN/Rice University*

Nanoscale Science and Engineering Centers (NSEC)

Nanotechnology, which addresses technology on the smallest of scales, is projected to be one of the largest drivers of technological innovation for at least the next decade and beyond. This potential was recognized in the National Nanotechnology Initiative and more recently in the American Competitiveness Initiative, particularly in the burgeoning area of nanomanufacturing. Research at the nanoscale through NSF-funded Nanoscale Science and Engineering Centers aims to advance the development of the ultrasmall technology that will transform electronics, materials, medicine, environmental science and many other fields. Each center has a long-term vision for research. Together they provide coherence and a long-term outlook to U.S. nanotechnology research and education; they also address the social and ethical implications of such research. Support is provided for education and outreach programs from K-12 to the graduate level, and is designed to develop a highly skilled workforce, advance precollege training, and further public understanding of nanoscale science and engineering. The centers have strong partnerships with industry, national laboratories and international centers of excellence, which puts in place the necessary elements to bring discoveries in the laboratory to real-world, marketable innovations and technologies. The NSECs currently supported by NSF are:

- Affordable Nanoengineering of Polymer Biomedical Devices - Ohio State University
- Integrated and Scalable Nanomanufacturing - University of California, Los Angeles
- Directed Assembly of Nanostructures - Rensselaer Polytechnic Institute
- Electronic Transport in Molecular Nanostructures - Columbia University
- High Rate Nanomanufacturing - Northeastern University, University of New Hampshire, University of Massachusetts-Lowell
- Integrated Nanomechanical Systems - University of California, Berkeley, California Institute of Technology, Stanford University, University of California, Merced
- Integrated Nanopatterning and Detection Technologies - Northwestern University
- Molecular Function at the Nano/Bio Interface - University of Pennsylvania
- Nanotechnology in Society Network: Center at ASU - Arizona State University
- Nanotechnology in Society Network: Center at UCSB - University of California, Santa Barbara
- Nanoscale Chemical-Electrical-Mechanical Manufacturing Systems - University of Illinois at Urbana-Champaign
- Nanoscale Systems in Information Technologies - Cornell University
- Nanoscience in Biological and Environmental Engineering - Rice University
- National Nanomanufacturing Network: Center for Hierarchical Manufacturing - University of Massachusetts Amherst
- Probing the Nanoscale - Stanford University, IBM
- Science of Nanoscale Systems and their Device Applications - Harvard University
- Templated Synthesis and Assembly at the Nanoscale - University of Wisconsin-Madison

NSEC researchers are making discoveries that advance knowledge in wide-ranging fields of science. Two examples:

- A team of researchers at the NSEC for Integrated Nanopatterning and Detection Technologies at Northwestern University have developed an experimental procedure that has detected miniscule amounts of proteins known as ADDLs in fluid samples from around the brain and spinal cord. The proteins have been linked in other studies to Alzheimer's disease. The procedure, announced in 2005, uses the team's novel bio-bar-code (BCA) amplification technology as a extremely sensitive and highly selective biosensing system. BCA is about one million times more sensitive than standard enzyme-linked immunoassays, according to the researchers. If proven successful in further clinical studies, the procedure could become the first tool for early diagnosis of Alzheimer's and the first test to conclusively identify the disease in living patients.

- Researchers associated with the Center for Nanotechnology in Society at Arizona State University surveyed a national random sample of American households and more than 360 leading nanoscale science and engineering researchers in the U.S., and they found differences between the public's and scientists' perceptions about the risks and benefits of nanotechnology. Often with emerging technologies, researchers perceive higher benefits while the public senses higher risks. The survey found that the researchers perceived higher benefits from nanotechnology than the public across most categories, especially in the areas of treating diseases, a cleaner environment and solving energy problems. The public perceived greater risks than the researchers in such areas as loss of privacy, use of nanotechnology by terrorists and a loss of jobs. But surprisingly, the researchers perceived higher risks from nanotechnology than the public in the categories of health and environment.

World's Smallest Radio

Harnessing the electrical and mechanical properties of the carbon nanotube, a team of researchers crafted a working radio from a single carbon fiber. Fixed between two electrodes, the vibrating tube successfully performed the four critical roles of a radio—antenna, tunable filter, amplifier and demodulator—to tune in a radio signal generated in the room and play it back through an attached speaker. Functional across a bandwidth widely used for commercial radio, the tiny device could have applications far beyond novelty, from radio-controlled devices that could flow in the human bloodstream to highly efficient, miniscule, cell phone devices. The device was developed by researchers at the Center of Integrated Nanomechanical Systems at the University of California, Berkeley and the Lawrence Berkeley National Laboratory. The center is one of NSF's NSECs. For more information, see the NSF news release at http://www.nsf.gov/news/news_summ.jsp?cntn_id=110566.

