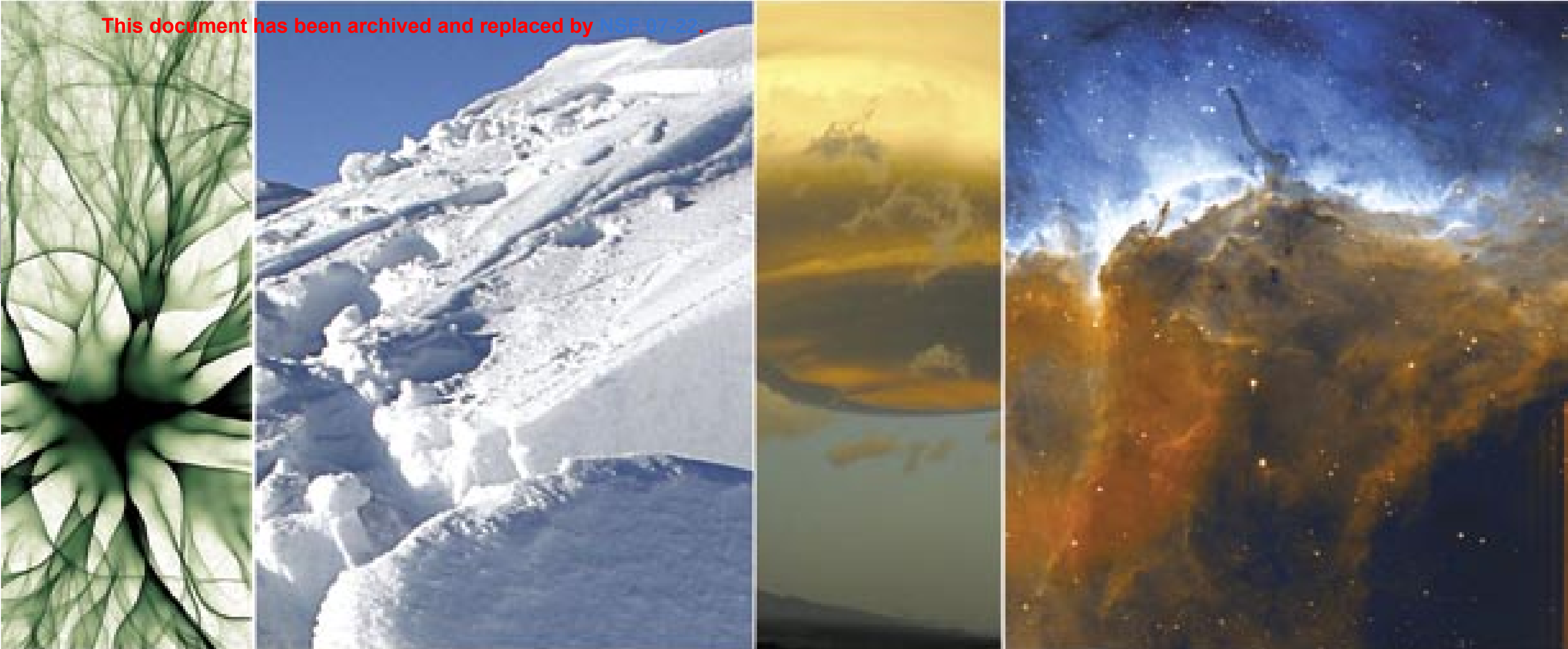
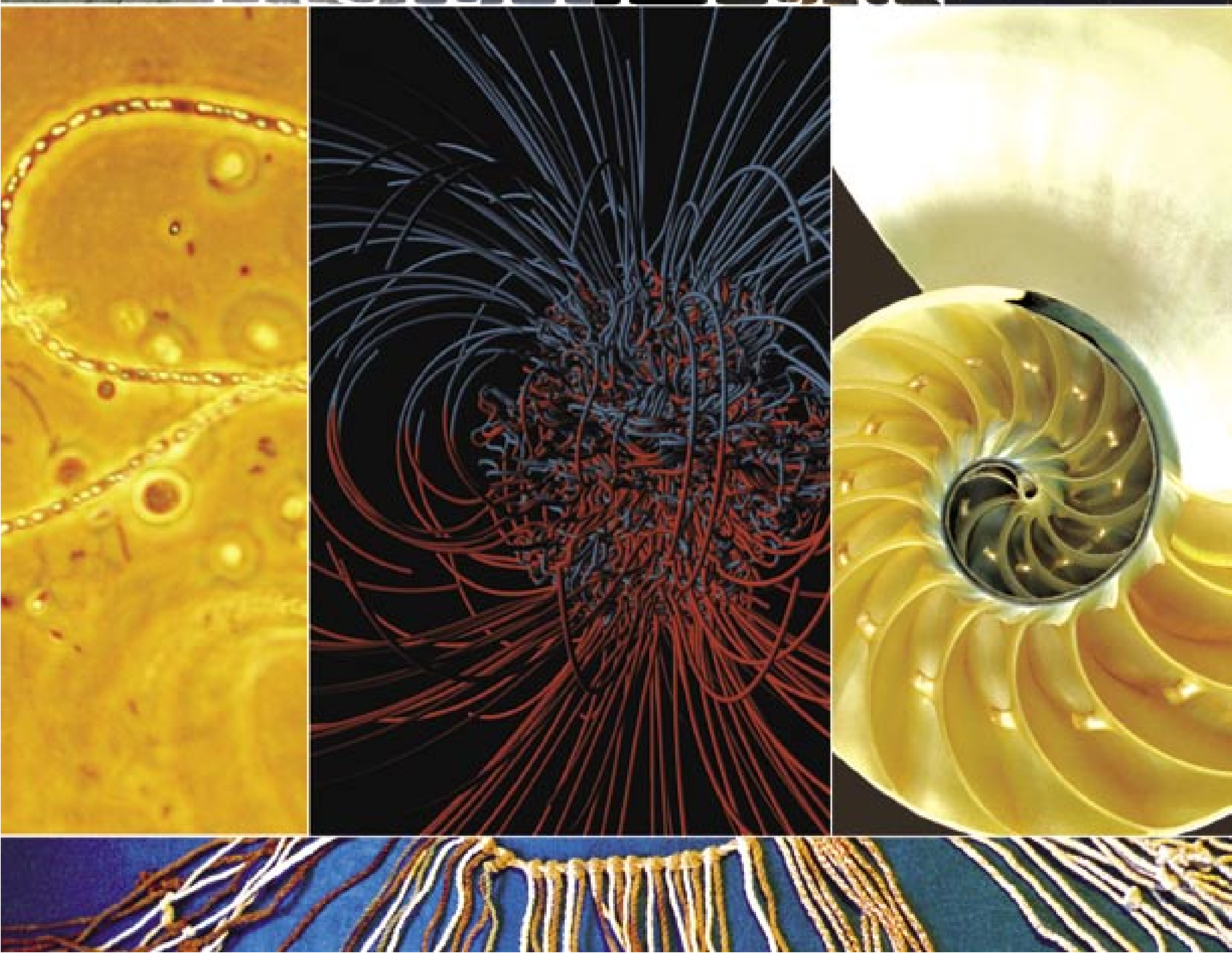


NATIONAL SCIENCE FOUNDATION SEPTEMBER 2005

FACILITY PLAN



CONTENTS

INTRODUCTION 5

CHAPTER 1: RESEARCH OBJECTIVES AND OPPORTUNITIES AT THE FRONTIERS OF SCIENCE AND ENGINEERING 7

Mesoscale 1 — From Millimeters to Hundreds of Kilometers 8

Mesoscale 2 — Thousands of Kilometers 10

Microscale 1 — Micrometers to Nanometers 11

Microscale 2 — Subatomic 14

Macroscale 1 — Millions of Kilometers to Thousands of Light Years 15

Macroscale 2 — Millions to Billions of Light Years 16

Multiscale or Scale-Independent Objectives 17

CHAPTER 2: MAJOR RESEARCH EQUIPMENT AND FACILITIES CONSTRUCTION PROJECTS (MREFC) 18

I. Status Reports on Facilities under Construction with MREFC Account Funding and MREFC New Starts in the FY 2006 Congressional Budget Request 20

FIRST PRIORITY: Ongoing Projects in FY 2006 20

Atacama Large Millimeter Array (ALMA) 20

EarthScope 22

High-performance Instrumented Airborne Platform for Environmental Research (HIAPER) 23

IceCube Neutrino Observatory 24

National Ecological Observatory Network (NEON) 26

NEES: The George E. Brown Jr. Network for Earthquake Engineering Simulation 29

Rare Symmetry Violating Processes (RSVP) 31

Scientific Ocean Drilling Vessel (SODV) 32

South Pole Station Modernization Project (SPSM) 33

Terascale Computing Systems (TCS) 34

SECOND PRIORITY: New Starts in FY 2007 and FY 2008 35

Ocean Observatories Initiative (OOI) 35

Alaska Region Research Vessel (ARRV) 37

Advanced LIGO (AdvLIGO) 39

II. Status Report on National Science Board Approved New Starts 42

III. Readiness Stage Projects and Projects Recommended for Advancement to Readiness Stage 42

IV. Projects under Exploration 42

Advanced Technology Solar Telescope (ATST) 43

Collaborative Large-scale Engineering Analysis Network for Environmental Research (CLEANER) 44

Coherent X-Ray Light Source 45

Deep Underground Science and Engineering Laboratory (DUSEL) 46

Expanded Very Large Array (EVLA) Phase II 47

Global Navigation Satellite System (GNSS) Earth Observing System (GEOS) 48

Interferometric Synthetic Aperture Radar (InSAR) 49

Large Synoptic Survey Telescope (LSST) 50

Petascale Earth System Collaboratory 51

South Pole Future Communication Needs 52

Square Kilometer Array (SKA) 54

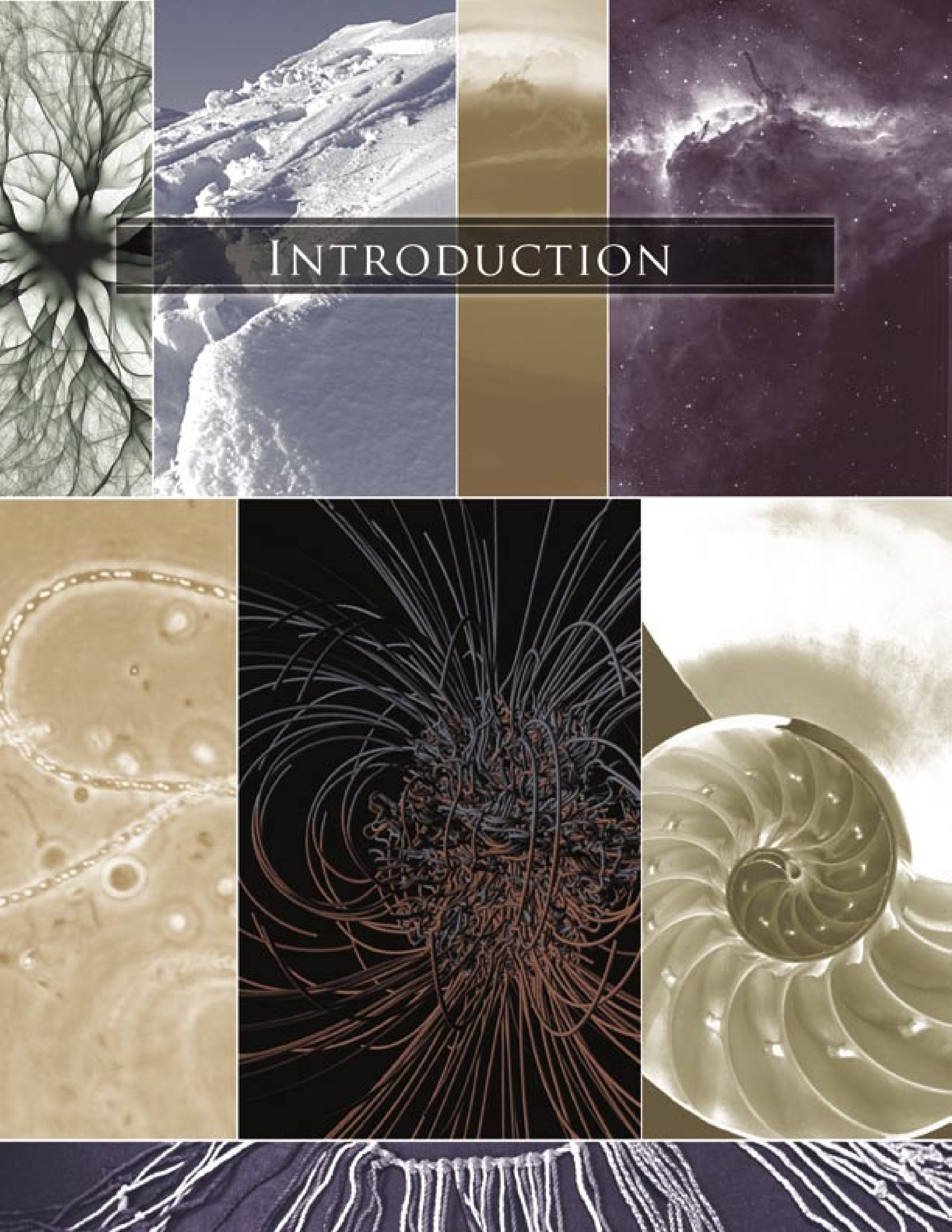
Thirty Meter Telescope (TMT) 55

V. Glossary of Acronyms 56

VI. References 58

VII. Image Credits 60

INTRODUCTION



INTRODUCTION

Successful exploration — whether in uncharted wilderness or at the frontiers of knowledge — demands commitment, vision, daring and ingenuity. But those qualities alone are not always sufficient. Progress also requires the right kind of equipment. Often new territory is accessible only with new tools; and sometimes even a seemingly unstoppable rush of discovery must halt to await novel means of seeing, manipulating and analyzing natural phenomena.

That is why the National Science Foundation (NSF)[1] supports not only research and education, but also the physical implements that make both possible. Our investments range from modest laboratory instruments and information technology (IT) resources to the sorts of world-class projects that make up a special category of NSF funding designated as Major Research Equipment and Facilities Construction (MREFC).

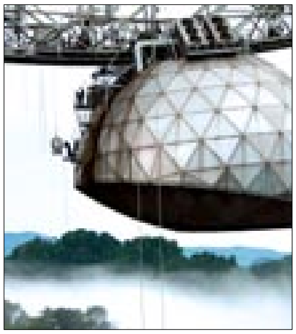
During the past half-century, unique tools provided by NSF have enabled scores of unprecedented discoveries and remarkable innovations. To cite only a very few: The first observations of extrasolar planets and the first evidence for gravitational waves came from our radio telescope at Arecibo, Puerto Rico. The Nobel Prize-winning investigation of ion channels in biological cell membranes used the special X-ray capabilities of an NSF accelerator at Cornell University. NSF's solar observatories revealed the first evidence of seismic activity in the Sun and detected sunspots on the far side of our star — weeks before they rotated into position to affect space weather near Earth.

Seafloor sediment cores retrieved by NSF's drilling ships have transformed our understanding of ancient climate and oceanography, and data recovered from ultra-deep submersibles have revealed unexpected rift activity in the Earth's crust and exotic "vent communities" with wholly unanticipated metabolic systems. Sensitive measurements of ancient light made at the South Pole confirmed the structure of the cosmos 13.7 billion years ago. And the astonishing revelation that the universe is expanding at an accelerating rate — apparently propelled by a mysterious entity called "dark energy" — arose directly from NSF's optical telescope resources. These and similar advances have altered the course of scientific history.

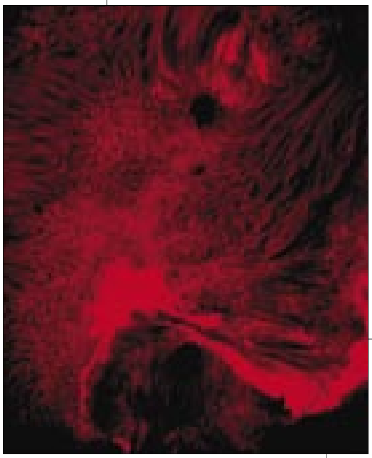
Identifying and funding the kind of tools that will truly transform research in science and engineering is an essential part of the NSF's mission. As in all NSF endeavors, inquiry begins with the research communities, which alert program staff to the most promising and exciting topics, and the most important equipment needed to explore them. NSF then assists the communities in refining their insights, forming a consensus and focusing on paramount objectives and their corresponding hardware requirements. At that point, if a project clearly offers revolutionary potential, it may qualify for further consideration in a rigorous and deliberative process designed to select only the best of the best as candidates for substantial program funds or MREFC support.

This process of identification and selection is, and must be, continuously repeated. Despite the stunning pace of research progress in the 21st century, the future success of entire fields depends critically upon development of new and powerful tools, some of which are described below. Such projects are increasingly large and complex, with highly sophisticated IT components, including distributed sensor networks and vast data-storage and transmission capabilities. Costs of construction now typically extend to tens or hundreds of millions of dollars, with millions more required for decades of operation and maintenance.

So great is the potential effect of these



The Gregorian dome high above the Arecibo dish in Puerto Rico.



Strong magnetic fields twist and turn on the Sun, building up tremendous amounts of energy that can be released explosively in what is called a flare, pictured here.

A re-entry cone, used to re-enter an existing drill hole on the ocean floor, starts its journey to the seafloor from the deck of the drillship *JOIDES Resolution*.

[1] A glossary of acronyms is included in the Appendices.

expenses that in 1995 Congress created a special, separate MREFC account to support the acquisition, construction and commissioning of major research facilities and equipment. It is intended to prevent such periodic expenditures from disrupting the budgets of NSF directorates and threatening NSF's traditional support of "core" research programs, which are funded from the $4 billion Research and Related Activities (R&RA) account. Typically the threshold for MREFC projects is 10 percent of the annual budget of the proposing directorate or office.

But cost is by no means the sole criterion. Each MREFC candidate project must represent an outstanding opportunity to enable research and innovation, as well as education and broader impacts. Each should offer the possibility of transformative knowledge and the potential to shift existing paradigms in scientific understanding, engineering processes and/or infrastructure technology. Moreover, each must serve an urgent contemporary research need that will persist through the often lengthy process of planning and development.

As in any sort of exploration, the horizon keeps moving. Every year new opportunities will arise and new priorities will assert themselves. As a result, no roster of potential projects is ever final. Responsible stewardship of public funds demands that all candidate efforts be evaluated and reevaluated constantly in the context of the latest, most pressing research goals and the most profoundly important unanswered questions. To that end, the National Science Board (NSB) and the Director, in their joint report *Setting Priorities for Large Research Facility Projects Supported by the National Science Foundation*, define the process used by the NSF for developing, reviewing, approving and prioritizing large-scale research facility projects.

The first chapter of this Facility Plan provides an overview of those objectives and opportunities, and their intellectual context, as of 2005. The contents derive from workshops, advisory committees, National Research Council (NRC) reports, the expertise of visiting and permanent scientific staff and unsolicited proposals from the community. Many NSF directorates also conduct internal priority setting and strategic planning activities that endeavor to locate the leading edge of research, anticipate where it might be in the future, and determine the most valuable areas of discovery and innovation.

The second chapter describes MREFC facilities already in operation or under construction and suggests some of the promising candidates identified by the nation's research communities. Taken as a whole, the Facility Plan constitutes a conceptual snapshot of the science and engineering community's views in 2005. It is the first iteration of a product that will be revised and updated regularly as needed.

The Degree Angular Scale Interferometer (DASI), shown here, operates from the Amundsen-Scott South Pole Station is designed to measure temperature and polarization anisotropy of the cosmic microwave background radiation over a large range of scales with high sensitivity.

CHAPTER 1

Research Objectives and Opportunities at the Frontiers of Science and Engineering

Research exploration operates at many frontiers simultaneously. One useful way to distinguish them is by physical scale of inquiry. There are fundamental questions to be answered across more than 50 orders of magnitude in space and time, ranging from the subatomic to the cosmic, and from quintillionths of a second to billions of years. Each scale presents special challenges — and special opportunities — for revolutionary facilities and the work they can make possible.

Achieving many important objectives will require a new generation of computing, communication, analysis and information technologies to revolutionize the conduct of science and engineering research and education. These resources, many of which are now in development, are collectively known as "cyberinfrastructure" (CI). They will enable researchers to conduct detailed "experiments" on computer models and to investigate phenomena that are inherently difficult to visualize. Equally important, they will serve one of NSF's most important and most ambitious goals: to make possible information and resource sharing on a scale unparalleled in human history, including instantaneous access to data repositories, digital libraries and field-specific instruments, as well as tools for collaboration, data management, analysis, visualization and simulation.

In addition, answering many of the most profound questions will often involve combining insights from two or more scales, and from radically different kinds of equipment. For example, progress in cosmology will demand dramatically improved understanding of particle physics, just as a complete understanding of gravity — the dominant force at astronomical distances — will entail reconciling it with quantum mechanics — the rules that govern matter and energy at the very smallest dimensions.

To Index Page

MESOSCALE 1

From Millimeters to Hundreds of Kilometers

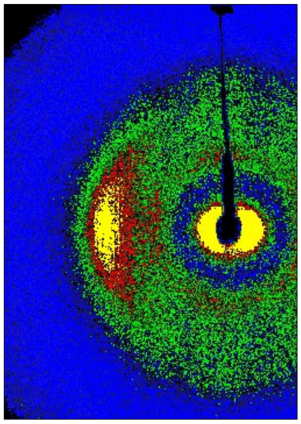
Although this size range encompasses the familiar world in which we live — and in which most traditional science and engineering work has been done — it will never exhaust its mysteries. Indeed, entire new horizons of research have appeared in the past few years thanks to developments made possible by the convergence of fresh insight and powerful new technologies.

Fundamental questions in a host of mesoscale fields can only be answered satisfactorily using the next generation of tools. A few examples include:

THE BIOSPHERE.

How can we detect, model and predict the ways in which coupled natural and human systems respond to different kinds of stresses and modifications? Such models must include the consequences of the interplay among air, water, land and biota and predict the effects of altering one variable (e.g., a particular pollutant, precipitation or invasive species) on one or more other variables. Those effects, it now appears, can be hugely complicated and are frequently nonlinear. Understanding them will require novel collaborations of researchers and collation of data taken simultaneously in many ways at many physical and temporal scales.

It will also require researchers to view holistically different kinds of interrelated phenomena that have never been regarded as systems. For example: How do population trends, land use and industrial and urban processes affect hydrological systems and water quality in rivers, lakes and estuaries? How can research about human and social behavior at all levels, from small groups to communities to regions — especially in response to crises or destabilizing events — lead to effective engineering approaches to managing these dynamic systems?



X-ray scattering pattern of a stretched DuPont fuel cell membrane. This project was funded in part with a grant through NSF's Experimental Program to Stimulate Competitive Research (EPSCoR).

Such efforts will require new kinds of ecological observatories enabling collection and integration of data from a number of different kinds of distributed sensors, both for empirical research and for creation of effective models. The results can profoundly affect our ability to understand the spread of infectious diseases, quality of water supplies in critical regions, stability of essential ecosystems, optimal engineering solutions to complex problems and many other issues.

ENERGY AND WASTE.

What are the essential power sources and industrial processes of the future? To a large extent, 21st-century civilization is still running on 19th-century technologies — most notably, combustion of fossil fuels. And humanity is still practicing a social paradigm unchanged in 100,000 years — burying or burning its copious wastes. Finding alternatives to those situations is one of the most pressing goals facing engineers, chemists and physicists. Fuel cells, photovoltaic devices, biologically produced fuels and superconducting materials are only in preliminary stages of development, and they are merely the first generation of their kind. Fundamental research is needed to improve performance and identify new methods of storing and transporting energy. At the same time, investigators must devise much more efficient and benign forms of manufacturing, recycling and disposal, while discovering or creating new materials that blur the distinction between organic and inorganic, combining the characteristics of metals, films, polymers and ceramics.

