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Space Administration

Goddard Space Flight Center
Greenbelt, Maryland 20771
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NASA's Goddard Space Flight Center The First Forty Years

Proud of the Past, Prepared for the Future

Since its establishment on May 1, 1959, the Goddard Space Flight Center in Greenbelt, Md. has played a major role in space and Earth science research. Goddard's fundamental mission is to expand knowledge of the Earth and its environment, the solar system and the universe through observations from space. Goddard has been instrumental in making observations of our terrestrial sphere and the observable universe. Goddard also is committed to the advancement of essential technologies. Goddard scientists and engineers have pushed the edge of the envelope in sensor, instrument, satellite, and mission design and implementation.

Listed here are examples of 40 years of scientific and technological accomplishments from the Goddard Space Flight Center.

Space Science

Orbiting Astronomical Observatory (OAO)

OAO-2, which was launched in December 1968, determined properties of interstellar dust and hot stars in the Milky Way, and gathered basic information on comets. OAO-3 followed three years later. OAO-3 reached farther into the ultraviolet region than its predecessors and provided data on physical conditions in the interstellar gas.

International Ultraviolet Explorer (IUE)

An international project between NASA, the European Space Agency and the British Science Research Council, IUE was launched in 1978. Given a mission life of five years, IUE surprised everyone by continuing to produce substantial data for 19 years. IUE enabled scientists to study the ultraviolet light from much dimmer and more distant objects than previously observable. Astronomers now were able to

The International Ultraviolet Explorer was the first satellite totally dedicated to ultraviolet astronomy.

study distant stars in the Milky Way, other galaxies, and even quasars in the ultraviolet. Among the objects studied were many planetary nebulae, clouds of gas that are shed by Sun-like stars near the ends of their lives. The aurora of the planet Jupiter was examined in detail for the first time.

The long operating lifetime of IUE enabled it to catch several rare celestial phenomena in the act. These included the Comet Iras-Araki-Alcock, which came unusually close to the Earth. IUE also observed the once-in-76-years return of Comet Halley in 1986 and the first bright supernova in almost 400 years, Supernova 1987A. A supernova is the exploding remains of a massive star. IUE became the first space observatory to be used regularly and systematically by guest observers. Over its 19-year lifetime, astronomers became accustomed to observing with an orbiting telescope just as they do with ground-based national observatories. When IUE was finally retired in September 1996, it had become one of the most successful space science missions ever launched.

High Energy Astronomy Observatories (HEAO)

The High Energy Astronomy Observatories, three satellites in all, were launched in the late 1970s. HEAO-1 made a sensitive survey of the entire sky over a broad band of X-ray wavelengths. It obtained especially useful information on the poorly understood X-ray background radiation, a diffuse glow coming to us from all directions in space. HEAO-2 carried the first large X-ray telescope with focusing mirrors on a satellite. Among other accomplishments, HEAO-2 observed the X-ray emission from over 200 galaxies; previously only four galaxies had been detected in X-rays. And, HEA0-2 revealed that many stars have hot coronae (tenuous outer layers) that emit X-rays. HEAO-3 was instrumented to detect gamma rays, a form of light even more energetic than X-rays, and to study cosmic rays. Cosmic rays are high-speed atomic nuclei and subatomic particles that bombard the solar system from all directions. HEAO-3 discovered the first gamma ray emission line ever detected from interstellar space. A gamma ray emission line is the characteristic signature of a specific atomic nucleus. The line found by HEAO-3 is produced by the radioactive isotope Aluminum-26.

Solar Maximum Mission (SMM)

SMM was launched by Goddard in 1980. It was the first Sun-watching satellite equipped with a suite of instruments to concentrate on determining the nature

An astronaut approaches the Solar Max spacecraft for an on-orbit service call on Shuttle mission 41-C.

A picture of the Milky Way taken by the COBE satellite showing the plane of our galaxy in infrared light.

of solar flares. Solar flares are powerful explosions on the Sun. SMM was also the first satellite designed to be repaired in space. After fuses blew on board, and an instrument power supply also failed, NASA astronauts rendezvoused with SMM in orbit, took it on board the Space Shuttle where they repaired it, and dropped it safely back in space. Besides mapping the locations of the highest energy X-ray sources in the flaring regions, and gathering other new knowledge on the nature of solar flares, SMM made a basic contribution to the study of solar energy. A small onboard instrument made measurements of extraordinary sensitivity that revealed systematic changes in the total energy received from the Sun, called the "solar constant." Changes in the solar constant may ultimately be related to changes in climate on Earth.

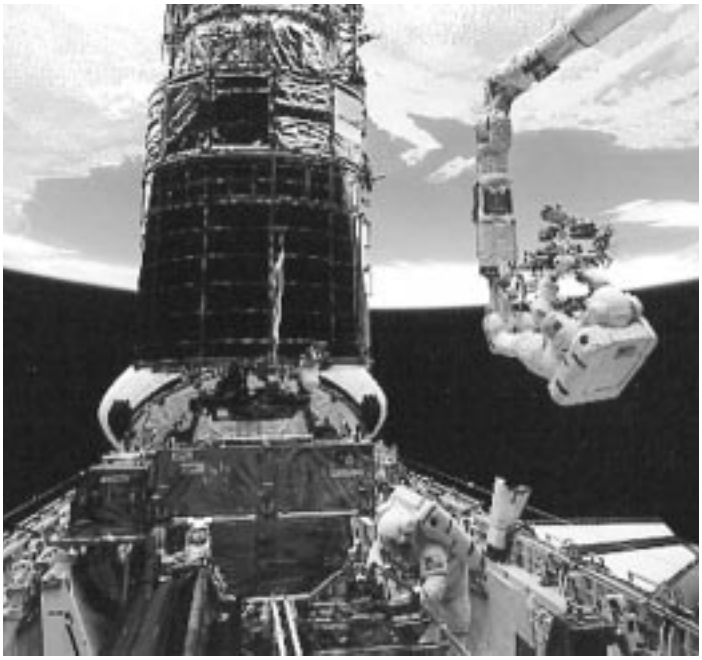
Cosmic Background Explorer (COBE)

COBE, which launched in 1989, will forever be remembered as the satellite that confirmed the Big Bang Theory. This theory holds that all the matter and energy in the universe was created in one explosion and has been expanding since the initial explosion. In other words, no additional energy inputs have occurred since the original explosion some 14 billion years ago. The results from COBE's Far Infrared Absolute Spectrophotometer, which looked at cosmic radiation, confirmed what Goddard and scientists elsewhere theorized. COBE also discovered traces of the first structure in the history of the universe, the irregularities in the microwave background radiation from the aftermath of the Big Bang. COBE also detected the cumulative infrared radiation from all the stars that ever formed in the early and distant universe.

