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**June 2 – August 8**

# NASA Goddard Space Missions

**Compiled by Alexander Soucek, MSS**

**International Space University, Strasbourg, France**

**(Work in Progress)**

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**University Programs Office, Code 603.1, NASA-GSFC, Greenbelt, MD 20771**

**http://academy.gsfc.nasa.gov/2003/publications/missions.pdf**

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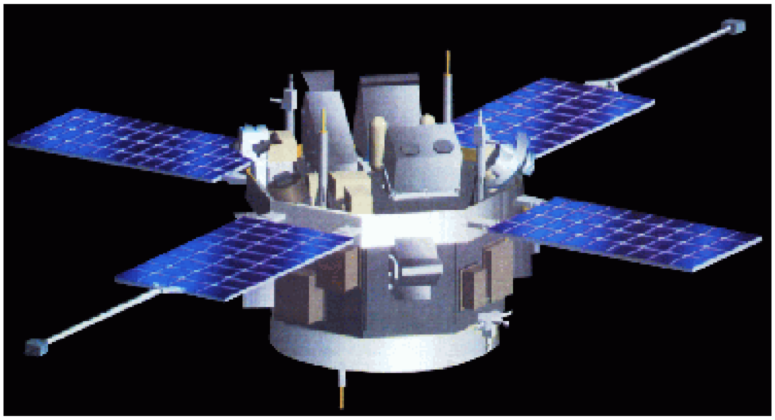
# Foreword

## Table of Contents

# ACE

## Status: in orbit since August 25, 1997



## Mission Summary

**The Advanced Composition Explorer (ACE) is an Explorer mission that was managed by the Office of Space Science Mission and Payload Development Division of NASA.**

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The Earth is constantly bombarded with a stream of accelerated particles arriving not only from the Sun, but also from interstellar and galactic sources. Study of these energetic particles will contribute to our understanding of the formation and evolution of the solar system as well as the astrophysical processes involved. The Advanced Composition Explorer (ACE) spacecraft carrying six high-resolution sensors and three monitoring instruments samples low-energy particles of solar origin and high-energy galactic particles with a collecting power 10 to 1000 times greater than past or planned experiments.

From a vantage point approximately 1/100 of the distance from the Earth to the Sun ACE performs measurements over a wide range of energy and nuclear mass, under all solar wind flow conditions and during both large and small particle events including solar flares. ACE provides near-real-time solar wind information over short time periods. When reporting space weather ACE can provide an advance warning (about one hour) of geomagnetic storms that can overload power grids, disrupt communications on Earth, and present a hazard to astronauts.

ACE orbits the L1 libration point which is a point of Earth-Sun gravitational equilibrium about 1.5 million km from Earth and 148.5 million km from the Sun. With a semi-major axis of approximately 200,000 km the elliptical orbit affords ACE a prime view of the Sun and the galactic regions beyond. The spacecraft has enough propellant on board to maintain an orbit at L1 until ~2019.

# Science Goals

The primary purpose of ACE is to determine and compare the isotopic and elemental composition of several distinct samples of matter, including the solar corona, the interplanetary medium, the local interstellar medium, and Galactic matter. The nine scientific instruments on ACE are performing:

- **Comprehensive and coordinated composition determinations**
  - Elemental
  - Isotopic
  - Ionic charge state
- **Observations spanning broad dynamic range**
  - Solar wind to galactic cosmic ray energies (~100 eV/nucleon to ~500 MeV/nucleon)
  - Hydrogen to Zinc (Z = 1 to 30)
  - Solar active and solar quiet periods
- **Investigations of the origin and evolution of solar and galactic matter**
  - Elemental and isotopic composition of matter
  - Origin of the elements and subsequent evolutionary processing
  - Formation of the solar corona and acceleration of the solar wind
  - Particle acceleration and transport in nature

# Mission Status

Last update available on the internet: November, 2002

*"ACE has been at the L1 point for more than 4 years, and things are still working very well, with the exception of the SEPICA instrument. SEPICA is having trouble with the gas regulation of its proportional counters and with a high-voltage power supply. Two thirds of the instrument is non-functional, but the third counter is returning good science data. The problems are still under investigation."*

# Astro-E2

## Status: scheduled for launch in January/February 2005

## Mission Summary

Astro-E2 is the fifth in a series of Japanese astronomy satellites devoted to observations of celestial X-ray sources. It is a joint Japanese-US mission, with the US contributing significantly to two of the three types of instruments on-board. It is being developed at Japan's Institute of Space and Astronautical Science (ISAS) in collaboration with other Japanese institutions, as well as NASA's Goddard Space Flight Center and the Massachusetts Institute of Technology (MIT).

Astro-E2 is designed for "broad-band, high-sensitivity, high-resolution" spectroscopy. This means that not only are its instruments sensitive to both low and high energy X-rays, but they can distinguish very small differences in the energy of the X-ray photons that are being detected.

## Science Goals / Instruments

Astro-E2 will cover an energy range of 0.4 to 700 keV using three kinds of instruments with the following energy ranges:

- X-Ray Spectrometer (XRS) - 0.4 - 10 keV
- X-ray Imaging Spectrometers (XIS) - 0.4 - 12 keV
- Hard X-ray Detector (HXD) - above ~10 keV

The XRS instrument, which is an X-ray micro-calorimeter, will provide high-resolution spectroscopy. At the same time, the XIS instruments (there are four identical units, each with a CCD camera), will take X-ray images of the objects, and the HXD instrument will measure high-energy X-rays.

Astro-E2 will also have five foil X-Ray Telescopes (XRTs), four of which will be in front of an XIS, the fifth in front of the XRS. These telescopes play an important role. Just as an optical telescope collects light so your eye or a CCD camera can process it, the X-Ray Telescopes collect light in the form of X-ray photons, allowing the instruments behind them to process those photons.

Some of the key themes that astronomers hope that Astro-E2 will be able to advance are:

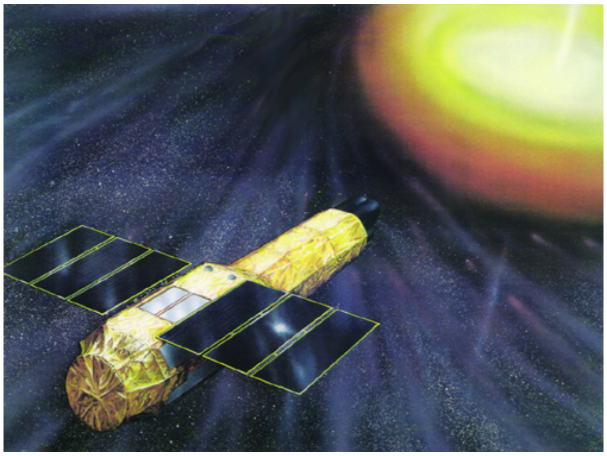
- When and where are the chemical elements created?
- What happens when matter falls onto a black hole?
- How do you heat gas to X-ray emitting temperatures?

# Additional information

It is customary for Institute of Space and Astronautical Science satellites to have two names, one given before launch and one after. The pre-launch name is a project name that designates which series the satellite belongs to and a letter that designates what number that satellite is in that series. Astro-E2 is the re-flight of the 5th satellite in the 'ASTRO' series (due to a first stage malfunction, ASTRO-E failed to reach orbit). The ASTRO series of satellites are often for cosmic X-ray astronomy, although one was a Solar X-ray astronomy satellite and ASTRO-F will be an infrared astronomy mission. Other series include 'MUSES' (engineering led projects), 'SOLAR', and 'PLANET'.

The post-launch name is a proper name, chosen shortly after launch.

*This picture shows the helium insert (the XRS detector itself, electronics, the ADR, and the helium tank) being lowered into the neon tank.*



*Artist's impression of ASTRO-E2.*

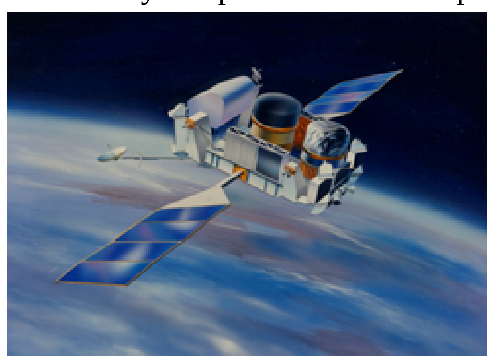
# CGRO

## Status: Mission completed (1991 – 2000)

## Mission Summary

The Compton Gamma Ray Observatory was the second of NASA's Great Observatories. Compton, at 17 tons, was the heaviest astrophysical payload ever flown at the time of its launch on **April 5, 1991** aboard the space shuttle Atlantis. Compton was safely deorbited and re-entered the Earth's atmosphere on **June 4, 2000**.

