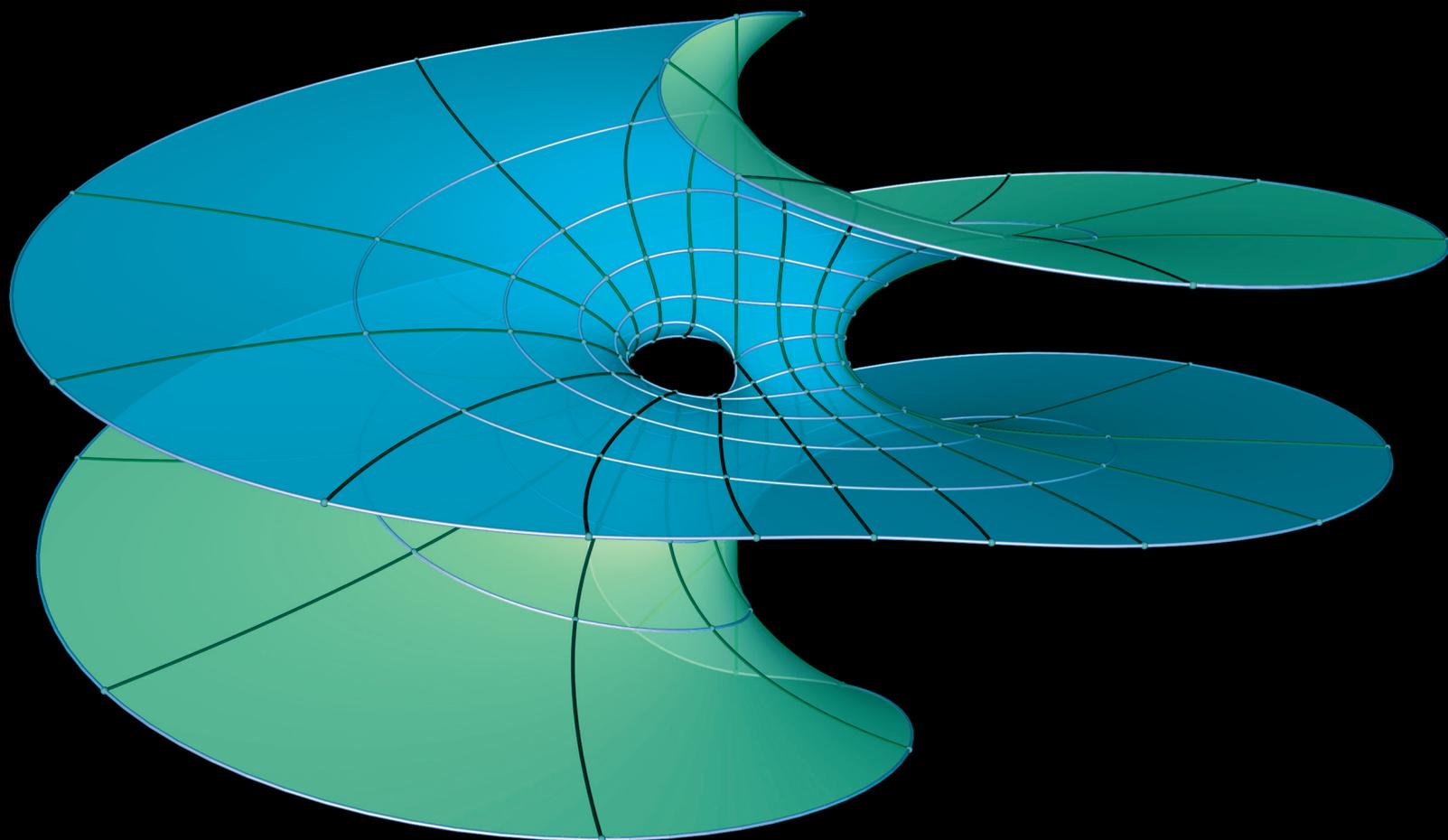


ENRICHING THE LANGUAGE OF DISCOVERY



Mathematical & Physical Sciences



National Science Foundation

Focusing on the Physical World

We live in a world underpinned by extraordinary physical and mathematical concepts. From neutrinos and nanoparticles to dark energy and black holes, a multitude of complex and remarkable objects, substances and phenomena shape our lives. Research funded by the National Science Foundation's (NSF) Directorate for Mathematical and Physical Sciences (MPS), one of the agency's seven research-supporting arms, discovers and explains these abstract concepts that impact our everyday lives.