INDIVIDUAL AND SOCIAL DYNAMICS.

How can we understand the totality and complexity of human and organizational behavior? The integration of vast computing power, massive data sets, large complex models and new analytical tools will be necessary to enable researchers to comprehend, simulate, visualize and predict such behavior. Among the many outstanding questions: How do organizational and collective behaviors differ from the behavior of the individuals that made up such collectivities? What forces shape the various subsystems of societies, such as the economy, the polity and the legal system? What determines creativity and innovation at the individual and organizational levels? How do social and biological factors combine to shape human preference? How do emotions and cognition combine to influence human choices? How do people, organizations and social systems respond to sudden shocks and extreme events, such as market collapses, ethnic violence, floods, earthquakes, tsunamis and terrorist assaults?

These questions cannot be answered without integrating information collected across a wide range of scales, from individuals and peer groups to regional and ethnic clusters, and throughout diverse disciplines, from psychology and anthropology to economics and law. Ensuring the statistical validity of such unprecedented data sets presents a separate and equally formidable challenge to current understanding.

SENSORS AND SENSOR SYSTEMS.

How can we detect subtle — but potentially crucial — changes in materials or the environment, and combine sensor signals into a coherent picture? Numerous scientific and technical problems, from making sense of collisions at a particle accelerator to monitoring the security of facilities to tracking alterations in brain waves or blood chemistry, require steady progress in two areas: developing ever more sensitive and ever-smaller sensors, and devising robust systems of assembling multiple signals into useful information. Those objectives will require basic research that brings together specialties as diverse as surface chemistry, microelectronics, biophysics, photonics, information theory and mathematics.

COGNITIVE AND BEHAVIORAL SCIENCES.

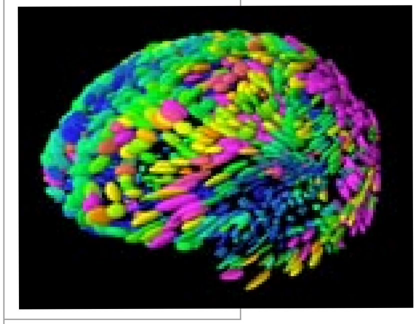
How are brain functions at the molecular, cellular, physiological and neural network levels related to human functions such as memory, learning and decision-making? Within the past two years, both invasive and non-invasive sensing technologies have expanded rapidly. It is now possible to design experiments that could simultaneously measure brain function in large numbers of experimental subjects and/or interacting individuals. Indeed, we may soon be on the verge of characterizing at the neurological level how people learn — that is, how the brain acquires, organizes and retains knowledge and skills.

The goal is to better understand the biological underpinnings of behavior, as well as the ways in which behavior feeds back into neural activity. The implications of such research for educational theory and practice — as well as potential applications to various neural disabilities and other deficits — are extraordinary.

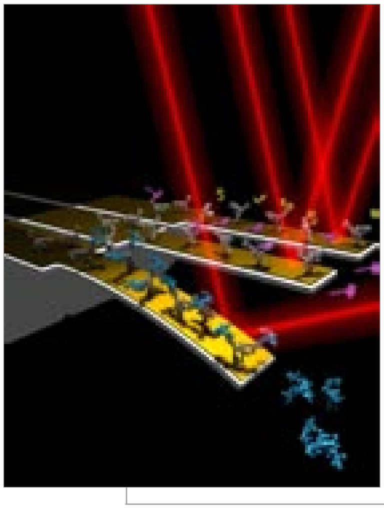
GENETIC AND OTHER DATA SETS.

Across the stupendous spectrum of living things, what are the most significant similarities and differences? One of the most promising ways to answer that question entails the creation of comprehensive genome databases. At present, only a few organisms have been fully sequenced, and those sequences are still incompletely understood. Furthermore, broader and faster research is needed to answer basic, enduring questions such as: What is the minimal biological "tool kit" of living things? What biochemical and physiological processes are conserved across kingdoms and 3.5 billion years of evolution, and what major forms do variations take? What genes are responsible for human cognitive capabilities? And what are the origins and development of the human species and the nature of human adaptation processes over the last five to six million years?

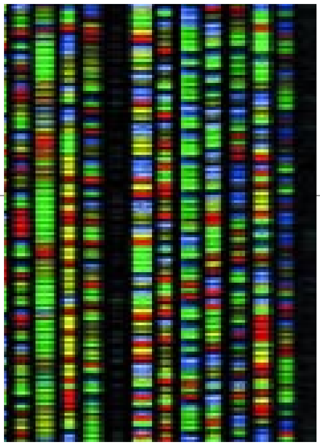
Moreover, the current successes of genomic research have revealed new opportunities. No counterpart to GenBank, the public DNA sequence database maintained by the National Center for Biotechnology Information (NCBI), exists for other kinds of biological data (e.g., morphology, anatomy, ecology, behaviors, or ontogenies). Serious efforts are needed to systematize the vast hoard of biological information.



Researchers have created virtual template brains that can assist in the study of anatomical brain differences related to aging and disease. The variation in color and shape of the spheres indicates the magnitude and principal directions of the anatomical differences across subjects.



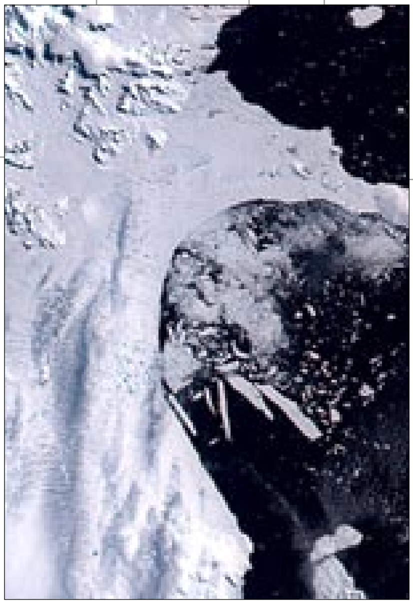
Cantilevers specifically modified for a biochemo-optomechanical chip are illustrated above. The chip is currently being developed for high-throughput multiplexed biomolecular analysis.



The DNA sequencing process makes it possible for researchers to discover the amino-acid sequence in a substance. Shown here is the last step in the process: the end result.

MESOSCALE 2

Thousands of Kilometers



One of a series of satellite images of the Antarctic Peninsula that recorded the catastrophic break-up of a massive portion of the Larsen B ice shelf — an area larger than Rhode Island — in 2002. NSF is responsible for managing all United States (U.S.) activities in the Antarctic as a single, integrated program, making possible research in Antarctica by scientists supported by NSF and by certain other U.S. mission agencies.

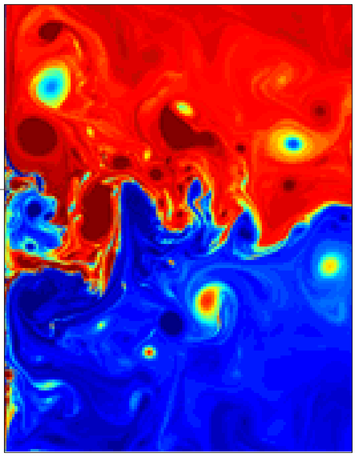


Image from a numerical simulation of an idealized wind-driven ocean basin, calculated on massively parallel computers at the San Diego Supercomputer Center (SDSC).

Thanks to a growing network of global sensors and data repositories, and a new awareness of relationships and "teleconnections" among disparate variables, it is increasingly possible to understand natural (and anthropogenic) phenomena on a planet-wide scale. Investigators are finally poised to expand understanding and predictability of the complex, interactive processes that determine variability in the past, present and future states of the Earth. These processes control the origin and current status of the forms of life on the planet and affect the interdependencies of society and planetary processes.

GLOBAL ENERGY BUDGET AND PLANETARY "METABOLISM."

How can we better understand the links between physical and chemical processes by focusing on the exchanges of energy within and among the components of the Sun-Earth systems, including the oceans and atmosphere? Among other goals, progress is necessary to improve the accuracy and projective power of global climate models, and to understand how ocean circulation — and therefore climate — responds to global temperature changes. In addition, comprehending the present and future state of the planet demands improved and more detailed understanding of the links and feedbacks among physical, chemical, geological, biological and social systems; how they have evolved; and how they affect the biocomplexity in the environment.

PLANETARY STRUCTURE.

How do the shape and composition of Earth's components change over time, from the inner core to the upper atmosphere? Included here is the detection of motion of the Earth's surface on the scale of millimeters per year, the deformation resulting from the buildup of stress by tectonic processes that lead to earthquakes, the deformation of volcanoes preceding eruption and the movement of ice sheets and glaciers.

CHEMICAL BALANCE AND FUNDAMENTAL CYCLES.

What processes determine the ways in which carbon, nitrogen, sulfur and other key elements cycle through the Earth's biological, geological and ocean systems? For example, what factors govern the amount of carbon sequestered in seawater and biomass, and what are the variables, parameters and limits of those processes? How much buffering, regulating or offsetting chemical action do natural systems offer to increased concentrations of man-made compounds, and what are the likely points at which irreversible changes may occur in chemical regimes?

WHOLE-EARTH MODELS OF BIOLOGICAL SYSTEMS.

A major gap in large-scale simulations of global processes to date has been in the dynamic simulation of biological systems at a global scale. A major integrated hardware and software effort could elucidate some of the most vexing questions in life sciences, such as: What is the biological "carrying capacity" of the Earth and the effects of different variables on it? What is the optimal global spatial allocation of crops and livestock for sustainable production? How do alleles, genes and genotypes move dynamically through populations, organisms and ecosystems? What factors will allow us to predict accurately the occurrence of new species and the imminent extinction of others?

MICROSCALE 1

Micrometers to Nanometers

In recent years, imaging, manipulation and testing of objects has become possible at smaller and smaller sizes and time scales, resulting in an explosion of progress across dozens of fields and holding the promise of truly transformational understanding of matter and energy. With today's equipment, even students can pick up and move a single atom on a surface. Researchers have learned how tiny modifications in the assembly, composition or placement of atoms and molecules produce strikingly different behaviors that can be customized for particular effects. One of the most intriguing and valuable discoveries is the fact that the properties of matter can change dramatically as dimensions approach a nanometer (one billionth of a meter, or about 10 atomic diameters).

Numerous devices are already exploiting these characteristics. For example, a structure called a "quantum dot" can hold just one electron, making it a "single electron transistor" hundreds of times smaller than those in today's most sophisticated microchips. Even mechanical systems such as gears, turbines, levers and fluid channels can now be constructed on the scale of a few microns (millionths of a meter — or about one-fiftieth the width of a human hair), enabling investigators to create microchips for rapid analysis of blood or genetic material.

At the same time, miniaturization and growing sophistication of "photonic" devices, which generate and control light just as electronic devices generate and control electrons, are transforming communications and signal processing. Because light moves through matter much faster than electrons, and can carry numerous superimposed datastreams at different wavelengths, photonics research promises spectacular changes in the speed of computing and information transfer.

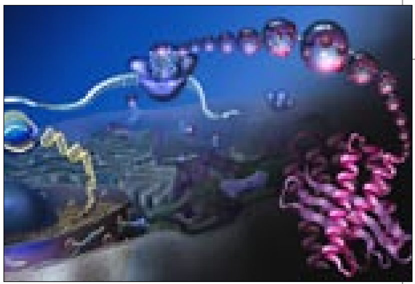
Finally, research is now approaching another long-sought goal: To view chemical reactions in fine detail and in small time increments. Just as fast camera shutter speeds can "stop" even rapid motion, the advent of lasers with pulses as short as one millionth of a billionth of a second are making it possible to create "slow motion" images of chemical reactions, vastly increasing our understanding of the ways atoms combine or break apart.

Continuing fundamental research at the micro- and nanoscales will have a major impact on our comprehension of many important phenomena. Among them:

MOLECULAR UNDERSTANDING OF LIFE PROCESSES.

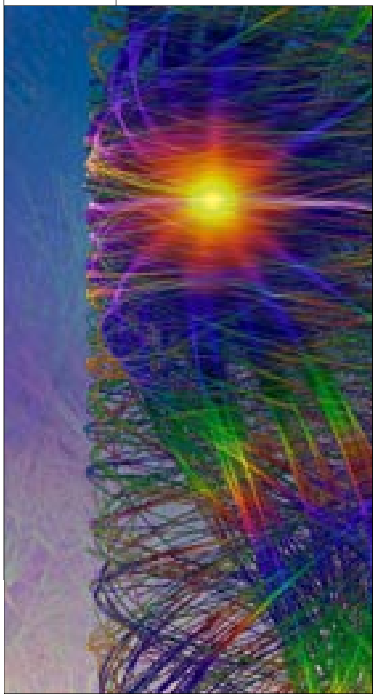
Humanity's recently acquired ability to investigate fundamental biological functions at the molecular scale has revealed the marvelous complexity of microscale cellular processes — and in the process raised a host of truly profound questions, among them: How do proteins fold and bind, producing many of the essential biochemical reactions of life? How do membranes work to permit selective entry and exit of molecules and ions, permitting cells to interact with their surroundings? What are the molecular origins of the emergent behavior that underlies life processes from heartbeats and circadian rhythms to neurological activity? How do biological systems assemble themselves? How did the first biologically relevant molecules form and how did they organize into self-replicating cells? How does a single fertilized cell become a multi-cellular organism? And how does a common set of genes give rise to a wide range of morphologically and ecologically distinct organisms?

Medical researchers seek to apply those insights to treatments, and engineers require them for innovation in fields such as bioengineering and nanotechnology.



An artist's rendition of the inside of a cell.

To Index Page



Electron paths in a nanowire, including imperfections in the wire, are pictured here. NSF has been a pioneer among federal agencies in fostering the development of nanoscale science, engineering and technology. It supports fundamental knowledge creation across all disciplinary principles at the nanoscale.

And biologists need to fill these gaps to understand how organisms operate and evolve at the most fundamental level. It has been understood for many years that everything in a living cell is connected to everything else, but mapping out the networks has been an extraordinarily difficult task. Understanding gene expression, for example, involves thousands of genes and their products, many of which combine, cooperate, antagonize and/or collaborate to regulate the expression of thousands of other genes at multiple levels. Modeling this enormously complex system will demand large amounts of new knowledge that microscale science promises.

MOLECULES AND MATERIALS BY DESIGN.

Among its "grand challenges" for chemistry and chemical engineering, a recent National Academies (NA) report urges researchers to "learn how to synthesize and manufacture any new substance that can have scientific or practical interest, using compact and safe synthetic schemes and processes with high selectivity for the desired product, and with low energy consumption and benign environmental effects in the process."

That will require knowledge of how to design and produce functional molecules, devices and systems from first principles, atom by atom, and will demand the ability to image and control individual atoms and molecules in three dimensions. Investigators will have to learn how to design and produce new material structures, nanoscale devices and system architectures with properties that can be predicted, tailored and tuned before production. In particular, that effort will include the understanding and exploitation of self-assembly. Part of the challenge will be finding ways to mimic and modify the creation of natural substances as different as silk and seashells. Part will consist of creating entirely new compounds and structures that do not occur naturally. And part will combine both into hybrid materials with specific desired properties.

The results will prompt revolutionary scientific advances and engineering innovations in areas such as individualized pharmaceuticals, new drug delivery systems, more resilient materials and fabrics, catalysts for industry and much faster computer chips, among others.

EFFICIENT MANUFACTURING AT THE NANOSCALE.

New kinds of fabrication will require widely available instruments, metrics and positioning equipment that permit standardization and dimensional control on a scale much smaller than most existing facilities provide. In order for nanoscale manufacturing to become affordable, the National Nanotechnology Initiative (NNI) Supplement to FY2004 Budget calls for "highly capable, low-cost, reliable instrumentation and internationally accepted standards for the measurement of nanoscale phenomena and for characterization and manipulation of nanostructures," as well as "standard reference materials and standardized instruments with nanoscale resolution."

ELECTRONICS BEYOND SILICON.

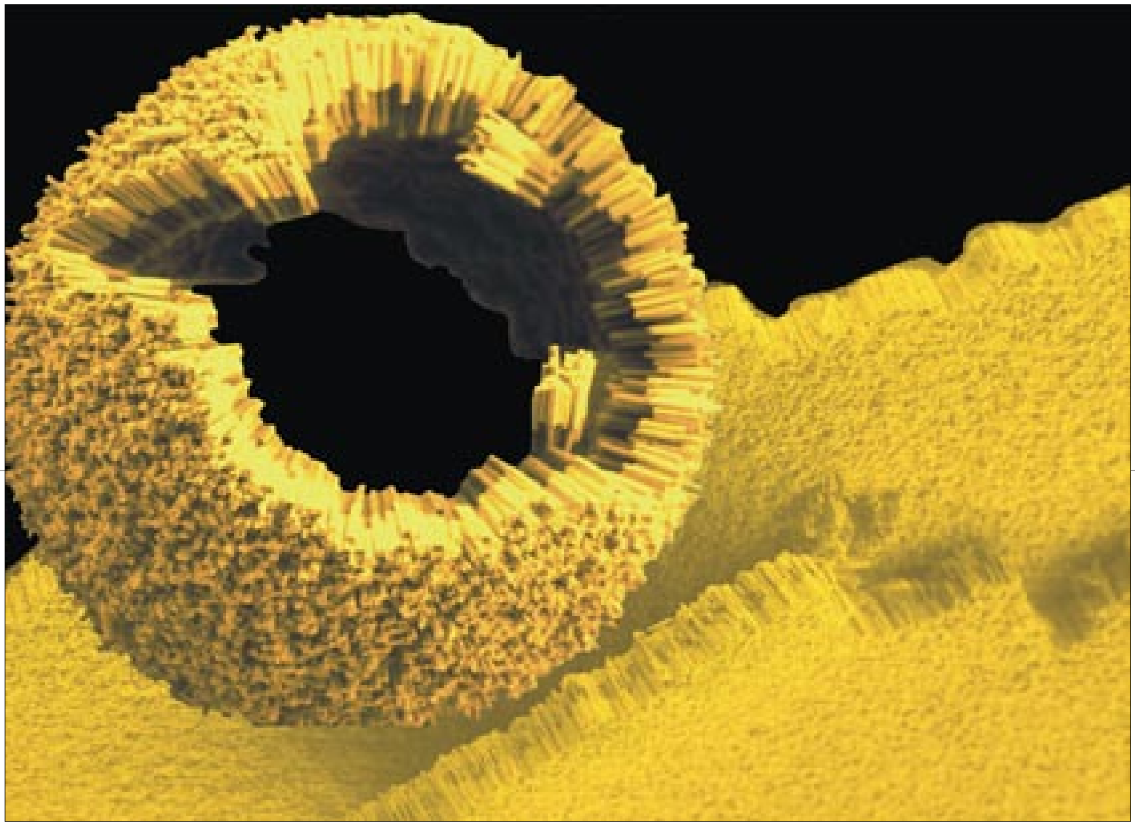
Since the arrival of the first miniaturized integrated circuits more than 30 years ago, the number of transistors that can be packed onto a microchip has increased exponentially, doubling approximately every 18 months. But this progression, known as "Moore's Law," cannot continue unless individual components are made much smaller — and engineers are reaching the physical limits of traditional semiconductor and metal devices. The next generation of microprocessors will rely on molecular-scale electronics.

Making and controlling such nanostructures demands entirely new areas of knowledge and expertise. For example, researchers will have to create novel architectures to accommodate drastically smaller voltages and currents, and find ways to make the processing elements synchronize with each other directly rather than follow a central clock, among dozens of other problems.

At the same time, scientists and engineers will be struggling to construct useful "quantum computers" in which a unit of information does not exist only in one of two states (0 or 1, on or off, as in conventional binary computers), but in a "superposition" of multiple states simultaneously. This condition, made possible by the often counterintuitive laws of quantum mechanics, can permit a variety of calculations to be made at once — potentially reducing the timetable for solving certain problems from years to hours. However, the same quantum uncertainty that makes the superposition possible also makes it intensely difficult to keep such a machine in a steady state and to read out information accurately. The obstacles to quantum computing are daunting, and call for the utmost ingenuity in creating new instruments and devices.

NEW STATES AND BEHAVIORS OF MATTER.

As recently as 10 years ago, physics recognized only four states of matter: solids, liquids, gases and plasmas. Then researchers devised equipment and techniques that made it possible to create an entirely new state — predicted by theory and called a Bose-Einstein condensate — in which multiple atoms coalesce into a single condition equivalent to one "super atom" at extremely low temperatures. This is only one of the peculiar phenomena that occur in such conditions, along with superconductivity and superfluidity, the flow of fluid without viscosity or resistance. Continuing research in the field of cryogenics, where work is done as close to absolute zero as possible, is expected to prompt the emergence of even more unusual properties.

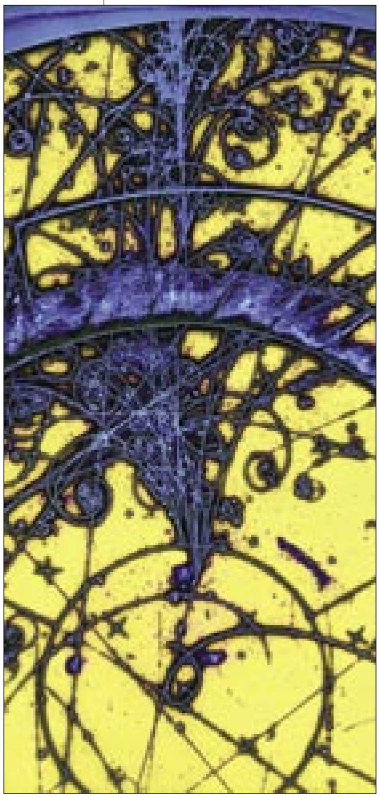


Inspired by the molecular assembly techniques used in living cells, chemist Chad Mirkin and his colleagues at Northwestern University have created a new class of nanometer-scale building blocks that can spontaneously assemble themselves into ultra-tiny spheres, tubes and curved sheets.

To Index Page

MICROSCALE 2

Subatomic



An artistically enhanced picture of particle tracks in the Big European Bubble Chamber (BEBC).

Over the past 100 years, research has revealed the structure of the atom, the substructure of its neutrons and protons, the existence of antimatter, and the behavior of particles that carry three of the four fundamental forces. This collected knowledge, embodied in the consensus theory of particles and interactions known as the "standard model," is one of the grand triumphs in the history of science, making predictions that can be confirmed by observation to 10 decimal places. But it is incomplete.

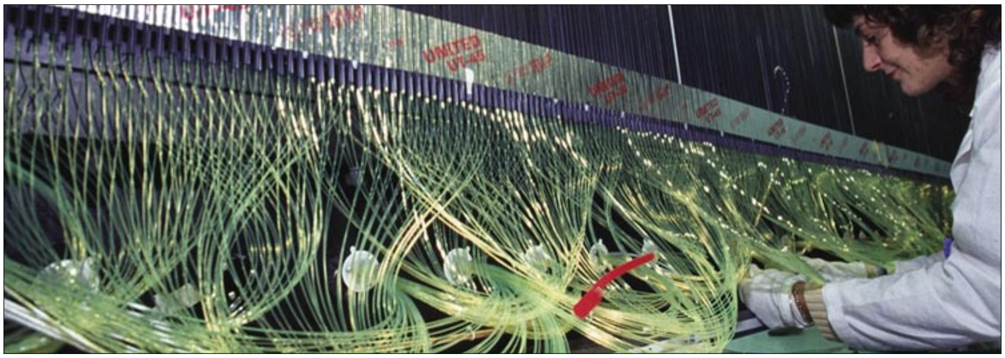
Among other problems, the standard model does not explain why the elementary particles have such a remarkable variety of masses, nor how the property of mass itself arises. It cannot account for certain inconsistencies, or "asymmetries," in the behavior of particles and their antiparticles. So both theorists and experimentalists are working to expand, refine or replace the model. In the process, they are asking the most fundamental questions possible. Among them: What is the full set of nature's building blocks? Have we detected them all, or are there a few — or dozens — more? How many space-time dimensions are there and did they emerge from something more fundamental? Is there a single, unified force that underlies electromagnetism, the weak and strong forces and gravity? If so, how is it described?

