National Aeronautics and
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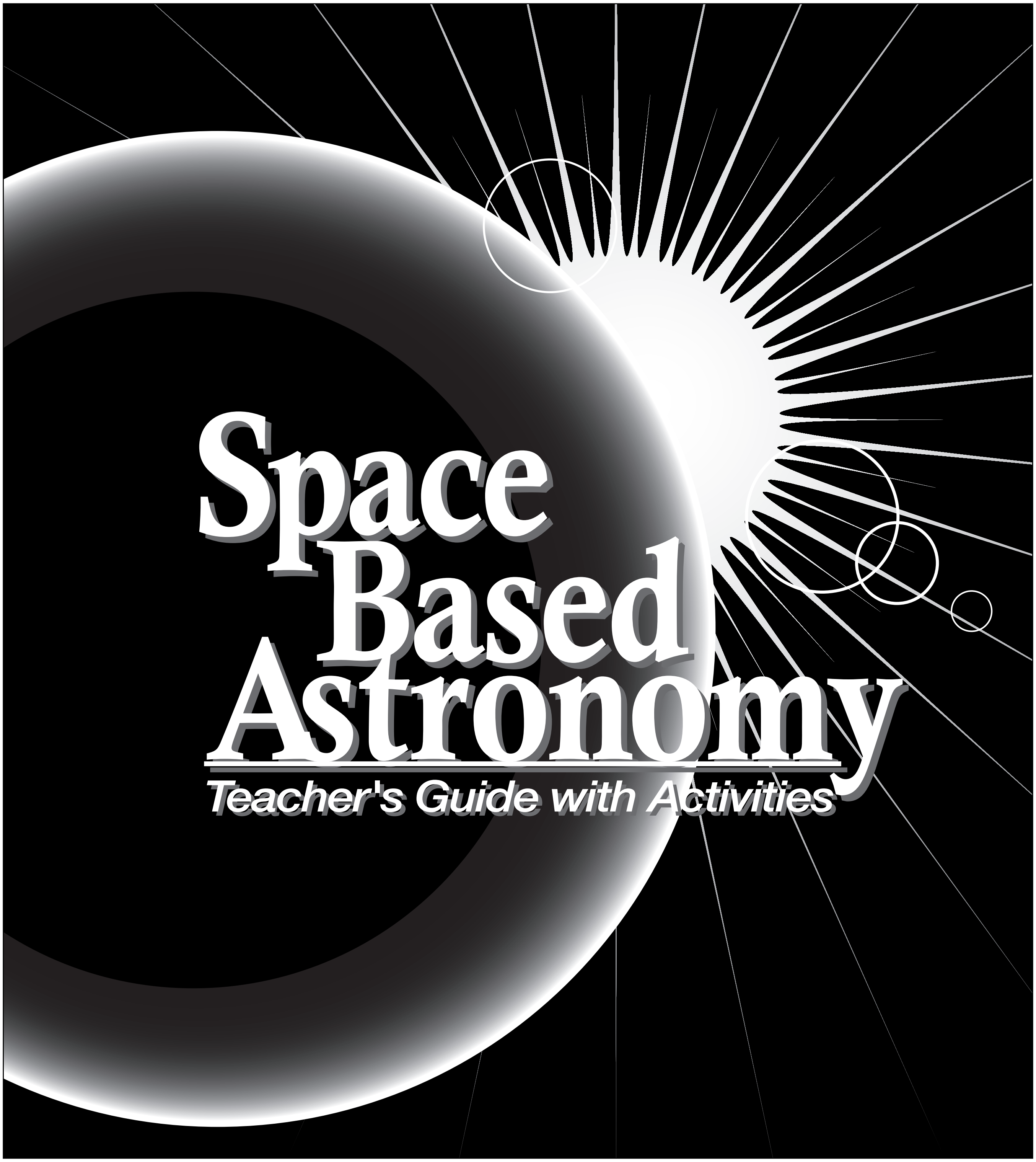