MPS-funded mathematical scientists create models to assist in the search for mineral deposits deep in the Earth's crust. Chemists study mussels to help create glue that will work under water. Astronomers discover planets outside our solar system, including Earth-like exoplanets. Physicists adapt laser technology to lessen the invasiveness of medical procedures. Materials scientists improve the strength of ceramics used in spacecraft by incorporating microscopic nanomaterials.

Studies of the world's fundamental physical components facilitate innumerable scientific discoveries that will continue to revolutionize the world.

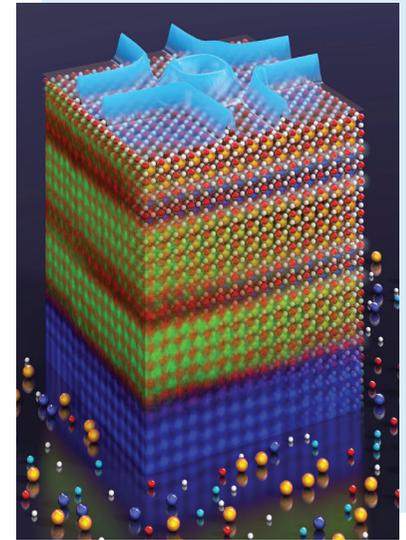
Advancing the Frontiers of Science

By employing NSF's process of merit review, MPS makes nearly 2,100 awards annually to support some of the best ideas in astronomy, chemistry, materials science, mathematical science and physics. In fact, NSF provides 45 percent of the federal support for physical science research and 64 percent for mathematical science research at U.S. universities and colleges.

This funding directly supports more than 33,000 mathematical and physical scientists whose research explores physical laws, chemical compositions and mathematical theories governing the vast, complex universe. Almost half of these individuals are undergraduate and graduate students participating directly in mathematical and physical science research. This integration of research and education helps develop the next generation of science and engineering (S&E) leaders for the nation's research and development enterprise.

MPS-funded researchers tackle the most complex scientific challenges, generating knowledge that translates into discovery to improve our daily lives. MPS-supported research has advanced mammogram imaging and cancer treatments; optimized mass spectrometers to aid in forensic science; enhanced solar cells; improved wireless Internet connections; remediated water supplies; laid the foundation for cyberinfrastructure; incorporated newly invented materials into medical implants; transformed electronics, photonics and optics; and captured the first image of a chemical reaction.

These examples epitomize the many ways MPS illuminates the cryptic language of the universe and natural world—making the mysterious relevant to everyone's daily lives.



Newly created “atomic sandwiches” enable more exotic magnetic and electronic properties that could lead to future-generation devices and electronics.



Not only is applied mathematics the foundation for scientific discoveries in many disciplines, it can be fun. Rhombic dodecahedrons at the San Francisco Exploratorium's “Geometry Playground” teach young students basic math principles.