Compton had four instruments that covered an unprecedented six decades of the electromagnetic spectrum, from 30 keV to 30 GeV. In order of increasing spectral energy coverage, these instruments were the Burst And Transient Source Experiment (BATSE), the Oriented Scintillation Spectrometer Experiment (OSSE), the Imaging Compton Telescope (COMPTEL), and the Energetic Gamma Ray Experiment Telescope (EGRET). For each of the instruments, an improvement in sensitivity of better than a factor of ten was realized over previous missions.



The Observatory was named in honor of Dr. Arthur Holly Compton, who won the Nobel prize in physics for work on scattering of high-energy photons by electrons - a process which is central to the gamma-ray detection techniques of all four instruments.

Background / Scientific Goals and Discoveries / Instruments

The Compton Gamma Ray Observatory (GRO) is a sophisticated satellite observatory dedicated to observing the high-energy Universe. It is the second in NASA's program of orbiting "Great Observatories", following the Hubble Space Telescope. While Hubble's instruments operate at visible and ultraviolet wavelengths, Compton carries a collection of four instruments which together can detect an unprecedented broad range of high-energy radiation called gamma rays. These four instruments are much larger and more sensitive than any gamma-ray telescopes previously flown in space. The large size is necessary because the number of gamma-ray interactions that can be recorded is directly related to the mass of the detector. Since the number of gamma-ray photons from celestial sources is very small compared to the number of optical photons, large instruments are needed to detect a significant number of gamma rays in a reasonable amount of time. The combination of these instruments can detect photon energies from 20 thousand electron volts (20 keV) to more than 30 billion electron volts (30 GeV).

An appreciation of the purpose and design of Compton's four instruments is gained from understanding that above the energies of X-ray photons (~10 keV - about 10,000 times the energy of optical photons) materials cannot easily refract or reflect the incoming radiation to form a picture. Hence, alternative methods are required to collect gamma-ray photons and thereby image sources in the sky. At gamma-ray energies, three methods are currently used, sometimes in combination:

- partial or total absorption of the gamma ray's energy within a high-density medium, such as a large crystal of sodium iodide
- collimation using heavy absorbing material, to block out most of the sky and realize a small field of view
- at sufficiently high energies, utilization of the conversion process from gamma rays to electron-positron pairs in a spark chamber, which leaves a telltale directional signature of the incoming photon.

The Compton Observatory has a diverse **scientific agenda**, which includes studies of very energetic celestial phenomena: solar flares, gamma-ray bursts, pulsars, nova and supernova explosions, accreting black holes of stellar mass, quasar emission, and interactions of cosmic rays with the interstellar medium.

Many exciting discoveries have been made by the instruments on Compton, some previously expected and some completely surprising. The all-sky map produced by EGRET is dominated by emission from interactions between cosmic rays and the interstellar gas along the plane of our Galaxy, the Milky Way. An all-sky map made by COMPTEL illustrates the power of imaging in a narrow band of gamma-ray energy, in the light of radioactive aluminum 26. In another map of the Galactic center region, scanning observations made by OSSE reveal gamma-ray radiation from the annihilation of positrons and electrons in the interstellar medium, another line emission. The spectrum of a solar flare recorded by OSSE yields direct evidence accelerated particles smashing into material on the sun's surface, exciting nuclei which then radiate in gamma rays.

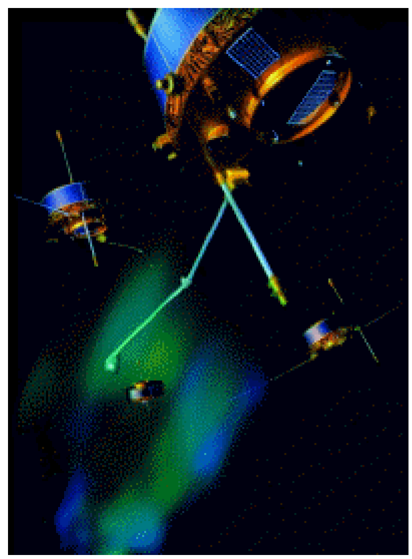
*The Laboratory for High Energy Astrophysics at Goddard Space Flight Center has three areas of involvement with Compton: the team in charge of the EGRET instrument, part of the spectroscopy analysis team for the BATSE instrument, and the Compton Observatory Science Support Center, which supports the Guest Investigator program and archival analysis research.*

# Cluster II

## Status: in orbit since July and August 2000

## Mission Summary

The Cluster II mission consists of four similar spacecraft and is part of ESA's and NASA's Solar-Terrestrial Science Program (STSP). The purpose of the mission is to study small-scale structures in three dimensions in the Earth's plasma environment, such as those involved in the interaction between the solar wind and the magnetospheric plasma, in global magnetotail dynamics, in cross-tail currents, and in the formation and dynamics of the neutral line and of plasmoids.



In the summer of 2000, the European Space Agency (ESA) began a unique experiment to explore near-Earth space. The Cluster project got under way with the launch of two Russian Soyuz rockets from Baikonur Cosmodrome in Kazakhstan, each carrying a pair of identical satellites.

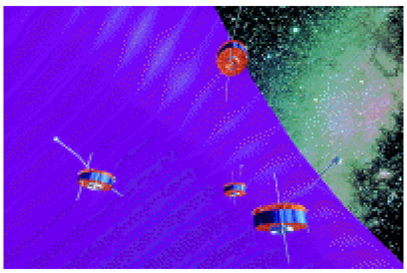
Cluster is part of an international programme to find out more about how the Sun and Earth interact. The four satellites join an armada of spacecraft from many countries (including ESA's SOHO and Ulysses satellites) which are already studying the Sun and the high-speed wind of charged particles - mainly electrons and protons - which it continually blasts into space. Once in orbit, the four Cluster spacecraft will spend several years passing in and out of our planet's magnetic field. Their mission will be to complete the most detailed investigation yet made into the ways in which the Sun and Earth interact.

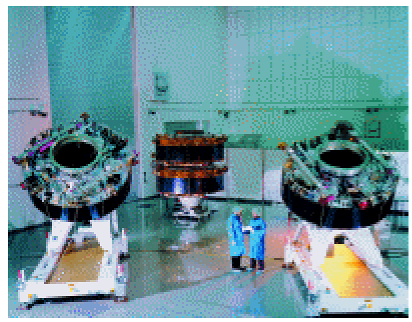
## Raising from the ashes (background story)

The story began in February 1986, when ESA chose two interrelated missions as the first 'Cornerstone' in its Horizons 2000 Science Programme. Cluster would study rapid changes in the Earth's magnetic shell - the magnetosphere - while the SOlar and Heliospheric Observatory (SOHO) would stare at the Sun and measure the energetic solar particles which stream towards our world. These two missions are known as the 'Solar-Terrestrial Science Programme' and have the American space agency NASA as a partner.

Since its successful launch on 2 December 1995, SOHO has sent back a stream of new discoveries about our nearest star. Unfortunately, the four Cluster spacecraft were destroyed when the Ariane-5 rocket exploded during its maiden launch on 4 June, 1996. Ten years of work seemed to have been wiped out in less than a minute.

But the Cluster team refused to give up. They suggested reviving the unique project by using spare parts to build another spacecraft. It was named Phoenix after the mythical bird that rose from the ashes. Eventually, the mission's importance was recognized by the ESA Member States. On 3 April 1997, the ESA Science Programme Committee agreed that three new Cluster craft should be built alongside Phoenix, and Cluster II was born.





*Four Cluster spacecraft in the clean room at IABG in Munich, Germany*

Since the launches in July and August 2000, Cluster has been delighting scientists with the wealth of exciting data gathered by the four spacecraft. By making simultaneous measurements and sometimes flying in a lopsided pyramid or tetrahedron formation, they will be able to make the first detailed, three-dimensional study of the changes and processes taking place in near-Earth space. The Cluster mission will be the first time that four identical spacecraft have flown in formation around the Earth.

When they are only a few hundred kilometers apart, they will be able to study small-scale features in the surrounding space. At other times, they may be separated by up to 20 000 kilometers, to obtain a broader view of what is going on.

The satellites follow highly elongated, polar orbits which take them between 19 000 and 119 000 kilometers from the planet. Sometimes, they are inside the Earth's magnetic shield and sometimes they are outside, fully exposed to the supersonic solar wind.