Some of the answers, if they arrive, will be found on Earth at high-energy accelerators that smash particles into their antiparticles, creating brief showers of very exotic material. Physicists use exquisitely sensitive detectors to examine the results, in search of new particles and processes. Over the next decade, the Large Hadron Collider (LHC) at the European Organization for Nuclear Research (CERN) is expected to reveal — or possibly rule out — the existence of particles beyond the standard model. But numerous other high-energy devices around the world will be required to conduct complementary and confirmatory research. And researchers will be watching those results closely to see if they provide support for "string theory," which posits that what we regard as different kinds of particles are actually simply different vibration modes of infinitesimal string-like entities comprising 10, 11 or more dimensions.

At the same time, particle physicists are teaming with astronomers and astrophysicists to use the awesome variety of extreme conditions detectable in space as "laboratory specimens" for new theories of matter and force. Many experts now believe that any complete revision of the standard model will have to combine ground-based and astronomical observations into a comprehensive understanding.

Some of the most interesting phenomena, and many of the most potentially revolutionary theories, span spatial scales from the smallest to the largest. To cite only two: What is the connection between elementary particles and the dark matter and dark energy that make up 95 percent of the universe? And how do the properties of individual atoms and molecules interact to create the properties of bulk materials?

NSF's contribution to the international LHC project includes the construction of two detectors: the Compact Muon Solenoid and ATLAS, A large Toroidal LHC Apparatus. ATLAS' tile calorimeter will collect the energy released in the LHC's proton-proton collisions. Special plastic manufacturing techniques have been adapted to mass produce the ATLAS elements.



To Index Page

In science, new answers always bring even newer questions.

That has clearly been the case during the past quarter century, which constitutes a golden age of discovery in astronomy and cosmology. Through powerful tools and ideas, astronomers and physicists have extended our vision further out in space and our understanding further back in time. They have also uncovered new puzzles, unexplained phenomena and areas of interest. The list is long, and begins close to home.

LIVING WITH THE SUN.

A deep understanding of our local star, the Sun, is enormously important for many practical reasons — including the need to anticipate solar events and protect against their effects on communications, and to discern the Sun's stability and its role in Earth's climate and evolution. Comprehending solar phenomena will also provide a wealth of information about millions of similar stars in the universe, and particularly about the activity and variability of solar-type stars.

Specific research questions regarding solar/terrestrial connections include: What are the processes that cause solar variability? What are the mechanisms responsible for powerful solar activity such as solar flares and coronal mass ejections? What is the impact of solar activity on terrestrial communications and power systems? What is the connection between solar activity and space weather? What is the origin of the Sun's 22-year solar cycle, and why is it manifested in the number and location of sunspots? How does the solar dynamo work to create the star's titanic magnetic field? What powers the solar corona, which is hundreds of times hotter than the surface of the Sun?

Answering these questions fully will require new and very sophisticated devices and telescopes, both Earth-based and space-based. It will also demand instruments that can discern fine structure in the magnetic fields and trajectories of solar plasma, whether in "active regions" in and around sunspots or within ejected material in prominences, flares and coronal mass ejections.

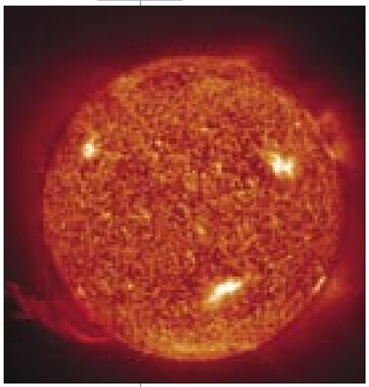
OUR GALAXY AND ITS NEIGHBORS.

It has been decades since the presence of "dark matter" — the invisible material that makes up most of the mass of the universe — was first inferred from the rotation of spiral galaxies. Yet its nature is still a mystery. Further understanding will combine astrophysical observations with Earth-based efforts at detection, several of which are already under way. Those activities, in turn, will have to be tempered by and reconciled with discoveries in particle physics from existing and future accelerators and other facilities.

Conversely, it was only a few years ago that astronomers produced the first evidence of planets around stars besides our Sun. Now about 150 are known. But it is still unclear how planets form, which mechanisms determine their composition, and whether there are habitable analogues to Earth in nearby space. Much higher telescopic resolution, and new sensor suites, will be needed to begin to understand these topics.

Different science will be required to explain many ultrahigh-energy phenomena observed recently, from gamma-ray "bursters" to superenergetic cosmic ray particles whose method of acceleration is unknown but may indicate new phases of matter.

Finally, the sky is full of stars, and there are about 100 billion in our galaxy alone. Yet there is still insufficient understanding of how stars form, what factors determine their ultimate qualities, how long they live and how they die. There is evidence of stars in our region of space that are practically as old as the universe itself. And there may be stellar phenomena that we have not yet observed.

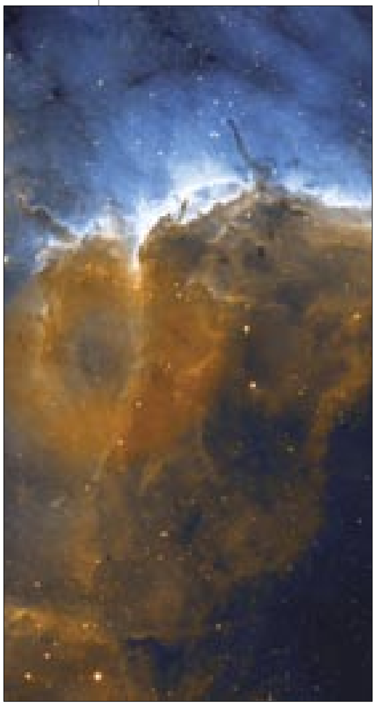


Millions of miles away, coronal mass ejections from the Sun blast billions of tons of plasma into our magnetosphere with the potential to disturb space systems, power grids and communications.

Stars surrounding the South Celestial Pole appear to spin over the Gemini South dome in this digital star trail image. Images obtained every minute for a period of about four and a half hours were stacked in Photoshop to create this image.

MACROSCALE 2

Millions to Billions of Light Years



This is an image of the Pelican Nebula, produced by the National Optical Astronomy Observatories' (NOAO) survey program, "Deep Imaging Survey of Nearby Star-Forming Clouds." A faint jet squirts out of the tip of one of the pillars, apparently indicating the presence of an unseen protostar.

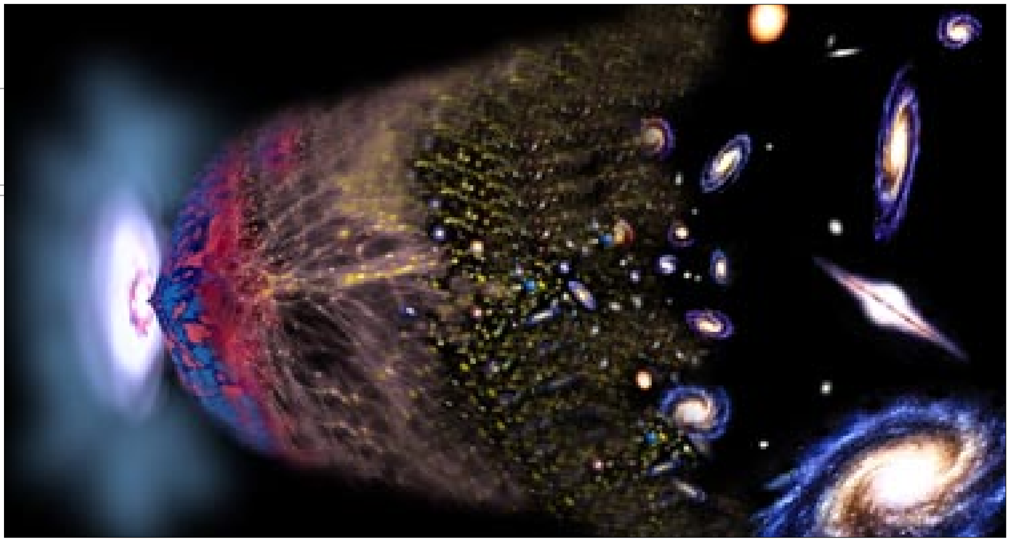
Some recent discoveries have shaken conventional ideas so fundamentally that they are obliging researchers to rethink some of their most familiar notions. For example, our understanding of cosmology was challenged less than a decade ago when researchers produced evidence that the expansion of the universe — known since the early 20th century and presumed to be relatively constant — was in fact speeding up.

What currently undetectable "dark energy" could be fuelling that expansion? What does it mean for the destiny of our universe? What are the components of the 95 percent of the cosmos that is not made up of ordinary matter? And what do the new revelations portend for our comprehension of elemental forces?

Gravity is perhaps the most spectacular example. It was the first fundamental force to be understood scientifically, when Newton united the heavens and the Earth through his equations. Maxwell's equations then united the forces of electricity and magnetism in the theory of electromagnetism, and a century later electrodynamics was explained on the quantum scale. The strong and weak forces were characterized with varying degrees of success. By the end of the 20th century, it appeared to many observers that the nature's fundamental interactions were, at last, comprehensible, requiring only some refinements and calibrations.

That was by no means the case. Einstein's Theory of General Relativity revealed much about the force of gravity on the cosmic scale. But if it is to be part of a truly cohesive and complete description of what shapes the universe, gravity must be made consistent with quantum mechanics, the rules that govern interactions at the smallest spatial scales. So far, the two theories are incompatible. Researchers expect that current and future gravitational wave observatories will add abundant insight by detecting space-time perturbations that occur when two neutron stars or two black holes collide.

Attempts to reconcile gravity and quantum theory will also have to take place in the context of other large questions about the origin and evolution of the cosmos, including: What was the "Big Bang" that produced the universe some 13.7 billion years ago? Did the cosmos experience a split-second period of "inflation" that expanded it? How and where did the chemical elements form and how has the composition of the universe evolved? How did galaxies form and how are they evolving?



An artist's conception illustrating the history of the cosmos, from the Big Bang and the recombination epoch that created the microwave background, through the formation of galactic superclusters and galaxies themselves. The dramatic flaring at right emphasizes that the universe's expansion currently is speeding up.

To Index Page

OBJECTIVES

Finally, some of the most ambitious research objectives transcend scale, and achieving them will have repercussions across numerous disciplines and dimensions.

COMPUTER SCIENCE.

What is computable? What are practical realizations of machines composed of hardware and software that can correctly implement computable procedures and functions in bounded, practical amounts of time? What are the principles of organization and the structure of software that will permit increasingly large collections of machines to work together effectively on a common problem? How can collections of machines communicate with each other effectively? What principles underlie the activities of humans (perhaps aided by other machines) in the task of designing hardware and software?

How can interlocking systems, or "networks of networks," be made secure, fault-tolerant and robust to the greatest degree possible? How can those systems be integrated with social and cultural norms so as to provide the greatest utility to populations in time of crisis? How can vast databases be organized so that they can be queried rapidly?

What are the limits of artificial intelligence, and how can they be approached to expand human cognitive capabilities? Can heuristic or probabilistic decision schemes be maximized in machine intelligence? What are the possibilities of computerized learning? How can we manage and oversee the structure of complex computer systems with millions or billions of components? And how can systems with different characteristics and/or architectures communicate — especially in searching for patterns in enormously large data sets?

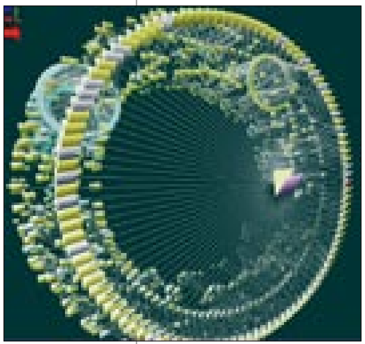
MATHEMATICS.

How can uncertainty be quantified and controlled? Which mathematical structures best describe multiscale phenomena? How can large datasets be mined for information? How fast can large numbers be factored? And how can data be archived so as to be accessible decades from now?

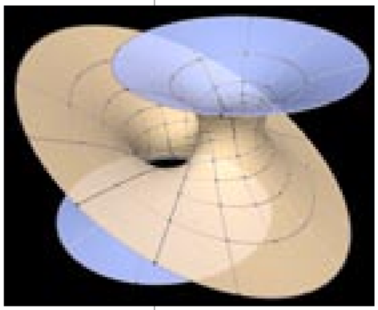
How can we best model complexity, self-organization and "chaotic" or nonlinear phenomena? How can patterns of data — including "unvisualizable" situations such as geometries in more than four dimensions, or sensor data streams from diverse instruments — be assembled into shapes and structures that have explanatory meaning? What rules govern complicated natural processes from the differentiation of cells and the expression of genes to the folding of proteins or the self-arrangement of crystalline nanostructures? What sorts of algorithms are suitable to test systems — such as multibillion-transistor computer chips or 100-billion-neuron human brains — whose total possible data routes are astronomically large?

What sorts of mathematical forms best achieve different kinds of optimization, from efficient transportation and manufacturing networks to maximum return on financial portfolios to deployment of armies and materiel? How can rare events of interest be extracted from huge data sets? How can significant patterns be discerned from the inherent "noise" and stochastic artifacts that arise in such large collections? And similarly, how can one identify, record and analyze the complicated interplay of numerous covariables in large systems — whether ecological, social, neurological or geophysical?

So profound are the foregoing questions, and so uncertain the approaches to answering them, that the requisite instruments and facilities can barely be imagined in 2005. They will test the limits of science and engineering, and the power of human ingenuity.



This Ferris wheel-like arrangement represents an elegant solution for managing unwieldly amounts of information. The three-dimensional interface organizes computer contents by their relationships rather than their physical position on a hard drive. The program displays relationships that would not be clear in a normal, two-dimensional file tree and could be applied to any sort of hierarchical database.



This surface illustrates the failed attempt to construct a complete, properly embedded minimal surface without handles and three ends: No matter what one does, the three ends can not all be simultaneously parallel and will thus eventually intersect.

CHAPTER 2

Major Research Equipment and Facilities Construction Projects

The variety of facilities that are ongoing or requested as new starts includes:

- single-location, dedicated facilities for observation/experimentation, sometimes with e-capabilities for remote control and/or transfer of data for analysis (e.g., the Atacama Large Millimeter Array (ALMA), IceCube);
- single-location, multiple instruments and associated infrastructure providing resources for a variety of research activity of varied but related types (e.g., South Pole Station) to which users travel or send samples or connect electronically;
- distributed/connected instrumentation taking common sets of data for integrated analysis (e.g., EarthScope);
- distributed/connected instruments of varied types that provide a suite of user capabilities (e.g., the George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES), National Ecological Observatory Network (NEON), etc.);
- mobile research platforms such as the Alaska Region Research Vessel (ARRV).

To Index Page

The table below, taken from the NSF FY 2006 Congressional Budget Request, summarizes recent, current and projected expenditures from the MREFC account.

MREFC Account[1]

(Dollars in Millions)

	FY 2004 Actual	FY 2005 Current Plan	FY 2006 Request	FY 2007 Estimate	FY 2008 Estimate	FY 2009 Estimate	FY 2010 Estimate
ONGOING PROJECTS							
Atacama Large Millimeter Array (ALMA) Construction	50.70	49.30	49.24	47.89	46.49	37.37	20.91
EarthScope	43.24	46.97	50.62	26.80			
High-performance Instrumented Airborne Platform for Environmental Research (HIAPER)	12.54						
IceCube Neutrino Observatory	38.36	47.62	50.45	28.65	21.78	11.33	0.95
National Ecological Observatory Network (NEON)				12.00	12.00	20.00	
Network for Earthquake Engineering Simulation (NEES)	8.05						
Rare Symmetry Violating Processes (RSVP)[3]		14.88	41.78	48.00	30.75	15.00	8.00
Scientific Ocean Drilling Vessel (SODV)		14.88	57.92	42.20			
South Pole Station	21.03						
Terascale Computing Systems (TCS)	10.05						
NEW STARTS							
Ocean Observatories Initiative (OOI)				13.50	42.00	65.50	66.90
Alaska Region Research Vessel (ARRV)				49.32	32.88		
Advanced LIGO (AdvLIGO)					28.48	42.81	46.31
Totals	$183.96	$173.65	$250.01	$268.36	$214.38	$192.01	$143.07

Totals may not add due to rounding.
Estimates for 2007 and beyond do not reflect policy decisions and are presented for planning purposes only.

[1] The FY 2005 total includes $37.13 million carried forward from previous years. This includes $29.87 million for the South Pole Station Modernization (SPSM) project, $115,000 for Polar Support Aircraft upgrades, $34,418 for the South Pole Safety project, and $7.11 million for IceCube.

[2] This table does not reflect changes to the priority order, which the National Science Board made at its May 2005 meeting, for the four projects that have not begun to receive MREFC funding. The NSB considers NEON to be a New Start under the MREFC account, and the revised priority order of the New Starts is ARRV, NEON, OOI and AdvLIGO.

[3] At the August 2005 meeting of the NSB, NSF recommended and the NSB approved the termination of RSVP. See the RSVP narrative for additional information.

In FY 2004, MREFC funding was provided for three ongoing construction projects: ALMA, EarthScope and IceCube. In addition, the FY 2005 omnibus appropriation bill provided the first increment of funding for two new starts, SODV and the RSVP project. Several other MREFC projects are still under construction, although MREFC funding has concluded. These include HIAPER, the Large Hadron Collider (LHC), NEES, SPSM, and the Extensible Terascale Facility (ETF), previously known as TCS. Very detailed information about all of these projects is found in the MREFC and the Facilities Chapters of the NSF FY2006 Budget Request, which is available on the NSF Website at http://www.nsf.gov/about/budget/fy2006/.

To Index Page

Status Reports on Facilities under Construction with MREFC Account Funding and MREFC New Starts in the FY 2006 Congressional Budget Request[1]

For many major research facilities there is substantial overlap of the Construction and Operations Stages, with operations beginning well before construction is complete. One example is radio telescopes, for which subsets of the antennas in an array may be used for data collection well before the array has been completed. This overlap is especially true for distributed facilities, when the components in some locations may be fully ready for operations and data collection while those in other locations are in early stages of construction. A good example is EarthScope, for which sensor arrays in some locations will be operational much earlier than in other locations.

All MREFC projects use an internal NSF advisory group called a Project Advisory Team (PAT) during their development and implementation phases. The PATs generally consist of representatives from interested and/or participating directorates and offices, the NSF Deputy for Large Facility Projects (DLFP) and routinely the Office of General Counsel (OGC), the Office of Budget, Finance and Award Management (BFA), and the Office of Legislative and Public Affairs (OLPA).

FIRST PRIORITY: ONGOING PROJECTS IN FY 2006

ATACAMA LARGE MILLIMETER ARRAY (ALMA)

The ALMA VertexRSI test antenna, one of two prototypes constructed at the site of the Very Large Array near Socorro, NM.

Originally referred to as the Millimeter Array (MMA) in the United States, this international project will be an aperture-synthesis radio telescope operating in the wavelength range from 3 to 0.4 mm. ALMA will be the world's most sensitive, highest-resolution, millimeter-wavelength telescope, combining sub-arcsecond angular resolution with the sensitivity of a single antenna nearly 100 meters in diameter. The array will provide a testing ground for theories of star birth and stellar evolution, galaxy formation and evolution and the evolution of the universe itself. The interferometer will be located at 5,000-meter altitude near San Pedro de Atacama in the Second Region of Chile, the ALMA host country. ALMA will also play a central role in the education and training of U.S. astronomy and engineering students; at least 15 percent of ALMA's approximately 2,000 yearly users are expected to be students.

North America and Europe were equal partners in ALMA as originally planned (the baseline ALMA). Japan joined ALMA as a third major partner in September 2004, and will deliver a number of enhancements to the baseline instrument. The North American side of the project, consisting of the United States and Canada, is led by Associated Universities Inc./National Radio Astronomy Observatory (AUI/NRAO). Funding and execution of the project in Europe is carried out through the European Southern Observatory (ESO). Funding of the project in Japan is carried out through the National Institutes of Natural Sciences of Japan and project execution is the responsibility of the National Astronomical Observatory of Japan. ALMA instrumentation will push gallium arsenide and indium phosphide transistor amplifier technology to high frequencies, will challenge production of high-density, high-speed integrated circuits for computational uses, and can be expected to stimulate commercial device and communication technologies development.

Programmatic management is the responsibility of the ALMA Staff Associate in the Division of Astronomical Sciences (AST) in the Directorate for Mathematical and Physical Sciences (MPS). AST's external MMA Oversight Committee has been advising NSF on the project since early 1998, and comprises half of the International ALMA Management Advisory Committee. Management of the NRAO

[1] As in the budget table on the previous page, the categorization and priority order of projects in this section reflect the structure and priority order of the FY 2006 Budget to Congress, and do not reflect the revisions made by the National Science Board at its May 2005 meeting. The NSB considers NEON to be a New Start under the MREFC account, and the revised priority order of the New Starts is ARRV, NEON, OOI and AdvLIGO.

effort on ALMA is carried out under cooperative agreement with AUI.

A $26.0 million, three-year design and development phase was originally planned for the MMA project. However, since the original three-year plan was initiated, the United States entered into a partnership with a European consortium to develop ALMA. Because of the expanded managerial and technical complexity of the ALMA concept, an additional year of design and development was supported in FY 2001, at a budget level of $5.99 million. U.S. construction was initiated in FY 2002, and in Europe in 2003. The U.S. share of ALMA construction is estimated to be $344.21 million.

Significant project events during FY 2004 included:

+ groundbreaking at the site near San Pedro de Atacama in the second region of Chile in November 2003;
+ the completion of all project agreements with the government of Chile;
+ the completion of the ALMA construction camp at the site of the mid-altitude Operations Support Facility (OSF), and ongoing progress with road and other site works;
+ the establishment by the government of Chile of a radio quiet zone centered on the ALMA site;
+ the entry of Japan into an Enhanced ALMA project in September 2004;
+ the receipt and evaluation of bids for the ALMA production antennas.

U.S.-funded construction activities are currently scheduled to continue through 2010, with project completion and full operation beginning in 2012, and with early science scheduled to begin at the end of 2007. However, a thorough reexamination of the project scope, cost and schedule is now under way, and is likely to result in a rebaselining.

Two areas of concern in the project are:

+ The cost of the production antennas will be higher than originally budgeted. This is largely the result of very steep commodity price increases over the past 18 months. The project intends to purchase fewer antennas than originally planned in order to remain as close as possible to the original baseline budget.

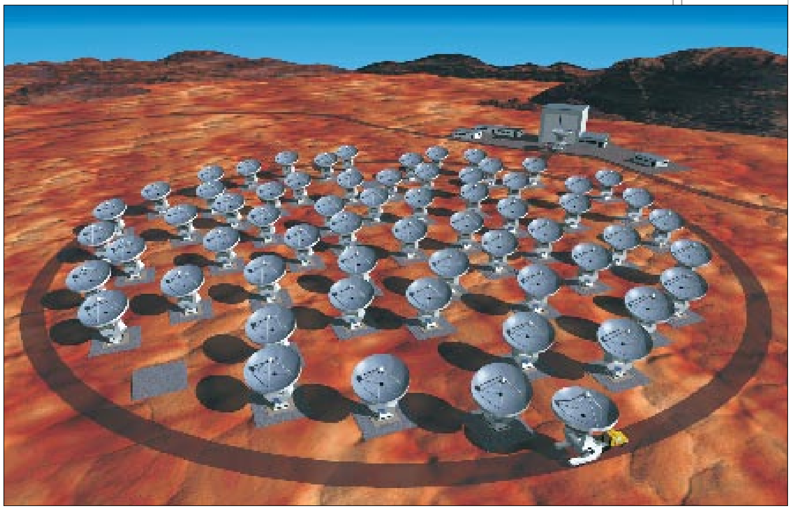
+ Delays associated with the antenna procurement process, details of the Japanese involvement, phasing differences in European and U.S. contributions, and a better understanding of integrated project requirements generated by the new ALMA project office have required that a new baseline be established.