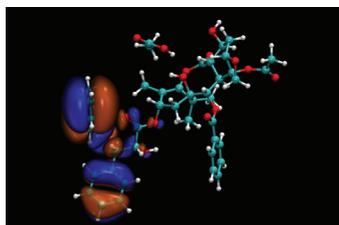
Cover caption: The figure illustrates a minimal surface, the shape, for instance, of a soap film suspended from a wire at the edge of the surface. Study of minimal surfaces is one example of a class of mathematical problems called optimization problems, which arise in a wide range of practical applications, including physics, chemistry, nanotechnology, biology and architecture. Credits: (cover) Matthias Weber, Indiana University; (page 1 top to bottom) Kyle Shen, Cornell University; Amy Snyder[®] Exploratorium

Mastering the Fundamentals

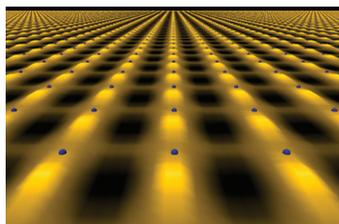
As global resource and technology needs expand, MPS research drives the ability to innovate in a fast-paced, competitive world. MPS supports basic research that spans from subatomic particles to macro-scaled phenomena—furthering our understanding of fundamental laws that govern the physical world from the quark to the cosmos. This research, supported by the divisions below, enables discovery and innovation in all fields of S&E.



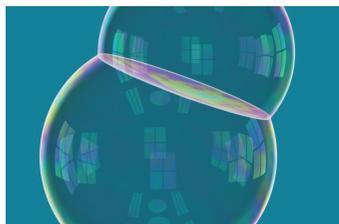
Astronomical Sciences funds the national ground-based astronomy efforts, providing access to world-class astronomical instrumentation and facilities, as well as funding research ranging from the nature of exoplanets to the mysteries of dark energy.



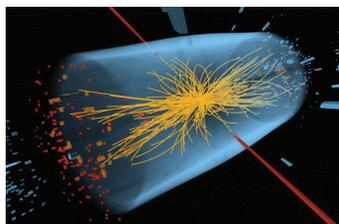
Chemistry supports investigations of the ever-changing composition, energetics and interactions of molecules that make up the world.



Materials Research funds work that creates innovative materials to enable transformative technologies, and discovers new phenomena and properties that control the behavior of matter and materials.



Mathematical Sciences supports research leading to new discoveries in mathematics and statistics that inspire novel theory and experiments and that drive advances throughout S&E.



Physics funds research that explores the nature of space and time, the origin and structure of the universe, and the complex behavior of multi-component systems.

Credits: (top to bottom) T.A. Rector, University of Alaska Anchorage and H. Schweiker/WIYN and NOAO/AURA/NSF; Ivan S. Ufimtsev, Stanford University, image created using VMD; Kazuhiro Fujita, Cornell University; John M. Sullivan, Technical University of Berlin and University of Illinois at Urbana-Champaign; CERN/CMS collaboration 2011

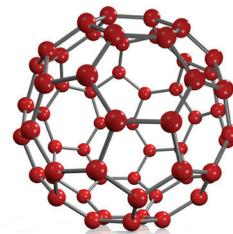
A Commitment to National Needs

MPS-supported research has enriched the understanding of Earth's chemical composition, underpinned insight into physical laws governing lives, and provided a glimpse into the depths of space. As researchers continue to expand knowledge of the world, this list of innovations will continue to grow.



Screening Counterfeit Pharmaceuticals

Worldwide sales of illegal, ineffective, counterfeit pharmaceuticals are likely to top \$75 billion this year—a 90 percent increase in the past five years. MPS-supported researchers have optimized mass spectrometers—complex chemical screening devices—to aid in the identification of counterfeit medications. The production of counterfeit drugs, particularly those used to treat malaria and diabetes, is rampant in subtropical and tropical locations. MPS-supported research will help protect the lives of millions endangered by the sale of these fake medicines.



Novel Nanomaterials

MPS-funded researchers won the Nobel Prize for their discovery of buckyballs—clusters of 60 carbon atoms that resemble a soccer ball. Although measured in just nanometers, or 1 billionth of a meter, buckyballs led the way to creating the strongest materials in the world. Numerous products such as surface coatings to improve wear resistance and drug delivery systems have come from this research. Novel nanomaterials also have applications as sensors, catalysts, and optical and magnetic devices. These developments have fueled rapid growth in the nanotechnology product industry, which is estimated to be valued at more than \$2.5 trillion in 2014.