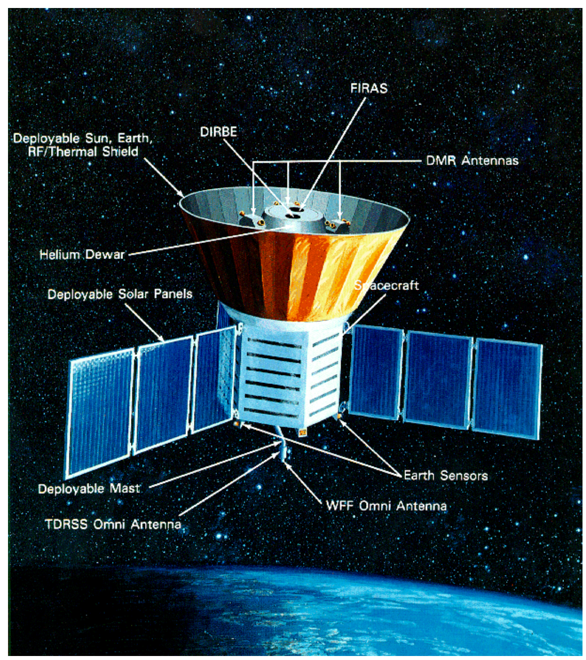
# COBE

## Status: in orbit since November 1989

## Mission Summary

The COBE satellite was developed by NASA's Goddard Space Flight Center to measure the diffuse infrared and microwave radiation from the early universe to the limits set by our astrophysical environment. It was launched November 18, 1989 and carried three instruments, a Far Infrared Absolute Spectrophotometer (FIRAS) to compare the spectrum of the cosmic microwave background radiation with a precise blackbody, a Differential Microwave Radiometer (DMR) to map the cosmic radiation sensitively, and a Diffuse Infrared Background Experiment (DIRBE) to search for the cosmic infrared background radiation.

## Scientific Discoveries / Instruments




Each COBE instrument yielded a major cosmological discovery:

- FIRAS - The cosmic microwave background (CMB) spectrum is that of a nearly perfect blackbody with a temperature of 2.725 +/- 0.002 K. This observation matches the predictions of the hot Big Bang theory extraordinarily well, and indicates that nearly all of the radiant energy of the Universe was released within the first year after the Big Bang.
- DMR - The CMB was found to have intrinsic "anisotropy" for the first time, at a level of a part in 100,000. These tiny variations in the intensity of the CMB over the sky show how matter and energy was distributed when the Universe was still very young. Later, through a process still poorly understood, the early structures seen by DMR developed into galaxies, galaxy clusters, and the large scale structure that we see in the Universe today.
- DIRBE - Infrared absolute sky brightness maps in the wavelength range 1.25 to 240 microns were obtained to carry out a search for the cosmic infrared background (CIB). The CIB was originally detected in the two longest DIRBE wavelength bands, 140 and 240 microns, and in the short-wavelength end of the FIRAS spectrum. Subsequent analyses have yielded detections of the CIB in the

near-infrared DIRBE sky maps. The CIB represents a "core sample" of the Universe; it contains the cumulative emissions of stars and galaxies dating back to the epoch when these objects first began to form. The COBE CIB measurements constrain models of the cosmological history of star formation and the buildup over time of dust and elements heavier than hydrogen, including those of which living organisms are composed. Dust has played an important role in star formation throughout much of cosmic history.

# Technical Details

The need to control and measure potential systematic errors led to the requirements for an all-sky survey and a minimum time in orbit of six months. The instruments required temperature stability to maintain gain and offset stability, and a high level of cleanliness to reduce the entry of stray light and thermal emission from particulates. The control of systematic errors in the measurement of the cosmic microwave background anisotropy and the need for measuring the interplanetary dust cloud at different solar elongation angles for subsequent modeling required that the satellite rotate. In near-Earth orbit, the Sun and Earth are the primary continuous sources of thermal emission and it was necessary to ensure that neither the instruments nor the dewar were exposed to their radiation. A circular Sun-synchronous orbit satisfied these requirements. An inclination of 99 deg and an altitude of 900 km were chosen so that the orbital plane precesses 360 deg in one year due to the Earth's gravitational quadrupole moment. The 900 km altitude is a good compromise between contamination from the Earth's residual atmosphere, which increases at lower altitude, and interference due to charged particles in the Earth's radiation belts at higher altitudes. A 6 PM ascending node was chosen for the COBE orbital plane; this node follows the terminator (the boundary between sunlight and darkness on the Earth) throughout the year. By maintaining the spacecraft spin axis at about 94 deg from the Sun and close to the local zenith, it is possible to keep the Sun and Earth below the plane of the instrument apertures for most of the year. However, since the Earth's axis is tilted 23.5 deg from the ecliptic pole, the angle between the plane of the COBE's orbit and the ecliptic plane varies through the seasons from -14.5 deg to +32.5 deg. As a consequence, the combination of the tilt of the Earth's axis, the orbit inclination, and the offset of the spacecraft spin axis from the Sun brings the Earth limb above the instrument aperture plane for up to 20 minutes per orbit near the June solstice. During this period the limb of the Earth rises a few degrees above the aperture plane for part of each orbit, while on the opposite side of the orbit the spacecraft goes into the Earth's shadow. In the nominal COBE orbit, the spacecraft's central axis scans the full sky, though not with uniform coverage, every six months. The orbital period is 103 minutes, giving 14 orbits per day.

# CONTOUR

## Status: mission failed

## Mission Summary

The Comet Nucleus Tour (CONTOUR), a NASA Discovery mission, should have visited and study at least two comets. It was planned to assess for the first time how diverse these original building blocks of the solar system are. CONTOUR was tasked to clear up the many mysteries of how comets evolve as they approach the Sun and their ices begin to evaporate.

Comas and tails of a comet are big enough for easy study with Earth-based telescopes, but a comet's nucleus is so tiny that we can study it only by getting close. So far, we've gotten close enough to see the nucleus of a comet only twice: the European Space Agency's **Giotto** spacecraft glimpsed Comet Halley's nucleus in 1986, and NASA's **Deep Space 1** gathered photos and data on Comet Borrelly in 2001.

CONTOUR's two baseline targets, the comets *Encke* and *Schwassmann–Wachmann 3*, are part of Jupiter's family of comets. Encke, CONTOUR's first planned target, has the shortest orbital period of any known comet; it takes only 3.2 years to circle the Sun. Encke is probably the most famous comet after Halley; it has been observed since 1786. The American astronomer Fred Whipple studied Encke in the 1950's, when he developed the model of a comet nucleus as icy conglomerate. CONTOUR was thought to visit Encke in November 2003

CONTOUR's other target, Schwassmann–Wachmann 3, has probably come close to the Sun less often than has Encke. Most likely, a smaller fraction of its ice has evaporated. In 1996, astronomers saw several large pieces split off the nucleus of Schwassmann–Wachmann 3. CONTOUR was expected to fly by in June 2006.

The CONTOUR spacecraft was programmed to fly by each comet at the peak of its activity, close to the Sun. During each encounter, the target comet would have been well situated in the night sky for astronomers worldwide to make concurrent observations from the ground. Protected by its dust shield, the CONTOUR spacecraft would have flown by each comet at a distance of about 100 kilometers (60 miles).

CONTOUR's mission design was so flexible that the spacecraft could be retargeted to intercept an unexpected cometary visitor (like Comet Hale-Bopp, which appeared in 1997). The appearance of such a comet cannot be predicted in time to plan a space mission, but CONTOUR was thought to take advantage of the opportunity if a "new" comet passes close enough to Earth's orbit.

# What happened…

Launched July 3, 2002, CONTOUR fell silent after firing its onboard STAR 30 solid-propellant rocket motor on Aug. 15, during a maneuver to boost the spacecraft from a parking orbit around Earth. Ground-based telescope images taken shortly after showed three objects near CONTOUR's expected path, indicating CONTOUR had broken up near the scheduled end of the burn. Without data from the spacecraft, however, the mission team could only infer whether CONTOUR was fatally damaged. Attempts to contact the craft in the weeks after the anomaly proved unsuccessful.


CONTOUR Neutral Gas and Ion Mass Spectrometer (NGIMS)

CONTOUR team members planned the final contact effort for this December 2002, when they believed the spacecraft's multidirectional pancake beam antenna would be better positioned to receive signals from Earth. On Dec. 17, and again on Dec.20, mission operators at APL sent several "transmit" commands through NASA's Deep Space Network (DSN) antennas toward the suspected location of the largest piece, thought to be the bulk of the spacecraft, about 42.5 million miles (68 million kilometers) from Earth. After 16 total hours of sending and watching, no signal came back.