# Space-Based Astronomy

## A Teacher's Guide With Activities

National Aeronautics and Space Administration

Office of Human Resources and Education
Education Division

Office of Space Science
Astrophysics Division

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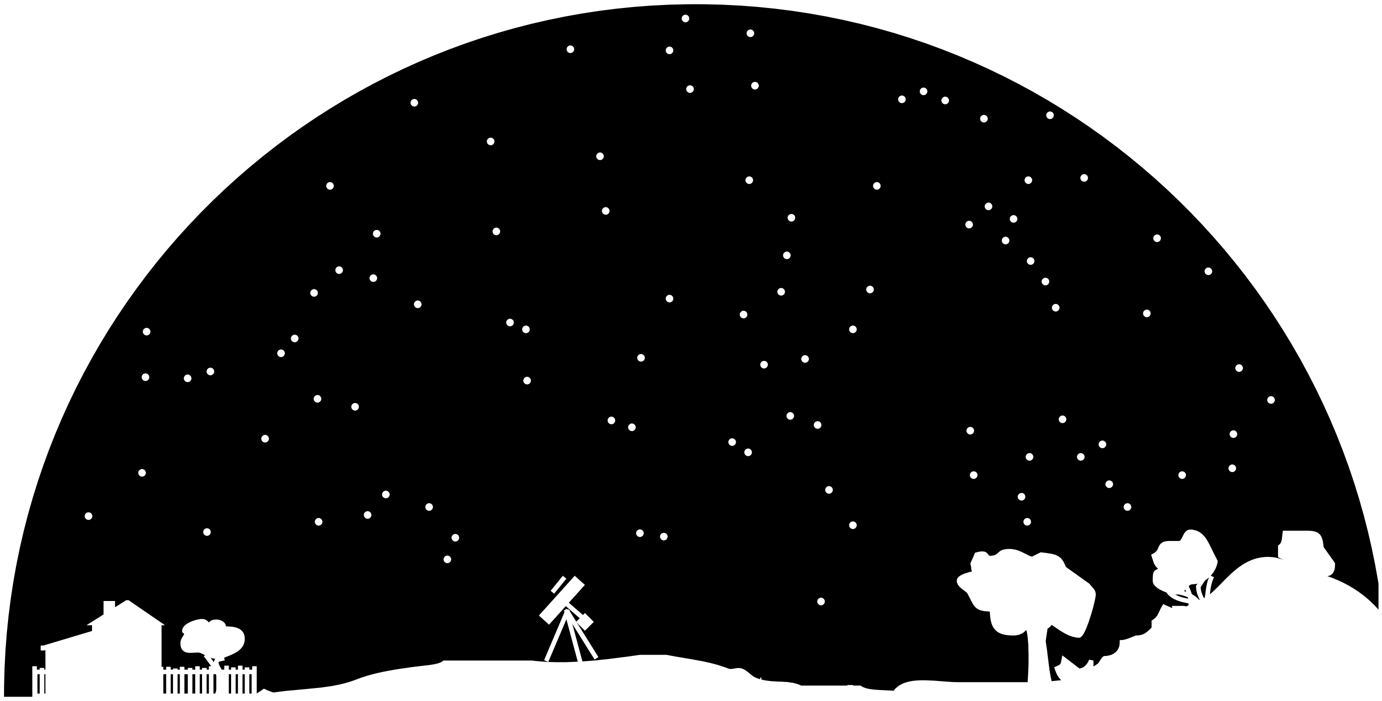


## Introduction

If you go to the country, far from city lights, you can see about 3,000 stars on a clear night. If your eyes were bigger, you could see many more stars. With a pair of binoculars, an optical device that effectively enlarges the pupil of your eye by about 30 times, the number of stars you can see increases to the tens of thousands. With a medium-sized telescope with a light collecting mirror 30 centimeters in diameter, you can see hundreds of thousands of stars. With a large observatory telescope, millions of stars become visible.

It would seem that when it comes to observing the universe, the larger the instrument, the better. This is true up to a point, but there are limits—limits not imposed by technology but by nature itself.

Surrounding Earth is a life-sustaining atmosphere that stands between our eyes and the radiations that fall upon Earth from outer space. This radiation comprises a very broad spectrum of energies and wavelengths. Collectively, they are referred to as the electromagnetic spectrum. They range from radio and microwave radiation on the low energy (long wavelength) end through infrared, visible, ultraviolet, and x-rays to gamma rays on the high energy (short wavelength) end. Gases and other components of our atmosphere distort, filter, and block most of these radiations, permitting only a partial picture, primarily visible radiation and some radio waves, to reach Earth's surface. Although many things can be learned about our universe by studying it from the surface of Earth, the story is incomplete. To view celestial objects over the whole range of the electromagnetic spectrum it is essential to climb above the atmosphere into outer space.