Hubble Space Telescope (HST)

Goddard is responsible for HST project management including mission and science operations, servicing missions, and all associated development. Launched in 1990, HST became the largest telescope ever to be placed in space. HST was expected to show the clearest images of the universe ever taken; however this did not immediately happen. The very first images came back blurry. It was discovered that the telescope's primary mirror had been ground or polished to the wrong specifications. The mirror had been polished too much (by a fraction of the width of a human hair). To the naked eye it did not seem like much, but it was enough to cause the first images to blur. Until the telescope could be serviced, astronomers had to make the best use they could of the images. New computer programs were developed to clarify the images. The scientists revised the operational program of the telescope to concentrate on bright objects within the universe.

NASA scientists designed Hubble for servicing in space. The telescope's instruments were created as modular units, comparable to dresser drawers that can be easily removed and replaced. Designers also equipped the telescope with handholds and other special features to make servicing tasks less difficult for astronauts wearing bulky spacesuits. Hubble was



Astronauts install new equipment on the Hubble Space Telescope, the first observatory designed for on-orbit maintenance and refurbishment.

designed for servicing to keep it in top working order and to install new components and instruments using cutting-edge technology to enhance scientific capability.

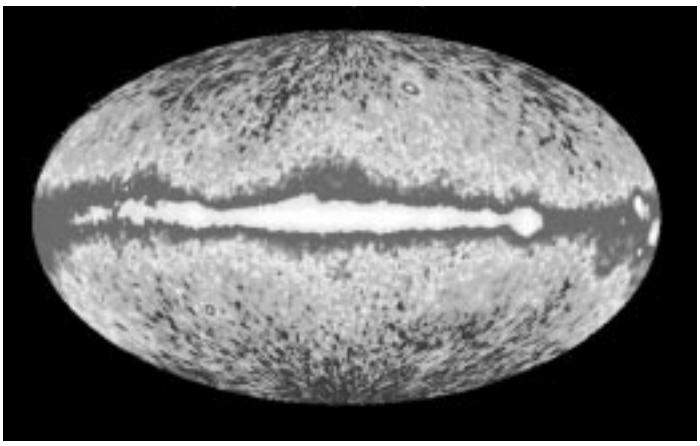
In December 1993, the first servicing mission took place. HST was fitted with the Corrective Optics Space Telescope Axial Replacement (COSTAR) and the Wide Field Planetary Camera II (WFPC II). COSTAR contained 10 mirrors that refocused and corrected the light reflected from the primary mirror before it entered the other main instruments. The second generation WFPC was the first instrument designed and built with its own set of corrective optics. Many of HST's greatest images and discoveries were made after the first servicing mission. These included the first very strong evidence for the presence of a super massive black hole at the center of a galaxy, the first direct image of the accretion disk from which a star was born, and the Hubble Deep Field and Hubble Deep Field South. The Hubble Deep Fields, our most sensitive look at the universe of distant galaxies, reveal how galaxies have changed over more than 10 billion years of cosmic time, and they indicate that there are at least 125 billion galaxies in the observable universe.

The second servicing mission in 1997 installed the Near Infrared Camera and Multi-Object Spectrometer (NICMOS) and the Space Telescope Imaging Spectrograph (STIS). NICMOS enabled the telescope to peer in greater detail into the cooler infrared regions of the universe. NICMOS has aided astronomers in gaining new insights into the dusty centers of the galaxies and the formation of stars. STIS is capable of obtaining simultaneous information on the spectra of hundreds of separate locations in a galaxy, and used to make a census of giant black holes in galaxies. Also, STIS detected tantalizing evidence of a possible planet whose gravity warps a disk of matter orbiting the star Beta Pictoris.

In preparation for an upcoming servicing mission, the HST project flew equipment aboard the STS-95 mission. The project wanted to test equipment prior to installation on the servicing mission. Of particular interest was the NICMOS cooling system. This new cooling system would provide cooling to NICMOS without using nitrogen ice which depletes with age. With the installation of the new cooling system NICMOS's operational life is expected to be extended by at least five years. The Hubble Space Telescope has given us new insights into the nature of the universe and the stars, nebulae, galaxies, and other objects within it.

Compton Gamma Ray Observatory (CGRO)

In 1991, CGRO became the largest satellite launched from a Space Shuttle. Since then, CGRO has made unparalleled contributions to the study of the universe in gamma rays. It found that gamma ray bursts arrive from all directions in the distant universe rather than coming from the Milky Way as had been believed. CGRO detected a great cloud of anti-matter in the general direction of the center of the Milky Way, where anti-matter positrons annihilate together with ordinary matter electrons, to produce strong gamma rays. And, CGRO discovered that the strongest sources of gamma rays among the galaxies are so called blazars, in which strong jets of energy are beamed almost directly at Earth. CGRO detected



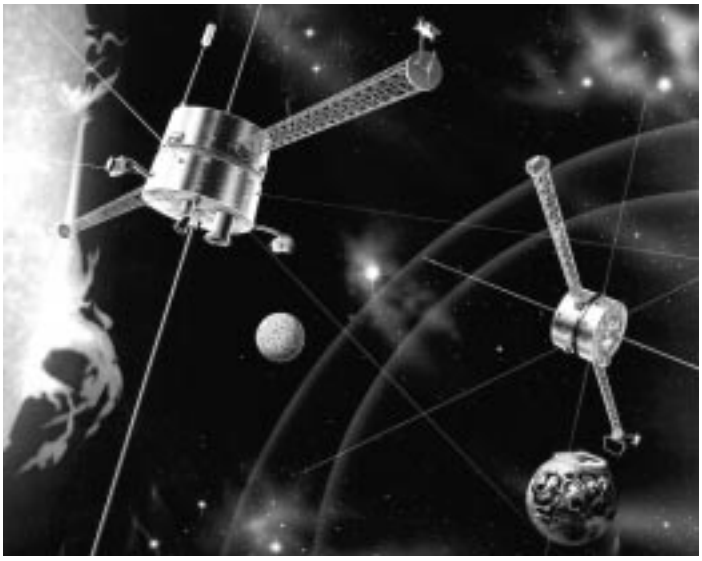
A map of the whole sky in gamma rays. The prominent white band represents emission from the disk of the Milky Way. Bright spots above and below are high energy sources, such as quasars.

the gamma rays from the Moon for the first time, revealing that the gamma ray region is the only one where the Moon is normally brighter than the Sun.

International Solar-Terrestrial Physics (ISTP)

The goal of the ISTP program was to study the behavior of the solar terrestrial system in order to predict how Earth's atmosphere will respond to changes in solar wind. The first mission in the program was Geotail, which was launched in 1992. Geotail examined the effect of solar wind on the magnetospheric tail of Earth. Geotail is a collaborative project of Japan's Institute of Space and Astronautical Science and NASA. Wind, launched in November 1994, was designed to measure the properties of solar wind before it reaches Earth. In addition, Wind sampled conditions in a poorly known gaseous medium that extends from the Moon in the direction opposite the Sun, called the lunar plasma wake.