Both the ALMA Science Advisory Committee and the NRC's Committee on Astronomy and Astrophysics have indicated that an array with fewer than 64 antennas will still produce the transformational results called for in the project's Level-I science requirements. Based on the current understanding of costs, NSF is reviewing a proposed contract package for the U.S.-funded antennas. A similar proposal to procure the same antenna design in Europe is now under consideration by ESO.

The project completed rebaselining once the new Project Management and Control System was in place and fully operational. The entire project is now conducting an in-depth, independent review of the cost, schedule and management parameters of the new baseline using an outside group of experts. The NSB has been informed of the antenna procurement situation and of plans to rebaseline the project at its October 2004, December 2004 and March 2005 meetings.

The expected operational lifespan of ALMA is at least 30 years. Early estimates for steady state operational costs, which are fully attained in 2012, are about $23 million annually. Along with direct operations and maintenance support for ALMA, NSF will support research performed at the facility, through ongoing research and education programs. The annual support for such activities is estimated to be about $10 million once the facility reaches full operations.

Additional information on ALMA can be found in the MREFC Chapter of NSF's FY 2006 Budget Submission to Congress (http://www.nsf.gov/about/budget/fy2006/).



An artist's conception of ALMA in Compact Configuration. When construction is finished in 2011, ALMA will be the world's largest and most powerful radio telescope, operating at millimeter and sub-millimeter wavelengths.

To Index Page

EarthScope

The complete EarthScope footprint. 1,600 of the transportable sites (moving west to east) and all 2,400 campaign stations will continue to be deployed after the conclusion of the MREFC project. Locations of the campaign stations will be determined through the annual proposal review process; many of these sites likely will change annually.

The EarthScope Facility is a distributed, multi-purpose geophysical instrument array that will make major advances in our knowledge and understanding of the structure and dynamics of the North American continent. EarthScope instrumentation is expected to inhabit nearly every county within the United States over the life span of the program. The principal goal of the project is to enhance the understanding of the structure and evolution of the North American continent, including earthquakes and seismic hazards, magmatic systems and volcanic hazards, lithospheric dynamics, regional tectonics, continental structure and evolution, fluids in the crust and associated educational aspects. EarthScope also seeks to engage science and non-science students in geosciences discovery through the use of technology in real time or retrospectively with the aim of integrating research and education.

The U.S. Geological Survey (USGS), the National Aeronautics and Space Administration (NASA), the Department of Energy (DOE) and the International Continental Scientific Drilling Programme are funding partners, with USGS and NASA expected as operating partners. Project partners may also include state and local governments, geological and engineering firms and Canadian and Mexican agencies. Over 3,000 earth scientists and students are expected to use the facility annually. Geotechnical and engineering firms directly use data and models, which will be enabled by EarthScope. Instrumentation firms will collaborate on development for state-of-the-art seismic systems, down-hole instrumentation and high-precision global positioning system (GPS) antenna designs.

The EarthScope Program Director, located in the Earth Sciences Division (EAR) in the Directorate for Geosciences (GEO), provides NSF oversight. The Deep Earth Processes Section Head in EAR and the PAT, provide other internal oversight. Following the recommendations of a National Academies review of EarthScope, an EarthScope Science and Education Advisory Committee (ESEC) was formed to provide an advisory structure to ensure coordination of facility construction and operation, science, education and outreach and information technology efforts.

Startup activities for Phase 2 drilling at the San Andreas Fault Observatory at Depth (SAFOD) site are under way, with drilling expected to begin on June 1, 2005. At this time, the projected date to intersect the main trace of the San Andreas Fault is in mid-July. In April, 2005, scientists from across the United States met at the core repository (Texas A&M) to examine the core from the Phase 1 drilling and to requests samples for scientific investigations. Overall, GPS and seismic station equipment acquisition and installation are slightly behind schedule. The Plate Boundary Observatory (PBO) installed the 100th permanent geodetic station on March 17, 2005. USArray installed the 75th Transportable Array station in February 2005. Installations continue on schedule. Data from EarthScope have already been used in earthquake studies, earthquake responses, presentations at professional meetings and in some university and other educational settings. An EarthScope Education and Outreach Manager has been hired. FY 2005 highlights to date also include the use of USArray seismic data in analyses of the Sumatra-Andaman earthquake (one of the largest earthquakes ever recorded), completion of the first borehole strainmeter installation and a very successful national meeting. The EarthScope project has been represented at over a dozen professional meetings and conferences through an exhibit booth, presentations and scientific sessions.

U.S.-funded construction activities are scheduled to continue through 2007, with project completion and full operation beginning in 2008. Scientific results utilizing data collected by the EarthScope facility have already been presented at national meetings and in professional publications. The project will undergo a baseline review in the fall of 2005. Conceptual planning for the EarthScope project developed over the past decade. NSF funded planning, design and development since FY 1998, and began the implementation of a five-year period of acquisition, construction and commissioning in FY 2003. The total project cost for EarthScope implementation is $197.44 million.

The expected operational lifespan of EarthScope is 15 years after construction is complete in FY 2007. Along with direct operations and maintenance support for the EarthScope Facility, expected to total approximately $24 million by FY 2007, NSF will support research performed utilizing the facility through ongoing research and education programs. The annual support for such activities is estimated to be about $15 million once the facility reaches full operations.

Additional information on EarthScope can be found in the MREFC Chapter of NSF's FY 2006 Budget Submission to Congress (http://www.nsf.gov/about/budget/fy2006/).

High performance Instrumented Airborne Platform for Environmental Research (HIAPER)

This project is the acquisition, modification and instrumentation of a high-altitude research aircraft capable of conducting science at or near the tropopause (approximately 51,000 feet) with an extensive scientific payload and a flight range in excess of 6,000 nautical miles. The aircraft will fly between 400 and 500 research flight hours each year, with extensive mission-specific outfitting preceding each research campaign. The remaining time will be devoted to aircraft maintenance and technology refreshment of the platform infrastructure. HIAPER will be a national facility, available to the university community as well as to NSF's federal partners such as the National Oceanographic and Atmospheric Administration (NOAA), NASA, the Office of Naval Research (ONR) and DOE under existing interagency agreements. HIAPER will be based at the National Center for Atmospheric Research's (NCAR) Research Aviation Facility (RAF) and Jefferson County Airport in Broomfield, Colorado. Deployments of the aircraft will occur worldwide. HIAPER was ferried from the Gulfstream facility to NCAR's Jefferson County facility on March 11, 2005. It is currently undergoing infrastructure integration and is scheduled to begin its initial progressive science mission in late August.

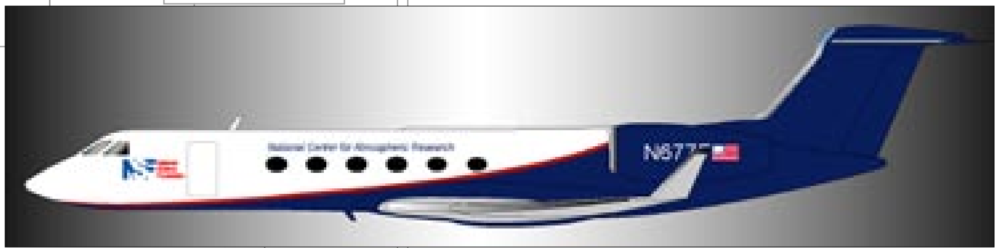
The HIAPER project officially will conclude this year and, as noted above, the aircraft will transition to progressive science missions to test and evaluate the platform in late summer; full operations are anticipated at the beginning of FY 2006. Numerous requests to use HIAPER already have been received. Because the aircraft has been formally accepted, it will no longer be reported separately, but as part of the activities of the aircraft's operator, NCAR.

HIAPER is a research platform with altitude, range and endurance capabilities that enable investigators to perform critical Earth system science research. With a maximum altitude for the aircraft of 51,000 feet, the ability to carry significant payloads to such high altitudes enables scientists to conduct important atmospheric studies in and near the tropopause. The modified aircraft is capable of covering a range of 6,000 nautical miles in a single flight, allowing for such varied missions as research flights covering the borders of the continental United States, the world's large ocean basins, and studies of the South Pole environment conducted from South America or New Zealand. The platform will serve the entire geosciences community: atmosphere, cryosphere, biosphere and hydrosphere.

At NSF a Program Officer in the Atmospheric Sciences (ATM) Division in GEO oversees the HIAPER project. At NCAR a Project Director manages the day-to-day activities of HIAPER, and a separate HIAPER Advisory Committee (HAC), consisting of representatives of the university research community, national laboratories, the University Corporation for Atmospheric Research (UCAR), NCAR and NSF provides advice and recommendations to the NCAR Director, to whom the HIAPER Project Director reports.

In late December 2001, UCAR and Gulfstream Aircraft Corporation (GAC), a subsidiary of General Dynamics, signed a contract for the acquisition of a Gulfstream V. The green airframe was delivered to Lockheed-Martin in June 2002 for extensive airframe structural modifications to meet science requirements. By October 2004, all the structural

The HIAPER aircraft backs into the new RAF hangar at the Jefferson County Airport in Broomfield, CO



HIAPER will serve the atmospheric science community's research needs for the next several decades.

This is an image of the HIAPER aircraft in flight.

modifications were completed and the aircraft was ferried back to Savannah (Gulfstream) for painting and final infrastructure installations. The painting was completed in December and HIAPER exited the paint hangar on December 21, 2004 with its final paint scheme. The aircraft was ferried to NCAR on March 10, 2005, and UCAR accepted the aircraft on behalf on NSF; installation of interior infrastructure is in progress. At NCAR the RAF is currently installing the scientific infrastructure and also working with the instrument developers on instrument integration issues as they arise. Fifteen research instruments were funded as part of the HIAPER MREFC project, and include instruments developed at NCAR, other national laboratories, universities, private industry and collaboration between universities and industry or NCAR.

Funds were appropriated by the Congress beginning in FY 2000. The total construction cost for the project is $81.50 million, and the project to date is on schedule and under budget. Funds set aside for contingency are being used to enhance instrumentation and follow on phased developments. NCAR, Gulfstream, Lockheed Martin and Savannah Air Center have executed a superb team effort.

HIAPER's expected operational lifespan is 25 years, pending the full integration of scientific instrumentation. A steady state of about $5.0 million in operations support will occur in FY 2006. Along with direct operations and maintenance support for HIAPER, NSF will support research performed at the facility, through ongoing research and education programs. The annual support for such activities is estimated to be about $10 to $12 million, once the facility reaches full operations.

Additional information on HIAPER can be found in the Facilities Chapter of NSF's FY 2006 Budget Submission to Congress (http://www.nsf.gov/about/budget/fy2006/).

IceCube Neutrino Observatory

IceCube will be the world's first high-energy neutrino observatory and will be located under the ice at the South Pole. It represents a new window on the universe, providing unique data on the engines that power active galactic nuclei, the origin of high-energy cosmic rays, the nature of gamma ray bursters, the activities surrounding supermassive black holes, and other violent and energetic astrophysical processes. IceCube construction is being carried out by the IceCube Consortium, led by the University of Wisconsin. Approximately one cubic kilometer of ice is being instrumented with photomultiplier (PM) tubes to detect neutrino-induced, charged reaction products produced when a high-energy neutrino interacts in the ice within or near the cubic kilometer fiducial volume. An array of Digital Optical Modules (DOMs), each containing a PM and associated electronics, will be distributed uniformly from 1.5 km to 2.5 km beneath the surface of the South Pole ice cap, a depth where the ice is highly transparent and bubble-free. When completed, IceCube will record the energy and arrival direction of high-energy neutrinos ranging in energy from 100 GeV (10^{11} electron Volts[eV]) to 10 PeV (10^{16} eV).

To Index Page

The principal tasks in the IceCube Project are: production of the needed DOMs and associated electronics and cables; production of an enhanced hot water drill and a DOM deployment system capable of drilling holes for and deploying DOM strings in the ice at the Pole; installation of a surface array of air shower detectors to both calibrate and eliminate background events from the IceCube DOM array; construction of a data acquisition and analysis system; and associated personnel and logistics support.

IceCube will be the world's first observatory capable of studying the universe with high-energy neutrinos. Measurement of the number, direction, timing and energy spectrum of such neutrinos will provide unique insights regarding the dynamics of active galactic nuclei, the acceleration mechanisms and locations of the sources of high-energy cosmic rays, the properties and dynamics of gamma ray bursters and the types of processes that take place near the event horizon of supermassive black holes at the centers of galaxies. Many of these phenomena take place at cosmological distances in regions shielded by matter and shrouded by radiation. Since neutrinos carry no charge and interact very weakly with matter, easily passing through the entire Earth, they are unique messenger particles for understanding the astrophysics of such extreme phenomena and are capable of bringing us information about previously undiscovered cosmic objects, ones that are invisible to existing observatories that record electromagnetic signals or charged particles. IceCube data on sources will also complement data from existing astrophysical observatories in the optical, X-ray and gamma ray regions of the electromagnetic spectrum, providing new tests of theories of the underlying dynamics of these objects.

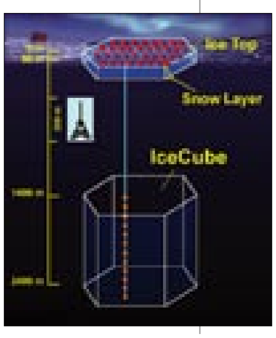
IceCube also provides a vehicle for helping to achieve national and NSF education and outreach goals based on the conduct of visionary science in the exciting South Pole environment. These goals include broadening the scientific workforce base in the United States and creating a technologically facile workforce with strong ties to fundamental research that is the core of a strong economy. Specific outcomes will include the education and training of next generation leaders in astrophysics, including undergraduate students, graduate students and postdoctoral research associates; K-12 teacher scientific/professional development, including development of new inquiry-based learning materials; increased diversity in science through partnerships with minority institutions; and enhanced public understanding of science through broadcast media and museum exhibits (one is currently under construction). Some of these outcomes will result from separate R&RA grants to universities and other organizations for work associated with IceCube, selected following the standard NSF merit review process.

The IceCube Collaboration consists of 12 U.S. institutions and institutions in three other countries: Belgium, Germany and Sweden. DOE, through its Lawrence Berkeley Laboratory, is also participating. The strong project management structure at the University of Wisconsin, which includes international participation, provided the framework for the Start-up Project funded in FY 2002 and FY 2003, and the initiation of full construction with FY 2004 funding. The University of Wisconsin has in place an external Scientific Advisory Committee, an external Project Advisory Panel and a high-level Board of Directors (including the Chancellor) providing for their oversight of the project. IceCube is managed by a Project Director and a Project Manager. Internally, NSF has appointed a Project Coordinator to manage and oversee the NSF award. A comprehensive external baseline review of the entire project (including cost, schedule, technical aspects and management) was carried out in February 2004. There was a follow-up external cost review in fall 2004, and comprehensive annual external reviews are planned for each subsequent spring following the annual deployment season. This is interspersed with written monthly progress reports and quarterly reports, site visits, weekly teleconferences and weekly internal NSF project oversight and management meetings. Oversight and funding responsibility for IceCube construction are the responsibility of the Office of Polar Programs (OPP); support for operations, research, education and outreach using IceCube will be shared by

Pictured in the University of Wisconsin-Madison Physical Sciences Laboratory before being vacuum-sealed, each IceCube digital optical module or DOM is very much like a small computer. A total of 4,200 DOMs, designed to sample high-energy neutrino particles from deep space, are being deployed in 70 deep holes in the Antarctic ice. (November 2004)

To Index Page

A digital optical module (DOM) disappears down the first hole drilled for the National Science Foundation-supported project known as IceCube. When completed, 4,200 DOMs will be seeded in a cubic kilometer of Antarctic ice, making IceCube the world's largest scientific instrument. (2005)



IceCube will occupy a volume of one cubic kilometer. Here we depict one of the strings of optical modules (number and size not to scale). IceTop located at the surface, comprises an array of sensors to detect air showers. It will be used to calibrate IceCube and to conduct research on high-energy cosmic rays.

OPP and MPS as well as other organizations and international partners.

The primary IceCube Project tasks carried out to date are: (1) completion and testing of the Enhanced Hot Water Drill (EHWD) system for drilling the required deep-ice holes into which the strings of DOMs will be placed; (2) completion and commissioning of the three planned DOM production and low temperature (-80°C) testing facilities in the United States, Germany and Sweden; (3) production and testing of the DOMs needed for deployment of four DOM strings during one austral summer season (November 2004 to mid-February 2005); (4) shipping and assembly of the entire drilling and deployment camp at the Pole, including the shipment and re-testing at the Pole of the needed DOMs and cables; (5) design, construction and installation of the initial data acquisition system at the Pole; (6) completion of plans for commissioning and verification of the initial DOM strings; (7) placement at the Pole of the building that will serve as the IceCube permanent counting house next season (2005/2006); (8) successful drilling of the first deep hole at the Pole and the deployment of the first IceCube string (60 DOMs), which is now connected to the data acquisition, fully operational, and functioning well; and (9) successful deployment and operation at the Pole of eight surface cosmic ray air shower detector modules (2 DOMs/module).

U.S.-funded construction activities are scheduled to continue through 2010, with project completion and full operation beginning in 2011. Early science is scheduled to begin at the end of 2007. Projected outyear milestones are based on current project planning and represent a general outline of anticipated activities. These activities are also dependent on weather conditions and the Antarctic logistics schedule.

The total project cost for IceCube is $271.80 million. Of this amount, $242.07 million will be from the United States and $29.70 million will come from foreign contributions. The funding history of IceCube includes: $15.0 million appropriated in FY 2002 for startup activities; $24.54 million appropriated in FY 2003 for continuation of startup activities; $41.75 million appropriated in FY 2004 to initiate construction; and $47.62 million appropriated in FY 2005 for continued construction. The FY 2006 Request is $50.45 million for continued construction of IceCube.

The expected operational lifespan of IceCube is 25 years after construction is complete in FY 2010. Operations support is estimated at $3.5 million for FY 2007 and ramps up to an estimated level of $12 million in FY 2011 and beyond. These estimates are developed for planning purposes and are based on current cost profiles. Efforts are underway to further develop operating cost estimates; they will be updated as new information becomes available. NSF will support activities at U.S. institutions working on more refined and specific data analyses, data interpretation (theory support), and instrumentation upgrades, through ongoing research and education programs. The annual support for such activities is estimated at $2.0 million once the facility reaches full operations.

Additional information on IceCube can be found in the MREFC Chapter of NSF's FY 2006 Budget Submission to Congress (http://www.nsf.gov/about/budget/fy2006/).

National Ecological Observatory Network (NEON)

NEON will be a continental-scale research platform consisting of geographically distributed infrastructure, networked via state-of-the-art communications. It will allow researchers to address major ecological questions such as: how are the structure and function of U.S. ecosystems changing as a result of the effects of climate change on biogeochemical cycles, and what are the ecological drivers for the emergence, spread and evolution of infectious disease organisms? NEON will include laboratory and field instrumentation, sensor arrays, analytical and archival infrastructure, and computational, analytical and modeling capabilities, all linked via cutting edge cyberinfrastructure. The suite of technologies would include, for example, instrumented eddy flux correlation towers to measure ecosystem exchange of CO_2, water and trace gases; sensor arrays to remotely assess photosynthesis; and acoustic sensors for animal biodiversity research. Deployed sensor networks connected to data portals and repositories will permit rapid and widespread sensing of the environment. NEON will be implemented as a "shared-use" research platform. Scientists and engineers will use

To Index Page

NEON to conduct real-time ecological studies spanning all levels of biological organization, across scales ranging from seconds to geological time, and from microns to thousands of kilometers. NSF programs will support NEON research projects and educational activities. Data collected using NEON will be publicly available.

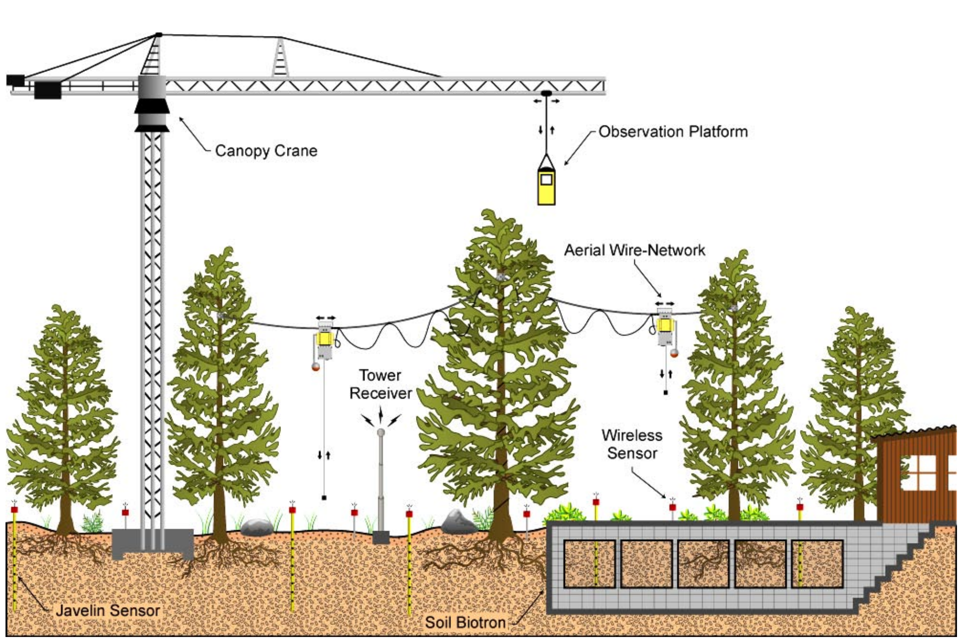
Two federal agencies — the United States Department of Agriculture (USDA) Forest Service (USFS) and the USGS — are represented on the NEON Advisory Board. Both are also members of various NEON planning committees along with USDA Agricultural Research Service (USDA-ARS), the Environmental Protection Agency (EPA), and DOE.

In addition, a NEON Federal Agency Coordinating Committee meets on a regular basis, and includes representatives from USFS, NASA, NOAA, USGS, EPA, DOE, USDA-ARS, asa well as the National Parks Service; the USDA Cooperative State Research, Education, and Extension Service; and the U.S. Army Corps of Engineers.

International perspectives are provided through two NEON Advisory Board members (Environment Canada and CONABIO[1], Mexico), and by the presence of the Argentine National Research Council on planning committees. Private foundations including the Heinz Center, Nature Serve, and U.S. Landtrust participate on the NEON Design Consortium.

NEON-generated information will be useful to natural resource industries, such as forestry and fisheries. In addition, the NEON Program Officer participates in planning for the U.S. component of the Global Earth Observation System of Systems, the Integrated Earth Observation System, which is an interagency activity of the National Science and Technology Council (NSTC) Committee on Environment and Natural Resources. NEON's technological and networking infrastructure will be forging new technological frontiers and thus, will require partnerships with industry for development, deployment and operation.

The Division of Biological Infrastructure (DBI) in the Directorate for Biological Sciences (BIO) manages NEON. A dedicated Program Officer in consultation with a BIO-NEON committee, which includes the Deputy for Large Facility Projects, formulates NEON programmatic development (e.g. drafting of program announcements). In addition, a cyber sub-committee of the BIO Advisory Committee provides external advice about specific programmatic elements. The NEON Program Officer ensures coordination with other NSF observatories and networks by serving on the NSF Environmental Observing Networks



Planning for NEON includes visual rough drafts of sensors and research infrastructure deployed across a forest ecosystem, from the forest canopy to the soil community.

[1]Comision Nacional para el Conocimiento y Uso de la Bioversidad (National Commission for the Understanding and Use of Biodiversity).