From its earliest days, the National Aeronautics and Space Administration (NASA), has used the emerging technology of rockets to explore the universe. By lofting telescopes and other scientific instruments above the veil of Earth's atmosphere, NASA has delivered a treasure house of information to astronomers, leading them to rethink their most fundamental ideas about what the universe is, how it came to be, how it functions, and what it is likely to become.

## How To Use This Guide

This curriculum guide uses hands-on activities to help students and teachers understand the significance of space-based astronomy—astronomical observations made from outer space. It is not intended to serve as a curriculum. Instead, teachers should select activities from this guide that support and extend existing study. The guide contains few of the traditional activities found in many astronomy guides such as constellation studies, lunar phases, and planetary orbits. It tells, rather, the story of why it is important to observe celestial objects from outer space and how to study the entire electromagnetic spectrum. Teachers are encouraged to adapt these activities for the particular needs of their students. When selected activities from this guide are used in conjunction with traditional astronomy curricula, students benefit from a more complete experience.

The guide begins with a survey of astronomy-related spacecraft NASA has sent into outer space. This is followed by a collection of activities organized into four units: The Atmospheric Filter, The Electromagnetic Spectrum, Collecting Electromagnetic Radiation, and Down to Earth. A curriculum matrix identifies the curriculum areas each activity addresses. Following the activities is information for obtaining a 35 mm slide set with descriptions showing current results from NASA spacecraft such as the *Hubble Space Telescope (HST), Compton Gamma Ray Observatory (CGRO), and the Cosmic Background Explorer (COBE)*. The guide concludes with a glossary, reference list, a NASA Resources list, and an evaluation card. Feedback from users of this guide is essential for the development of future editions and other classroom supplementary materials.

## The Space Age Begins

Within months of each other the United States and the Soviet Union launched their first artificial satellites into orbit around Earth. Both satellites were small and simple. *Sputnik 1*, a Soviet spacecraft, was the first to reach orbit. It was a 58-centimeter-diameter aluminum sphere that carried two radio transmitters, powered by chemical batteries. The satellite reached orbit on October 4, 1957. Although an extremely primitive satellite by today's standards, *Sputnik 1* nevertheless enabled scientists to learn about Earth's geomagnetic field, temperatures in space, and the limits of Earth's atmosphere.

A much larger *Sputnik 2* followed *Sputnik 1*, carrying a small dog as a passenger. Although primarily investigating the response of living things to prolonged periods of microgravity, *Sputnik 2* did sense the presence of a belt of high-energy charged particles trapped by Earth's magnetic field. *Explorer 1*, the United States' first satellite, defined that field further.

The cylindrical, 13.6 kilogram *Explorer 1* rode to space on top of a Juno I rocket on January 31, 1958. It was launched by the United States Army in association with the National Academy of Sciences and the Jet Propulsion Laboratory of the California

Artist's concept of *Explorer 1* in space

Institute of Technology.  NASA was not formally authorized by an act of Congress until the following October.

*Explorer 1* carried scientific instruments designed by Dr. James Van Allen of the University of Iowa.  Circling Earth in an orbit ranging from 360 to 2,531 kilometers, the satellite radioed back radiation measurements, revealing a deep zone of radiation surrounding Earth.

Born of the technology of World War II and the tensions of the Cold War, the space age began in the peaceful pursuit of scientific discovery.  In the more than 35 years that have followed, thousands of spacecraft have been launched into Earth orbit, to the Moon, and to the planets.  For the majority of those spacecraft, the goal has been to learn about Earth, our solar system, and the universe.