The third in the series was the Solar and Heliospheric Observatory (SOHO) launched in 1995 to study the Sun, its magnetic field, plumes, flares and coronal mass ejections. SOHO is a project of international cooperation between the European Space Agency and NASA. SOHO has made many discoveries, including the detection of "rivers" of hot electrified gas streaming within the Sun. It made the first detailed maps of the flow of gas streams beneath the solar surface, including their temperatures, speeds, and flow directions. And, SOHO detected the layer within the Sun where the solar magnetic field is generated. SOHO also observed large numbers of coronal mass ejections, and together with the other ISTP spacecraft, it observed the complete sequence of events "from cradle to grave" as a coronal mass ejection was expelled from the Sun, traveled through interplanetary space, and struck the Earth's magnetosphere. In other discoveries, SOHO found what may be the source of the high-speed solar wind, a constant outpouring of electrified gas from the Sun, and gathered new evidence on the energy source of the Sun's corona. It also discovered dozens of small comets falling to their doom in the Sun, and on one occasion, observed two comets falling into the Sun at the same time.



The ISTP series of satellites has made outstanding observations on how solar plasma, coronal holes and particles are transported to Earth.

Cluster, a combination of four spacecraft, was launched in 1996. Cluster was designed to gather three-dimensional readings on the shape and make-up of magnetic structures. Unfortunately, this particular spacecraft never reached its destination because the Ariane 5 booster rocket that carried Cluster exploded during launch. Cluster II is scheduled for launch in 2000. The last in the series was Polar. Polar was launched in 1996 in a polar orbit of the Earth. This satellite is equipped to observe the Earth's auroral zones in ultraviolet and visible light and in X-rays. It determines the response of the auroral zones to incoming solar wind disturbances. Polar detected the "polar wind" from the Earth's upper atmosphere, in which large quantities of oxygen escape from the Earth after the Earth's magnetosphere is struck and compressed by a travelling interplanetary cloud shot from the Sun in a coronal mass ejection.

ISTP as a program has been a scientific success. The series of satellites has made outstanding observations on how solar plasma, coronal holes and parti-

The Small Astronomy Satellite-C, launched on May 7, 1975, studied X-ray sources within and beyond the Milky Way galaxy.

cles are transported to Earth. The research findings from the spacecraft are answering many questions on the relationship between the Sun and Earth.

Rossi X-ray Timing Explorer (RXTE)

Goddard launched RXTE in 1995. It carries an X-ray detecting instrument with the largest collecting area ever flown in space, so that it can make very sensitive measurements of celestial x-ray sources at very rapid intervals. By this means, RXTE has explored very rapidly changing phenomena in the universe. At the same time, the satellite is an observatory facility that is open 100 percent of the time to guest observers. Among its discoveries are the episodes of regular outbursts (every 30 minutes) from the so called "Old Faithful Black Hole," as well as evidence for possible dragging of the reference frame of time and space by rapidly rotating massive compact objects (pulsars and black holes). RXTE observed the fastest spinning pulsar, and the neutron star with the strongest known magnetic field in the universe. It provided evidence for a new test of Einstein's General Theory of Relativity by detecting what may be evidence for the smallest stable orbit around a black hole, a phenomenon that is predicted only by this theory.

Advanced Composition Explorer (ACE)

ACE was launched in 1997 to investigate the chemical composition (the relative amounts of the elements and their isotopes) of particles in space, including subatomic particles from the Sun and cosmic rays from the Milky Way galaxy or beyond. By detailed measurements of the respective numbers and energies of the particles, ACE will enable scientists to deduce the physical conditions that affect them in space. ACE has made measurements of copper and zinc in galactic cosmic rays for the first time. And, in studies of interplanetary matter, ACE made the first measurements of the respective numbers of individual isotopes of sulfur. The sulfur data may help scientists to understand the physical processes that acted to separate sulfur from other substances during the formation of our solar system.

EXPLORER SERIES - Small Explorer (SMEX)

Since its inception, the SMEX program exemplifies the slogan "faster, better, cheaper." Comprised of a series of small, quickly developed, low-cost missions, SMEX has provided frequent flight opportunities in the areas of astrophysics and space physics. Since the program embodies a short development time, it has provided training opportunities for new scientists and engineers.

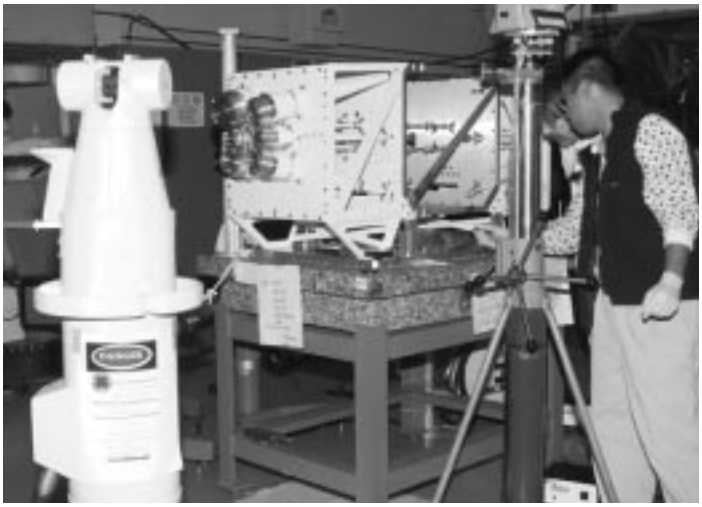
The Advanced Composition Explorer began its two-year mission with a successful launch aboard a Delta II rocket.

SAMPEX, the Solar, Anomalous, and Magnetospheric Particle Explorer, was launched in 1992 and discovered a previously unknown radiation belt of the Earth. FAST, the Fast Auroral Snapshot Explorer, was launched in 1996. It is studying the processes that produce the aurora, or so called "Northern and Southern Lights." TRACE, the Transition Region and Coronal Explorer, was launched in 1998. It provides the most rapid time series of sharp images of the Sun in ultraviolet light ever obtained. This capability has allowed TRACE to capture images of magnetic reconnection in action for the first time. Magnetic reconnection is the process in which magnetic lines of force are disrupted and then connect up in new ways, in a kind of "short circuit" that can release enormous amounts of energy. SWAS, the Submillimeter Wave Astronomy Satellite, was launched in 1998. In its first ten days of scientific operations, SWAS revealed that water vapor is present in many clouds in space where it could not previously be detected. The Wide-Field Infrared Explorer (WIRE) was launched March 1999, but a malfunction caused the spacecraft's entire supply of frozen hydrogen needed to cool its primary scientific instrument to be released into space, ending its scientific mission.

EXPLORER SERIES - MIDEX

The Medium-class Explorers or MIDEX are space science and astrophysics missions pioneering new technologies. The Far Ultraviolet Spectroscopic Explorer (FUSE) will enable the study of the distant universe in the relatively unexplored far ultraviolet region of the electromagnetic spectrum. Far ultraviolet rays are much shorter than ultraviolet and visible light, but longer than X-rays. This part of the spectrum carries key information on the chemical composition and physical conditions in the gas between the stars and the gas between the galaxies. FUSE will pay particular attention to the presence of deuterium, a heavy isotope of hydrogen that is a telltale trace of conditions in the Big Bang. FUSE will search for and measure deuterium in many regions throughout the universe.