This image, taken by a transmission electron microscope, shows a single carbon nanotube protruding from an electrode. The nanotube is less than a micron long and only 10 nanometers wide, or 10,000 times thinner than the width of a single human hair. The radio waves, added for visual effect, are not part of the original microscope image. Credit: Zettl Research Group, Lawrence Berkeley National Laboratory and University of California at Berkeley

National Nanotechnology Infrastructure Network (NNIN)

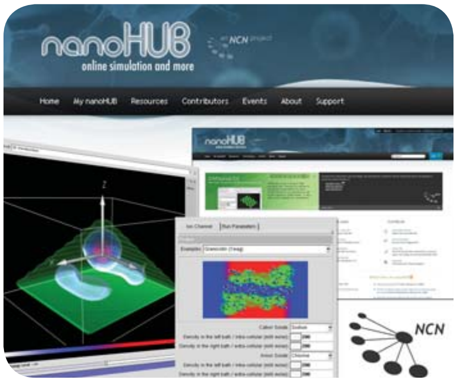
The National Nanotechnology Infrastructure Network is an integrated partnership of thirteen user facilities, supported by NSF, that provide unparalleled opportunities for nanoscience and nanotechnology research. The network provides extensive support in nanoscale fabrication, synthesis, characterization, modeling, design, computation and hands-on training in an open environment, available to all qualified users. NNIN partners are:

- Center for Nanoscale Systems - Harvard University
- Center for Nanotechnology - Nanotech User Facility - University of Washington
- Cornell Nanoscale Facility - Cornell University
- Howard Nanoscale Science and Engineering Facility - Howard University
- Michigan Nanofabrication Facility - University of Michigan
- Microelectronics Research Center - University of Texas-Austin
- Microelectronics Research Lab - Georgia Tech
- Minnesota Nanotechnology Cluster - University of Minnesota
- Nanoscience @UNM - University of New Mexico
- Nanotech - University of California, Santa Barbara
- Penn State Nanofabrication Facility - Penn State University
- Stanford Nanofabrication Facility - Stanford University

Network for Computational Nanotechnology (NCN)

The Network for Computational Nanotechnology is a multi-university initiative that was launched in September 2002 to create a unique, Web-based infrastructure to serve researchers, educators and students. The NCN Web site, www.nanohub.org, is a “science gateway” that hosts collaborative tools and delivers unique educational resources such as online courses, learning modules, lectures and seminars on nanotechnology. The institutions involved in NCN are Purdue University, Northwestern University, Morgan State University, Stanford University, University of Florida, University of Illinois and the University of Texas at El Paso.

The Network for Computational Nanotechnology (NCN) Web site is a “science gateway” that hosts collaborative tools and delivers unique educational resources. Pictured at right are the nanoHUB home page and several nanoHUB applications including the bioMOCA tool and quantum dot simulation results. The nanoHub enables researchers to use the simulations on their personal computers with an ordinary Web browser. *Credit: Mark Lundstrom, Director, Network for Computational Nanotechnology, Purdue University*



The NCN is making it possible for more researchers to conduct nanoscale research from remote locations. Researchers at Purdue University are operating a virtual environment of Web-based simulation tools, believed to be the first of their kind, that enable scientists and engineers to remotely interpret raw data collected with powerful microscopes. Since the virtual environment for dynamic atomic force microscopy, or VEDA, went online in 2007, more than 300 researchers from around the world have used it to learn about the magnetic, electrical and physical properties of materials. The tools are provided through the nanoHub, a unique cyberinfrastructure provided by the NCN. The nanoHub uses NSF’s TeraGrid high-speed fiber optic network. The VEDA virtual environment was described in a cover story in the June 2008 issue of the journal *Review of Scientific Instruments*. For more information, see the NSF news item at http://www.nsf.gov/news/news_summ.jsp?cntn_id=111957.