To Index Page

Using biotelemetry, animals and large insects can now be tracked on regional to landscape scales (tens to hundreds of miles). Such technological abilities can provide information on animal health, movement, and survival that can be used to predict ecosystem and human health. In the future, NEON will transform our ability to capture this information by providing a networked continental observation platform capable of providing rapid information on mobile organisms.

Task Force (EONTF) and on the PATs for several other large facility projects.

Recent Planning Activities: The American Institute of Biological Sciences (AIBS) organized six community workshops between August and September 2004 to identify NEON-specific science questions and requirements based on the environmental grand challenges identified in the NRC NEON report "NEON: Addressing the Nation's Environmental Challenges," the NSB environment report, and the NRC report "Grand Challenges in Environmental Sciences."

Fostering Technology and Cyberinfrastructure Development: In FY 2004, two workshops were conducted in coordination with the Ocean Observatories Initiative, and the Long Term Ecological Research (LTER) program to define the cross cutting needs, challenges, and opportunities in sensors and cyberinfrastructure. The workshops addressed emerging issues of interoperability among evolving observing systems, leveraging emerging technologies and research frontiers, fostering collaboration, and stimulating robust technology development.

Award for NEON Design Consortium and Project Office: In FY 2004, Congress instructed NSF to continue planning activities for NEON with R&RA funds. On September 15, 2004, BIO made a two-year, $6.0 million R&RA award to the AIBS to establish a NEON Design Consortium and Project Office for the purpose of refining the reference design in light of recommendations in the NRC NEON report and drafting the Project Execution Plan for NEON.

In FY 2005, NSF requested $12.0 million in the MREFC account and $4.0 million in R&RA to baseline and develop the final design for NEON research infrastructure and begin construction of NEON networking and informatics infrastructure. While the FY 2005 omnibus appropriation did not provide MREFC funding, Congress instructed NSF to continue NEON planning through the R&RA account. In FY 2005 the NEON Design Consortium and Project Office was established. The Design Consortium appointed the NEON Advisory Board and Design Consortium subcommittees to (1) refine the NEON requirements; (2) develop the facilities and infrastructure reference design, along with the preliminary baseline definition for networking and informatics, and the infrastructure requirements for education, training and outreach; and (3) design the governance and management structures.

Future Activities: In FY 2006, the NEON Design Consortium and Project Office will finalize the Science Plan and Requirements, baseline the Networking and Informatics Plan, and review and complete the preliminary Project Execution Plan. Construction activities are scheduled to begin in FY 2007 and continue through 2011. Initial operations could begin as early as 2009 with NEON fully operational in 2012.

The expected operational lifespan of this project is 30 years after construction is completed in FY 2011. A steady state of $20 million is initially estimated for operations support, anticipated by FY 2011. Along with direct operations and maintenance support, NSF programs will support research using NEON. Thousands of researchers will be able to use NEON, tens of thousands of children may participate in NEON activities through its educational programs, and hundreds of thousands of individuals will be able to access NEON data, information and research products via the Internet.

Additional information on NEON can be found in the MREFC Chapter of NSF's FY 2006 Budget Submission to Congress (http://www.nsf.gov/about/budget/fy2006/).

To Index Page

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

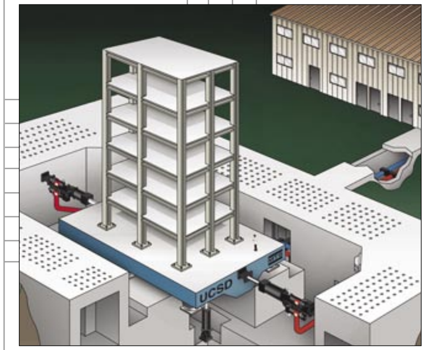
NEES is a national, networked simulation resource of 15 geographically distributed, shared-use next-generation experimental research equipment sites with teleobservation and teleoperation capabilities. NEES provides national resources to advance earthquake engineering research and education through collaborative and integrated experimentation, computation, theory, databases and model-based simulation to improve the seismic design and performance of U.S. civil infrastructure systems. Research equipment includes shake tables, geotechnical centrifuges, a tsunami wave basin, large-scale laboratory experimentation systems, and mobile and permanently installed field equipment. NEES equipment is located at academic institutions (or at off-campus field sites) throughout the United States, networked together through a high performance Internet2 CI system. NEES completed primary construction on September 30, 2004, and opened for user research and education projects on October 1, 2004. Between FY 2005 and FY 2014, NEES will be operated by the non-profit corporation NEES Consortium Inc. (NEESinc), located in Davis, CA. Through a cooperative agreement with NSF, NEESinc operates the 15 equipment sites and the NEES cyberinfrastructure center; coordinates education, outreach and training; and develops national and international partnerships.

NEES' broad-based national research equipment and cyberinfrastructure will enhance understanding and provide more comprehensive, complete, and accurate models of how civil infrastructure systems respond to earthquake loading (site response, soil-foundation-structure interaction, tsunami effects, and structural and nonstructural response). This will enable the design of new methods, modeling techniques and technologies for earthquake hazard mitigation. NEES also engages engineering, science and other students in earthquake engineering discovery through on-site use of experimental facilities, telepresence technology, archival experimental and analytical data, and computational resources with the aim of integrating research and education. NEES has developed an education, outreach and training strategic plan to develop a broad spectrum of education and human resource development activities with special emphasis on nontraditional users and underrepresented groups.

Through the congressionally mandated National Earthquake Hazards Reduction Program (NEHRP), the Federal Emergency Management Agency (FEMA), the National Institute of Standards and Technology (NIST), NSF and the USGS participate to support research related to earthquake hazard mitigation. Connections to industry include private engineering consultants and engineering firms engaging in NEES research or using data and models developed through NEES. NEES is leveraging and complementing its capabilities through connections and collaborations with large testing facilities at foreign earthquake-related centers, laboratories and institutions. Through such partnerships and joint meetings and workshops, NEES shares its expertise in testing and cyberinfrastructure, provides specialized training opportunities, and coordinates access to unique testing facilities and the central data repository.

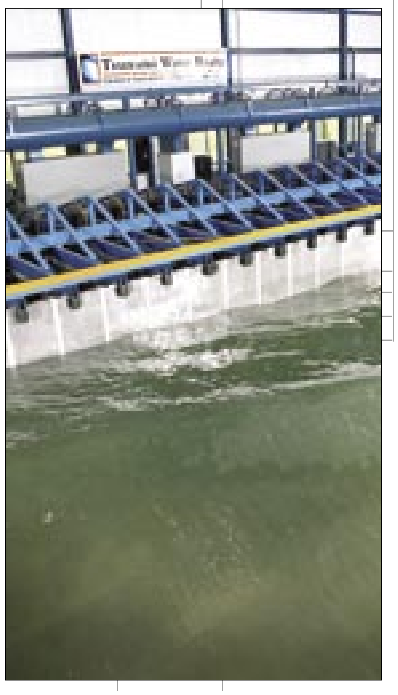
As a non-profit corporation, NEESinc operates under its own governance structure and is overseen by a Board of Directors elected from its membership in accordance with its by-laws. Day-to-day operation of NEESinc is overseen by its headquarters staff led by an Executive Director. Each equipment site has a facility director responsible for local day-to-day equipment management, operations and interface with NEESinc, other NEES equipment sites, users, and the NEES CI center for network coordination. The NEES cyberinfrastructure center maintains the telepresence, data, collaborative, simulation, and other related services for the entire NEES network.

NSF provides oversight to NEES under a cooperative agreement. NEES is reviewed through annual site visits. The NSF Program Manager for NEES is located in the Civil and Mechanical Systems (CMS) Division in the Directorate for Engineering (ENG).



Currently under construction, the University of California, San Diego's (UCSD) Large High Performance Outdoor Shake Table, will result in a one-of-a-kind worldwide seismic testing facility, and the world's first outdoor shake table. This unique facility will enable next-generation seismic experiments to be conducted on very large structural systems such as full-scale buildings, and utility/lifeline structures such as electrical sub-stations, with no overhead space and lifting constraints.

To Index Page



The tsunami wave basin at Oregon State University is the world's largest and most comprehensive shared-use research facility for the study of effects of tsunami inundation and storm waves on coastal buildings and lifeline infrastructures.

NEES completed its primary construction activities at the end of FY 2004. About $2.7 million in remaining FY 2004 MREFC funds were used to fund construction of deferred capabilities for NEES during FY 2005. This included four new capabilities for CI system integration and new capabilities at 13 equipment sites. The four new system integration capabilities will be completed on September 30, 2005. The deferred capabilities at the 13 equipment sites will be completed by September 30, 2006. NEES opened for user research and education projects on October 1, 2004, under the management of NEESinc. Commensurate with opening, the first round of research awards were made by NSF in September/October 2004 to use the NEES facilities. NEESinc operates the 15 equipment sites and the NEES CI center; coordinates education, outreach and training; and develops national and international partnerships. The NEES tsunami wave basin provides a national resource to calibrate and validate tsunami propagation and inundation modeling tools, model inundation patterns to understand where the threat is most significant, and develop design criteria for coastal community shelters and other critical facilities. Researchers at this facility participated on a post-tsunami rapid-response reconnaissance team with respect to the December 26, 2004 Indian Ocean earthquake.

NSF received $7.70 million in FY 2000 to initiate construction of NEES. Total MREFC funding for this project was $81.76 million during FY 2000–2004, with an additional $1.10 million provided to the project for one equipment site construction through the Education and Human Resources (EHR) account.

The expected operational lifespan of this project is 10 years, from FY 2005 to FY 2014. NEES operations for FY 2005—FY 2009 were approved by the NSB in May 2004 for up to $106.52 million total, approximately $21.3 million annually. Operations estimates for FY 2007 and beyond are developed strictly for planning purposes and are based on current cost profiles. They will be updated as new information becomes available. Along with direct operations and maintenance support for NEES, NSF provides support for research performed at NEES equipment sites through ongoing research and education programs. The NEES cyberinfrastructure also provides a platform for the earthquake engineering community as well as other communities to develop new tools for shared cyberinfrastructure. In addition, NSF has initiated an annual research program solicitation for research projects that will utilize the NEES experimental sites, data and computational resources to comprehensively address major research questions in earthquake engineering and seismic hazard mitigation. The FY 2005 solicitation includes partnerships with the directorates for Computer and Information Science and Engineering (CISE) and GEO, as well as the Japanese E-Defense shake table operated by the National Research Institute for Earth Science and Disaster Prevention. Support for such activities is estimated at about $9.0 million annually.

Additional information on NEES can be found in the Facilities Chapter of NSF's FY 2006 Budget Submission to Congress (http://www.nsf.gov/about/budget/fy2006/).

To Index Page

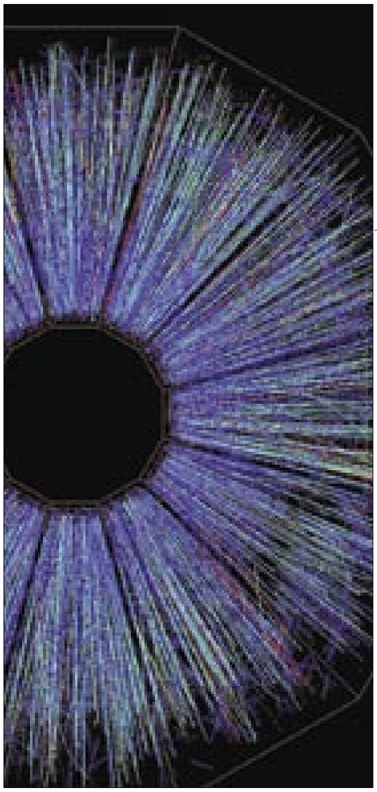
Rare Symmetry Violating Processes (RSVP)

RSVP was planned as an NSF-funded, university-led project that would use the existing Alternating Gradient Synchrotron (AGS) at Brookhaven National Laboratory (BNL) at incremental cost to advance the frontiers of particle physics. Researchers from almost 30 institutions from the United States, Canada, Switzerland, Italy, Japan and Russia were involved. The RSVP experiments were designed to address two great mysteries: the predominance of matter over antimatter in the universe today and the difference between the electron and the muon, the former by studying matter-antimatter symmetry (CP)-violating decays of K-mesons and the latter by searching for muon-to-electron conversion. By extending current sensitivities for these rare processes by orders of magnitude, RSVP would shed light on the existence of atomic matter in the universe, the nature of dark matter, and could even provide evidence for superstrings.

Planning for RSVP was conducted with NSF support beginning in FY 2001. Significant concept and design work was carried out with DOE support prior to this. Congress appropriated $14.88 million for RSVP in FY 2005. The FY 2006 President's Budget specifies $41.78 million for RSVP. The activities to date include R&D for the technology needed for the project, simulations of the data expected, and design of major components.

In the fall of 2004, significant cost increases were identified. NSF notified the NSB, the Office of Science and Technology Policy (OSTP), the Office of Management and Budget (OMB) and the relevant congressional committees. Subsequently, the project completed a detailed technical, cost and schedule baseline review in the spring of 2005, and NSF convened an independent panel of experts to review it. To complement the baselining activities, NSF requested that the High Energy Physics Advisory Panel (HEPAP) carry out a re-evaluation of the science value of the two experiments. Based on the results of the baseline review and the HEPAP report, NSF has concluded that continuing the RSVP project would lead to the unacceptable loss of opportunities in research in elementary-particle physics, other areas of physics, and across all disciplines in the MPS directorate as well as in the construction of large facilities across NSF.

At the August 2005 meeting of the NSB, NSF recommended and the NSB approved the termination of RSVP.[2]



End view of a collision of two 30-billion-electron-volt gold beams in the Solenoidal Tracker at the Relativistic Heavy Ion Collider (STAR) at BNL. The beams travel in opposite directions at nearly the speed of light before colliding.

[2]The resolution states "Resolved, that the National Science Board concurs with the recommendation that the Rare Symmetry Violating Processes (RSVP) Project be terminated before the start of construction as a result of the significantly increased construction and operations costs identified during the final stages of planning and the negative impact on the NSF portfolio that would result from proceeding with the project under such circumstances. The National Science Board notes the significant lost scientific opportunity that will result from this project termination."

To Index Page

Scientific Ocean Drilling Vessel (SODV)

Scientists examine and discuss deep-sea rock cores on an Integrated Ocean Drilling Program expedition to the western rift flank of the mid-Atlantic Ridge.

This project supports the contracting, conversion, outfitting and acceptance trials of a deep-sea drilling vessel for long-term use in a new international scientific ocean drilling program. Commercial drillships are not routinely configured or equipped to meet the requirements of scientific research. The SODV will be prepared for year-round operations and will be capable of operating in all ocean environments. The vessel will accommodate a scientific and technical staff of approximately 50. The converted drillship will provide the U.S. facility contribution to the Integrated Ocean Drilling Program (IODP), which began on October, 1 2003. The IODP is co-led by the NSF and the Ministry of Education, Culture, Sport, Science and Technology (MEXT) of Japan. European and Asian nations are also participating in the program.

The IODP will recover sediment and crustal rock from the seafloor using scientific ocean drilling techniques, and place observatories in drillholes to study the deep biosphere, the flow of fluids in sediments and the crust, the processes and effects of environmental change, and solid Earth cycles and geodynamics. MEXT will provide a heavy drillship for deep drilling objectives of the programs. NSF will provide a light drillship and science support services for high-resolution studies of environmental and climate change, observatory and biosphere objectives.

The project is managed and overseen by a project manager in the Ocean Sciences (OCE) Division in GEO. A conversion oversight committee has been established to provide technical, financial and scheduling recommendations and advice for the SODV project.

In September 2003, NSF awarded a contract to Joint Oceanographic Institutions, Inc. (JOI) for IODP drilling operations, which included as one task the planning and implementation of the SODV project. JOI has issued an Request for Proposals (RFP) to acquire, upgrade and operate a commercial vessel for scientific ocean drilling, and a contract award is anticipated by September 2005. The SODV Project received $14.88 million in FY 2005. Engineering design, science lab development and long lead item equipment procurement activities will be the primary FY 2005 SODV activities.

U.S.-funded construction activities are scheduled to continue through 2007, with full operations beginning in FY 2008. Planning through FY 2004 cost approximately $3.60 million. In FY 2005, approximately $5.40 million will be provided to initiate contract activity, planning and design. Between FY 2005 and FY 2007, approximately $110.0 million of funds from the MREFC account will be required for conversion/equipping/testing of the drillship. The expected operational lifespan of the SODV is 15 years, once construction is complete in FY 2007. A steady state of about $55 million in operations support for the IODP is expected to occur beginning in FY 2008 as the SODV vessel begins full operations, but these estimates are based on current cost profiles and will be updated as new information becomes available. Along with direct operations and maintenance support for IODP, NSF will support research performed at the facility through ongoing research and education programs. The annual support for such activities is estimated to be about $31 million.

Additional information on SODV can be found in the MREFC Chapter of NSF's FY 2006 Budget Submission to Congress (http://www.nsf.gov/about/budget/fy2006/).

South Pole Station Modernization Project (SPSM)

The SPSM project provides a new station to replace the current U.S. station at the South Pole, built 30 years ago and currently inadequate in terms of capacity, efficiency and safety. The new station is an elevated complex with two connected buildings, supporting 150 people in the summer and 50 people in the winter. There are approximately 385 separate subcontractors for supplies and technical services. The U.S. Antarctic Program (USAP) prime support contractor is Raytheon Polar Services Company (RPSC).

OPP has the overall management responsibility for SPSM, including development of the basic requirements, design, procurement and construction. OPP has contracted for procurement and construction management for all phases of the project, including design reviews of all drawings and specifications; conformance of the designs and procurements with established standardization criteria; assistance in establishing functional interfaces; transition from the existing to the new facilities; and systems integration. Naval Facilities Engineering Command, Pacific Division (PACDIV) selects, monitors and manages architectural and engineering firms for design, postconstruction services, and construction inspection for the project. The project status, including cost expenditures and cost projections, is monitored on a periodic basis by OPP staff and the project's PAT.

The original estimate for SPSM was $127.90 million. NSB approved a change in project scope, increasing station capacity from 110 to 150 people, as well as a project schedule extension, increasing the cost estimate to $133.44 million (plus $2.52 million for increased scope; plus $3.02 million due to weather-induced schedule delays). Weather delays in previous years adversely impacted planned material deliveries resulting in revised schedules. The estimated projection has been for conditional acceptance (i.e., occupation and operations) of the entire station by the end of FY 2007, with demolition/retrograde of the old station and work on punchlist items occurring in FY 2008. The current status of the project, both schedule and budget, is currently under review.

SPSM has received appropriations totaling $133.78 million through FY 2004, exceeding the most recent NSB-approved cost estimate of $133.44 million. Using the last updated schedule, the estimated total cost of SPSM is $136.96 million. An updated project cost and schedule review was completed shortly after the end of the 2004/2005 operating season. No funds are being requested for FY 2006.

Advance funding provided in the project's early years made possible advance bulk buys of materials, which is ultimately more cost-efficient. However, this project's overall outlay is relatively slow due to the unusual logistics and shortened Antarctic season. As a result, the project has carried over fairly significant amounts each year since FY 1998, resulting in obligations that are significantly lower than appropriated amounts.

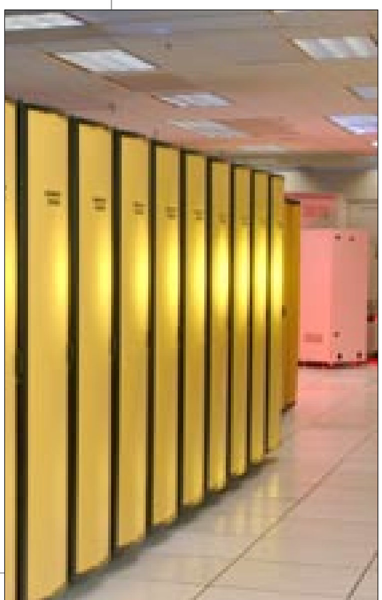
The expected lifespan of the modernized station is 25 years, through 2031. A steady state of operational support is anticipated at $15 million by FY 2007, slightly higher than the current operational costs. Operations estimates for FY 2007 and beyond are developed strictly for planning purposes and are based on current cost profiles. They will be updated as new information becomes available. Along with direct operations and maintenance support for South Pole Station, NSF will support science and engineering research through ongoing research and education programs. The annual support for such activities is currently estimated to be approximately $8.0 million.

Additional information on the SPSM, including information on appropriations and obligations, can be found in the MREFC Chapter of NSF's FY 2006 Budget Submission to Congress (http://www.nsf.gov/about/budget/fy2006/).

Aurora Australis — the Southern lights — over NSF Amundsen-Scott South Pole Station. This image shows the atmospheric phenomenon over a wing of the new station that NSF is building.

To Index Page

Terascale Computing Systems (TCS)



Photos of the new Cray XT3, "Big Ben," at the Pittsburgh Supercomputing Center.

The NSF Terascale Computing Systems project funded the construction of the Extensible Terascale Facility (ETF). ETF, also commonly known as the TeraGrid, provides the broad-based academic science and engineering community with access to scalable, balanced, terascale computing resources, including two 10+ teraflops supercomputing systems (one at the National Center for Supercomputing Applications — NCSA — and one scheduled to come on line in the spring of 2005 at the Pittsburgh Supercomputing Center — PSC) and over 35 teraflops across the ETF. Users also have access to at least 1,000 terabytes (1 petabye) of storage at a single site (at the SDSC) and nearly 2 petabytes across the ETF. Using ETF, researchers and educators are able to conduct analyses at unprecedented scale, to merge multiple data resources seamlessly, and to advance discovery at the frontiers of science and engineering.

The principal scientific goal of ETF is to provide state-of-the-art cyberinfrastructure capabilities that position the nation's researchers and educators to address a broad range of state-of-the-art challenges, across all science and engineering fields. ETF's distributed architecture permits the seamless integration of large, managed scientific data archives; high-performance computational resources available within ETF can be used to mine, analyze, visualize, and perform related simulations on these data. ETF's principal educational goal is to provide current and future generations of scientists and engineers with access to unique, state-of-the-art cyberinfrastructure that promises to advance discovery, learning and innovation across all fields.

Management and oversight of this project is provided by a Program Director in CISE. During the construction phase, an external Technical Advisory Panel made periodic site visits to the ETF partner institutions to review construction progress and provide technical advice to the Program Director. The Technical Advisory Panel participated in resolution of major technical, managerial or scheduling concerns; provided technical guidance/advice, especially with regard to the integration and coordination with other SCI-funded program activities; and reviewed and – where required – approved technical reports and information to be delivered by the awardees.

With the October 1, 2004, initiation of the operations phase of ETF, a new ETF management structure is now in place. It consists of a single integrative activity, termed the TeraGrid Grid Infrastructure Group (GIG), and nine coordinated resource provider (RP) activities, one at each of the nine participating sites. The GIG is designed with a single Project Director, supported by four technical Area Directors, a Program Manager, a Science Coordinator and an Executive Steering Committee. Each RP participates in a TeraGrid-wide Resource Provider Forum and participates in TeraGrid-wide operational structures of the GIG in areas such as coordinated operations, allocations and security. All 10 awardees, both the GIG and the nine RPs, report directly to a single NSF Program Director. A Cyberinfrastructure User Advisory Committee (CUAC) is currently being established to provide input to ETF and NSF's other shared cyberinfrastructure partners on the needs of the broad user community.

The ETF construction phase was completed on September 30, 2004; ETF resources began allocated usage as part of "early operations" in October 2004. Allocations for ETF were included, for example, in the National Resource Allocation Committee's September 2004 and March 2005 allocations. The full operations phase for ETF is scheduled to begin in the spring of 2005.