The Imager to Magnetopause to Aurora Global Exploration (IMAGE) will study the global response of the magnetosphere to the changes in the solar wind. Major changes occur to the configuration of the magnetosphere as a result of changes in and on the Sun, which in turn change the solar wind. IMAGE will utilize neutral atom, ultraviolet, and radio imaging techniques to detect and gather data on these changes. IMAGE is scheduled for launch in January 2000.



Elements of the Microwave Anisotropy Probe undergo checkout at Goddard.

The Microwave Anisotropy Probe (MAP) will probe the conditions of the early universe by measuring the properties of the cosmic microwave background radiation over the full sky. MAP will seek to answer questions on the formation of galaxies in the universe and the cosmology of the Big Bang. To answer these questions, MAP will measure the temperature fluctuations of the cosmic microwave background radiation over

The Submillimeter Wave Astronomy Satellite, launched December 1, 1998, detects water vapor throughout the Milky Way.

Scientific balloons, like this one, are a cost-effective method to get lightweight research equipment into high altitudes.

the entire sky. MAP is scheduled for launch in November 2000.

EXPLORER SERIES - University-class Explorers (UNEX)

The UNEX program is designed to study the vast region between our Sun and nearby stars and the interaction of Earth's radiation belts with the solar wind. The first mission selected under this program is the Cosmic Hot Interstellar Plasma Spectrometer or CHIPS. CHIPS will study the thin cloud of hot gas surrounding our solar system. Scientists believe that the gas in this region has been affected by supernovae (exploding stars) and by stellar winds from hot stars in the Milky Way. CHIPS is scheduled for launch in mid-2001.

The second mission, the Inner Magnetosphere Explorer (IMEX), will study the response of Earth's Van Allen radiation belts to variations in the solar wind. The energized particles in the radiation belts are potentially hazardous to both astronauts and satellites. Data obtained from IMEX should lead to the ability to predict hazardous conditions in the radiation belts and to understand the process of solar wind to the radiation belts. UNEX is scheduled for launch in June 2001.

Next Generation Space Telescope (NGST)

The successor to the Hubble Space Telescope is the NGST. NGST is scheduled for launch in 2007. By looking in infrared light, this new telescope will peer into the very early stages of the universe with more power than even Hubble possesses.

The Future of Space Science

The Office of Space Science is organized into four themes. NASA's Origins Program looks at the birth of the universe; the formation of galaxies, planets, and stars, other forms of life outside of our solar system; and the origination of life here on Earth. Some of the missions included in this theme are HST, FUSE, WIRE, Space Interferometry Mission, NGST, Terrestrial Planet Finder and Planet Imager.

The Structure and Evolution (SEU) theme seeks to explain the structure of the universe and forecast Earth's destiny; to explore the cycles of matter and energy evolving in the universe; and to examine the limits of gravity and energy within the universe. SEU seeks to identify and understand gamma ray bursts, cosmic rays, black holes, dark matter as it shapes galaxies, and much more. SWAS, CGRO, RXTE, and the Extreme Ultraviolet Explorer are current operating missions. Future missions include: Gamma-ray Large Area Space Telescope, the Galaxy Evolution Explorer, and High Energy Transient Explorer 2.

Sun-Earth Connection, formerly space physics, observes and interprets the variable radiation in Earth's environment. Sun-Earth Connections focuses on solar flares and atmosphere; the magnetosphere; and the upper atmosphere. Wind, Polar, SAMPEX, IMAGE and TRACE are just a few of the missions in this particular theme. The High Energy Solar Spectroscopic Imager, the Global Electrodynamics Mission and Solar B are all future missions under the Sun-Earth Connection theme.

The fourth theme is Solar System Exploration (SSE). Solar System Exploration seeks to explore the formation and evolution of the solar system and Earth's relationship it; to search for evidence of past and present life elsewhere in our solar system; and to understand how solar system forces affect life on Earth. MUSES-CN, CONTOUR, and Europa Orbiter are all future SSE missions.

Engineers perform tests on a model of the NGST inflatable sunshield.

A technician checks Goddard's Radio Astronomy Explorer satellite prior to its launch on July 4, 1968.

Earth Science

Television and Infrared Observation Satellite (TIROS) and Polar-orbiting Operational Environmental Satellite (POES)

Satellites whose mission it is to examine the Earth's environment to help analyze and predict the weather play a major role in the Earth sciences and in everyday life. The world's first meteorological satellite was launched on April 1, 1960. TIROS returned thousands of cloud cover images, and became a giant step forward in weather forecasting.

Subsequent TIROS launches accrued other firsts: adding an infrared instrument that allowed the satellite's instruments to make observations of cloud cover at night; observation of hurricanes, tropical storms, and other adverse conditions that were not detectable in a timely fashion by existing ground networks; and the first TIROS satellite to be launched into a polar orbit, thereby allowing the satellite's sensors to view virtually the entire Earth surface.

Eventually, the TIROS series of satellites became part of the POES system with satellites named for the National Oceanic and Atmospheric Administration, or NOAA, the agency responsible for their operational activities. The satellites, designated NOAA-A (also known as NOAA-6, launched in 1979), through the current NOAA-K (also known as NOAA-15, launched in 1998), continue to play a major role in meteorological activities.

An instrument that has provided a long heritage of Earth observations was first launched on TIROS N in 1978. The Advanced Very High Resolution Radiometer (AVHRR) provides measurements of radiance for investigation of clouds, land-water boundaries, snow and ice extent, sea surface temperature, day and night cloud distribution, and vegetation index. The benefit of AVHRR data lies in its high temporal frequency of coverage, providing global coverage at least once per day. These data have applications in operational meteorology, oceanography, climatology, vegetation monitoring, and land and sea ice observation. The instrument's ability to provide data for all these phenomena has made it a veritable workhorse for Earth system observations. AVHRR's descendants are in use today, and will continue to provide significant data for Earth system scientists for years to come.

Earth Resources Technology Satellite (ERTS) / Landsat

The first Landsat, originally called ERTS, was developed and launched by NASA in 1972. The satellite carried a television camera and an experimental sensor called the Multi-Spectral Scanner. The images provided by the Multi-Spectral Scanner proved so valuable that a version of the sensor was flown on each of the following four Landsat satellites (NASA changed the name of ERTS to Landsat 1 in 1975). By the time Landsat 1 was retired in 1978, its Multi-Spectral Scanner had acquired over 300,000 images providing repeated coverage of the global land surfaces. The quality and impact of the resulting information exceeded all expectations.