Centers for Chemical Innovation (CCI)

The Centers for Chemical Innovation are designed to support research on strategic, transformative “big questions” in basic chemical research. Appropriate research problems for the centers (originally known as Chemical Bonding Centers) are high-risk but potentially high-impact and will attract broad scientific and public interest. Among the grand challenges of interest to center researchers are emulating or even surpassing the efficiency of photosynthesis to capture the Sun’s energy; learning how molecules combine to become living things; activating strong bonds as a means to store and use chemical energy and to lower energy costs in chemical processing; and designing self-assembling, complex structures with useful functions. The CCI program is a two-phase program. Phase I centers receive significant resources to develop the scientific, educational, innovation and management aspects of a CCI before requesting Phase II funding. NSF is currently supporting the following CCIs:

Phase II

- Center for Enabling New Transformations Through Catalysis - University of Washington
- Powering the Planet - California Institute of Technology (2008 award)

Phase I

- Center for Molecular Cybernetics - Columbia University
- Chemistry at the Space-Time Limit - University of California, Irvine
- Orchestrating Proton Transport Through Supramolecular Alignment of Functionalities - University of Massachusetts Amherst
- The Origins Chemical Inventory and Early Metabolism Project - Georgia Tech
- Center for Green Materials Chemistry – Oregon State University (2008 award)
- Center for Molecular Interfacing – Cornell University (2008 award)
- Center for Chemistry of the Universe – University of Virginia (2008 award)

New Technique for Extracting Oxygen From Water

Using a simple and inexpensive technique, researchers at the Massachusetts Institute of Technology announced a way to pull pure oxygen from water using relatively small amounts of electricity and common chemicals. Daniel Nocera, the Henry Dreyfus Professor of Energy at the Massachusetts Institute of Technology, and Matthew Kanan, a postdoctoral fellow in Nocera's lab, developed the process using a new catalyst that produces oxygen gas from water. Another catalyst produces valuable hydrogen gas. The oxygen and hydrogen could be recombined inside a fuel cell, creating carbon-free electricity, day or night. The technology could remove the biggest barrier to large-scale use of solar energy—the need to store solar energy for use when the Sun isn't shining. Nocera is a member of the Powering the Planet center's partnership between the California Institute of Technology, the Massachusetts Institute of Technology and several other institutions. In his role as a co-investigator with the center, Nocera has been pursuing sustainable energy technology through a broader effort to learn from, and apply, the lessons of photosynthesis and other natural processes. For more information, see the NSF news release at http://www.nsf.gov/news/news_summ.jsp?cntn_id=111975.

Massachusetts Institute of Technology chemist Daniel Nocera and his postdoctoral student Matthew Kanan discovered this new, efficient catalyst that produces oxygen gas from water. Nocera is a member of Powering the Planet, one of NSF's Centers for Chemical Innovation (CCI). *Credit: MIT/NSF*

Materials Research Science and Engineering Centers (MRSECs)

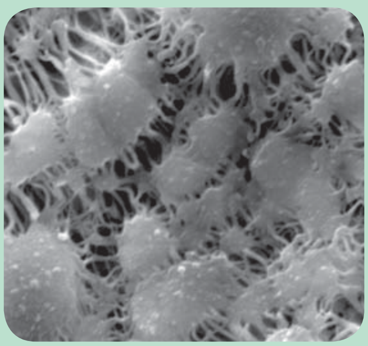
Materials Research Science and Engineering Centers address fundamental materials research problems of intellectual and strategic importance that are critical for American competitiveness and the development of future technologies. MRSECs also support shared experimental facilities, place strong emphasis on the integration of research and education at all levels, and provide seed support to stimulate emerging areas of materials research. They support cutting-edge materials research in areas such as electronic and photonic materials, polymers, biomimetic and biomolecular materials, magnetic and ferroelectric materials, nanoscale materials, structural materials, and organic systems and colloids. MRSECs have strong links to industry and other sectors, enabling the development of marketable technologies that depend on new classes of materials and the discovery, control and innovative exploitation of materials phenomena. The following MRSECs are supported by NSF:

- Center for Nanostructured Materials - Columbia University
- Center on Polymer Interfaces and Macromolecular Assemblies - Stanford University
- Response-Driven Polymeric Films Center - University of Southern Mississippi
- MRSEC - University of Alabama Tuscaloosa
- MRSEC - University of Pennsylvania
- Cornell Center for Materials Research - Cornell University
- MRSEC at UCSB - University of California, Santa Barbara
- Carnegie Mellon University MRSEC – Carnegie Mellon University
- The University of Maryland MRSEC - University of Maryland College Park
- MRSEC - Johns Hopkins University
- MRSEC for Research on Interface Structures and Phenomena - Yale University
- Multifunctional Nanoscale Material Structures - Northwestern University
- MRSEC on Nanostructured Interfaces - University of Wisconsin-Madison