ETF was created through a coordinated series of investments as follows:

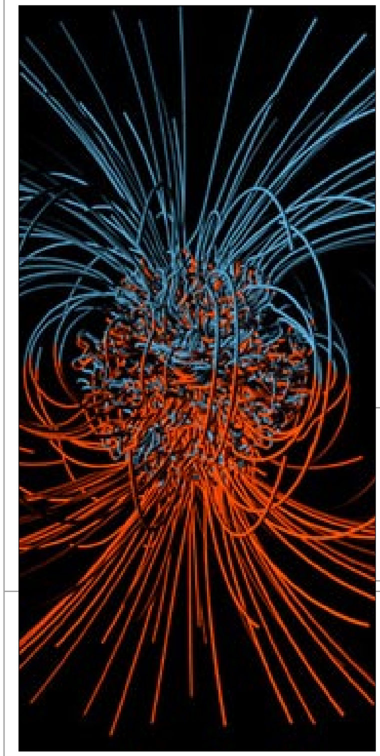
+ In FY 2000, PSC built TCS with peak performance of 6 teraflops.
+ The Distributed Terascale Facility (DTF) was initiated in FY 2001 by a partnership including the NCSA, SDSC, Argonne National Laboratory and the California Institute of Technology (Caltech). Based

To Index Page

on multiple Linux clusters, DTF linked its sites through a high-performance "DTF backplane."
+ In FY 2002, NSF provided funding to enhance the TCS and DTF and initiated the creation of the ETF by extending the "DTF backplane" to TCS and by placing extensible hubs in Chicago and Los Angeles that permitted further expansion of this new distributed facility.
+ In FY 2003, NSF made awards to extend the ETF to four additional sites — Indiana University, Purdue University, Oak Ridge National Laboratory (ORNL), and the Texas Advanced Computing Center at the University of Texas at Austin. Via high-speed network connections, the Spallation Neutron Source at ORNL and other unique computational and data resources in Indiana and Texas were integrated into ETF for use by the nation's research and education communities.
+ In FY 2004, PSC received an award to acquire a 10-teraflop Cray Red Storm capability system that has the potential to be scalable to 150 teraflops. This acquisition constituted the final award funded from the MREFC account, TCS.

NSF will support science and engineering research and education enabled by ETF through ongoing research and education programs. Annual support for research and education using the ETF is estimated to be about $200 million.

Additional information on the Terascale Computing Systems can be found in the Facilities Chapter of NSF's FY 2006 Budget Submission to Congress (http://www.nsf.gov/about/budget/fy2006/).



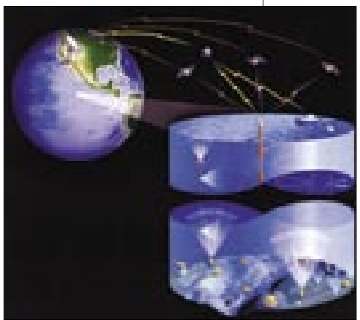
This image of the Earth's magnetic field represents the result of simulations performed on some of the highest-performance computers available to the U.S. academic community. NSF supports these and other computing, information and networking resources at three of the supercomputer centers established by NSF in 1985: NCSA at the University of Illinois, Urbana-Champaign; PSC at Carnegie Mellon University and the University of Pittsburgh; and SDSC at the University of California, San Diego.

SECOND PRIORITY: NEW STARTS IN FY 2007 AND FY 2008

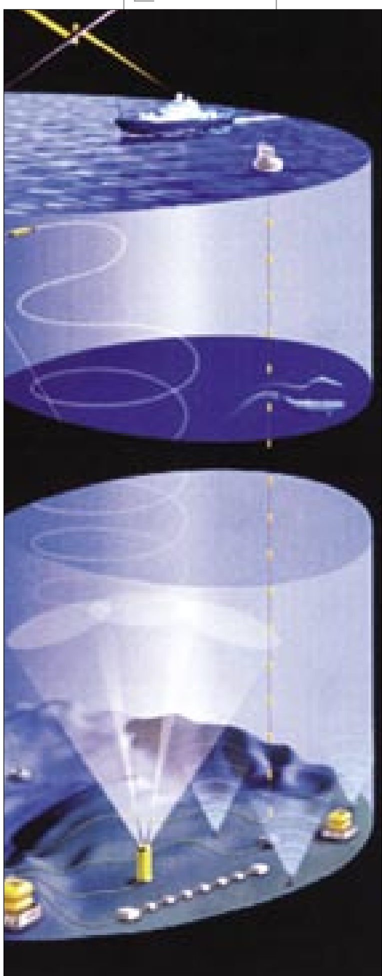
Ocean Observatories Initiative (OOI)

This project will construct an integrated observatory network that will provide the oceanographic research and education communities with continuous and interactive access to the ocean. The OOI will have three elements: (1) a global-scale array of relocatable deep-sea buoys; (2) a regional-scaled cabled network consisting of interconnected sites on the seafloor spanning several geological and oceanographic features and processes; and (3) an expanded network of coastal observatories, developed through new construction or enhancements to existing facilities. The primary infrastructure for all components of the OOI consists of an array of seafloor junction boxes connected to cables running along the seafloor to individual instruments or instrument clusters. Depending upon proximity to the coast and other engineering requirements, the junction box is either terminated by a long, dedicated fiber-optic cable to shore, or by a shorter cable to a surface buoy that is capable of two-way communications with a shore station. The observatory infrastructure of the OOI will be operated as a shared-use facility with open community access to data.

To Index Page



Artist's rendition of elements of the OOI.



Scientific problems requiring OOI infrastructure are broad in scope and encompass nearly every area of ocean science. Once established, seafloor observatories will provide Earth, atmospheric and ocean scientists with unique opportunities to study multiple, interrelated processes over time scales ranging from seconds to decades; to conduct comparative studies of regional processes and spatial characteristics; and to map whole-Earth and basin-scale structures. This project will establish facilities to meet the following goals: continuous observations at frequencies from seconds to decades; spatial scales of measurement from millimeters to kilometers; high-power and bandwidth capabilities, as well as two-way data transmission for interactive experimentation; an ability to operate during storms and in harsh conditions; an ability to easily connect sensors, instruments, and imaging systems; profiling systems for cycling instruments up and down the water column, either autonomously or on command; docking stations enabling autonomous underwater vehicles to download data and recharge batteries; ability to assimilate data into models and make three-dimensional forecasts of the oceanic environment; means for making data available in real time to researchers, schools and the public over the Internet; and low cost relative to the cost of building and maintaining ships and manned submersible systems.

Scientific discoveries arising from the OOI will provide new 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. Educational links will be made with the Digital Library for Earth Science Education (DLESE), and OCE's Centers for Ocean Science Education Excellence (COSEE). In addition, with the planned establishment of the U.S. Integrated Ocean Observing System (IOOS), there will be an unprecedented need for oceanographers skilled in the use and manipulation of large, oceanographic, time-series data sets. The facilities comprising the OOI will provide the ideal platforms to train this new generation of oceanographers.

The project will be managed and overseen by a program manager in OCE in GEO. The management structure proposed for the acquisition and implementation phase of the OOI is based on a structure that has been successfully used by the Ocean Drilling Program (ODP). In this structure, management, coordination and oversight of the OOI will be the responsibility of the Executive Director of the Ocean Observatory Project Office established through a cooperative agreement with NSF. This Director will be accountable to an Executive Steering Committee under which will be established Scientific and Technical Advisory Committees. The Executive Steering and Advisory Committees will draw their membership from individuals with expertise in ocean-observing science and engineering. The design of the OOI network and experiments utilizing OOI infrastructure will be selected on a peer-reviewed basis. This project will be coordinated with the IOOS that will support operational mission objectives of agencies such as NOAA, Navy, NASA, and the Coast Guard.

Numerous community workshops have been held and reports written since 2000. These activities helped to define the scientific rationale, determine the technical feasibility and develop initial implementation plans for the OOI. These include two NRC reports, as well as two reports for each of the three components of the OOI. These planning activities were followed by a large, multi-disciplinary workshop held in January 2004 to develop an initial science plan for the OOI across coastal, regional, and global scales. In March 2004 a cooperative agreement was awarded to establish the Ocean Research Interactive Observatory Networks (ORION) project office. The primary tasks of this office are to identify and facilitate committees for continued refinement of the OOI network design; to develop a consensus vision for the OOI organizational structure, governance, and operating plans; to identify and engage all constituencies of the ocean science research community in consensus-building activities; and to operate an interactive Web site for communicating with the ocean science community in regard to OOI activities and planning. The project office has established an executive steering committee that provides a direct link between project office planning and

To Index Page

the research community and is currently in the process of establishing the additional advisory committees that will make up the OOI advisory structure.

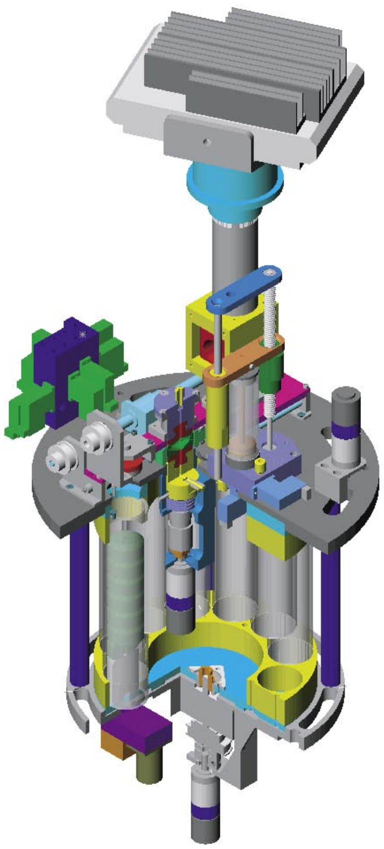
Using R&RA funds, the NSF's Ocean Technology and Interdisciplinary Coordination (OTIC) program has continued to provide support for proposals whose goals are to ensure that infrastructure needed to enable OOI experimentation is available for the implementation phase of the OOI. As part of this process, an announcement has been released by NSF to advance interactive observing technologies and understanding of the coastal benthic boundary layer. To accomplish this goal, one or more pilot/testbed study sites will be established to develop and enhance new technologies needed to investigate coastal processes at appropriate temporal and spatial scales. Furthermore, to continue community planning for OOI implementation, detailed conceptual proposals for ocean science research experiments have been solicited through the Ocean Observatories Project Office. These proposals will be used to further refine designs for OOI and to identify specific experimental instrumentation needs of the user community. A primary goal of this request is to determine the nature and cost of ocean observatory science and enabling infrastructure to be constructed though the OOI.

U.S.-funded construction activities are scheduled to continue through 2012, with project completion and full operation beginning in the same year. The construction schedule for this project is still under review, and therefore the milestones will likely be revised as the project's schedule is finalized.

NSF expects to spend approximately $30 million in concept and development activities through FY 2005. The total construction cost for OOI is $269.10 million, beginning in FY 2007. Management, operations and maintenance will be funded through the R&RA account.

The expected operational lifespan of this project is 30 years, beginning in FY 2012. A steady state of about $50.0 million in operations support is expected to occur in or about FY 2012. These estimates are developed strictly for planning purposes and are based on current cost profiles. They will be updated as new information becomes available. Along with direct operations and maintenance support for the OOI, NSF will support research performed using this infrastructure through ongoing research and education programs. The annual support for such activities is estimated to be about $50 million, once the network is fully implemented.

Additional information on OOI can be found in the MREFC Chapter of NSF's FY 2006 Budget Submission to Congress (http://www.nsf.gov/about/budget/fy2006/).



The Environmental Sample Processor (ESP) is an instrument developed to detect multiple microorganisms with molecular probe technology, as well as to perform sample collection, concentration, different analyses, and sample archival. The system will also process data and transmit results. The ESP is in a period of transition from prototype and short-term deployments to development and application of a 'second generation' unit by Chris Scholin, Monterey Bay Aquarium Research Institute.

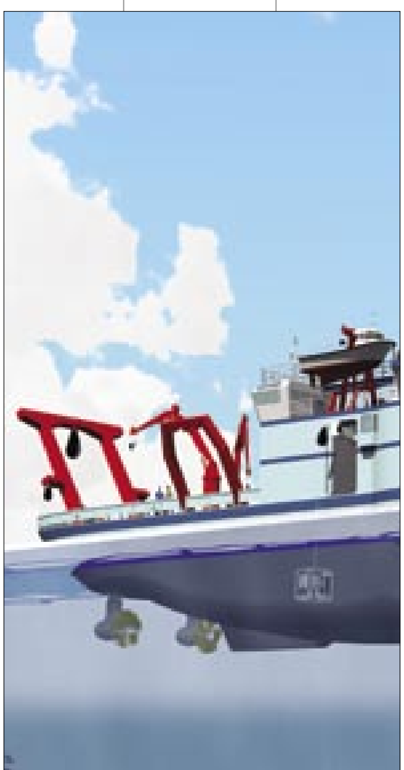
Alaska Region Research Vessel (ARRV)

The ARRV is proposed to replace the Research Vessel (R/V) *Alpha Helix*, which at 39 years is the oldest ship in the national academic research fleet. At present, science activities in the Alaskan region are limited by the capabilities of the R/V *Alpha Helix*, which cannot operate in ice or in severe winter weather in the open seas. The ARRV will operate in the challenging waters of the Chukchi, Beaufort and Bering Seas, as well as the open Gulf of Alaska, coastal Southeast Alaska and Prince William Sound.

As we strive to understand a variety of complex regional and global ecosystem and climate issues, the need to conduct research at the ice edge and in seasonal ice (up to three feet thick) has become increasingly urgent. The ARRV will provide improved access to the region, enabling further exploration to address critical issues. With an operating year of 275-300 days, the ARRV could accommodate upwards of 500 scientists and students at sea annually.

To Index Page

Artist's rendition of the ARRV, an MREFC Project that will replace the smaller, aging R/V *Alpha Helix*.



Satellite observations have shown the perennial ice in the Arctic thinning at 9 percent per decade, which will have major regional and global consequences. Research is urgently needed on topics ranging from climate change, ocean circulation, ecosystem studies and fisheries research to natural hazards and cultural anthropology. Most of these cutting-edge science projects require an oceanographic platform in the Alaska region to conduct field research. The ARRV will also provide a sophisticated and larger platform for scientists, graduate and undergraduate students to participate in complex multidisciplinary research activities and will train the next-generation scientists with the latest equipment and technology. Broadband connections capable of relaying data, including high-definition video from tools such as remotely operated vehicles capable of exploring under the ice and the ocean depths, will bring research into the K-12 classroom and to the general public.

The NSF Coordinator will be the Program Director for Ship Acquisition and Upgrade Program, Integrative Programs Section (IPS) in OCE, with other staff in IPS providing program management assistance. The Section Head in IPS and another section member hold the Master's Certificate in Project Management through NSF-sponsored training. The awardee will hire a Systems Integration Manager to establish and staff an office to provide management oversight to the vessel construction phase and to report to the NSF Coordinator. In addition, the University-National Laboratory System (UNOLS) Fleet Improvement Committee, an external committee composed of representatives from the community that meets several times a year, will review progress and provide advice regarding vessel construction.

Final model tank testing and data analysis were successfully completed in 2003. Results from model testing concluded that the current design has excellent sea-keeping and enhanced icebreaking capabilities. In addition, acoustic testing demonstrated that the vessel will have sufficient "quieting" characteristics to support unique fisheries research. Results from the design studies have been shared with the community on several occasions, offering opportunities for interactive exchanges to take place between potential vessel users and the naval architects. Following minor design adjustments based upon these inputs, the design phase was completed in 2004. A meeting of the Oversight Committee and agency representatives held at the Seattle offices of the naval architects Glosten Associates in December 2004 reviewed and accepted the final "contract design" document. This document provides the complete list of specifications and drawings from which a shipyard could make a construction bid. The next action will be for NSF to issue a solicitation for a cooperative agreement for the construction and operation of this ship.

The Federal Oceanographic Facilities Committee (FOFC) continues to endorse the ARRV as the next vessel needed to help renew the aging national academic research fleet, as it originally stated in its 2001 report "Charting the Future for the National Academic Research Fleet: A Long Range Plan for Renewal," submitted to the National Ocean Research Leadership Council.

NSF plans to release a solicitation to build and operate the ARRV in FY 2006, and to initiate vessel construction in FY 2007. U.S.-funded construction activities are scheduled to continue through 2008, with project completion and full operation beginning in 2009.

Recognizing from the outset that the R/V *Alpha Helix* was of marginal size and capability for Alaskan waters, replacement planning has been ongoing since the 1980s. NSF funded design studies in 1980 and 1995, but neither was implemented. After community-derived science mission requirements were developed in 1999, NSF has since funded the concept design, detailed design and model testing for a replacement vessel and is prepared to initiate a two-year construction phase.

The expected operational service life of the ARRV is 30 years after construction is complete. Ship operations costs are estimated to be approximately $6 million per year. These estimates are developed strictly for planning purposes and are based on current cost profiles. They will be updated as new information becomes available. Along with direct operations and maintenance support for the ARRV as part of the Academic Research Fleet (ARF), NSF will support research performed using this infrastructure through ongoing research and education programs. It is anticipated that the ARRV will greatly expand research capabilities in the region, going from a maximum of 160 ship operating days with the R/V *Alpha Helix*, up to 275-300 days with the ARRV. It is anticipated that the vastly increased capability of the ARRV, both with regard to its ability to accommodate much larger interdisciplinary research teams and greatly enlarged geographical and seasonal ranges, will dramatically increase the number of proposals addressed to NSF for its utilization.

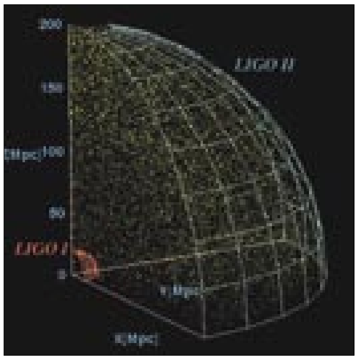
Additional information on ARRV can be found in the MREFC Chapter of NSF's FY 2006 Budget Submission to Congress (http://www.nsf.gov/about/budget/fy2006/).

Advanced Laser Interferometer Gravitational Wave Observatory (AdvLIGO)

AdvLIGO is the upgrade of the Laser Interferometer Gravitational Wave Observatory (LIGO) that will allow LIGO to approach the ground-based limit of gravitational-wave detection. LIGO consists of the world's most sophisticated optical interferometers, operating at two sites (Hanford, WA and Livingston, LA). Each interferometer has two 4-km arms at 90 degrees to one another. In addition, the interferometer at Hanford contains a 2-km interferometer within the same vacuum enclosure used for the 4-km interferometer. These interferometers are designed to measure the changes in arm lengths resulting from the wave-like distortions of space-time caused by the passage of gravitational waves. The changes in arm length that can be detected by the present, Phase I LIGO are a thousand times smaller than the diameter of a proton over the 4-km arm length. AdvLIGO is expected to be at least 10 times more sensitive. The frequency range for which LIGO and AdvLIGO are designed will be sensitive to many of the most interesting cataclysmic cosmic phenomena believed to occur in the universe. Furthermore, because LIGO and AdvLIGO will push the sensitivity of gravitational-wave detection orders of magnitude beyond existing frontiers, the potential for making discoveries of completely new phenomena is significant.

LIGO will achieve its objectives as planned and may detect the first gravitational waves. AdvLIGO will greatly increase the sensitivity to ensure the detection of gravitational waves and to launch the new field of gravitational-wave astronomy.

The LIGO project was planned in two phases from the very beginning. Phase I would produce a gravitational-wave detector that would be as sensitive as possible with the technology available in the early 1990s on a platform that could be upgraded to the ultimate sensitivity as the critical technologies were further developed. The goal of Phase I was to obtain a year's worth of accumulated data at the design sensitivity for Phase I (expressed as a dimensionless strain $h \sim 10^{-21}$, the ratio of the change in arm length to the length of the arm). The LIGO Laboratory expects to have those data in 2006. The second phase or AdvLIGO project will upgrade LIGO to enable attainment of the ultimate sensitivity of an Earth-based gravitational-wave observatory, limited only by the irreducible effects of fluctuations in the Earth's gravitational field. From the outset, the overall LIGO strategy was to produce a broadband gravitational-wave detector with an unprecedented astronomical reach and then to upgrade the initial facility to achieve the most sensitive gravitational-wave detector possible on Earth.



The MREFC Project AdvLIGO will improve the sensitivity of LIGO by more than a factor of 10, which will expand the volume of space LIGO will be able to "see" by more than 1,000.

To Index Page

An aerial photograph of the LIGO site in Livingston, LA.

The LIGO program has strongly stimulated the interest in gravitational-wave research around the world, producing very vigorous programs in other countries that provide strong competition. LIGO has pioneered the field of gravitational-wave measurement, and a timely upgrade is necessary to reap the fruits of this bold initiative. International partners are contributing significant human and financial resources.

Einstein's general theory of relativity predicts that cataclysmic processes involving super-dense objects in the universe will produce gravitational radiation that will travel to Earth. Detection of these gravitational waves is of great importance, both for fundamental physics and for astrophysics. And, although the universe is believed to be filled with gravitational-waves from a host of cataclysmic cosmic phenomena, scientists have never detected a gravitational wave and measured its waveform.

The principal scientific goals of the LIGO — AdvLIGO project are to detect gravitational waves on Earth for the first time and to develop this capability into gravitational wave astronomy — a new window on the universe — through which we can observe phenomena such as the inspiral and coalescence of neutron stars in binary orbit, black hole collisions, unstable dynamics of newborn neutron stars, supernovae, a stochastic background from the early universe, and a host of more exotic or unanticipated processes.

LIGO has played a significant role in the training of Ph.D. graduates for the country's workforce. In addition, LIGO has a diverse set of educational activities at its different sites, activities that involve a large number of undergraduates and outreach activities for the public. In 2004 NSF entered into a cooperative agreement with Caltech and Southern University/Baton Rouge to build a Visitor's Center at the Livingston site.

Substantial connections with industry have been required for the state-of-the-art construction and measurements involved in the LIGO projects. Some have led to new products. Areas of involvement include novel vacuum-tube fabrication technology, seismic isolation techniques, ultrastable laser development (new product introduced), development of new ultra-fine optics polishing techniques, and optical inspection equipment (new product).

Active outreach programs have been developed at both the Livingston and Hanford sites. Teams at both sites have provided visual displays, hands-on science exhibits, and fun activities for visiting students and members of the public. In the last three years, more than an average of 2,000 students per year have taken advantage of this opportunity. More formal programs at the sites include participation in the Research Experience for Teachers (RET) Program, a set of "scientist-teacher-student" research projects in support of LIGO, and participation in the Summer Undergraduate Research Fellowships/Research Experience for Undergraduates (SURF/REU) programs for college students. In collaboration with RET participants and networks of local educators, both sites have developed Web-based resources for teachers that include information on research opportunities for schools and a set of standards-based classroom activities, lessons and projects related to LIGO science. Well under way is the project to build the Visitor's Center at the Livingston site that will be filled with Exploratorium exhibits and will be the focal point for augmenting teacher education at Southern University and other student-teacher activities state-wide through the Louisiana Systemic Initiative Program. Outreach coordinators have been hired at each site to augment the existing activities. New this year is Einstein@home, a World Year of Physics project led by a LIGO Scientific Collaboration (LSC) scientist from the University of Wisconsin/Milwaukee, that allows almost anyone in the world with a computer to participate in LIGO data analysis.

LIGO is sponsored by NSF and managed by Caltech under a cooperative agreement. Under the current agreement, NSF oversight is coordinated internally by a dedicated LIGO program director in the Physics Division in MPS, who also participates in the PAT. NSF conducts annual scientific and technical reviews involving external

To Index Page

reviewers and participates in meetings of the LSC as well as making site visits to the Hanford and Livingston interferometers. During the AdvLIGO construction phase, NSF will continue the activities described above and exercise more intensive oversight through more frequent reporting requirements, stepped-up interaction with the project personnel, scheduled reviews and site visits at least twice yearly and more frequently if need arises. The NSF LIGO program director will work closely with the LIGO Deputy Director for the AdvLIGO Project who has already been named. Project management techniques used in the successful completion of the initial LIGO construction will be employed to benefit management of the AdvLIGO construction.