Fundamental Physics for a Better GPS

Einstein's theories of relativity are fundamental to the current understanding of cosmic phenomena, ranging from black holes to the origin of the universe to the accuracy of global positioning system (GPS) devices. Their use in navigation, disaster relief, defense mapping and more is widely known. Less known is the essential role that relativistic corrections play in the accuracy of GPS devices. Without them, GPS localization would accumulate errors at a rate of 10 km a day.



911: Astronomy to the Rescue

The National Emergency Number Association estimates that there are 240 million 911 calls in the U.S. each year. Research in radio astronomy has created technology that enables specification of the location of a 911 call with an accuracy of 500 feet. This same technique, called interferometry, also locates faulty transmitters that disrupt communication satellite operation.



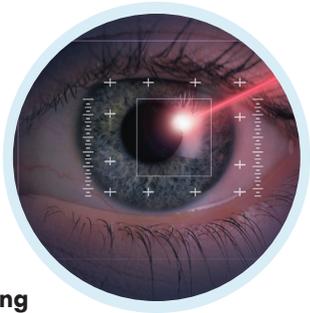
From Algorithm to Early-Threat Detection

Today's national security rests on preparedness and readiness. MPS-supported mathematical scientists have developed algorithms to analyze massive amounts of data related to chemical, biological, radiological, nuclear or explosive threats. This work will help ensure early detection of threats inferred from satellite and geospatial information before damage is done—saving thousands of lives and millions of dollars in property damage.

Opening Hearts

Coronary artery disease, the major cause of heart attacks, afflicts more than 700,000 Americans and costs the nation nearly \$110 billion in treatments annually. MPS-funded researchers developed mathematical tools to better understand and control interactions between arterial walls and blood flow. Subsequently, scientists improved stents to help open narrowed arteries, and they later formed a biotechnology company based on this technology. Endologix Inc., which markets new heart stents, is publicly traded on NASDAQ, with a current value of nearly \$950 million.





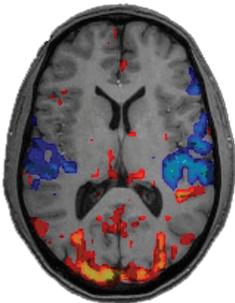
Seeing is Believing

Astronomer-developed adaptive optics not only significantly reduce distortion in images from ground-based telescopes but also help study the human retina in vivo—something originally thought impossible. This non-invasive imaging helps diagnose retinal disease early enough to prevent blindness. Three-dimensional eye mapping also led to important improvements in LASIK—a laser procedure administered to nearly 18 million people in the U.S. last year.



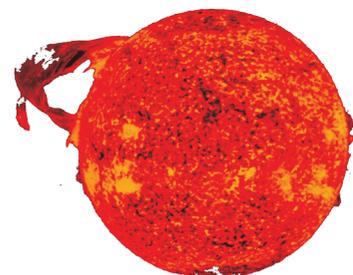
Managing Crop Pests: An Eye for Aphids

The 275,000 soybean farms in the U.S. account for more than 50 percent of the world's soybean production. But a new pest from Asia, the soybean aphid, has reduced yield by 10-15 percent. The standard approach to managing these plant pests is to manually count the number of insects, a tedious and time-consuming process. When the count reaches a critical threshold, farmers apply a treatment. NSF-funded mathematicians have developed a new image-analysis technique that can rapidly count soybean aphids. The new automated method provides accurate, efficient aphid counts so growers know if, and when, they need to treat their soybeans with pesticides—saving growers time and resources and reducing chemicals in the environment.



Fantastic fMRI

Each year, millions of people in the U.S. get an MRI or magnetic resonance imaging scan. MPS-funded researchers helped develop this important diagnostic procedure that allows doctors to view internal structures. Now, MPS-funded researchers are upping the game and working to refine fMRI, or functional MRI technology. This new approach allows scientists to view both structure and function. Over the last decade, fMRI has enabled scientists to study the formation of memories, language, pain, learning and emotion. This technology is helping researchers predict behaviors, including the propensity to develop addictions or commit a violent crime.