This meant the end of a spacecraft which was operating wonderfully. In the six weeks after launch, mission operators and navigators guided the solar-powered craft through 23 propulsive maneuvers, positioning it precisely for the 50-second rocket burn that was to send CONTOUR toward close-up encounters with at least two comets. Several technical aspects of CONTOUR itself - such as an innovative non-coherent navigation system - met controllers' high expectations and could find places in future spacecraft designs. Also, new developments within CONTOUR's imaging instruments are being incorporated into upcoming missions to Mercury, Mars and Pluto.

*"A lot of people worked hard to build CONTOUR and prepare for this mission, and we're deeply disappointed that it didn't work out," E. Reynolds – CONTOUR's project manager says. "The interest in CONTOUR was remarkable; people from around the world told us how excited they were about the chance to learn more about comets than any mission had taught before. We hope this team will have another opportunity to make that happen."*

# EUVE

## Status: Mission completed (1992 – 2001)

## Mission Summary

The Extreme Ultraviolet Explorer (EUVE) is a NASA-funded astronomy mission operating in the relatively unexplored extreme ultraviolet (70-760 Å) band. The science payload, which has been designed and built at the Space Sciences Laboratory at the University of California, Berkeley, under the direction of Dr. Roger F. Malina, consists of three grazing incidence scanning telescopes and an extreme ultraviolet (EUV) spectrometer/deep survey instrument. The science payload is attached to a Multi-Mission Modular spacecraft.

The EUVE mission, which launched on June 7, 1992 on a Delta II rocket from Cape Canaveral, is the culmination of nearly thirty years of effort at the University of California at Berkeley to create the field of EUV Astronomy. EUVE opens up this last unexplored spectral window in astrophysics.

The first six months of the mission were dedicated to mapping the EUV sky with the scanning telescopes. From then on, a Guest Observer phase allowed participation in the scientific program. Satellite operations have ended 31 January 2001.

**Box:**
EUVE reentry news on spacetoday.net

### EUVE reentry over Egypt

Updated: Thu, Jan 31, 2002, 8:33 PM ET (0133 GMT)
Originally Posted: Thu, Jan 31 7:52 AM ET (1252 GMT)

The Extreme Ultraviolet Explorer (EUVE) spacecraft came back to Earth over central Egypt Wednesday night, according to NASA reports Thursday. According to a space agency press release Thursday EUVE came down at 11:15 pm EST Wednesday (0415 GMT Thursday) over central Egypt. There were no information regarding whether any spacecraft debris survived reentry, and if so, where it might have landed. Late Wednesday NASA had said that EUVE came down at 11:25 pm EST (0425 GMT) over the Persian Gulf, after previously predicting an impact time of 11 pm EST (0400 GMT) over Brazil. EUVE lacked thrusters that would have permitted spacecraft operations to make a controlled reentry, as was done in 2000 for the Compton Gamma Ray Observatory, hence the uncertainty about the exact time and location of reentry. Up to 100 kilograms of titanium and stainless steel components of the spacecraft could have survived reentry.

# Scientific Goals

- Carry out an all-sky, all-band survey in the extreme ultraviolet (70 -760 Å) in four bandpasses with an angular resolution of 6 x 6 arc minutes with ~ 500 seconds average exposure
- Carry out a deep survey in the EUV in two bandpasses along the ecliptic
- Carry out pointed spectroscopy observations identified by Guest Observers
- Identify the emission physics of EUV sources and study of the ISM
- Probe whether compelling science can be done with increased sensitivity

# EUVE Mission Phases

- Initial Operations and Check-out: During the first month, the spacecraft and instruments were fully checked and the instrument front covers were opened.
- Sky Survey: The three scanning telescopes mapped the entire sky in the EUV over a period of six months. A Deep Survey was also performed during these six months.
- Deep Survey/Spectroscopy: Guest Observers (GOs) from around the world used the spectrometers and deep survey instruments to investigate EUV sources. The three scanners continued with serendipitous observations throughout this phase.
- Extended Mission: Science, Testbed, Education.
- Deorbiting and reentry.

# FAST

## Status: mission completed (1996 – 1997)

## Mission Summary

FAST, the second mission in NASA's Small Explorer Satellite Program (SMEX), is a satellite designed to study Earth's aurora. This highly successful spacecraft has helped scientists answer fundamental questions about the causes and makeup of the aurora. FAST's primary objective is to study the microphysics of space plasma and the accelerated particles that cause the aurora.


FAST was launched on August 21, 1996 from a Pegasus rocket into a highly elliptical orbit. It crosses Earth's auroral zones (donut shaped regions centered on the poles) four times each orbit, and only collects high-resolution data ("snapshots") while in those zones. It ventures high into the charged particle environment of the aurora to measure the electric and magnetic fields, plasma waves, energetic electrons and ions, ion mass composition, and thermal plasma density and temperature.

## Spacecraft Design and Instruments

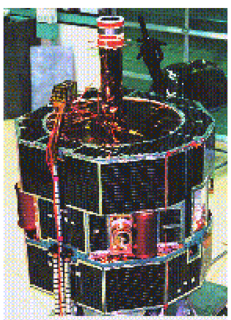
FAST was designed as a single unified scientific instrument made up of particle detectors and magnetic and electric field sensors. While spinning in its elliptical orbit around the Earth, FAST periodically passes through the auroral zones located near the Earth's northern and southern poles. FAST has a mass of 191 kg, a diameter and height of approximately 1m , and carries no on-board fuel.

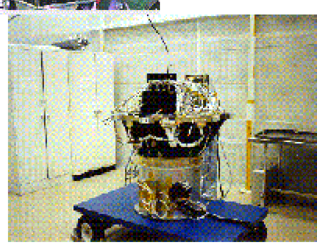
The spacecraft carries the following instruments onboard:

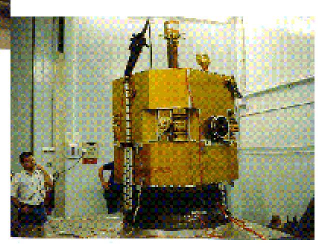
- **Electric Field Experiment:** The electric field experiment is composed of three orthogonal boom pairs. Spherical sensors deployed on radial wire and axial stacer booms will provide information on the plasma density and electron temperature.
- **Magnetic Field Experiment:** The magnetic field experiment consists of two magnetometers mounted 180° apart on deployable graphite epoxy booms. The

search coil magnetometer uses a three-axis sensor system to provide magnetic field data over the frequency range of 10 Hz to 2.5 kHz. The flux gate magnetometer is a three-axis system using high, stable, low noise, ring core sensors to provide magnetic field information for DC to 100 Hz.

- **Time-of-Flight Energy Angle Mass Spectrograph (TEAMS**): The TEAMS instrument is a high sensitivity, mass-resolving spectrometer that measures full three-dimension distribution functions of the major ion species with one spin of the spacecraft. The TEAMS experiment covers the core of all plasma distributions of importance in the auroral region.
- **Electrostatic Analyzers (ESA):** Sixteen ESAs configured in four stacks will be used for both electron and ion measurements. The four stacks are placed around the spacecraft such that the entire package is provided a full 360° field of view. The ESAs can provide a 64-step energy sweep, covering approximately 3 eV to 30 KeV up to 16 times per second.



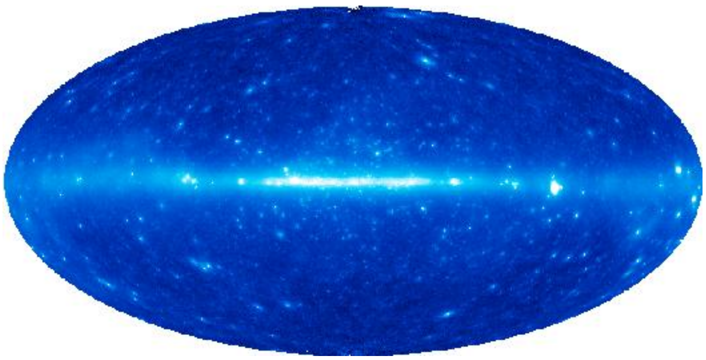




# GLAST

## Status: scheduled for launch in March 2006

## Mission Summary



The Gamma-ray Large Area Space Telescope (GLAST) is an international and multi-agency space mission that will study the cosmos in the energy range 10 keV - 300 GeV. Several successful exploratory missions in gamma-ray astronomy led to the Energetic Gamma Ray Experiment Telescope (EGRET) instrument on the Compton Gamma Ray Observatory (CGRO). Launched in 1991, EGRET made the first complete survey of the sky in the 30 MeV - 10 GeV range. EGRET showed the high-energy gamma-ray sky to be surprisingly dynamic and diverse, with sources ranging from the sun and moon to massive black holes at large redshifts. Most of the gamma-ray sources detected by EGRET remain unidentified. In light of the discoveries with EGRET, the great potential of the next generation gamma-ray telescope can be appreciated.