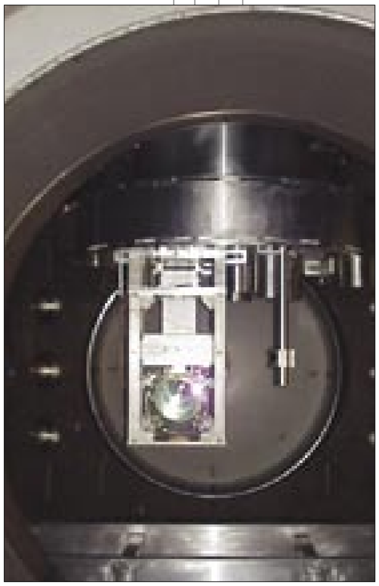
All three LIGO interferometers were fully operational by the spring of 2002. Since then, activity has been divided between improving the sensitivity of the interferometers and collecting scientific data. Four science runs have been performed: S-1, in the period from August 23, 2002, to September 9, 2002, with a sensitivity of about a factor of 100 from the design goal; S-2, lasting 59 days from February 14, 2003, to April 14, 2003, with a sensitivity of about a factor of 10 from the design goal; S-3 in the period from October 31, 2003, to January 8, 2004, with a sensitivity of about a factor of 3.5 from the design goal; and S-4 from February 22, 2005, to March 23, 2005. The improvements achieved in S-4 were remarkable. The addition of the Hydraulic External Pre-Isolation (HEPI) system to the Livingston interferometer to eliminate interference from anthropogenic noise sources was totally successful, as indicated in the improvement of the Livingston duty cycle from 21.8 percent in S-3 to 74.5 percent in S-4 leading to more than 50 percent triple coincidence observing during the run. In addition, during S-4 all three interferometers improved their sensitivity to within a factor of 2 of design sensitivity.

The LIGO Laboratory submitted a proposal for AdvLIGO in early 2003. The proposal was reviewed in June 2003 and the project was considered to be ready for construction. The AdvLIGO upgrade will include the laser, suspension, seismic isolation, and optical subsystems. Advanced detector research and development has proceeded to the point where technology needed for the upgrade is well in hand. In particular the development of the laser subsystem has achieved performance levels essentially at the final specifications, and part of the AdvLIGO seismic isolation system is already in operation at the Livingston site where it has successfully eliminated excess vibration from various sources. The LIGO Laboratory will have spent $40.74 million of R&RA funds on advanced R&D for AdvLIGO in the period from FY 2000–2007. U.S.-funded construction and commissioning activities are scheduled to continue through FY 2013, with project completion and full operation at both sites beginning in September 2013.

The expected operational lifespan of LIGO is about 20 years. Along with direct operations and maintenance support for LIGO, NSF supports science and engineering research directly related to LIGO activities by members of the LIGO Scientific Collaboration from universities through ongoing research and education programs. The annual support for such activities is estimated to be about $5 million.

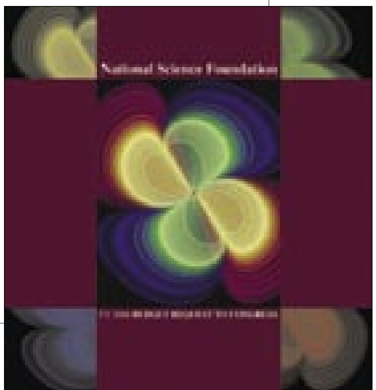
In 1997 LIGO founded the LSC to organize the major international groups doing research that was supportive of LIGO. The LSC now has more than 40 collaborating institutions with about 500 participating scientists. The role and membership responsibilities of each participating institution are determined by a Memorandum of Understanding (MOU) between the LIGO Laboratory and the institution. The LSC plays a major role in many aspects of the LIGO effort, including: R&D for detector improvements, R&D for Advanced LIGO, data analysis and validation of scientific results, and setting priorities for instrumental improvements at the LIGO facilities.

Additional information on AdvLIGO can be found in the MREFC Chapter of NSF's FY 2006 Budget Submission to Congress (http://www.nsf.gov/about/budget/fy2006/).



The End Test Mass in the x-arm of the 2k-IFO. (Hanford, WA)

To Index Page

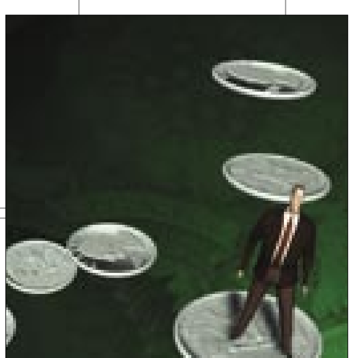


Status Report on National Science Board Approved New Starts

This category is reserved for NSB-approved new starts that have not yet been included in an NSF Budget Request to Congress. At the time of the writing of this Facility Plan, NSF has requested funding (in FY 2006 or later) for all NSB-approved new starts in the FY 2006 Budget Request to Congress.

Readiness Stage Projects and Projects Recommended for Advancement to Readiness Stage

The MREFC panel annually evaluates projects for admission to this category. Candidates are brought forward by the sponsoring directorates and offices when those organizations consider the projects ready for MREFC funding consideration. At the time of the writing of this Facility Plan, there are no projects in the Readiness Stage.



Projects Under Exploration

Many NSF programs, divisions, offices and directorates are exploring and funding the preliminary development of concepts that might eventually evolve into MREFC projects. The following projects, which have been brought to the attention of the MREFC Panel, illustrate both the wide variety of concepts being investigated and the various stages of project development. Some are very embryonic and others well-advanced in their planning. Some may become MREFC candidates and others perhaps not, either because they prove infeasible or because better ways of meeting the scientific objectives come to light in the planning process. This chapter is not meant to provide a comprehensive overview of projects on either the near or distant horizon.

To Index Page

Advanced Technology Solar Telescope (ATST)

The main purpose of the ATST will be to enable study of magnetohydrodynamic phenomena in the solar photosphere, chromosphere and corona. Understanding the role of magnetic fields in the outer regions of the Sun is crucial to understanding the solar dynamo, solar variability and solar activity, including flares and mass ejections which can affect life on earth. As the first new large solar telescope constructed in nearly 30 years and because of the new range of scientifically compelling questions that it can address, the ATST is expected to rejuvenate the ground-based solar research community in U.S. universities and enable training of the next generation of solar physicists and instrument builders. Strong linkages will be established with a diverse set of collaborating institutions, including universities, industrial partners, NASA centers and other federally funded research and development centers (FFRDC). There will also be synergy with planned space missions such as the Solar Dynamics Observer. ATST will contribute to curriculum development and teacher training through ongoing National Solar Observatory (NSO) and NOAO programs, and to public outreach through NSO Visitors Center, Web presence, etc.

NSF has provided $11.0 million for a five-year (FY 2001-2005) design and development phase of the ATST project. The project conducted an extensive and successful conceptual design review in August 2003. A set of preliminary and systems design reviews will be held in early 2005. The project has selected Haleakala Peak on the island of Maui in Hawaii as its primary site, and the environmental assessment process has begun. A construction proposal for the telescope is currently under review by AST. Construction costs that would be requested of MREFC are now estimated at $161.40 million. Annual ATST operations costs will be approximately $11.0 million, about $4.0 million of which will be accommodated by closing existing NSO facilities. Enhanced university research enabled by ATST would require an additional $3.0 million annually from NSF grants. The earliest possible start date for construction is FY 2007.

Artist's conception of the ATST.

Collaborative Large-scale Engineering Analysis Network for Environmental Research (CLEANER)

CLEANER will contribute to the NSF Science Objective of integrated research to understand complex environmental systems. The main goal of CLEANER is to provide the physical infrastructure and CI to develop the knowledge base that can be used to solve large-scale, multifaceted environmental problems, especially in systems that are heavily impacted by human activities. CLEANER will be a distributed collaborative network of interacting sites for large-scale research on human-dominated environmental systems, comprising a series of interacting field sites, an integrating CI including data and model repositories, and an enabling management infrastructure. CLEANER will support data collection from advanced sensor arrays and analytical tools for data mining, aggregation and visualization. This will lead to predictive multi-scale modeling of dynamic environmental systems and experimentation to improve engineering approaches for environmental protection and management. The long-term goal is to foster adaptive management strategies for large-scale human-dominated environmental systems. CLEANER will provide information (some in real-time) from a series of comparable nationwide sites. Theory and computation will be used to develop a deep understanding of the interplay among air, water and land, and how controlling pollutants in one compartment affects environmental quality in the other media.

Fish Kill at Chautauqua National Wildlife Refuge in Illinois.

Pollution at the Kanai Moose Range.

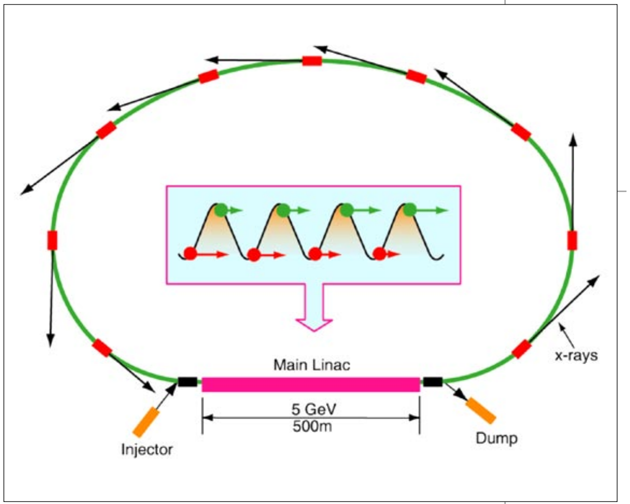
To Index Page

Coherent X-Ray Light Source

A coherent X-ray light source will be a transformational facility, impacting many scientific disciplines and enabling new types of scientific investigations that cannot be done today. For example, it will impact chemistry by allowing time-resolved investigations of the structures of macromolecules in solution and of the structural evolution of transition states in ultrafast chemical reactions. It has the potential to do “crystallography without crystals” — that is, to enable the determination of structural data for macromolecules without requiring that they be in crystalline form. This is especially valuable for biology, as many important biomolecules do not form crystals. It will also provide biologists with the potential to image subcellular organelles, yielding protein locations in the natural state. In addition, the phase contrast at hard X-ray energies provides the potential for real-time, high-resolution medical imaging of low-contrast tissues. In condensed-matter physics and materials research, a coherent X-ray light source will enable measurements of microstructure in bulk materials, studies of stresses and strains on individual grains, and investigations of structure and dynamics in materials (e.g., by providing a picosecond view of melting, recrystallization and annealing, and enabling fundamental investigations of plastic deformation). In geology and geophysics, a coherent X-ray light source will enable time-resolved experiments on plasticity, rheology, and phase transitions, as well as allowing studies of matter at high pressures, probing conditions that exist in planetary interiors.

Two concepts for a coherent X-ray light source have been discussed with NSF: an Energy Recovery Linac (ERL) project at Cornell University and an X-ray Free Electron Laser (XFEL) project at MIT. Both the ERL and XFEL concepts have been explored in a number of workshops dating back several years. Since NSF expects to support the construction of at most one coherent X-ray light source, the two projects are effectively in competition with each other. Either project would provide orders of magnitude improvement over existing synchrotron X-ray sources in reduced pulse duration and intensity of coherent X-ray flux. Advanced CI will be required for optimal performance of either design of instrument (e.g., to provide “smart” control of the phasing of electron bunches (ERL), or of the phasing between electron bunches and laser pulses (XFEL), or to achieve synchronization of multiple lasers at femtosecond time scales for multiple beamlines). Robotic control of experiments would often be required to enable efficient data collection, including software-based data reduction with the capability of handling data rates of order 10 megabytes per second. Data analysis software will confront new challenges either in concatenating the collection of ERL data from billions of individual pulses or in analyzing data from “Coulomb explosions” produced by an XFEL.

NSF recently awarded $5.15 million to Cornell to begin construction of a prototype ERL, with which to address the many technical issues that must be satisfactorily resolved before the potential of a full-scale ERL can be realized. These issues include the generation of high average current high-brightness electron beams; acceleration of these beams to suitable energies without unacceptable emittance degradation; and stable and efficient operation of superconducting linear accelerators at very high gradients. A full-scale ERL is estimated to cost $300 million. A full-scale XFEL is expected to cost as much as $500 million.



This image depicts a schematic diagram of an ERL, which is a source of synchrotron radiation. This source injects electrons at up to a 1.3GHz rate into superconducting radio frequency (RF), which is instrumental in accelerating the electrons to their full energy of 5 GeV, illustrated by the green balls “surfing” on the rest of the RF traveling wave in the image. Upon circulating, they produce X-ray beams in undulators, shown by the red rectangles and return to the linac, decelerating to a low-energy state, ready to be directed to a beam dump.

To Index Page

Deep Underground Science and Engineering Laboratory (DUSEL)

DUSEL will be to enable experiments that require the conditions that are achieved only at extreme depths in the earth (8,000 to 10,000 feet), such as very low rates of background cosmic rays or extremes of geological temperature (in excess of 120ºC) and rock stress. The need for and possible research programs for an underground laboratory have been documented in two long-range plans (high energy and nuclear physics communities), an NSF sponsored workshop, "International Workshop on Neutrinos and Subterranean Science 2002," and two major NRC reports, "Connecting Quarks with the Cosmos" and "Neutrinos and Beyond." The laboratory will add major new dimensions to the U.S. and worldwide research efforts in particle and nuclear physics, astrophysics, geosciences and engineering. Work in the DUSEL, which will use rare decay processes and collisions of neutrinos from astrophysical sources with matter in underground detectors, will help unlock the secret of neutrino mass, diagnose the core collapse of a massive star, and perhaps solve the mystery of the domination in the universe of matter over antimatter. Studies of life forms that thrive under extreme conditions may provide clues to the origin and evolution of life on Earth.

To support planning for the project for the next two years, MPS has initiated a three-phase solicitation process aimed at identifying: (1) the scientific and engineering case for experiments that would make up the underground laboratory, as well as the technical and infrastructural requirements of each experiment; (2) conceptual designs for specific sites that will accommodate as much of the research as possible; and (3) baseline designs for the infrastructure for an underground laboratory, including detailed costs and time required for the permitting, construction and development of an initial suite of experiments. Up to $3 million was provided for proposals resulting from solicitations 1 and 2, and up to three awards totaling up to $1 million each will result from solicitation 3. This process is expected to result in the information needed to decide whether NSF will proceed with the project. The actual costs associated with the development of the infrastructure of the laboratory are estimated to be about $300 million, and the cost of the initial suite of experiments that would go into the laboratory is also estimated to be approximately $300 million.

Located 2,000 feet underground in the Japanese Alps, the SuperKamiokande neutrino detector is composed of thousands of PM tubes, which collect light produced by the interaction of the neutrinos and the ultra-pure water filling the detector. This device has detected neutrino oscillations among atmospherically generated neutrinos, providing evidence that neutrinos have a small but finite mass. It has also detected solar neutrinos, contributing to the understanding of the problematic detection rate of neutrinos from the Sun.

Expanded Very Large Array (EVLA) Phase II

The Expanded Very Large Array Phase II (EVLA Phase II) would enhance the capabilities of the most productive radio telescope ever built, the Very Large Array (VLA), which is reportedly second only to the Hubble Space Telescope in total production of resulting publications. The key scientific inquiries will follow the evolution of the universe: tracing the neutral hydrogen mass function back in time; observing galaxy and star formation in the early universe; studying the formation of galaxy clusters; observing the environs of active galactic nuclei, including jets; using variability of gravitational lensing to understand galactic and intergalactic dynamics; responding quickly to gamma ray burst events; and observing, with unprecedented resolution and sensitivity, the structure and evolution of our own galaxy. The expanded VLA will open a vast “discovery space” that is currently inaccessible to any instrument. The Phase II expansion will add eight new antennas to the array at larger physical spacings (up to 300 km), will connect inner antennas from the Very Long Baseline Array (VLBA) to the EVLA by fiber-optic cables, and will add the physical infrastructure to support a new, extremely compact array configuration. The result of the expansion will be an array with an order of magnitude improvement in sensitivity to both large-scale and small-scale astrophysical structure. The very compact array configuration will provide maximum sensitivity to extended emission. Combined with the Phase I expansion, the array will improve its sensitivity, frequency agility and resolution by an order of magnitude.

The preliminary estimates for the Phase II expansion cost is $110 million total (in 2004 dollars), with the bulk of the cost (approximately $90 million) consisting of siting and construction of the eight new antennas and the installation of last-mile fiber-optic cable. The remainder will be used to build the physical infrastructure for the new compact array configuration. Included in these costs is approximately 15 percent contingency. Phase II construction is expected to take approximately seven years from commencement. Conceptual development, proposal writing, and preliminary design work for Phase II has been funded from NRAO’s operations budget. NRAO is well under way on CI planning that will allow acquisition, processing, dissemination and archiving of the large data sets. The major cyber-requirements for this initiative are vast storage media, advanced search and retrieval technology, rapid data-transfer/disk-access technology, and wide-bandwidth interconnections. All of these requirements are being addressed in the present Phase I deployment and in the Phase II planning process. The Phase II proposal is under review by NSF.

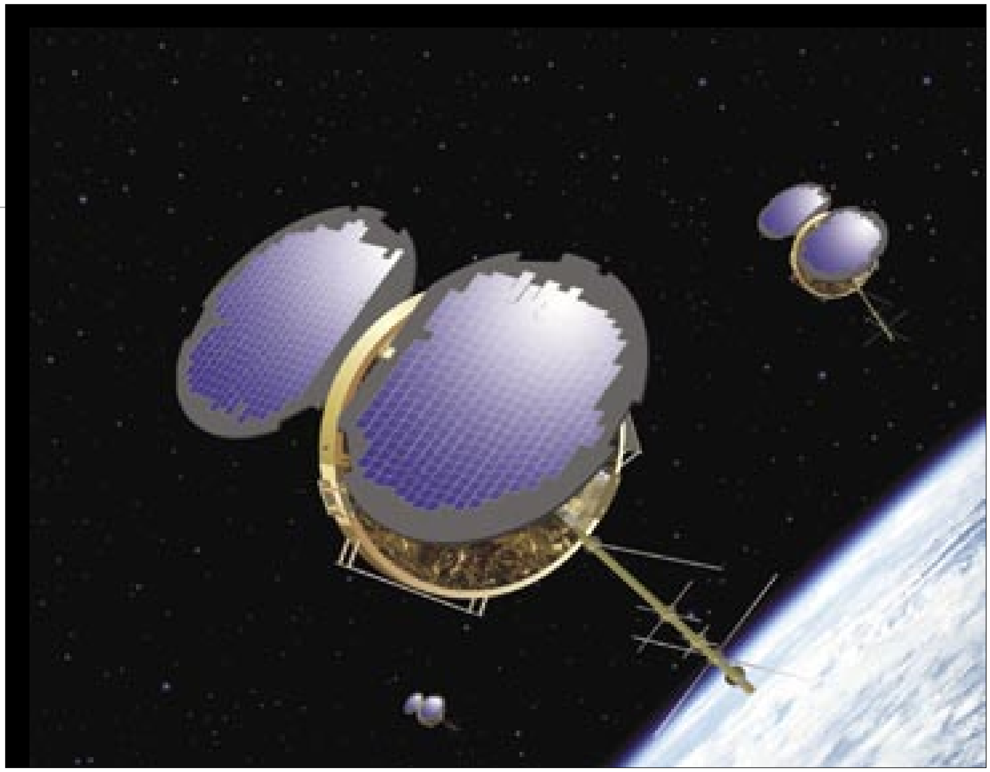
The VLA at sunset.

To Index Page

GNSS Earth Observing System (GEOS)

The GNSS (Global Navigation Satellite System) Earth Observing System (GEOS) is based on UCAR's COSMIC (Constellation Observing System for Meteorology, Ionosphere and Climate) and the Jet Propulsion Laboratory's (JPL) AMORE (Atmospheric Moisture and Ocean Reflection Experiment) concepts. A constellation of 12 small instrumented spacecraft will explore the global atmosphere, from the surface of the Earth to an altitude of several hundred kilometers, providing unique geoscience measurements to study the oceans, troposphere, stratosphere and ionosphere as an integrated, interacting system. Using multiple radio frequencies, GEOS will provide high-quality, time-continuous measurements of temperature, water vapor, ozone, ocean topography and surface wind, ionospheric electronic density distribution and Earth gravity. This will enable significant advances in the following scientific disciplines: climate, meteorology, atmospheric chemistry, space weather, oceanography, and solid earth structure and dynamics. GEOS will provide 12,000 GPS radio occultation soundings per day from which 1,600 water vapor profiles per day could be obtained over all parts of the globe. Presently, vertical profiles of the atmosphere are made twice a day at fewer than 700 sites globally, and vast areas of the ocean are not sampled at all. In addition, the GEOS constellation will provide ocean topography measurements with an accuracy of a few centimeters in the vertical with a horizontal resolution of less than 25 kilometers. Also, other geophysical parameters, such as gravity variation with wavelength 500~1,000 km. will be made by GEOS.

It is expected that the development, construction and launching of these observing tools will build on existing partnerships between NSF and NASA. The respective communities supported by these agencies have expertise in design, development, evaluation, data processing and distribution, and use of the GEOS system. The earliest possible start date for construction of the satellites is FY 2007. The total budget for this project is estimated at $425 million based on an FY 2007 start date and 2011 launch date. A six-year operating life time for the satellite system is expected, with eight to 10 years of post-mission data analysis and research.

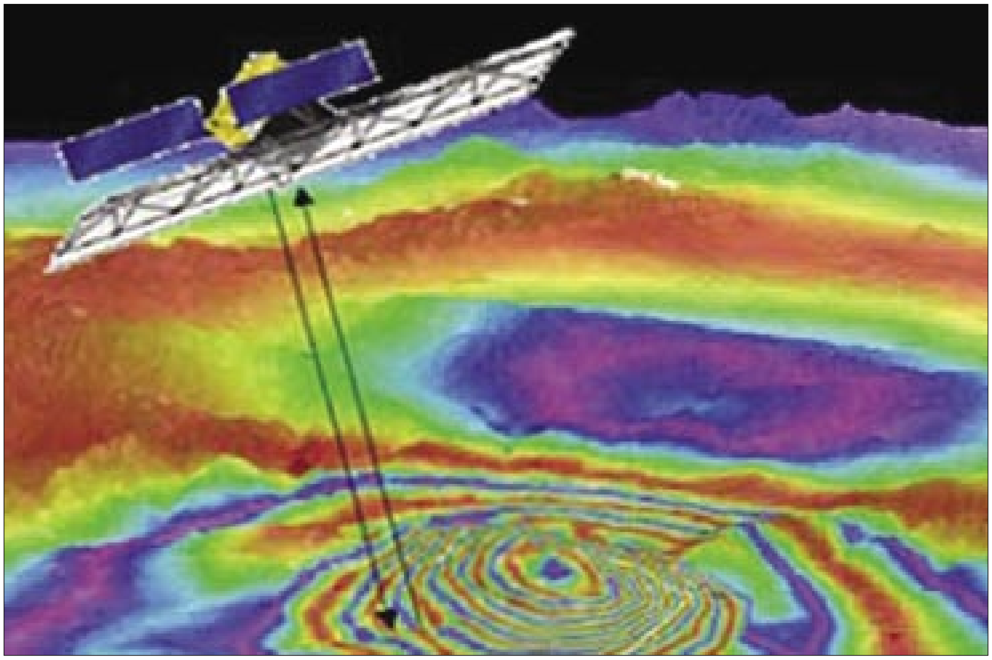


This COSMIC constellation would be the third generation of applications of the radio occultation techniques.