Landsat 4, launched in 1982, carried a new sensor, the Thematic Mapper, inaugurating a second generation of remote-sensing satellites. The Thematic

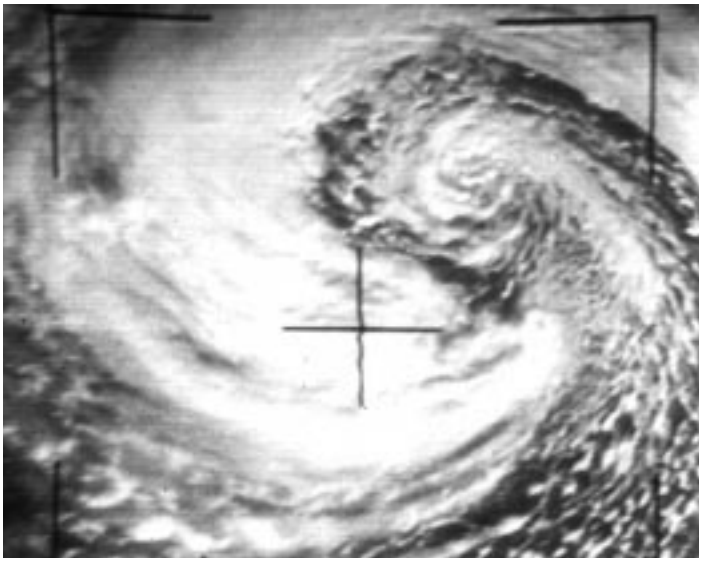
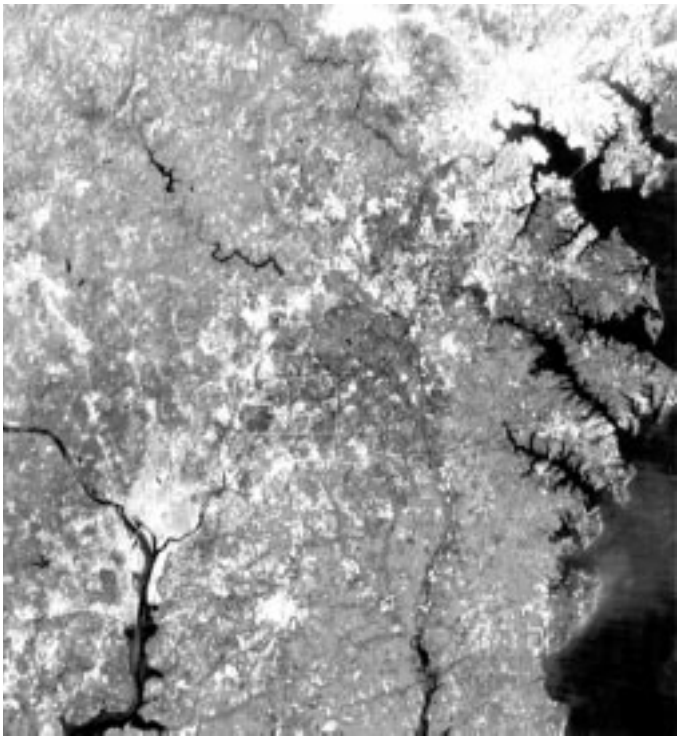
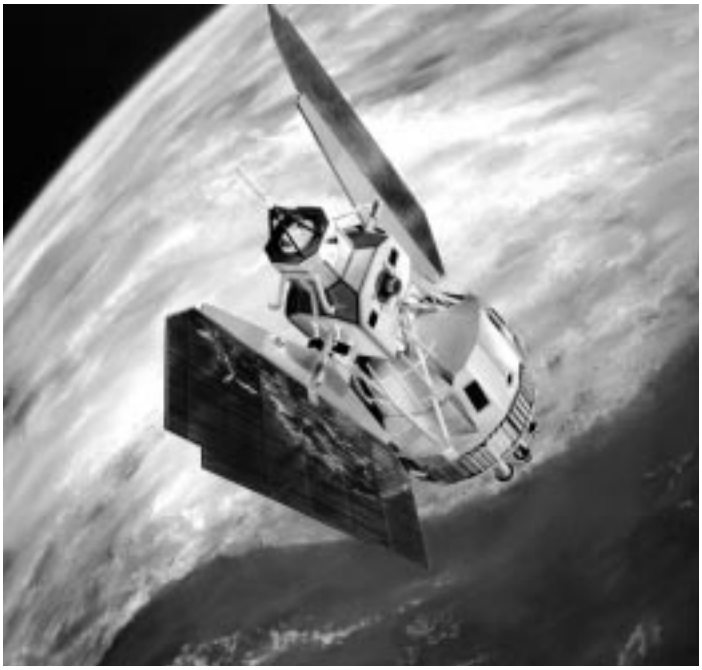


Image from Television Infrared Observation Satellite (TIROS) spacecraft, the beginning of a long series of polar-orbiting meteorological satellites.



Landsat image of the Baltimore/Washington area.



Landsat satellites (see artist concept above) gather remotely sensed images of the land surface and surrounding coastal regions for global climate change studies, and other government and commercial purposes.

Mapper was a significant improvement over the initial sensor. A second Thematic Mapper was launched aboard Landsat 5 on March 1, 1984. Landsat 5 remains in operation today, managed by a commercial firm, Space Imaging EOSAT, eight years beyond its design lifetime.

The instruments on the Landsat satellites have recorded millions of images. These images, archived in the United States and at Landsat receiving stations around the world, are a unique resource for global change research and other applications. These data have been used to monitor timber losses in the U.S. Pacific Northwest, estimate soil moisture and snow water equivalence, and measure forest cover at the state level. In addition, sensors on board Landsat have been used to monitor strip mining reclamation, population changes in and around metropolitan areas, and to measure water quality in lakes. Landsat images have even been used by law firms to gather legal evidence and by fast food restaurants to estimate community growth sufficient to warrant a franchise.

Landsat 7, the latest in the series, is scheduled for launch in April 1999. Landsat 7 will enable us to look at the cycle of vegetation growth, deforestation, erosion, snow accumulation and melt, agricultural land use and urbanization. With Landsat 7, scientists will gather remotely sensed images of the land surface and surrounding coastal regions for global change research, regional environmental change studies, national security uses and many other civil and commercial purposes.

Landsat's 25-year collection of land images serves hundreds of users annually who observe and study the Earth, who manage and utilize its natural resources, and who monitor the changes brought on by natural processes and man's activities. The images provide information meeting the broad and diverse needs of business, science, education, government, and national security.

Geostationary Operational Environmental Satellite (GOES)

GOES became the first operational geostationary satellite with its launch in 1975. Geostationary satellites are satellites whose orbits make them appear to remain in a fixed location above the Earth. The GOES I-M series of satellites is owned and operated by the National Oceanic and Atmospheric Administration. NASA manages the design, development, and launch of the spacecraft. Once the satellite is launched and checked out, NOAA assumes responsibility for the command and control, data receipt, and product generation and distribution.

The GOES satellites provide the pictures for television news weather reports. These data provide half-hourly observations; the instruments on board the satellites measure Earth-emitted and -reflected radiation, from which atmospheric temperature, wind speed and direction, moisture content, and cloud cover can be derived. With their apparently fixed location and broad field of view, GOES satellites have helped scien-

tists improve weather forecasting tremendously.