- Center for Semiconductor Physics in Nanostructures - University of Oklahoma Norman Campus
- Center for the Science and Engineering of Materials - California Institute of Technology
- Genetically Engineered Materials Science and Engineering Center - University of Washington
- Micro- and Nano- Mechanics of Materials - Brown University
- MIT MRSEC - Massachusetts Institute of Technology
- Princeton Center for Complex Materials - Princeton University
- University of Minnesota MRSEC - University of Minnesota-Twin Cities
- MRSEC - University of Chicago
- Semantophoretic Assemblies - New York University (2008 award)
- The Georgia Tech Laboratory for New Electronic Materials - Georgia Tech (2008 award)
- MRSEC: Center for Nanoscale Science - Penn State University
- Center for Emergent Materials - Ohio State University (2008 award)
- MRSEC - Harvard University
- Constraints and Frustration in Nano-Structured and Bio-Molecular Materials - Brandeis University (2008 award)
- Quantum and Spin Phenomena in Nanomagnetic Structures - University of Nebraska-Lincoln
- MRSEC on Polymers - University of Massachusetts Amherst
- Renewable Energy MRSEC - Colorado School of Mines (2008 award)
- Soft Materials Research Center - University of Colorado at Boulder

Penicillin-coated Polymer for Medical Devices to Ward Off Staph Infections

Imagine the advantage of having antibiotics built into objects that are inserted into the body during medical procedures instead of having to give patients antibiotics to ward off infections. That could be the reality one day. Researchers at MRSEC at the University of Southern Mississippi chemically attached penicillin to expanded polytetrafluoroethylene (PTFE) to produce an antibacterial surface that kills Staphylococcus aureus, the most common cause of staph infections. Expanded PTFE is a highly porous polymer commonly used in waterproof fabrics such as Gore-Tex. It is also extensively used in medical devices and implants. The research was published in the Feb. 12, 2007, issue of *Biomacromolecules*. Since then, the research team has been working on expanding their tool box by attaching an array of drugs to expanded PTFE, for example to control blood clotting, and other antibiotics to surfaces for control of an array of bacteria. For more information, see the NSF discovery story at http://www.nsf.gov/discoveries/disc_summ.jsp?cntn_id=110645&org=NSF.



Polymer science professor Marek Urban and his team of researchers at the University of Southern Mississippi have developed a new process to coat surfaces with antibiotics. Surgical instruments coated with antibiotics could potentially save thousands of lives and reduce the number of patients who contract infections following medical procedures. This scanning electron microscope image shows a polymer surface prior to its coating with penicillin. Credit: Marek W. Urban, The University of Southern Mississippi

Nanobiotechnology Center (NBTC)

The Nanobiotechnology Center, an NSF STC led by Cornell University, brings together life scientists, physical scientists and engineers to apply the tools and processes of nano/microfabrication to build devices for biomedical and biological research. Center researchers have developed a new kind of nanoparticle, called Cornell dots or "CU dots." Consisting of fluorescent dye molecules surrounded by a protective silica shell, the particles are small—about 25 nanometers in diameter—but could have a large impact in biological imaging. CU dots are brighter than single fluorescent dye molecules and there are other advantages over current technology as well. Cornell University has licensed the CU dot technology to a start-up company that hopes to commercialize it for biological imaging applications. Another of the center's teams has created "nanobarcodes"— multicolor fluorescent tags made out of synthetic DNA that attach to target species. Under ultraviolet light, the tags produce a combination of colors that is unique to the target species. The method can be used to rapidly identify genes, pathogens, drugs and other chemicals.

Center for Environmentally Responsible Solvents and Processes (CERSP)

Researchers at NSF's STC for Environmentally Responsible Solvents and Processes (CERSP) in North Carolina are developing innovative "green" manufacturing methods. The work involves technology using liquid and supercritical carbon dioxide (CO_2) as a cleaning agent and reaction medium. The technology would eliminate millions of tons of wastewater and airborne emissions created by conventional processes. The new technology is already being used in a new chain of dry-cleaning stores called "Hangers," where liquid CO_2 replaces the volatile organic solvent perchloroethylene, a known contaminant of groundwater. In addition, DuPont has adopted the technology in a new $40 million Teflon manufacturing facility, which unlike plants using the conventional water-based process, does not use a pollutant known as C8. Joseph DeSimone, center director and professor of chemistry at the University of North Carolina at Chapel Hill and professor of chemical engineering at North Carolina State University, was awarded the 2008 Lemelson-MIT prize. The award recognizes outstanding inventors, encourages sustainable solutions to real-world problems and seeks to inspire new generations of inventors.

On a smaller scale, an MRI award to a team of researchers at the University of Virginia enabled the development of a new technique for identification of chemical agents. The technique dramatically reduces the time required for studying chemical structures in gas phase. The "Chirped Pulse Fourier Transform Microwave" measures a broader range of microwave frequencies than existing spectrometers, and allows users to select the desired sensitivity when obtaining measurements. The new microwave has a number of potential applications in chemical analysis including breath analysis and detection of chemical warfare agents.