Taking the Heat From a Solar Flare

Scientists at the National Solar Observatory used a new set of instruments to capture the sharpest-ever images of solar flares. They recorded images and very precisely measured magnetic field strengths using adaptive optics to correct for distortion from the Earth's atmosphere. The new instruments will allow scientists to study the sun's magnetic activity and to understand the genesis of solar flares—the giant explosions that can disrupt satellites, cell phone, and radio signals and other communications systems.



Renewable Plastics

Scientists are working to reduce the nation's reliance on fossil fuels by developing environmentally friendly, cost-effective plastics from natural, sustainable and renewable materials such as vegetable oils, starches, sugars and even recycled grass clippings. MPS-funded researchers have worked with both established and startup companies, including 3M Co., Cargill, Dow Chemical Co., NatureWorks and Segetis, to create polymers from renewable, non-toxic, biodegradable starting materials. This work will contribute to the growing U.S. natural polymer market, projected to value \$7 billion by 2018.



A Sensitive Nose for Explosives

With funding from NSF and the Office of Naval Research, researchers developed a powerful tool that simply and quickly analyzes surfaces for the presence of a common explosive. The tool, Desorption Electro spray Ionization Mass Spectrometry, offers rapid detection of trace amounts of the explosive triacetone triperoxide (TATP). TATP has been used by terrorists for numerous bombings, including the 2005 bombing of London subway trains and the 2011 "shoe bomber." It has recently appeared as a weapon in the Middle East. The detection of the explosive by this new method, which is now available to the military, is both highly selective and takes less than five seconds.

More Ways

MPS Research Improves Our Lives

MPS research spans the range of distances and times accessible to human investigation—distances ranging from less than the diameter of an atom to the size of galaxies, and time spans ranging from the fastest chemical reactions to the beginning of the universe. These examples epitomize the scope of this important work and how it effects our daily lives.

Advancing medical imaging technologies, diagnostics and treatments, and pharmaceuticals

Delivering safer and more fuel-efficient cars and airplanes

Creating cyber-enabled designer materials

Cultivating knowledge to facilitate quantum computing

Developing biomaterials for human health

Discovering trends through big data

Enhancing national security through cryptography

Fashioning materials to clean water

Improving mammogram-reading technology with radio astronomy

Increasing access to the radio spectrum

Investigating the formation and evolution of the universe

Making electronic and communications devices smaller, lighter, faster and cheaper

Modeling disease spread

Pioneering clean energy technology

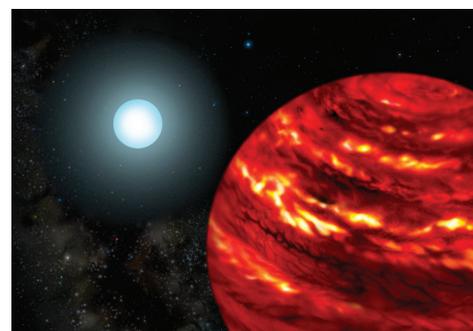
Preserving precious natural resources

Preventing damage from solar flares by improving warning systems

Promoting innovative data analysis tools to enable new science

Refining particle detectors important for homeland security and medical techniques

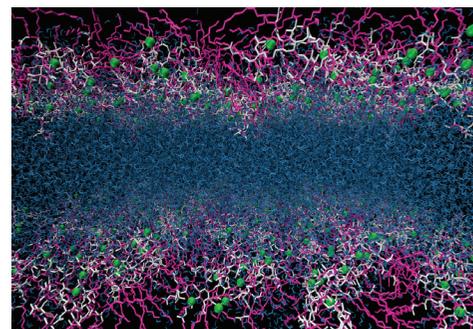
Synthesizing chemical compounds and materials for everyday use



Astronomers are constantly improving instrumentation and data reduction techniques to detect Earth-like planets around stars similar in size and temperature to the sun.