## Astrophysics

Just a few decades ago, the word *astronomy* was a general term that described the science of the planets, moons, Sun and stars, and all other heavenly bodies.  In other words, astronomy meant the study of anything beyond Earth. Although still an applicable term, modern astronomy, like most other sciences, has been divided and subdivided into many specialities.   Disciplines that study the planets include *planetary geology* and *planetary atmospheres*.   The study of the particles and fields in space is divided into *magnetospheric physics*, *ionospheric physics*, and *cosmic* and *heliospheric physics*.  The Sun has its own *solar physics* discipline.   The origin and evolution of the universe is the subject of *cosmology*. Generally, objects beyond our solar system are handled in the field of *astrophysics*. These include: stars, the interstellar medium, other objects in our Milky Way Galaxy, and galaxies beyond our own.

NASA defines *astrophysics* as the investigation of astronomical bodies by remote sensing from Earth or its vicinity. Because the targets of the astrophysicist are generally beyond human reach even with our fastest rockets, astrophysicists concentrate solely on what the electromagnetic spectrum can tell them about the universe.   NASA's astrophysics program has three goals: to understand the origin and fate of the universe, to describe the fundamental laws of physics, and to discover the nature and evolution of galaxies, stars, and solar system.  The investigations of astrophysicists are carried out by instruments aboard free-flying satellites, sounding rockets that penetrate into space for brief periods, high-flying aircraft and high-altitude balloons, and Space Shuttle missions.

## A Brief History of the United States Astronomy Spacecraft and Crewed Space Flights

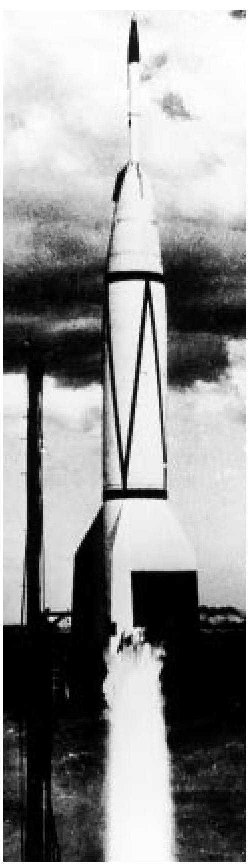
The early successes of *Sputnik* and the *Explorer* series spurred the United States to develop long-range programs for exploring space.  Once the United States was comfortable with the technical demands for spacecraft launches, NASA quickly began scientific studies in space using both crewed space flight and non-crewed satellite launches.

Teams of scientists began their studies in space close to home by exploring the Moon and the solar system.  Encouraged by those successes they have looked farther out to nearly the beginning of the universe.

Observing the heavens from a vantage point above Earth is not a new idea.  The idea of placing telescopes in orbit came quite early—at least by 1923 when Hermann Oberth described the idea. Even before his time there were a few attempts at space astronomy. In 1874 Jules Janseen launched a balloon from Paris with two aeronauts aboard to study the effects of the atmosphere on sunlight. Astronomers continue to use balloons from launch sites in the Antarctic; Palestine, Texas; and Alice Springs, Australia. After launch, scientists chase the balloon in a plane as the balloon follows the prevailing winds, traveling thousands of kilometers before sinking back to Earth. A typical balloon launch yields many hours of astronomical observations.

NASA's Kuiper Airborne Observatory

Rocket research in the second half of the 20th century developed the technology for launching satellites. Between 1946 and 1951 the U.S. launched 69 V2 rockets. The V2 rockets were captured from the Germans after World War II and used for high altitude research. Several of those flights studied ultraviolet and x-ray emissions from the Sun. Today, sounding rockets are used primarily by universities. They are inexpensive and quick, but provide only a few minutes of observations.


U.S. V2 rocket launch

NASA uses big rockets like the Atlas, Titan, and Space Shuttle as well as small rockets launched from a B52 aircraft to lift satellites into orbit. Except for the largest rockets, which are launched in Florida and California, rocket research and launches occur at many places around the United States. NASA also uses the Kuiper Airborne Observatory (KAO) that carries a 0.9 meter telescope inside a C-141 aircraft. It flies above the densest part of the atmosphere and observes in the far-infrared and submillimeter wavelengths. KAO flies approximately 80 times a year. KAO can reach an altitude of 13,700 meters with a normal flight time of 7.5 hours.