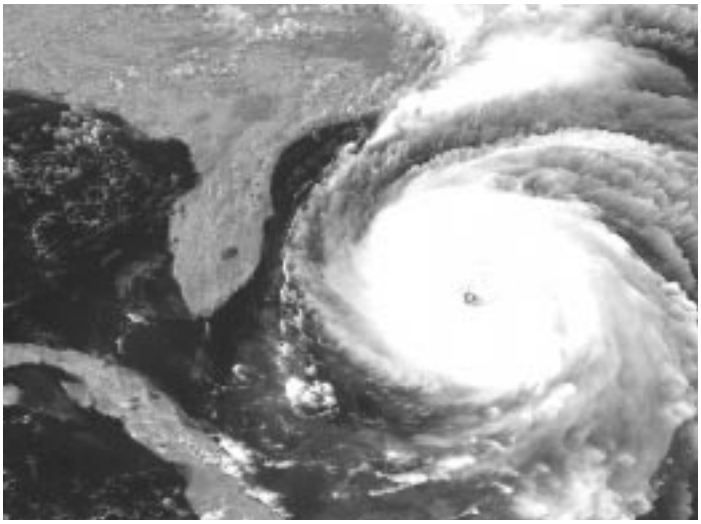
The major operational use of infrared imagery from GOES instruments is to provide early warnings of threatening weather. Forecasting the location of probable severe storms and the landfall position of tropical cyclones and hurricanes is heavily dependent upon GOES infrared and visible pictures. The quantitative temperature and moisture and wind measurements are useful for isolating areas of potential storm development.

GOES I-M data products are used by a wide variety of both operational and research centers. The National Weather Service's extensive use of multispectral imagery provides early warnings of threatening weather and is central to its weather monitoring and short-term forecast function. Most nations in the Western Hemisphere depend on GOES imagery for their routine weather forecast functions as well as other regional applications. GOES data products are also used by commercial weather users, universities, the Department of Defense, and the global research community, particularly the International Satellite Cloud Climatology Project, through which the world's cloud cover is monitored for the purpose of detecting change in the Earth's climate. Users of GOES data products are also found in air and ground traffic control, ship navigation, agriculture, and space services sectors.

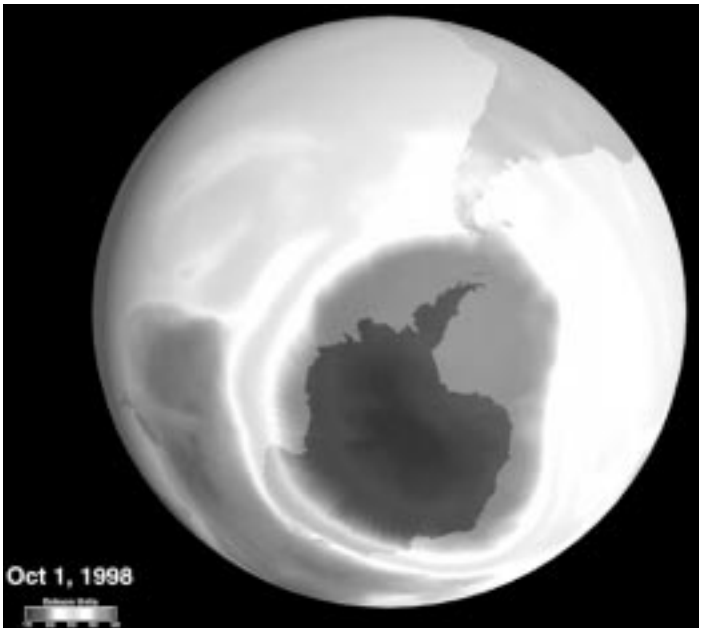
Nimbus-7

The Nimbus-7, launched in 1978, was a research and development satellite designed to test advanced systems for sensing and collecting data to address issues in pollution, oceanography, and meteorology.

With the eight experiments that were selected for flight on Nimbus-7, the mission afforded an opportunity to conduct a variety of experiments addressing



A computer-generated image of Hurricane Fran, using data from the GOES weather satellites.



Data from TOMS show the size of the region of depleted Antarctic ozone extended to a record16.8 million sq. miles.

atmospheric pollutants; ocean color, temperature, and ice conditions, particularly in coastal zones to examine pollutants, suspended material, mapping sediments and biologically active areas; ship route forecasting; quantitative measurements of air-surface boundary conditions (e.g., soil moisture, snow and ice cover, sea surface temperature and roughness, and albedo) and of precipitation; improvements in long-range weather forecasting in support of the Global Atmospheric Research Program; and continued measurements of radiation variations outside the atmosphere to determine the effect of these variations on the Earth's climate.

Total Ozone Mapping Spectrometer (TOMS)

In 1978, the first TOMS was launched on the Nimbus-7 satellite. TOMS instruments have been launched on many satellites since then, providing a near-continuous data set that provides highly accurate measurements of ozone within Earth's atmosphere. The NASA/GSFC TOMS Team processes those data, enabling scientists throughout NASA, the U.S. Government and the international science community to better understand the relationship between atmospheric chemical reactions and the elements that drive them.

The TOMS instrument generated a map of the total ozone amount in the atmosphere that indicated there was an ozone hole over Antarctica the size of the continental United States confirming earlier measurements made from ground-based instrumentation. Goddard researchers were able to generate visual images of the ozone layer, holes and all. As a result of

the outstanding scientific data it reported, the Nimbus-7 TOMS instrument was kept operational for almost 15 years. In 1996, Goddard launched another TOMS instrument aboard the Earth Probe satellite to continue the TOMS instrument coverage.

Other TOMS instruments have been launched on the Japanese Advanced Earth Observation Satellite (ADEOS), and the Russian-built and -launched Meteor-3 satellite. Another TOMS is scheduled to fly on the Triana satellite.

TOMS is the first satellite instrument that is able to detect aerosols over all kinds of surfaces (land, water, and snow/ice). This permits the sources of dust, smoke, volcanic ash, and air quality to be observed. The observations can be used as hazard warnings for aircraft (volcanic ash) and for major air quality events downwind of large fires (e.g., the 1998 Mexican fire that covered portions of the U.S. with plumes extending into Canada).

Upper Atmosphere Research Satellite (UARS)

Scientific studies have shown that natural events and human related activities cause changes in the chemistry and physics of the upper atmosphere. These studies have led to concern that mankind's activities may be altering weather, climate, and the shield of ozone that is important to the protection of life on Earth.

UARS, a Space Shuttle-launched, Earth-orbiting observatory, is the centerpiece of a program begun in response to a Congressional directive that NASA undertake a comprehensive program of research into the upper atmosphere.

The purpose of UARS is to provide data that will yield a better understanding of the upper atmosphere, and with it, a better understanding of the effects of natural events and human activities on that region. UARS was the first satellite dedicated to stratospheric science that focuses on the processes that lead to ozone depletion.

Deployed from the Shuttle on September 15, 1991, the Upper Atmosphere Research Satellite, depicted in this artist concept, was able to map chlorine monoxide, an ozone-destroying radical, within the Arctic vortex.