For this unique endeavor -- one that brings together the astrophysics and particle physics communities -- NASA is teaming up with the U.S. Department of Energy and institutions in France, Germany, Japan, Italy and Sweden. Spectrum Astro has been chosen to build the spacecraft.

*GLAST is part of the Structure and Evolution of the Universe theme, one of four major science themes within the NASA Office of Space Science. Through the SEU program, scientists seek to explore the limits of gravity and energy in the Universe, explain the structure of the Universe, and forecast our cosmic destiny.*

## Scientific Goals

The GLAST science team strongly supports Multiwavelength Observations as a way to obtain the best science with the mission.

GLAST will have an imaging gamma-ray telescope vastly more capable than instruments flown previously, as well as a secondary instrument to augment the study of gamma-ray bursts. The main instrument, the **Large Area Telescope (LAT)**, will have superior area, angular resolution, field of view, and deadtime that together will provide a factor of 30 or more advance in sensitivity, as well as provide capability for study of transient phenomena (Table 1-1). The **GLAST Burst Monitor (GBM)** will have a field of view several times larger than the LAT and will provide spectral coverage of gamma-ray bursts that extends from the lower limit of the LAT down to 10 keV. With the LAT and GBM, GLAST will be a flexible observatory for investigating the great range of astrophysical phenomena best studied in high-energy gamma rays.

The anticipated advances in astronomy and high-energy physics with GLAST are among the central subjects of NASA's Structure and Evolution of the Universe (SEU) research theme and the Department of Energy's non-accelerator research program. The GLAST mission is also supported by the physics and astrophysics programs in the partner countries of France, Germany, Italy, Japan, and Sweden. NASA recognizes the scientific goals of the GLAST mission as part of the SEU Cosmic Journeys planned for study of black holes and dark matter. Of course, with its capabilities, GLAST certainly may yield important unanticipated findings. The mission will be supported by a vigorous, multidisciplinary guest investigator program to maximize the discovery potential.

The LAT (principal investigator Peter Michelson, Stanford University) will have three subsystems: a solid state detector (silicon strip) pair conversion tracker for gamma-ray detection and direction measurement, a CsI calorimeter for measurement of the energies, and a plastic scintillator anticoincidence system to provide rejection of signals from the intense background of charged particles. The LAT will be modular, consisting of a 4 × 4 array of identical towers, and will have more than one million silicon-strip detector channels. The GBM (principal investigator Charles Meegan, MSFC, co-PI Giselher Lichti, Max-Planck-Institut für extraterrestrische Physik, Germany) will have 12 NaI scintillators and two BGO scintillators mounted on the sides of the spacecraft. The combined detectors will view the entire sky not occulted by Earth, with energy coverage from a few keV to 30 MeV, overlapping with the lower energy limit of the LAT and with the range of GRB detectors on previous missions.

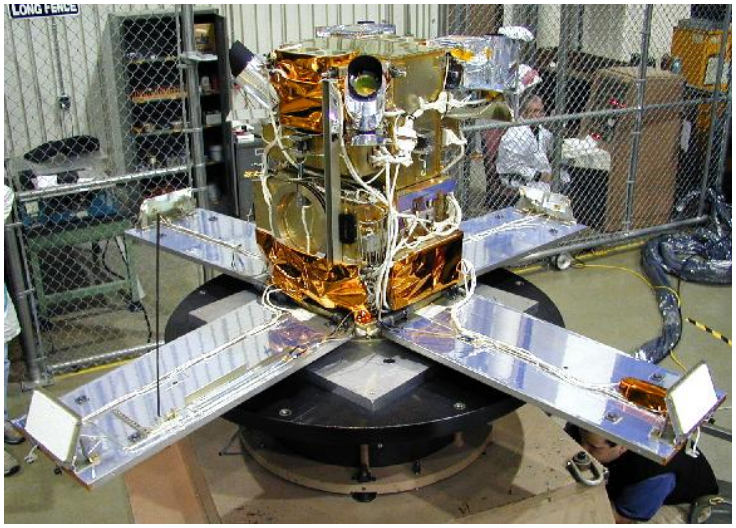
Credit: Hytec

# HETE II

## Status: in orbit since October 2000

## Mission Summary

**The High Energy Transient Explorer is a small scientific satellite designed to detect and localize gamma-ray bursts (GRBs). The coordinates of GRBs detected by HETE are distributed to interested ground-based observers within seconds of burst detection, thereby allowing detailed observations of the initial phases of GRBs.**



The HETE program is an international collaboration led by the Center for Space Research at the Massachussetts Institute of Technology. The collaborating institutions include the Institute for Chemistry and Physics (RIKEN), the Los Alamos National Laboratory (LANL), the Centre d'Etude Spatiale des Rayonnements (CESR), the University of Chicago, the University of California, Berkeley, the University of California, Santa Cruz, the Centre Nationale d'Etudes Spatiales (CNES), the Ecole Nationale Superieure de l'Aeronautique et de l'Espace (Sup'Aero), the Consiglio Nazionale delle Ricerche (CNR), the Instituto Nacional de Pesquisas Espaciais (INPE), and the Tata Institute of Fundamental Research (TIFR).

The primary goal of HETE-2 is to determine the origin and nature of cosmic gamma-ray bursts. This is accomplished through the simultaneous, broad-band observation in the soft X-ray, medium X-ray, and gamma-ray energy ranges, and the precise localization and identification of cosmic gamma-ray burst sources (GRBs). HETE-2 carries three science instruments:

(1) a set of wide-field gamma-ray spectrometers (FREGATE)
(2) a wide-field X-ray monitor (WXM)
(3) a set of soft X-ray cameras (SXC)

These instruments operate synergistically in order to:

- Identify the occurrence of a GRB.
- Establish precise localizations of gamma-ray bursts. These localizations shall be calculated on board the spacecraft within 10-100 seconds of burst onset, depending on burst duration and temporal structure (GRBs have durations ranging from 10 ms to 1000 seconds).
- Transmit coordinates of GRBs in near real time (< 10 seconds) through a network of primary and burst alert stations to the MIT Control Center. This information is immediately passed to the GCN and from there to the community of ground-based optical, IR, and radio observers in searches for GRB counterparts and their after glows.
- Establish relative GRB rates and intensities in the soft X-ray, mid X-ray, and gamma-ray bands.
- Perform spectroscopy of gamma-ray bursts in the energy range 1 - 400 keV, allowing searches for and studies of X-ray precursors, X-ray afterglows, and narrow spectral/ cyclotron lines.
- Measure the intensities, time histories, and spectra of soft gamma-ray repeater bursts, which may occur episodically during the HETE-2 mission.
- Measure the intensities, time histories, and spectra of X-ray bursts, including any accompanying bursts in the soft X-ray band due to reprocessing of X-rays by the accretion disk or companion star in these systems.
- Measure the intensities, time histories, and spectra of black hole X-ray transients.

# The fate of HETE I…

The original HETE I spacecraft program began in 1992. The instrument complement for HETE-1 consisted of

- Four wide-field gamma-ray detectors, supplied by the CESR of Toulouse, France
- A wide-field coded-aperture X-ray imager, supplied by a collaboration of Los Alamos National Laboratory and the Institute of Chemistry and Physics (RIKEN) of Tokyo, Japan.
- Four wide-field near-UV CCD cameras, supplied by the Center for Space Research at the Massachusetts Institute of Technology.

The HETE-1 satellite was launched on November 4, 1996, along with the Argentine satellite SAC-B, on a Pegasus rocket from Wallops Island, VA. **The Pegasus rocket achieved a good orbit, but the third stage failed to release the two satellites.** As a result, SAC-B and HETE-1 were unable to function as designed and both died due to lack of solar power within a day of launch.

Due to the tragic fate of HETE-1 and the continuing timeliness of GRB science (see below), NASA agreed to a re-flight of the HETE-1 satellite, using flight spare hardware from the first satellite. In July, 1997, funding for a second HETE satellite was granted, with a target launch date of late 1999 or early 2000.

# Hubble Space Telescope (HST)

## Status: in orbit since 1990

## Mission Summary

Not since Galileo turned his telescope towards the heavens in 1610 has any event so changed our understanding of the universe as the deployment of the Hubble Space Telescope.

Hubble orbits 600 kilometers (375 miles) above Earth, working around the clock to unlock the secrets of the Universe. It uses excellent pointing precision, powerful optics, and state-of-the-art instruments to provide stunning views of the Universe that cannot be made using ground-based telescopes or other satellites.