Over the years, NASA space probes have sent back detailed images of the planets Mercury, Venus, Mars, Jupiter, Saturn, Uranus, and Neptune. *Mariner 2* was the first spacecraft to explore another planet when it flew past Venus in 1962. The missions to the planets have redefined the picture of our solar system. Scientists have an incredible set of data from almost every planet in the solar system.


Black Brandt sounding rocket ready for launch to study Supernova 1987A

We learned that Venus is hotter than Mercury. Data from satellites in orbit around Venus have told us about the atmosphere and terrain of the planet. By monitoring Venus' atmosphere, scientists can study the effects of a runaway greenhouse effect. Several Russian spacecraft have explored the surface of Venus as well as the Moon and Mars.

Spacecraft have mapped the surface of Mars, but the Mars *Viking* mission gently deposited two landers on the surface that sent back data. They still sit on the surface there. The two

# Astronomy Space Missions
## (partial list)

| Year | Mission | Target | Highlights |
|---|---|---|---|
| 1957 | Stratoscope I | Sun | Balloon launch, sponsored by Princeton University |
| 1961 | Explorer 11 | gamma rays | 62 days, first look at gamma rays from space |
| 1962 | Arobee | x-ray sources | First x-ray source outside solar system: Sco- X-1 |
| 1962 | Mariner 2 | Venus | Flew past Venus |
| 1963 | Mars 1 | Mars | Russian probe - reached Mars and sent back pictures |
| 1965 | - | - | A series of NASA airborne astronomy missions aboard a Convair 990 jet observed the ultraviolet sky |
| 1965 | Mariner 4 | Mars | Flew by Mars and sent back pictures |
| 1967 | OSO-3 | gamma rays | Detected gamma rays from Milky Way |
| 1968 | RAE-1 | cosmic radio noise | Looked at cosmic radio noise |
| 1968 | OAO-2 | ultraviolet light | Studied ultraviolet radiation from the Sun |
| 1969 | Vela 5A | gamma rays | Detected gamma rays from space |
| 1969 | Apollo 11 | Moon | Successfully landed astronauts on the Moon - July 16, 1969 |
| 1970 | SAS-1 | x-ray sky | Renamed Uhuru (Explorer 42) - studied the x-ray sky |
| 1971 | Explorer 43 | solar wind/cosmic radio noise | Monitored solar wind and cosmic radio noise |
| 1971 | Mariner 9 | Mars | Orbited Mars |
| 1972 | Pioneer 10 | deep space | Launched |
| 1972 | Copernicus | ultraviolet | Operated for nine years - last OAO |
| 1973 | Pioneer 11 | deep space | Launched |
| 1973 | Skylab | major solar mission | Crewed mission that included study of the Sun |
| 1973 | Explorer 49 | radio sources | RAE-2 in lunar orbit monitored radio sources |
| 1973 | Pioneer 10 | deep space | Reached Jupiter |
| 1974 | Mariner 10 | Mercury | Returned detailed images of the surface |
| 1975 | SAS-3 | x-ray sources | SAS-3 launched—Explorer 53—determined positions of X-ray sources |
| 1975 | Viking 1 & 2 | Mars | Launched |
| 1976 | Viking 1 & 2 | Mars | Orbited and landed |
| 1977 | Voyager 2 | outer planets | Launched |
| 1977 | Voyager 1 | outer planets | Launched |
| 1978 | IUE | ultraviolet sky | Still in use in 1994 |
| 1978 | Pioneer Venus-A | radar studies | Conducted radar studies of Venus |
| 1978 | HEAO-2 | x-ray sky | Renamed Einstein studied x-ray sky |
| 1979 | Pioneer 11 | deep space | Reached Saturn - sent back pictures |
| 1979 | Voyager 1 & 2 | Outer planets | Reached Jupiter |
| 1980 | Voyager 1 | Outer planets | Reached Saturn |
| 1981 | Voyager 2 | Outer planets | Reached Saturn |
| 1983 | IRAS | infrared | US-Dutch - 300 day mission to observe universe in the infrared |
| 1983 | Pioneer | deep space | Crossed the orbit of Pluto |
| 1983 | Pioneer | deep space | Left the solar system |
| 1985 | Spacelab-2 | infrared | Spacelab-2 Infrared Telescope (IRT) carried in Shuttle to study infrared radiation in near Earth orbit |
| 1986 | Voyager 2 | Outer planets | Reached Uranus |
| 1989 | Voyager 2 | Outer planets | Reached Neptune |
| 1989 | Magellan | Venus | Launched from Space Shuttle |
| 1989 | Galileo | Jupiter/asteroids/Earth/Venus | Launched from Space Shuttle |
| 1989 | COBE | microwave sky | Launched from a Delta rocket to study the microwave sky Detected remnant radiation from the Big Bang |
| 1990 | HST | ultraviolet sky | Launched from Shuttle to study visible/ultraviolet sky |
| 1990 | ROSAT | x-ray sky | Launched from a Delta-II rocket to study the x-ray sky |