UARS was launched in 1991. Within its first two weeks of operation, UARS was able to confirm what Goddard scientists already suspected: that the chlorine in aerosols was reacting with the ozone to form chlorine monoxide in the atmosphere. As a result, the chlorine monoxide was destroying the ozone layer, which combined with other factors to create an ozone "hole." UARS also found that chlorine monoxide was present over mid-latitude regions of the Northern Hemisphere, where most of the Earth's human population lives. This finding may have implications for ozone depletion in regions other than the Antarctic. In addition to its atmospheric chemistry observations, UARS has provided the most complete data on upper atmospheric energy inputs and winds gathered to-date.

Ocean Topography Experiment (TOPEX/Poseidon)

TOPEX/Poseidon, launched in 1992, is a cooperative project between the United States and France to develop and operate an advanced satellite system to provide global sea level measurements with an unprecedented accuracy. The data obtained from this mission have helped scientists monitor global ocean circulation, discover the tie between the oceans and atmosphere, and improve global climate predictions. Every 10 days, the TOPEX/Poseidon satellite measures global sea level with unparalleled accuracy (to less than one inch).

TOPEX/Poseidon has been used to study the onset, development, and regression of the El Niño phenomenon, and the recent subsequent La Niña, with the global consequences arising from these phenomena.

Sea-viewing Wide Field of View Sensor (SeaWiFS)

Seastar, the first satellite dedicated to studying the world's oceans from space was launched in 1997 on a Pegasus launch vehicle. Seastar carries only one instrument: SeaWiFS, which is designed to study ocean color. SeaWiFS is a follow-on to the Coastal Zone Color Scanner that was on Nimbus-7, and which ceased operation in 1986. The principal objective for SeaWiFS is to acquire data that are critical for the study of the role of oceans, including the exchange of critical elements and gases between the atmosphere and ocean, and how these exchanges affect phytoplankton production in the ocean. Phytoplankton are

microscopic marine plants. SeaWiFS is able to view the world's oceans every two days. Since the Earth is comprised of 70% ocean, SeaWiFS will provide critical information on the global biosphere. The data resulting from the project are being distributed to scientists conducting research on ocean productivity and other related topics.

Ocean color varies depending on the concentration of phytoplankton in the oceans. By measuring the amounts of phytoplankton in the world's oceans, scientists can get a measure of the amount of dissolved organic materials. Phytoplankton removes carbon dioxide (a greenhouse gas) from the atmosphere and supports the food chain by photosynthesis. Because of its several roles in biology and atmospheric chemistry, scientists hope to learn how phytoplankton affect the global climate, and how the global climate affects the oceanic food chain.

Tropical Rainfall Measuring Mission (TRMM)

TRMM, a joint venture between NASA and the National Space Development Agency of Japan (NASDA), was launched on November 27, 1997. The mission was designed to monitor and study tropical rainfall and the associated release of energy that helps to power the global atmospheric circulation, shaping both weather and climate around the globe.

Since the majority of the world's rainfall occurs in the tropics, it is critical to understand the process of rainfall in this region. The data from TRMM have been very beneficial in providing scientists with the first near-global measurements of rainfall over the Earth. TRMM is designed to look into the inner structure of storms, as well as measure the precipitation from thunderstorms and rain showers. Because global rainfall is a key factor in heat circulation processes within the atmosphere, understanding the causes and distribution of rainfall can aid scientists in predicting several aspects of global climate change.

TRMM has already provided new insights into the roles and distribution of clouds in hurricanes, and understanding the process known as La Niña. La Niña is essentially the opposite of the El Niño phenomena, and is characterized by unusually cold ocean temperatures in the eastern equatorial Pacific, as compared to El Niño where warm ocean temperatures are warmer than normal. Both these phenomena have been shown to have consequences that range far beyond their geographic locations.

The Future in Earth Science

As Goddard looks toward the future, we will continue to focus on the way our planet's myriad of systems operate and interact with each other. To continue our analysis of the Earth's oceans, atmosphere, ice, and land, Goddard has major responsibilities in a multitude of Earth science missions for the new millennium, including Terra, EOS PM-1, IceSat-1, EOS CHEM-1, EO-1, EO-2, the Vegetation Canopy Lidar, and Earth System Science Pathfinder.

Data from these activities are used to generate increasingly higher-resolution computer models. Such efforts as the Goddard Earth Observing System Data Assimilation System and the NASA Seasonal-to-Interannual Prediction Project will allow scientists to analyze and understand Earth system phenomena and their interactions more accurately. Using data obtained from the instruments, satellites, missions, and computational activities described here (and others, some of which are still in the planning stages), Goddard will continue to play the lead role in NASA's contribution to the U.S. Global Change Research Program.

TRMM spacecraft in the cleanroom. TRMM was the first satellite designated to observe tropical rainfall.

Communications Technology

Tracking and Data Relay Satellite System (TDRSS)

In the 1980's TDRSS was developed in order to achieve the highest amount of communication coverage of low-Earth orbiting satellites, Space Shuttle missions and the Hubble Space Telescope. The TDRSS consists of a constellation of satellites in fixed geosynchronous positions above the Earth and three ground terminals. This system provides 100% coverage for user satellites. Prior to implementation of TDRSS, the tracking system was made up of a series of large antennas at ground stations located around the world. TDRSS was a marked improvement to prior tracking systems because the older system could only see a spacecraft when it was above the local horizon. As a result, coverage was severely limited. This system was and still is an important component in space exploration, utilization and research by providing science and environmental data for the benefit of humankind.

Six Tracking and Data Relay Satellites, like these shown in this drawing, provide NASA's primary communication link with the Space Shuttle, International Space Station and satellites in low-Earth orbit.

The Tracking and Data Relay Satellite (TDRS) is a three-axis stabilized spacecraft equipped with both fixed and steerable antennas on the payload. The satellites have two wing-like solar panels that provide approximately 1700 watts of power to the satellite over the 10-year expected life of the satellite. The solar panels rotate towards the Sun to provide maximum energy. Each TDRS provides for the relay of data via radio frequency communication links between the White Sands Complex (ground terminals) to and from user satellites. The TDRSS Space Network requires a minimum of three fully capable geosynchronous spacecraft. Presently, six TDRS spacecraft are on orbit. Services are provided from three areas of operations: the East node consists of TDRS spacecraft located at 41 degrees west, 47 degrees west and 49 degrees west longitude; the West node consists of TDRS spacecraft located at 171 degrees west and 174 degrees west longitude; and Indian Ocean coverage is provided by a TDRS spacecraft located at 85 degrees east longitude.

To maintain and expand the capabilities of the existing TDRS fleet of satellites for current and future missions, such as the International Space Station, NASA established the TDRS Replenishment Program. The program is made up of the TDRS-H, I, and J spacecraft. TDRS-H is the first of this new series that will replenish the aging TDRS fleet. TDRS H will enable Goddard and the NASA to meet their growing needs well into the 21st century. TDRS-H is scheduled for launch this summer.