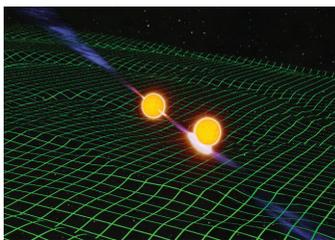
Scientists developed an undulating variety of robots to navigate rubble in search of trapped earthquake victims in Haiti, New Zealand and Japan.



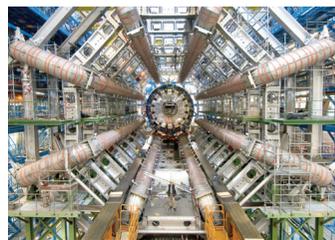
Seen here at the molecular level, the salty, fragrant sea spray one relishes on the beach may, in fact, answer important scientific questions about chemical exchanges between wind and water that affect weather and long-term climate.

Tools of the Trade

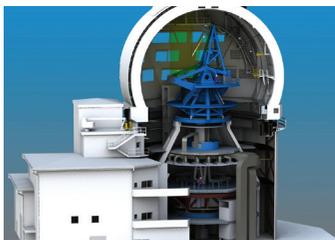
MPS supports major equipment and instrumentation such as telescopes, particle accelerators and state-of-the-art facilities that enable research at the cutting-edge of science in all fields and disciplines. These examples illustrate their reach—literally and figuratively.



The **Advanced Laser Interferometer Gravitational Wave Observatory** provides research in the field of gravitational wave astronomy and allows us to see the universe from a unique perspective.



The **Large Hadron Collider**, the world's largest particle accelerator, possesses the highest energies and discovers building blocks of the physical world.



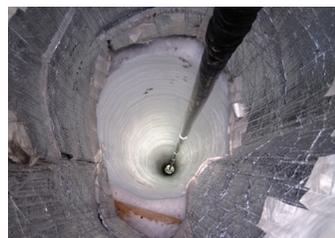
The **Daniel K. Inouye Solar Telescope** will be the world's most powerful solar telescope. It is designed to answer fundamental questions regarding the sun's magnetic field and the eruptions, flares and coronal mass ejections that it drives.



The **National High-Magnetic Field Laboratory** is one of the nation's only facilities dedicated to research at high magnetic fields. Its research advances technology development in the physical sciences.



The **Atacama Large Millimeter/Submillimeter Array (ALMA)** searches for the first traces of life around nearby young stars and for the first galaxies, and images forerunners of exoplanets. ALMA is part of NSF's National Radio Astronomy Observatory.



The **IceCube Neutrino Observatory**, the world's first high-energy neutrino observatory and detector, is located deep within the ice cap in Antarctica. It detects cosmic rays and particles that originate from outer space.



The **Mathematical Sciences Research Institutes** advance research in the mathematical sciences, enhance the synergy of math with other disciplines, and expand the talent base engaged in mathematical sciences research.



The **Gemini Observatory's** unparalleled adaptive optics and technology advance the quest to understand the universe.



Cornell High Energy Synchrotron Source is a high-intensity, high-energy X-ray source, housed in a ring buried under the campus, which provides state-of-the-art facilities for research in materials science and molecular disciplines.



The **National Superconducting Cyclotron Laboratory**, the nation's largest, campus-based nuclear facility, leads in rare isotope research and nuclear science education.

Credits: (left top to bottom) John Rowe Animation; LeEllen Phelps, National Solar Observatory/AURA/NSF; R. Hills, ALMA(ESO/NAOJ/NRAO); Ruth Crane, Institute for Computational and Experimental Research in Mathematics (ICERM); Cornell High Energy Synchrotron Source; (right top to bottom) CERN; Florida State University; B. Gudbjartsson, NSF; Joy Pollard, Gemini Observatory; NSCL, Michigan State University



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