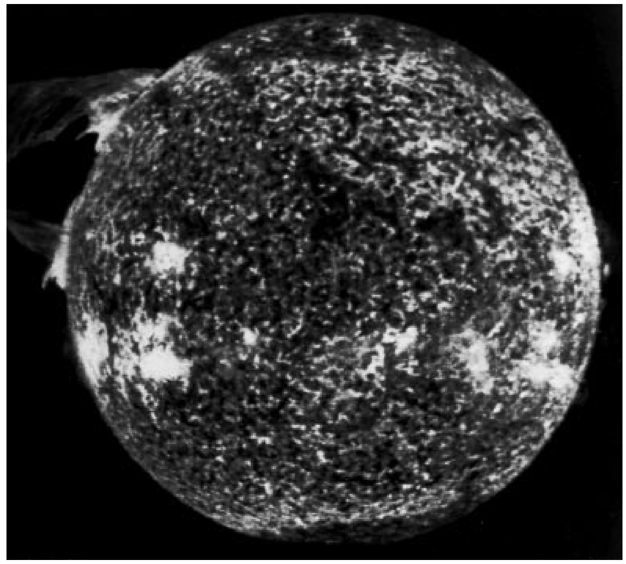
### Abbreviations

CGRO - Compton Gamma Ray Observatory
COBE - Cosmic Background Explorer
EUVE - Extreme Ultraviolet Explorer
HEAO - High Energy Astronomy Observatory
HST - Hubble Space Telescope
IRAS - Infra-Red Astronomical Satellite
IUE - International Ultraviolet Explorer
KAO - Kuiper Airborne Observatory
OAO - Orbiting Astronomy Observer
OSO - Orbiting Solar Observer
RAE - Radio Astronomy Explorer
SAS - Small Astronomy Satellite

interplanetary travelers, *Voyager 1 and 2* (launched in September and August 1977) visited Jupiter, Saturn, Uranus, and Neptune and are now leaving the solar system on the way into interstellar space. They sent back new data on these gas giant planets. Their discoveries included volcanoes on Io (a satellite of Jupiter), storms on Neptune, and ring shepherd satellites around Saturn. Two *Voyager* missions represent an incredible success story. They provided unique glimpses of the planets and redefined the history of our solar system.

Beginning in 1962, NASA launched a series of nine orbiting observatories to observe the Sun. Astrophysicists began to understand the interior of our nearest star. In the 1970s, *Skylab* astronauts brought back from orbit a wealth of data on the Sun, using x-rays to study its activity.

In 1978, one of the most successful astronomical satellite missions, the *International Ultraviolet Explorer* (IUE), was launched. This satellite has an ultraviolet telescope that has been used for more than 17 years to study the universe in the ultraviolet portion of the electromagnetic spectrum. Many scientists continue to use IUE simultaneously with other satellites and Earth telescopes to gather multi-wavelength data on astronomical objects.



*Skylab 4* picture of the Sun in ionized helium light

Final inflation of an instrument-carrying helium balloon before launch from Palestine, TX

Other NASA satellites have carried x-ray detectors into space. One of the first (1970)—called *Uhuru* (Swahili for freedom)—mapped the entire sky in x-ray wavelengths. Later (1978) the second *High Energy Astronomy Observatory* (HEAO-2) called *Einstein* imaged many objects in x-ray light. Today a satellite called ROSAT (a name honoring the physicist who discovered x-rays, Dr. Roentgen) continues the study of individual sources of x-rays in the sky. All of these satellites added new objects to the astronomical zoo and helped scientists understand the processes that make x-rays in space. The sheer number of high energy objects discovered by these satellites surprised and excited the scientific community.