Interferometric Synthetic Aperture Radar (InSAR)

This project, which will be led by NASA, will consist of a satellite-based Interferometric Synthetic Aperture Radar (InSAR) capable of measuring surface motions as slight as several millimeters per year, such as during strain accumulation between earthquakes. This revolutionary new geodetic tool for the measurement of Earth surface deformation will bring a fundamentally new data type to the study of changes of the Earth's surface: time series of spatially continuous surface deformation associated with earthquakes, volcanoes, ice sheets and glaciers. The principal geographic focus areas include regions of active tectonics, volcanics and glaciation, or approximately 10 percent of the area of the Earth. InSAR will achieve these diverse goals through a single type of measurement: millimeter-level surface deformation at resolutions of tens of meters with worldwide accessibility. For NSF, InSAR is the fourth and final component of EarthScope. InSAR will be a great improvement over the European Space Agency and Canadian Space Agency SAR instruments, which use short wavelengths and are therefore subject to interference from any ground disturbances. InSAR's mission will provide coverage of the same area every eight days, providing the large number of frequent observations necessary to understand the earthquake process. Recent workshops have emphasized the importance of InSAR for providing high-spatial-resolution distortion measurements to discriminate competing models of fault slip, viscoelastic response and volcanic magma movement. A significant fraction of the Earth's population lives in or near areas likely to experience earthquakes, volcanic eruptions or the consequences of sea-level change. Better understanding of these hazards through InSAR-related studies can help mitigate the consequences, potentially saving lives and reducing economic impact. The 744 earth science departments at U.S. universities that grant degrees at the bachelor level or above will be empowered to participate in the excitement of geoscience research and education by accessing InSAR results on line.

InSAR concepts were developed in numerous workshops and proposals over the past decade. Technologically, the project is low-risk with the instrumentation and scientific techniques proven. NASA has provided extensive planning, design, and development funding for approximately ten years. NSF would be expected to provide approximately $80 million toward construction of the satellite radar and ground down-link data systems. The earliest possible start for construction of EarthScope: InSAR is FY 2007.



InSAR illustrates the ground movement as fringes or contours taken from the satellite's radar picture of the Earth's surface. The fringes and contours represent identical images taken at various intervals to be compared for differences by a computer to produce this picture.

To Index Page

Large Synoptic Survey Telescope (LSST)

LSST will contribute to the Science Objective of Understanding the universe. The principal science drivers for the LSST are: understanding the physics of dark energy via three-dimensional mass tomography to great distances and the detection of moderate redshift supernovae; detecting and cataloging small bodies in the solar system, including potentially hazardous asteroids and objects in the outer solar system; opening the time domain through repeated deep imaging of the accessible sky, which can reveal transient and explosive events such as cataclysmic variable stars, gamma ray bursters and the optical counterparts of X-ray flashes; studies of the distances and motions of a complete, distance-limited sample of stars in the solar neighborhood; and measuring of the kinematics and structure of the galactic halo. The 8.4m optical telescope will be a special-purpose instrument, designed and operated for the benefit of the entire astronomical community. The LSST will be a digital celestial camera of unprecedented size and capability, collecting and processing nightly nearly 20,000 gigabytes of multi-color imaging data over its anticipated ten-year lifetime. The processing power required to stay abreast of the data stream is approximately 140 teraflops. Decimation of the data will occur on-site, but substantial network bandwidth will be required for dissemination of the data products and processed images to be produced nightly. The LSST data processing systems will produce the deepest, widest-field image of the sky ever taken along with daily catalogs of moving and transient objects.

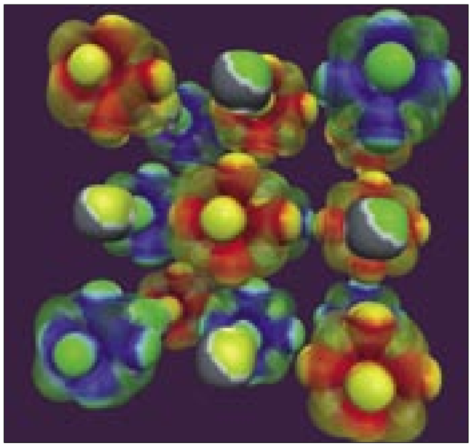
The site-selection process for LSST has narrowed the choices to four mountaintop sites: Cerros Pachon and Las Campanas in Chile, San Pedro Martir in Baja California, and La Palma in the Canary Islands (Spain). Meteorological conditions and image quality statistics for potential sites are being factored into detailed simulations of the design reference mission. Cyberinfrastructure, in particular the availability or cost of high bandwidth connectivity at a given site, is also of importance and will weigh heavily into the site-selection process. Downselect to two potential sites will be made in early 2005. A design and development proposal is currently under review by AST. Preliminary estimates excluding the cost of the camera are approximately $140 million in FY 2007 dollars. A full-time project manager with extensive experience in large distributed technical projects was hired in mid-2003, and $30 million of private funds has been raised, with some being used to mitigate schedule and technical risk by early procurement of glass needed for the large reflective optical elements. AST funded a three-year detector-technology development proposal for $1.3 million in FY 2003. NOAO's annual in-kind contributions to the LSST project totals approximately $1.2 million. The science cases are being developed by an independent science-working group and will be critically examined by NSF over the coming months. The earliest possible start for construction of the LSST is FY 2008, which would allow science operations to start in late 2012. If substantial funding is found from private sources or other agencies, the construction cost to the NSF could drop below the MREFC threshold. The adoption of a competing design for a large-aperture survey telescope, PanSTARRS, a project at the University of Hawaii funded by the U.S. Air Force to fulfill a limited mission using four 2m telescopes, could also drop the cost below the MREFC threshold.

Artist's conception of the LSST.

Petascale Earth System Collaboratory

The primary goal of the Petascale Earth System Collaboratory is to enable frontier research in which high-end computational modeling is the key investigative tool. One of the great intellectual challenges facing science in the early 21st century is the task of understanding the wide range of processes that make up the Earth system and the rich complexity that results from their interaction. The wide range of scales and processes involved are challenging to represent in laboratory experiments and, in most instances, direct manipulative experimentation is difficult or impossible. Two trends in Earth system research combine to offer scientists a way past these obstacles. The first is the accelerating development of new sensors and observing systems that promise to provide a wealth of data at appropriate time and/or space scales, and the second is the coming of age of numerical experimentation. The collaboratory will provide hardware and software that enhances the capability of computational geoscientists for to visualize and analyze structure within very large data sets, thereby enabling researchers to analyze the output of very large models. It will also provide two badly needed computational capabilities that are currently unavailable, namely (1) computational facilities which can cater to codes requiring large amounts of cycles and very high-bandwidth, low-latency processor-to-memory and inter-processor communications, and (2) facilities amenable to codes requiring very large main memory (100-500 TB).

The core facility will include a large disk-farm (eventually multi-petabyte) and off-line storage system to support the use of the system for very large jobs. The disk-farm and the network coupling it to the computational system will have to be customized to match the computational hardware. To facilitate the analysis of very large volumes of model output, a significant part of the storage will be implemented as a smart database rather than a traditional file system. Rounding out the capacity of the system will be five or six satellite facilities providing capabilities for medium-size computations so that the core facility can be dedicated to very high-end computations. Additional components will be specialized facilities for visualization and for maintaining large data sets.
All of the primary components of the collaboratory will be located in institutions connected by very high-bandwidth links and united by grid middleware to provide a virtualized resource for users. The grid associated with the Petascale Earth System Collaboratory will be extended to the data infrastructure of the major environmental observing systems so that data from these systems can be readily integrated with modeling. Such systems are being developed by several vendors both here and abroad; for example, as part of the Defense Advanced Research Projects Agency's (DARPA) High Productivity Computing System program. Instead of purchasing one hardware platform, the purchase of a "performance curve" is envisioned — that is, a specified level of performance, increasing over the duration of the project. The performance-curve approach provides flexibility to capitalize on emerging technology as it becomes commercially viable. Implemented at NCAR, this technique has proven to be a cost-effective and efficient method of providing computational resources to the research community.
Community identification of needs is now mature, and the current estimate of total infrastructure costs for this project is $489 million. Development of a science plan, system design document, and budget for the project has been undertaken by geoscience researchers.



Computed charge density for FeO within the Local Density Approximation, with spherical ions subtracted. The colors represent the spin density, showing the antiferromagnetic ordering. The strong d-lobes on the ions are apparent, and strongly affect elastic and partitioning behavior.

To Index Page

The Earth Station behind Palmer Station provides a communication link via the 5-meter-diameter antenna that sees a satellite orbiting the equator, allowing people to make phone calls and use the Internet, as well as providing the remote station with telemedicine capability.

South Pole Future Communication Needs

The goal of the project is to provide modern, broadband digital communications connecting South Pole Station with the global cyberinfrastructure on a 24-hour/seven-day-per-week basis. Such communications capabilities are desperately needed to support remote observation, instrument time-sharing among multiple investigators, remote troubleshooting, periodic software refreshment and continuous development, timely data transfer for downstream analysis, and timely feedback to experimental configuration and data acquisition protocols to adapt to changing experimental conditions and lines of inquiry. At 90ºS latitude, South Pole Station is outside the range of conventional geosynchronous satellites. The present communications infrastructure consists of a number of geosynchronous satellites in inclined orbits, which, when in sight of the South Pole Station, provide limited direct communications contact between the continental United States and the station. Line-of-sight connectivity is possible because those satellites have drifted into inclined orbits visible for a few hours at a time to the South Pole station.

Current and future science research programs at South Pole Station involve instrumentation based on sophisticated electronics and computing technology that generate large volumes of data. The benefits of improved communications already experienced by the research program are: reduction in cycle-time for fielding experimental apparatus and reaching productive data collection, minimization of the limitations imposed on staffing of wintering crews for instrument operation, broadening of participation by senior researchers who would otherwise not be able to physically travel to the instruments, and shortening the time required for analysis and publishing of results. The outcomes felt by the research community are significant: increasingly challenging and sophisticated research programs are successfully implemented; the time required to produce results and communicate findings to the research community is reduced; and greater access is provided to instrumentation to expand the numbers of researchers benefiting. Broadband communications also play an increasingly important role in the health and safety of all station personnel through our implementation of modern telemedicine capabilities. High-resolution digital video transmissions enable remote radiologists to guide real-time ultrasound diagnostic procedures administered by local staff. High-resolution digital video transmissions streamed via Internet-2 support real-time specialist supervision of locally administered clinical procedures when necessary. 24-hour/seven-day broadband communication capability will increase current telemedical capabilities, permit transmission of vital diagnostic information at any time, day or night, and leverage on-site medical staff with virtually unlimited access to specialized medical expertise in the United States. Continuous access eliminates the present risk that medical emergencies must wait for limited daily satellite contacts. Enhanced off-site support in medical emergencies is essential for positive patient outcomes in such a remote, hostile environment.

A conceptual plan for incrementally increasing South Pole communications capability and coverage has been developed through user workshops, responses to a Request for Information published in the *Commerce Business Daily*, and analysis by NSF, NASA and NOAA staff and contractors. The plan consists of two overlapping developmental phases.

Phase A (up to about 2010):

+ hardware and systems development to augment existing satellite service with 56 kb/s low/medium bandwidth Iridium service to achieve 24x7

To Index Page

coverage (ca. $15 million);
+ bring existing, more-capable NASA and/or existing commercial satellites into the constellation to achieve bulk data transmission; negotiate to incorporate NSF/USAP communication requirements in future NASA and commercial communication satellite design ($5-20 million);
+ research and possibly implement additional Iridium services. Implementation will require Earth station construction and Iridium system modifications Investment to achieve 1.544 Mb/s service would be at least $10 M.

Phase B — Long Term:
Strong possibilities include:
+ install a trans-Antarctic fiber-optic cable connecting South Pole Station over the inland high plateau to the more northern European Concordia Station, where a geosynchronous satellite link to the United States and Europe could be established (up to $250 million);
+ develop "pole sitter" satellites positioned in solar (not Earth) orbit so as to provide continuous line-of-sight to South Pole Station. Costs to share development of this option with NOAA, the Department of Defense (DOD), and private developers would be approximately $80 million.

Other options analyzed or under analysis include the use of tethered balloons as relay stations, as well as a series of ground-based microwave relay links from South Pole Station to Concordia Station.

This image of the Amundsen-Scott South Pole Station encompasses the skiway, science facilities, and a satellite radome.

To Index Page

Artist's conception of the SKA.

Square Kilometer Array (SKA)

SKA is conceived as the next-generation radio telescope for meter and centimeter wavelength astronomy. The U.S. SKA Consortium concept for the instrument consists of 4,400 12-meter-diameter parabolic dish antennas with a core concentration in the Southwest and outlier stations spread throughout the continental United States. It will require major infrastructure development since individual array antennas will be sited at many remote locations, requiring that signals from some stations be transported by optical fiber over thousands of kilometers. With roughly one square kilometer of collecting area, the SKA will be approximately an order of magnitude more powerful than current instruments and will provide unprecedented capabilities for discovery and analysis of the radio universe. The superior resolving power, sensitivity, and image quality will allow fundamental new studies of the formation and early history of stars, galaxies and quasars, with the potential for the discovery of totally new astrophysical phenomena. Since the focus of SKA design efforts is primarily at universities rather than at a national center, the development of the various technologies necessary for realizing SKA will provide training for students and postdoctoral researchers.

This is a project in the early stages of development, and preliminary design efforts are ongoing in a number of countries. The International SKA Steering Committee (ISSC) has adopted a development plan that calls for convergence on a single design and selection of a site in 2008-2010. The earliest possible start for construction of the SKA is FY 2010, possibly as late as 2015, with construction to be completed around 2020. MPS funded a three-year preliminary design study in 2001 for $1.5 million, and expects to receive a proposal for expanded technology and development during FY 2005. The site selection (possibly outside the U.S.) has yet to be made. Although the international community has a formal framework for decision-making, the final determination of antenna design and site selection may be contentious. A reasonably accurate cost estimate for SKA will require substantial research. However, the goal is to keep the total cost at or below $1 billion, which is to be shared among the international partners, with one-third each from the United States, Europe and from the rest of the world. Contributing to cost uncertainty is the requirement for a massive, special-purpose computer called a correlator to combine signals from all antennas and form the necessary “visibilities” needed to generate images of the sky. Such a computer will be affordable only if Moore's law continues apace for the next decade or more. Keeping total construction costs below $1 billion is a major challenge, and is the primary focus of the technology development program.

To Index Page

Thirty Meter Telescope (TMT)

The TMT will be a general-purpose telescope of unprecedented size, operated for the benefit of a broad segment of the astronomical community. It had been assumed that this telescope's primary mirror would consist of a collection of a large number of individual mirrors, so it was called the Giant Segmented Mirror Telescope. However, in light of recent design studies, it is not clear what the realization of such an instrument will be and the name "Thirty Meter Telescope" is now preferred. The TMT would dwarf the existing 8-10m optical/infrared ground-based telescopes, increasing the available light grasp nearly ten-fold and, assuming adaptive correction is used to realize the diffraction limit of the telescope, the angular resolution by a factor of three over the world's largest telescope. The TMT would utilize major technological breakthroughs in design and routine use of adaptive optics to provide extraordinary improvements over current capabilities. Two competing designs are currently being pursued: (1) a segmented mirror telescope design, which is a similar in concept to the Keck 10m telescope, but with a 30m collecting area; and (2) a smaller (22m) telescope employing seven 8.4m diameter round primary mirror segments. Both proposed designs will require adaptive correction significantly beyond the current state of the art. The largest technical hurdles will be those associated with extreme adaptive optics — achieving the diffraction limit at optical wavelengths. This will require significant algorithm development during the design and development phase and undoubtedly will also demand significant processor power at the TMT site. Off-site bandwidth requirements will be large but probably not much larger than those of current high performance telescopes. The effects of wind loading on such a large telescope must be modeled and may require the use of adaptive structures.

Other technical challenges include the development of durable reflective coatings for the primary mirror segments and possible alternatives to glass for the primary mirror substrate.

Both the CELT segmented mirror program (California Extremely Large Telescope) and the Giant Magellan Telescope (GMT) have established project offices and hired full-time project managers with extensive experience in large and complex projects. AURA (the Association of Universities for Research in Astronomy), CELT and ESO are actively collaborating on site identification and testing, and the test data will be shared among the groups. NOAO's in-kind contributions to TMT technology development amount to approximately $1.5 million per year. CELT has received $35 million from the Moore Foundation for design and development of a segmented mirror TMT. A 40-month, $40 million proposal to support the two design studies and development of enabling technologies common to both designs was submitted in the late spring of 2004. In addition, starting in FY 2003, $3 million per year is invested in adaptive optics technology development aimed at components (lasers, deformable mirrors) and algorithms needed for the TMT through the Adaptive Optics (AO) Development Program administered by NOAO.

Preliminary estimates for the segmented-mirror design are in the range $700 million to $1 billion; the GMT design would cost approximately $500 million. Depending on the final design selection and assuming roughly one-half of the construction costs would be borne by NSF, the required funding will be in the range $200 million to $400 million. A down select between the two potential designs could occur in 2008 with the earliest possible start for construction in FY 2010. Assuming construction starts in 2010, first light would occur in the middle of the next decade. The expected lifetime for TMT is approximately 30 years.

One concept for the Thirty Meter Telescope.

To Index Page

ACRONYMS

AdvLIGO	Advanced Laser Interferometer Gravitational Wave Observatory
AGS	Alternating Gradient Synchrotron
AIBS	American Institute of Biological Sciences
ALMA	Atacama Large Millimeter Array
AMORE	Atmospheric Moisture and Ocean Reflection Experiment
AO	Adaptive Optics
ARF	Academic Research Fleet
ARRV	Alaska Region Research Vessel
AST	Division of Astronomical Sciences
ATLAS	A large Toroidal LHC Apparatus
ATM	Division of Atmospheric Sciences
ATST	Advanced Technology Solar Telescope
AUI	Associated Universities, Inc
AURA	Association of Universities for Research in Astronomy
BEBC	Big European Bubble Chamber
BFA	Office of Budget, Finance and Award Management
BIO	Directorate for Biological Sciences
BNL	Brookhaven National Laboratory
Caltech	California Institute for Technology
CELT	California Extremely Large Telescope
CERN	European Organization for Nuclear Research
CI	Cyberinfrastructure
CISE	Directorate for Computer and Information Science and Engineering
CLEANER	Collaborative Large-Scale Engineering Analysis Network For Environmental Research
CMS	Division of Civil and Mechanical Systems
CONABIO	Comision Nacional para el Conocimiento y Uso de la Bioversidad (National Commission for the Understanding and Use of Biodiversity)
COSEE	Centers for Ocean Science Education Excellence
COSMIC	Constellation Observing System for Meteorology, Ionosphere and Climate
CP	Charge Parity
CUAC	Cyberinfrastructure User Advisory Committee
DARPA	Defense Advanced Research Projects Agency
DASI	Degree Angular Scale Interferometer
DBI	Division of Biological Infrastructure
DLESE	Digital Library for Earth Science Education
DLFP	Deputy for Large Facility Projects
DOD	Department of Defense
DOE	Department of Energy
DOM or DOMs	Digital Optical Modules
DTF	Distributed Terascale Facility
DUSEL	Deep Underground Science and Engineering Laboratory
EAR	Division of Earth Sciences
EHR	Directorate for Education and Human Resources
EHWD	Enhanced Hot Water Drill
ENG	Directorate for Engineering
EONTF	Environmental Observing Networks Task Force
EPA	Environmental Protection Agency
EPSCoR	Experimental Program to Stimulate Competitive Research
ERL	Energy Recovery Linac
ESEC	EarthScope Science and Education Advisory Committee
ESO	European Southern Observatory
ESP	Environmental Sample Processor
ETF	Extensible Terascale Facility
eV	Electron Volts; one billion ("giga") electon volts is abbreviated GeV, and one trillion ("peta") is abbreviated PeV.
EVLA	Expanded Very Large Array
FEMA	Federal Emergency Management Agency
FFRDC	Federally Funded Research and Development Centers
FOFC	Federal Oceanographic Facilities Committee
GAC	Gulfstream Aircraft Corporation
GenBank	The public DNA sequence database maintained by the National Center for Biotechnology Information, part of the National Library of Medicine.
GEO	Directorate for Geosciences
GEOS	GNSS Earth Observing System
GHz	Gigaherz
GIG	Grid Infrastructure Group
GMT	Giant Magellan Telescope
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HAC	HIAPER Advisory Committee
HEPAP	High Energy Physics Advisory Panel
HEPI	Hydraulic External Pre-Isolation
HIAPER	High-performance Instrumented Airborne Platform for Environmental Research
InSAR	Interferometric Synthetic Aperture Radar
IODP	Integrated Ocean Drilling Program
IOOS	Integrated Ocean Observing System
IPS	Integrative Programs Section
ISSC	International SKA (Square Kilometer Array) Steering Committee
IT	Information Technology
JOI	Joint Oceanographic Institutions Inc

JOIDES	Joint Oceanographic Institutions for Deep Earth Sampling
JPL	Jet Propulsion Laboratory
LHC	Large Hadron Collider
LIGO	Laser Interferometer Gravitational Wave Observatory
LSC	LIGO Scientific Collaboration
LSST	Large Synoptic Survey Telescope
LTER	Long Term Ecological Research
MEXT	Ministry of Education, Culture, Sport, Science and Technology (Japan)
MMA	Millimeter Array
MOU	Memorandum of Understanding
MPS	Directorate for Mathematical and Physical Sciences
MREFC	Major Research Equipment and Facilities Construction
NA	National Academies
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NCBI	National Center for Biotechnology Information, part of the National Library of Medicine.
NCSA	National Center for Supercomputing Applications
NEES	George E. Brown Network for Earthquake Engineering Simulation
NEESinc	NEES Consortium Inc
NEHRP	National Earthquake Hazards Reduction Program
NEON	National Ecological Observatory Network
NIST	National Institute of Standards and Technology
NNI	National Nanotechnology Initiative
NOAA	National Oceanographic and Atmospheric Administration
NOAO	National Optical Astronomy Observatory
NRAO	National Radio Astronomy Observatory
NRC	National Research Council
NSB	National Science Board
NSF	National Science Foundation
NSO	National Solar Observatory
NSTC	National Science and Technology Council
OCE	Division of Ocean Sciences
ODP	Ocean Drilling Program
OGC	Office of General Counsel
OLPA	Office of Legislative and Public Affairs
OMB	Office of Management and Budget
ONR	Office of Naval Research
OOI	Ocean Observatories Initiative
OPP	Office of Polar Programs
ORION	Ocean Research Interactive Observatory Networks
ORNL	Oak Ridge National Laboratory
OSF	Operations Support Facility for ALMA
OSTP	Office of Science and Technology Policy
OTIC	Ocean Technology and Interdisciplinary Coordination program
PACDIV	Naval Facilities Engineering Command, Pacific Division
PAT	Project Advisory Team
PBO	Plate Boundary Observatory
PM	Photomultiplier
PSC	Pittsburgh Supercomputing Center
R&RA Account	Research and Related Activities Account
R/V	Research Vessel
RAF	Research Aviation Facility
RET	Research Experience for Teachers
REU	Research Experience for Undergraduates
RF	Radio Frequency
RFP	Request for Proposals
RP	Resource Provider
RPSC	Raytheon Polar Services Corporation
RSVP	Rare Symmetry Violating Processes
SAFOD	San Andreas Fault Observatory at Depth
SDSC	San Diego Supercomputer Center
SKA	Sqaure Kilometer Array
SODV	Scientific Ocean Drilling Vessel
SPSM	South Pole Station Modernization project
STAR	Solenoidal Tracker at the RHIC (Relativistic Heavy Ion Collider), located at Brookhaven National Laboratory
SURF	Summer Undergraduate Research Fellowships
TCS	Terascale Computing Systems
TMT	Thirty Meter Telescope
UCAR	University Corporation for Atmospheric Research
UCSD	University of California, San Diego
UNOLS	University-National Oceanographic Laboratory System
U.S.	United States
USAP	United States Antarctic Program
USDA	United States Department of Agriculture
USDA-ARS	U.S. Department of Agriculture Agricultural Research Service
USFS	United States Forest Service
USGS	United States Geological Survey
VLA	Very Large Array
VLBA	Very Long Baseline Array
XFEL	X-ray Free Electron Laser

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To Index Page

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Introduction

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Chapter 2: Major Research Equipment and Facilities Construction Projects

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