Applications of Space Technology

NASTRAN (NASA Structural Analysis)

NASTRAN, also known as the NASA Structural Analysis, was originally written to help design more efficient space vehicles. The commercial use of NASTRAN has helped to analyze the behavior of elastic structures of any size, shape, or purpose. For example, the automotive industry uses the program to design front suspension systems and steering linkages. Railroad tracks and cars are designed with NASTRAN. It's also used in designing bridges, power plants, skyscrapers, and aircraft. This program alone was estimated to have returned $701 million in cost savings from 1971 to 1984.

Corrosion-Resistant Coating

Corrosion-Resistant Coating was developed by Goddard in 1977. It has been used on coastal bridges and other structures subject to corrosion. The inorganic paint is loaded with zinc particles for corrosion protection. It requires only one coat instead of the two normally required, and it is expected to last twice as long. In addition to bridges, it can be effectively used on pipelines, nuclear reactors, offshore drilling facilities, and ships. To protect gantries and other structures at Kennedy Space Center from corrosion and heat, Goddard developed an advanced coating. It is being marketed commercially by Inorganic Coatings, Inc. as K-Zinc 531. The coating bonds to steel in 30 minutes, creating a very hard ceramic finish. It is easy to apply and provides long-term protection and cost advantages in materials and labor.

Solar Energy

In 1978, the managers at Greenbelt Homes Inc., located in Greenbelt, Md., asked its neighbor, Goddard, for assistance in setting up a solar energy project. To study effectiveness, Goddard equipped one of GHI's buildings with solar collectors to determine oil consumption, water usage, and temperatures. Goddard engineers recorded information for two winter-summer cycles. Analyses of the data indicated that solar collectors save between 40 and 50 percent of oil needed to meet home heating and hot water needs.

Implantable Cardioverter Defibrillator

The Implantable Cardioverter Defibrillator (ICD) was conceived in the mid to late 1960s, and working circuits were built and tested at Sinai Hospital of Baltimore in the fall of 1969. After a number of years of pre-clinical testing, the device entered clinical trials at The John Hopkins Hospital in February 1980. It received Food and Drug Administration (FDA) approval in 1985. Since then, more tests were administered and the results have become landmarks in importance as they lead the way towards rational treatment of serious ventricular arrhythmia (any disturbance in the change of the heartbeat) of patients in clinical practice. The ICD is a fully implantable device, not much larger in size than the implantable pacemaker. The success of this therapy has become regarded as the "gold standard" in the treatment of malignant arrhythmias.

Programmable Implantable Medication System

In 1981, Goddard participated in the development of the Programmable Implantable Medication System, a device designed to be implanted in the human body to release precisely-controlled amounts of medication over a period of time. The implant can be monitored and the dosage controlled externally by means of telemetry. The medication reservoir can be refilled by injection. The most important immediate application is for administering insulin to patients with diabetes, freeing them from the need for daily injections and allowing better control of blood sugar levels.

Lixiscope

Lixiscope, developed by NASA in 1983, is a portable X-ray instrument developed by NASA now being produced commercially as an industrial tool. The instrument is a self-contained, battery-powered fluoroscope (tube or box) that produces an instant image through use of a small amount of radioactive isotope.

The Goddard-developed Lixiscope produces an instant image through use of a small amount of radioactive isotope.

Originally developed by Goddard, Lixiscope is now being produced by Lixi, Inc. which has an exclusive NASA license for one version of the device.

Breast Biopsy System

The Breast Biopsy System is a new nonsurgical and less traumatic breast technique called large-core needle biopsy. In the new breast imaging system, a special phosphor enables the Charge Coupled Device to convert X-rays to visible light, which provides the dig-

Radiologist operates the Breast Biopsy System that uses technology developed for the Hubble Space Telescope Imaging Spectrograph.

ital camera with X-ray vision. The stereotatic imaging device takes images of suspect mass from two different angles. The radiologist is able to determine the coordinates of the abnormality and extract a tiny sample from the spot with a needle. This technology is based on the Charged Coupled Device developed for the Space Telescope Imaging Spectrograph installed on the Hubble Space Telescope in 1997. This procedure costs about $850.00 and the patient can leave minutes after the procedure, instead of one week with traditional surgery which costs about $3,500.00. The commercial partner is LORAD Corporation.

LIDAR Topographical Mapping System

The Houston Advanced Research Center (HARC) and Goddard have miniaturized an Airborne LIDAR Topographic Mapping System (ALTMS) and begun to economically collect accurate data from a commercial, photogrammetry-based aircraft. LIDAR systems have been used by NASA for the experimental characterization of the atmosphere, landmasses and oceans. The ALTMS system operates by sweeping the ground with a pulsed laser from an aircraft. The ALTMS system will produce digital elevation maps rapidly and efficiently, compared to traditional methods.

In June 1998, TerraPoint LLC, a spinoff company of Transamerica Real Estate Information Companies, one of the nation's largest financial services companies, was formed to commercialize the airborne LIDAR mapping system technology. HARC also obtained the exclusive license for topographic mapping applications of Goddard's SBIR-developed Holographic Optical Element. Using this technology method, ALTMS can operate in various lighting, weather, and vegetation conditions. ALTMS also includes every feature on the surface, including grass and hedges. ALTMS provides more ecological data than was previously available. This additional data allows a host of new quantitative Earth science studies, ecological data and associated applications to be conducted.

Infrared Camera Helps Preserve the Star-Spangled Banner

In 1998, the Smithsonian Institution began a three-year project to preserve the flag that flew over Fort McHenry in 1814, prompting Francis Scott Key to write the poem that became the national anthem. Goddard's Acousto-optic Imaging Spectrometer (AImS) is a key element of this preservation effort. Decades of exposure to light, air pollution, and temperature fluctuations have taken their toll on the historic artifact. In particular, moisture can damage the flag's wool fabric by causing chemical reactions when in the presence of light. AImS helps to identify deteriorated and soiled areas not visible to the naked eye. The technology allows scientists to study the composition of layered materials without destroying the object being examined. AImS will take 72 separate image sets of the 30x34-foot flag. Composed of 35 infrared wavelengths, each image set will be combined into a mosaic of the massive flag. Unlike thermal infrared cameras, which make images based on differences in radiated heat, AImS makes images of reflected infrared light. This capability is essential in identifying contaminates on the flag because they are the same temperature as the flag itself.

This technology can be used in examining other works of art and prehistoric cave paintings. Goddard also has a cooperative agreement with Swales and Associates, Inc., and Georgetown University Medical Center to explore the use of AImS in skin cancer research.

Key facilities shown in the foreground of this aerial view of Goddard include the Spacecraft Systems Development and Integration Facility, which contains one of the world's largest "clean rooms"; the Spacecraft Test and Integration Facility, which contains thermal-vacuum chambers, a vibration platform, and an acoustic test chamber; and the High Capacity Centrifuge (circular building), which houses a rotary accelerator capable of rotating 5,000-lb payloads at up to 30-times Earth's normal gravity.