The *Infrared Astronomical Satellite* (IRAS) was launched in 1983. It mapped the sky in infrared wavelengths. IRAS scientists have discovered thousands of infrared sources never seen before. The infrared part of the spectrum tells about molecules in space and gas and dust clouds where new stars are hidden until they are bright enough to outshine their birth cloud.

The Space Shuttle is used to introduce instruments into low Earth orbit. Satellites like the *Hubble Space Telescope* orbit about 600 kilometers above Earth's surface. This is a low Earth orbit and accessible to the Shuttle. To put satellites into high Earth orbit, an upper stage must be carried in the Shuttle's payload bay or the satellite is lofted with one of several different kinds of uncrewed launch vehicles. For example, the *Geostationary Operational Environmental Satellite* (GOES) orbits about 40,000 kilometers above Earth's surface. A Delta rocket was used to put GOES into high orbit. The choice of altitude—high Earth orbit or low Earth orbit—depends on the data to be measured.

**Recent Astronomy Missions**

In May 1989, the crew of the Space Shuttle *Atlantis* (flight 30) released the satellite called *Magellan* on its way to orbit Venus. The atmosphere of Venus is unfriendly to humans. It has thick sulfuric acid clouds, high pressures, and high temperatures. *Magellan* used radar to penetrate Venus's dense atmosphere and map the planet's surface.

In October of that same year, the crew of the Shuttle *Atlantis* launched another planetary satellite—*Galileo*—on its way to visit the planet Jupiter. On its way out to Jupiter, *Galileo* (named after Galileo Galilei, an Italian astronomer of the 17th century) took pictures of several asteroids.

Just a month later, in November, the *Cosmic Background Explorer* (COBE) was launched from a Delta rocket. This satellite surveyed the entire sky in microwave wavelengths and provided the first precise measurement of the background radiation of the universe. The distribution of this radiation exactly matches the predictions of the Big Bang Theory.

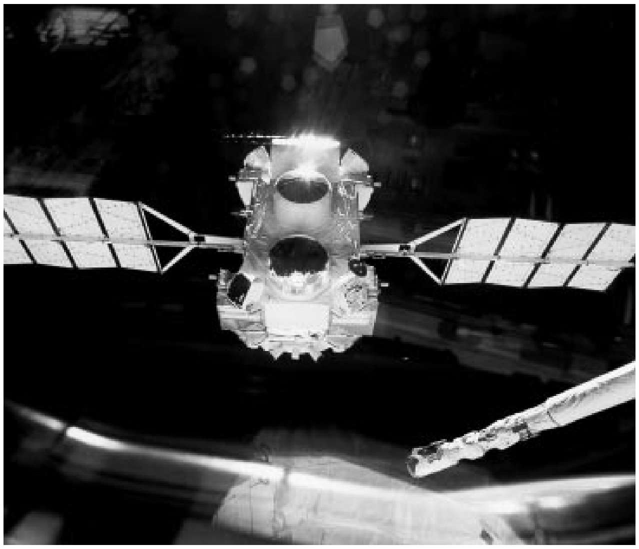
In April 1990, the crew of the Space Shuttle *Discovery* launched the HST. This telescope combines ultraviolet and optical imaging with spectroscopy to provide high quality data of a variety of astronomical objects. However, the primary mirror aboard the satellite was later discovered to be slightly flawed. Astronomers, however, were able to partially compensate for the slightly out-of-focus images through computer processing. In December, 1993 the Hubble servicing mission permitted astronauts to add compensating devices to the flawed mirror, to readjust its focus, and to replace or repair other instruments and solar arrays. The servicing mission has led to images of unprecedented light sensitivity and clarity.

In October 1990, the crew of the Space Shuttle *Discovery* released the spacecraft *Ulysses* (named after the famous voyager of the Trojan War) to travel out of the plane of the solar system on a long loop around the Sun's south and north poles. It will collect and send back data about conditions in the solar system out of the plane of Earth's orbit.