Hubble was originally designed in the 1970s and launched in 1990. Thanks to on-orbit service calls by the Space Shuttle astronauts, Hubble continues to be a state-of-the-art, model year 2001 space telescope.

Hubble is the first scientific mission of any kind that is specifically designed for routine servicing by spacewalking astronauts. It has a visionary, modular design which allows the astronauts to take it apart, replace worn out equipment and upgrade instruments. These periodic service calls make sure that Hubble produces first-class science using cutting-edge technology. Each time a science instrument in Hubble is replaced, it increases Hubble scientific power by a factor of 10 or greater!

## Instruments and Technical Data

To track the change of instruments onboard HST is not an easy task… With every servicing mission, some instruments were replaced or enhanced:

**1990 Initial complement at deployment:**

- WFPC (1) - Wide Field/Planetary Camera - First-generation imaging camera. WFPC (1) operated in either Wide Field mode, capturing the largest images, or Planetary mode with higher resolution.
- GHRS - Goddard High Resolution Spectrograph - First-generation spectrograph. GHRS was used to obtain high resolution spectra of bright targets.
- FOS - Faint Object Spectrometer - First-generation spectrometer. FOS was used to obtain

spectra of very faint or faraway sources. FOS also had a polarimeter for the study of the polarized light from these sources.

- FOC - Faint Object Camera - First-generation imaging camera. FOC is used to image very small field of view, very faint targets. This is the final, first-generation instrument still on Hubble.
- HSP - High Speed Photometer - First-generation photometer. This instrument was used to measure very fast brightness changes in diverse objects, such as pulsars.
- FGS - Fine Guidance Sensors - Science/guidance instruments. The FGS's are used in a "dual-purpose" mode serving to lock on to "guide stars" which help the telescope obtain the exceedingly accurate pointing necessary for observation of astronomical targets. They can also be used to obtain highly accurate measurements of stellar positions.

**1993 Servicing Mission 1:**

- WFPC2 - Wide Field Planetary Camera 2 - Second-generation imaging camera. WFPC2 is an upgraded version of WF/PC (1) which includes corrective optics and improved detectors.
- COSTAR - Corrective Optics Space Telescope Axial Replacement - Second-generation corrective optics. COSTAR is not an actual instrument. It consists of mirrors which refocus the abbreviated light from Hubble's optical system for first-generation instruments. Only FOC utilizes its services today.

**1997 Servicing Mission 2:**

- STIS - Space Telescope Imaging Spectrograph - Second-generation imager/spectrograph. STIS is used to obtain high resolution spectra of resolved objects. STIS has the special ability to simultaneously obtain spectra from many different points along a target.
- NICMOS - Near Infrared Camera/Multi-Object Spectrometer - Second-generation imager/spectrograph. NICMOS is Hubble's only near-infrared (NIR) instrument. NICMOS must operate at a very low temperature, requiring sophisticated coolers. *Problems with the solid nitrogen refrigerant have necessitated the installation of the NICMOS Cryocooler (NCC) on SM3B to continue its operation.*

**2002 Servicing Mission 3B:**

- NCS - NICMOS Cooling System - Like COSTAR, NCS is not a separate instrument but rather a device which will allow NICMOS to continue operations by providing mechanical cooling for the NICMOS detectors. Results from the HOST mission indicate that the NCS will allow NICMOS to operate for up to 5 years beyond SM3B.
- ACS - Advanced Camera for Surveys - The Advanced Camera for Surveys (ACS) is a third-generation imaging camera. This camera is optimized to perform surveys or broad imaging campaigns.

**2003 Servicing Mission 4:**

- WFC3 - Wide Field Camera 3 - Fourth-generation imaging camera. This camera will supplement ACS and guarantee imaging capability for Hubble after the Fourth Servicing Mission.
- COS - Cosmic Origins Spectrograph - Fourth-generation spectrometer. COS is an ultraviolet spectrograph optimized for observing faint point sources with moderate spectral resolution.

# HST Operations

The Hubble Space Telescope orbits far above the distorting effects of the atmosphere, about 600 kilometers above the Earth. This perch gives astronomers with their clearest view ever, but it also prevents them from looking directly through the telescope. Instead, astronomers use Hubble's scientific instruments as their electronic eyes.

Hubble uses mirrors to focus and magnify light. Its 8-foot-diameter main mirror is tucked inside a long, hollow tube that blocks the glare from the Sun, Earth, and Moon. Wing-like solar panels collect sunlight and convert it into electricity.

Radio antennas allow Hubble to communicate with its flight controllers at the Goddard Space Flight Center. Controllers send detailed instructions several times a day. This information is converted into a code that the spacecraft's main computer can understand. Imagine pointing a laser on a dime 200 miles away, and holding it steady for hours or days. This is the precision of Hubble's sophisticated pointing control system. Once Hubble locks onto an object, its sensors check for movement 40 times a second. If movement occurs, constantly spinning wheels change speeds to smoothly bring the telescope back into position.

As Hubble observes celestial targets, its computers turn the information into long strings of numbers. This digital data travels as radio signals to a communications satellite, which beams the information to Goddard. From there, it travels by landline to the Space Telescope Science Institute in Baltimore, Md., where is turned back into pictures and astronomical data.

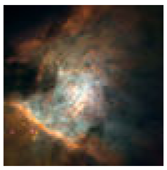
Hubble's daily downloads are stored on optical computer disks. The observations from a single day would fill an encyclopedia.

## *D I S C O V E R I E S*

INVASION OF JUPITER

In the solar system, the observatory witnessed an invasion of Jupiter in 1994 as pieces of Comet Shoemaker-Levy 9 plunged into the planet's atmosphere and exploded. The telescope's sharp "eyes" provided exquisite details on the plumes of debris kicked up by the explosions and for several days followed the expansion of the impact sites. This collision is a once-in-a-millenium occurrence.

LIFE CYCLE OF STARS

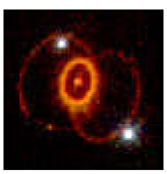


Moving from planets to stars, the telescope documented in colorful detail the births and deaths of these bright celestial objects. It provided visual proof that pancake-shaped dust disks around young stars are common, suggesting that the raw materials for planet formation are in place. The orbiting telescope showed for the first time that jets of material rising from embryonic stars emanate from the centers of disks of dust and gas, thus turning what was previously merely theory into an observed reality.

DYING IN STYLE

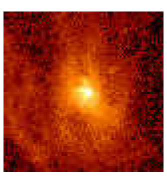
Hubble delivered many stunning pictures of stellar deaths, such as the glowing shrouds surrounding Sun-like stars (called planetary nebulae), the mysterious rings of material around the exploding, massive star called Supernova 1987A, and the twin lobes of matter billowing from Eta Carinae. Ground-based images suggested that many of these objects had simple shapes, but Hubble revealed that their shapes are more complex.

A COSMIC COLLISION



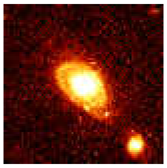
The telescope monitored Supernova 1987A, the closest exploding star in four centuries, providing (for the first time) pictures of a collision between a wave of material ejected from the doomed star and a ring of matter surrounding it. The collision has already begun to illuminate the central ring. In the next decade astronomers expect even more material to hit the ring, illuminating the surrounding material, and thereby literally throwing light on the exploding star's history.

A FEEDING FRENZY



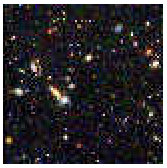
Hubble also is yielding clues to what is causing the flurry of activity in the hearts of many galaxies. These central regions are very crowded, with stars, dust, and gas competing for space. But Hubble managed to probe these dense regions, providing decisive evidence that supermassive black holes — compact "monsters" that gobble up any material that ventures near them — reside in the centers of many galaxies. These elusive "eating machines" cannot be observed directly, because nothing, even light, escapes their stranglehold. But the telescope provided indirect, yet compelling, evidence of their existence. Hubble's crisp images revealed a doughnut-shaped structure composed of dust and gas around a central object, presumably a black hole. The telescope also helped astronomers determine the masses of several black holes by measuring the velocities of material whirling around them.

NATURE'S "LIGHTBULBS"



Most scientists believe that black holes are the "engines" that power quasars, powerful light beacons located more than halfway across the universe. Hubble has surveyed quasars, confirming that nature's brightest "lightbulbs" reside in galaxies. The observations also revealed that many of these galaxies are merging with other galaxies. The mergers kick up lots of dust and gas, providing an important clue for how black holes feed and power quasars.