In December 1990, the crew of the Space Shuttle *Columbia* conducted two experiments during their flight. The Astro-1 instrument platform and the Broad-Band X-ray Telescope (BBXRT) both study the x-ray and ultraviolet emissions of astronomical objects.

A few months later, in April 1991, the crew of the Space Shuttle *Atlantis* launched the *Compton Gamma Ray Observatory* (CGRO). This satellite carried four experiments to study high

The *Hubble Space Telescope* attached to the Space Shuttle *Endeavour* during the 1993 servicing mission



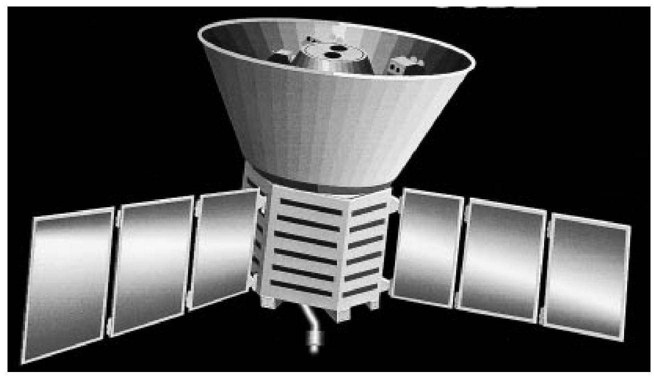
Deployment of the *Compton Gamma Ray Observatory* from the Space Shuttle *Atlantis* in 1991

energy gamma rays from several previously unknown sources. Satellites like CGRO can observe continuously for years instead of the few hours balloon experiments provide.

In May, 1992 a Delta II rocket boosted the *Extreme Ultraviolet Explorer* (EUVE) into orbit. This satellite continues to study the far ultraviolet part of the spectrum. One unexpected result from this mission was the distances at which ultraviolet sources were seen. The scientists expected to see ultraviolet radiation only from within 50 light years of the Sun. EUVE detected extreme ultraviolet emissions from distant galaxies in its first year of operation.

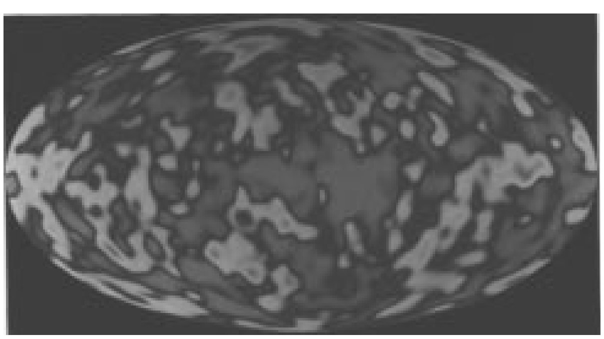
In September, 1993 the Space Shuttle *Discovery* (STS-51) carried an experiment called ORFEUS. It had ultraviolet telescopes aboard to study the light from hot variable stars. These emit most of their energy in the ultraviolet part of the spectrum.

Using space-borne instruments, scientists now map the universe in many wavelengths. Satellites and telescopes provide data in radio wave, microwave, infrared, visible, ultraviolet, x-ray, and gamma ray. By comparing data from an object in the sky, in all wavelengths, astronomers are learning more about the history of our universe.

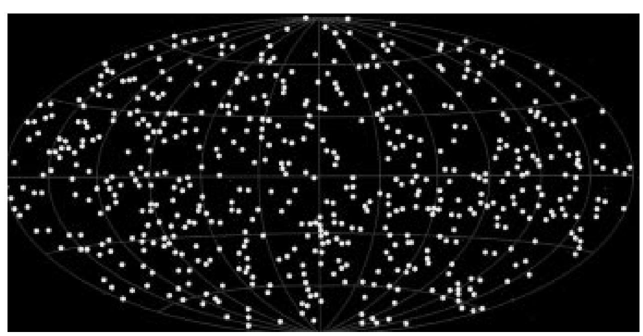


Artist's concept of the COBE spacecraft in space

**Note:** For more information about each of these missions and the discoveries that are being made, refer to the reference section of this guide or contact NASA Spacelink, the electronic information service described on page 89.



Thermal background radiation measured by the COBE spacecraft



Gamma ray bursts detected by the Compton Gamma Ray Observatory