GALAXY BUILDING BLOCKS

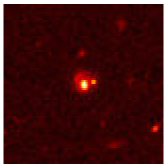


Hubble also peered across space to study galaxies in an infant universe. (Probing the distant cosmos means looking back in time.) Hubble's observations indicate that the young cosmos was filled with much smaller and more irregularly shaped galaxies than those astronomers see in our nearby universe. These smaller structures, composed of gas and young stars, may be the building blocks from which the more familiar spiral and elliptical galaxies formed, possibly through processes such as multiple galaxy collisions. The Hubble observations also show that the early universe more vigorously manufactured stars than it does today.

AN EXPANDING UNIVERSE

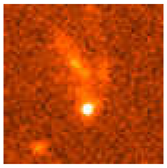
The universe doesn't remain still: it's expanding. Astronomer Edwin Hubble made that observation in the 1920s. Since then, astronomers have debated how fast it is expanding, a value called the Hubble constant. In May 1999 a team of astronomers announced they had obtained a value for the Hubble constant, an essential ingredient needed to determine the age, size, and fate of the universe. They did it by measuring the distances to 18 galaxies, some as far as 65 million light-years from Earth. By obtaining a value for the Hubble constant, the team then determined that the universe is 12 to 14 billion years old.

A SPEEDY UNIVERSE



One of the most dramatic astronomical discoveries of this century came in 1998, when two independent teams, using Hubble and other telescopes, found strong evidence that the cosmic expansion is accelerating. The orbiting observatory's major contribution was the accurate measurement of the luminosities of some of the most distant exploding stars, called supernovae.

COSMIC EXPLOSIONS



Hubble teamed up with a fleet of X-ray, gamma-ray, and visible-light observatories in a quest to analyze the sources of gamma-ray bursts. Gamma-ray bursts may represent the most powerful explosions in the universe since the Big Bang. Before 1997 astronomers were stumped: although they had observed more than 2,000 "bursts," they couldn't determine whether these fireballs occurred in our galaxy or at remote distances. Hubble images showed unambiguously that the bursts actually reside in far-flung galaxies rife with star formation.

# James Webb Space Telescope (JWST)

## Status: scheduled for launch in 2010

## Mission Summary

The James Webb Space Telescope (JWST) is an orbiting infrared observatory that will take the place of the Hubble Space Telescope at the end of this decade. It will study the Universe at the important but previously unobserved epoch of galaxy formation. It will peer through dust to witness the birth of stars and planetary systems similar to our own. And using JWST, scientists hope to get a better understanding of the intriguing dark matter problem. The JWST is also a key element in NASA's Origins Program.

## Facts at a glance

| | |
|---|---|
| **Scheduled Launch:** | 2010 |
| **Launch Vehicle:** | an expendable launch vehicle |
| **Mission Duration:** | 5 - 10 years |
| **Mass:** | 5400 kg (12,000 lbs) |
| **Diameter of primary Mirror:** | ~6.5 m (21.3 ft) |
| **Mass of primary mirror:** | TBD |
| **Focal length:** | TBD |
| **Number of primary mirror segments:** | 36 |
| **Optical resolution:** | ~0.1 arc-seconds |
| **Wavelength coverage:** | 0.6 - 28 microns |
| **Size of sun shield:** | ~22 m x 10 m (72 ft x 33 ft) |
| **Orbit:** | 1.5 million km from Earth at L2 Point |
| **Operating Temperature:** | <50 K (-370 °F) |
| **Cost:** | $824.8 million |

## Mission Goals and Major Innovations

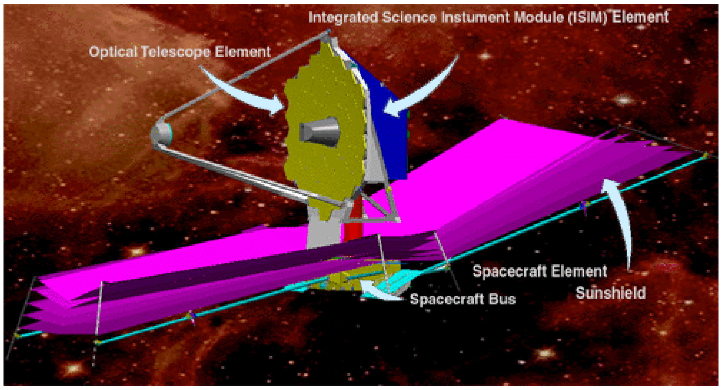
JWST will have a large number of scientific goals, such as:

- Determine the shape of the Universe.
- Explain galaxy evolution

- Understand the birth and formation of stars
- Determine how planetary systems form and interact.
- Determine how the Universe built up its present chemical/elemental composition.
- Probe the nature and abundance of Dark Matter.

The innovations of JWST include lightweight optics, a deployable sunshield, a folding segmented mirror, improved detectors, cryogenic actuators and mirror control as well as micro-shutters. Overall, the system is made up of three segments: the **Observatory** (Flight Segment), the **Ground Segment**, and the **Launch Segment**. The Observatory is the space-based portion of the JWST system, and is comprised of three elements: the Optical Telescope Element (OTE), the Spacecraft, and the Integrated Science Instrument Module (ISIM).

The JWST Observatory includes a large segmented primary mirror that will unfold, or deploy, to approximately 6 meters (20 ft) in diameter and a sunshield that will also deploy to about the size of a tennis court. Visually, the observatory is dominated by the sunshield subsystem, which separates the observatory into a sun-facing side with a temperature around 300 K (80°F) and a cold anti-sun side. The observatory will be pointed so that the Sun, Earth and Moon are always on one side, and will act like a parasol, keeping the mirrors and the science instruments cool by keeping them in the shade and protecting them from the heat of the sun and warm spacecraft electronics. The sunshield greatly attenuates the incident solar energy allowing the Optical Telescope Element and Integrated Science Instrument Module to passively cool to their cryogenic operating temperatures of around 35 Kelvin (about 400 degrees below zero on the Fahrenheit scale). In addition to providing a cold environment, the sunshield provides a thermally stable environment. This is one essential element to maintaining proper alignment of the primary mirror segments as the telescope changes its orientation to the Sun.




Segmentation of the primary mirror is required to allow the mirror to fold for accommodation in the launch vehicle. Segmentation also accommodates more mirror technologies for a cost-effective architecture. On the down side, the segments must be aligned relative to each other to an accuracy of a few tens of nanometers in order to achieve the full performance of the large 6-m primary mirror. This requires minimizing thermal expansion effects through a combination of good thermal isolation, ultra-low expansion composite structural materials and micro-dynamically stable mechanisms. The other principal disturbing effect is vibration from spacecraft mechanisms, particularly reaction wheels used to point the Observatory. Vibration effects are controlled through the use of vibration isolation and dampening devices.

# ICE

## Status: main mission completed (1978 – 1986)

## Mission Summary

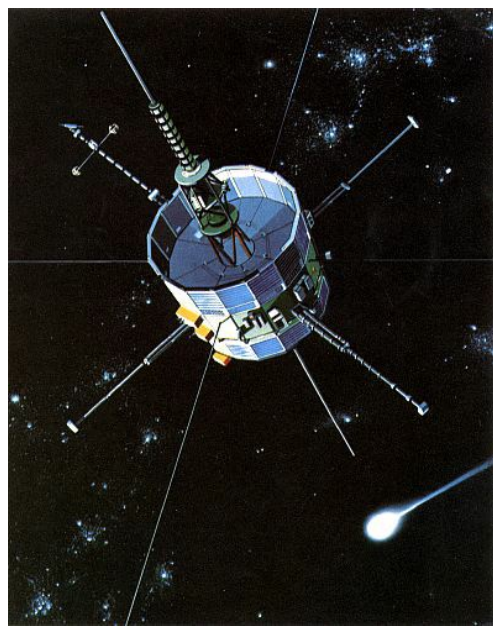
The **International Sun-Earth Explorer 3 (ISEE-3)** spacecraft was part of a three spacecraft mission (ISEE 1, 2 & 3) whose purpose was to study the solar wind and the solar-terrestrial relationship at the boundaries of the Earth's magnetosphere. After a series maneuvers and lunar flybys, ISEE-3 (renamed to ICE) would encounter Comet Giacobini-Zinner in 1985 and provide distance observations of Comet Halley in 1986.

Launched on August 12, 1978, ISEE-3 was placed into a halo orbit around the Sun-Earth L1 libration point, 235 Earth radii from the Earth. The three ISEE spacecraft were equipped with complementary instruments for making measurements of plasmas, energetic particles, waves, and fields (there was no camera). In 1981, it was proposed that ISEE-3 be maneuvered into Earth's magnetotail, and then later towards a comet. On June 10, 1982 the first of these maneuvers was started which moved the spacecraft out of its halo orbit around the L1 point where it has orbited for nearly 4 years. Fifteen manuevers were required through the magnetotail, along with the five lunar flybys to get the spacecraft out of the Earth-Moon system and on it way towards Comet Giacobini-Zinner. The fifth and final lunar flyby on December 22, 1983, passed only 119.4 km above the Moon's surface near the Apollo 11 landing site. At this point, the spacecraft was renamed **International Cometary Explorer (ICE).**

On June 5, 1985, the spacecraft was maneuvered 26,550 km behind Comet Giacobini-Zinner so that its fields and particles instruments could sample the comet's tail. On September 11, the first ever in situ cometary measurements were made as the first first ions were detected as ICE crossed a bow shock. The spaceraft found a region of interacting cometary and solar wind ions, and encountered a comet plasma tail about 25,000 km wide. Water and carbon monoxide ions were also identified, which confirmed the "dirty snowball" theory. The plasma density increased 100 times over the solar wind ambient, and the solar magnetic field was found to be wrapped around the comet nucleus. ICE approached the comet at a distance of 7,862 km at its closest approach on September 11, 1985, with a flyby velocity of 20.7 km/second. Because the spacecraft did not carry any dust protection equipment, it was expected to suffer some damage during the encounter. However, the spaceraft survived relatively unscathed, and analysis of the plasma wave data indicated an dust impact rate of about one per second, which was lower than expected.

In 1986, ICE made distant observations of Comet Halley on the sunward side of the comet. It flew by at a distance of 31 million km from the comet on March 28, 1986, and provided upstream solar wind data.

In 2014, ICE will return to the vicinity of Earth where it could possibly be captured for analysis of its exterior for dust impacts. NASA has already donated the spacecraft to the Smithsonian Institute for display if it is recovered.

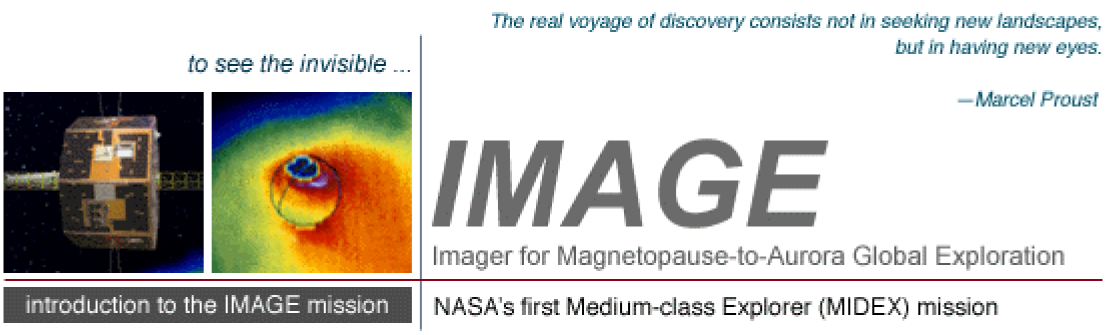


# IMAGE

## Status: in orbit since March 2000

## Mission Summary

On March 25th, 2000, after having been launched onboard a Delta II rocket, IMAGE was inserted into an elliptical orbit about the Earth's poles and began its two-year mission. The mission objective: **to obtain the first global images of the major plasma regions and boundaries in the Earth's inner magnetosphere and to study the dynamic response of these plasma populations to variations in the flow of charged particles from the Sun.**




## Imaging Techniques

To achieve its mission objective, IMAGE employs a variety of imaging techniques: the detection of energetic neutral atom (ENA) emissions from the ring current, inner plasma sheet, and polar ionospheric outflows; plasmaspheric imaging at extreme ultraviolet (EUV) wavelengths; radio sounding of the magnetopause and other boundary layers; and imaging of far-ultraviolet (FUV) auroral emissions. These are the "new eyes" with which IMAGE views the inner magnetosphere, rendering its invisible plasmas visible and discovering new aspects of our geospace "landscape." Using these various techniques, IMAGE is obtaining global images of different regions simultaneously, making it possible to relate processes occurring in one region to events observed in another, different region.

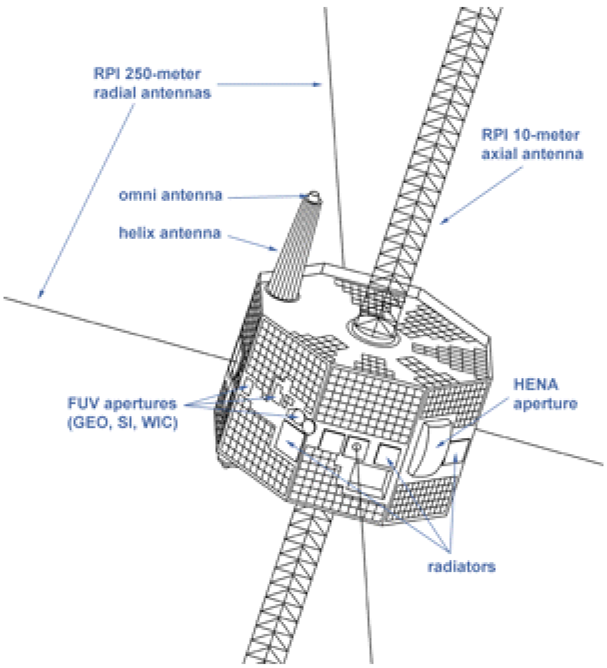
## Science Questions and Mission Phases

The IMAGE mission addresses three broad science questions that lie at the heart of our efforts to understand the geospace environment and its response to the solar wind:

**What are the dominant mechanisms for injecting plasma into the magnetosphere on the time scales of substorms and geomagnetic storms?**

**What is the directly driven response of the magnetosphere to changes in the solar wind?**

**How and where are magnetospheric plasmas energized, transported, and lost during geomagnetic storms and magnetospheric substorms?**




To address these questions, IMAGE employs energetic neutral atom (ENA) imaging, conventional photon imaging at ultraviolet wavelengths, and radio sounding to obtain global images of the principal plasma regions and boundaries of Earth's inner magnetosphere. Changes in the latitude and local time of orbit apogee allow the spacecraft to view the inner magnetosphere from a variety of perspectives and to focus on particular regions, processes, and phenomena. Science operations are thus conducted in different phases, corresponding to IMAGE's different orbital phases. The five main mission phases are:

- duskside phase (low latitudes) - science focus: dusk magnetopause and plasmapause structure
- dayside phase (low to middle latitudes) - science focus: plasma entry into the magnetosphere
- dawnside phase (middle to high latitudes) - science focus: dawn-dusk comparison
- polar high-latitude phase - science focus: substorms and geomagnetic storms
- end of mission phase - return to low-latitude dusk side/afternoon sector

# IMP-8

## Status: in orbit since March 2000

## Mission Summary

IMP-8 (IMP-J) was launched by NASA on October 26, 1973 to measure the magnetic fields, plasmas, and energetic charged particles (e.g., cosmic rays) of the Earth's magnetotail and magnetosheath and of the near-Earth solar wind. IMP-8, the last of ten IMP (Interplanetary Monitoring Platform) or AIMP (Anchored-IMP) spacecraft launched in 10 years, continues to operate to this day in its near-circular, 35 Earth Radii, 12-day orbit. It is an important adjunct to the International Solar Terrestrial Physics program, provides in-ecliptic, one Astronomical Unit baseline data for the deep space Voyager and Ulysses missions, and continues to accumulate a long-time series database useful in understanding long-term solar processes

IMP 8 (Explorer 50), the last satellite of the IMP series, was a drum-shaped spacecraft, 135.6 cm across and 157.4 cm high, instrumented for interplanetary and magnetotail studies of cosmic rays, energetic solar particles, plasma, and electric and magnetic fields. Its initial orbit was more elliptical than intended, with apogee and perigee distances of about 45 and 25 earth radii. Its eccentricity decreased after launch. Its orbital inclination varied between 0 deg and about 55 deg with a periodicity of several years. The spacecraft spin axis was normal to the ecliptic plane, and the spin rate was 23 rpm. The data telemetry rate was 1600 bps. The spacecraft was in the solar wind for 7 to 8 days of every 12.5 day orbit. Telemetry coverage was 90% in the early years, but only 60-70% through most of the 1980's and early 1990's. Coverage returned to the 90% range in the mid to late 1990's. The objectives of the extended IMP-8 operations were to provide solar wind parameters as input for magnetospheric studies and as a 1-AU baseline for deep space studies, and to continue solar cycle variation studies with a single set of well-calibrated and understood instruments.